Lecture Notes in Mechanical Engineering

Hari Vasudevan
Vijaya Kumar N. Kottur
Amool A. Raina *Editors*

Proceedings of International Conference on Intelligent Manufacturing and Automation

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Preface

Emerging area technologies in the Industry 4.0 era are ensuring that we continue to be in turbulent and challenging times as we attempt for wealth creation and business in the fields of manufacturing and automation. Industries constantly look up to manufacturing and automation engineers for their assistance in increasing the overall productivity in their organizations. It is also the time when policymakers across the globe have started to focus more of their attention on the manufacturing sector due to the presence of disruptive technologies in manufacturing. The International Conference on Intelligent Manufacturing and Automation 2022 (ICIMA 2022) was therefore designed to encourage discussions and research on Advancements and Applications in the areas of Manufacturing and Automation. The primary focus of this conference was to bring together academicians, researchers and scientists for knowledge sharing in various areas of manufacturing, automation and other allied domains. The conference covered topics encompassing automation, mechatronics, robotics, manufacturing processes, management and other related areas, such as product design and development, green manufacturing and smart materials with the objective of brainstorming and with specific emphasis on the applications in the field of intelligent manufacturing and automation. The response to the call for papers was overwhelming with 119 research articles submitted for the conference. Finally, 69 articles, covering a wide spectrum of topics related to the theme of the conference were accepted after a thorough review process. We express our sincere appreciation to the authors for their contribution to this conference. We would also like to express our sincere gratitude to all the experts and referees for their valuable comments as well as support extended during the review process. Thank you everyone once again!

Mumbai, India — Hari Vasudevan
Mumbai, India — Vijaya Kumar N. Kottur
Oxfordshire, UK — Amool A. Raina

Contents

About the Editors

Dr. Hari Vasudevan has his Masters in Production Engineering as well as Post Graduate Diploma in Industrial Engineering from VJTI (University of Mumbai) and Ph.D. from IIT Bombay. He has also done a 3 month full time certificate programme (ERP-BaaN) from S. P. Jain Institute of Management and Research, Mumbai under the University Synergy Programme of BaaN Institute, Netherlands. His areas of interest include Manufacturing Engineering, Manufacturing Systems and Strategy, Market Orientation of Manufacturing Firms and World Class Manufacturing. He is an approved Ph.D. guide at the University of Mumbai and NMIMS (Deemed to be University) and has so far guided 10 Ph.D. students for their degree. He is the President of Indian Society of Manufacturing Engineering (ISME), Life member of ISTE, New Delhi, Fellow of the Institution of Engineers India, Fellow of ISME and a Senior Member of IEDRC. He has 28 years of experience in teaching and 2 years of experience in industry. Presently he is working as the Principal of Dwarkadas J. Sanghvi College of Engineering, Mumbai. He has published over 132 papers in international conferences and journals as well as in national conferences and journals.

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Dr. Amool A. Raina is currently working as a Sr. Manager—Industrialisation and Production Technology at Oxford Space Systems (OSS). His work at OSS consists of managing the satellite component manufacturing and assembly team. He has successfully delivered 3 satellite in-orbit deployments. He heads the industrialisation programme for Helical and Wrapped Rib Antennas for telecom and SAR missions. He has a work experience of over 13 years in the aerospace and renewable industry. Previously, Dr. Raina led the aerospace programme at the Institut für Textiltechnik of RWTH Aachen University. His doctoral dissertation received highest distinction majoring in Aerospace Engineering at the University of Kansas. He has led projects in collaboration with NASA GRC, DLR and MTU Aeroengines. He serves as an expert reviewer for the European Union's funding programmes. Dr. Raina is the co-editor of 2 books and has published over 45 peer reviewed papers.

Manufacturing

Analysis of Poor Quality Cost in Auto Industry: A Case Study

Umesh Bhushi, Lokpriya Gaikwad, and Vivek Sunnapwar

Abstract Due to high competition and globalization in the current market, there is tremendous pressure on production to reduce the costs of the parts without compromising quality. After manufacturing the parts if it gets rejected, we have to bear the most costly than the raw material used. Continuous quality improvement is a key factor for competitiveness. By correctly applying quality tools, it is possible to find out the root cause of the quality problem to enhance productivity and quality. In this paper, the case study method is used to analyze the poor quality cost in the auto part manufacturing industry by using different tools and techniques to find the root causes and to improve the existing process that delivers quality products.

Keywords Cost of poor quality (COPQ) · Quality assessment · Case study

1 Introduction

Today, the cost of quality is more strategic and economically important than previously thought. Most of the researchers carried out an analysis of the cost of poor quality and how it affects the overall performance of the company. In some companies, it has been found that the quality costs for inadequate supplier performance in defect and delivery management approach more than 10% of purchase costs [1, 2]. Examples of COQs from a large automaker were included, which developed a cost component based on the PPM level achieved by the supplier and developed a COQ formula for the percentage of acceptable products received.

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Recently, companies have focused a lot of attention on quality management. The automotive industries are one of the largest industries in the world. There has been an increase in recalls from various car manufacturers around the world. Quality costs or COQs are a means of quantifying the total COQ-related efforts and shortcomings [3]. It is stated that "world-class quality means providing products and services that meet customer needs and expectations at a cost that represents customer value." Of course, it is not necessary to produce products or services that far exceed the customer's expectations, but it is always necessary to fully meet these expectations with an optimal production cost [4].

Furthermore, the "cost of quality" is not the price of creating a quality product or service. It is the cost of NOT creating a quality product or service. The costs related to quality are divided into two categories: cost of good quality and cost of poor quality. Prevention costs and evaluation costs are costs associated with good quality, while failure costs arise from poor quality. Costs are defined as the sum of costs over the life of a product. Management must understand these costs to create a quality improvement strategy. The primary goal of an organization is to survive and maintain high-quality goods or services, with a comprehensive understanding of quality related costs.

The cost of poor quality is accounted for as the annual monitored loss for a company in its balance sheet. Apparently, cost of poor quality (COPQ) is not just about quality but the cost of associated waste due to poor performance and process along with severe business market impact and goodwill. The cost of competition and customer satisfaction are the main challenges for the manufacturer, and therefore, the cost of poor quality has now become the most significant factor in minimizing it and associated with the culture of no defects [5]. The installation and use of the quality cost program will enable leadership to make a transition driven by an organization's current operating costs to a state of minimum quality costs [6, 7].

2 Methodology

In this paper, case study-based methodology is adopted. Case study is carried out in auto component manufacturing company to gather and analyze the data related to cost of poor quality and find out the root causes of the quality problems.

3 Case Study

3.1 Problem Definition

The company produces 15,000–20,000 condensers on production line. Out of which there are higher rejection rate of child parts (flat tube, fin coil, manifolds, side supports, jumper tube). Condenser child parts' last six-month scrap cost was Rs. 1,824,515/-. In average, cost is Rs. 30,408 6 per month. This cost was very high to target of scrap. Scrap target of this line was Rs. 90,000 per month. Average cost condenser at core builder was Rs. 800/- per condenser. If calculation of condenser in numbers that is 380, condensers per months have to scrap. The scrap cost is directly affecting company's economic strengths as well as delivery rating for customers. Poor quality cost is mainly driven by company to evaluate product and process quality. One of the parameters of COPQ is internal rejection cost. This is a focus of this research.

3.2 Details of Problems

The problem selected here is to reduce the scrap cost of child parts. The main process is core building. Currently, scrap cost of child parts is high due to lack of some process modification and addition of extra tools; child parts scrap details are as shown below in Table 1.

From details of the condenser, it is observed that child parts rejection is major contribution in cost and in occurrence so defects are identified as the priority research. The two most prevalent defects are fin rejection due to damage, cut, and compress and tube rejection for cut and damage in core building process. We had focused on fin, tube, and header plate rejection. This contributes about 90% of the total rejection. This average cost of this is about Rs. 3 lakhs per month, and it is 70% of the total rejection cost as shown in Fig. 1.

Inference:

As per monthly trend, scrap is Rs. 2.5 lakhs to 3.5 lakhs per month. And average of last six months cost is Rs. 3 lakhs per month. After condenser manufacturing, condenser moving for next process is brazing the condenser cores from Nocolok furnace. After brazing, next process is assembly of condenser. Condenser core manufacturing station is the main source of child parts scrap occurrence.

Scope of research: It is limited to corrective actions at core building stage. It is also related to corrections at previous level to have standard size of child parts. Fin, tube and manifolds, and side support damage will be taken into consideration.

Table 1 Six-month total scrap and price list

Sr. Nos.	Part	Quantity	Average/months	Price in INRs
1	Fin	1081.6 kg	180.26 kg	300 Rs/kg
2	Flat tube	21,227 nos.	3538 nos.	200 Rs./kg
3	Manifolds	6908 nos.	1152 nos.	5 Rs./piece
4	Side support	1188 nos.	198 nos.	10 Rs./piece
5	Jumper tube	42 nos.	7 nos.	10 Rs./piece

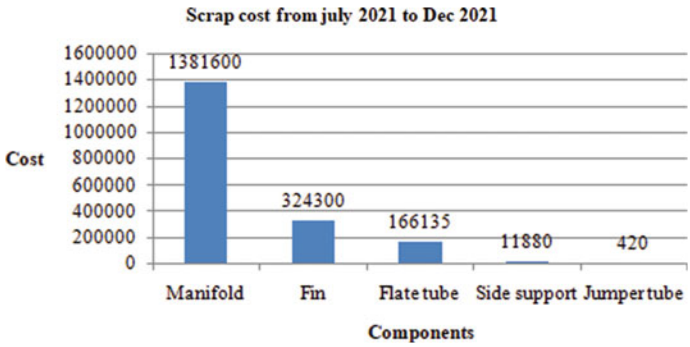

Fig. 1 Six-month scrap cost analysis

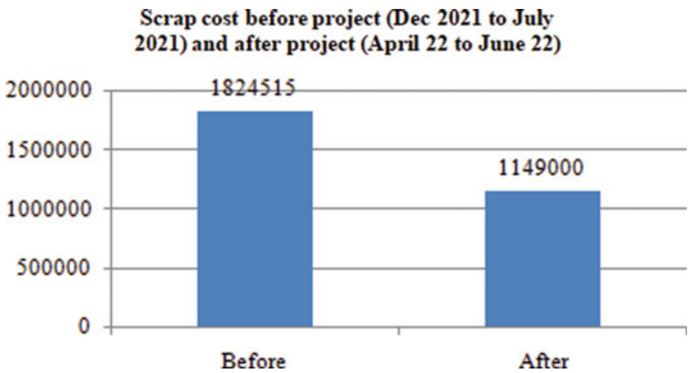

Fig. 2 Six-month cost comparison before and after

3.3 Decision Matrix

Various questions such as case in implementation, environmental effect, improvement in productivity, economic gain acceptance by the team members have discussed and accordingly rated. The weightage to each criterion is given as per 1–3 scale (1: for less impact, 2: for moderate impact, 3: for higher impact), and the total score is calculated and compared as shown in Table 2.

Above Table 1 decision matrix is based on discussion with team and shows problems for higher scrap and score of the problems that helped us to identify mostly contributor and solve it.

In this matrix, result of impact on scrap contributing by processes was observed.

Table 2 Decision matrix

Sr. Nos.	Problems	Score 1	Score 2	Score 3
1	Fin height variation			3
2	Oil supply variation			3
3	Tube damage	1		
4	Fin damage	1		
5	Manifolds damage		2	
6	In proper set-up		2	
7	Fin drop			3
8	Cutting problems			3
9	Matrix disassembly			3
10	Rework		2	
11	Fin short	1		

3.4 Cause-And-Effect Analysis

The causes as we found technically and economically suitable in our case will be categorized herewith under men, machine, material, and method as shown in Fig. 3.

The problem discussed herewith is rejection of child part at automatic core builder workstation.

Relatedness of these causes will be given importance according to our experience and situation. The highly important causes will be taken for why why analysis.

After brain storming, discussion with team, review, and analysis, we found the main issues which are contributing more for scrap are listed below:

1. Fin height variation
2. Oil supply variation
3. Need of modification in tools

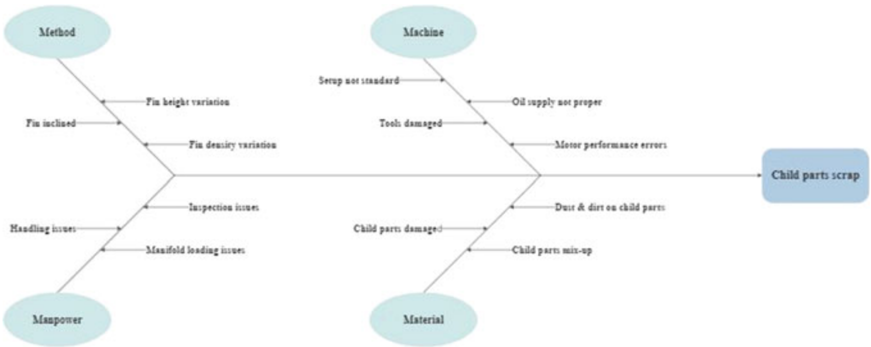

Fig. 3 Cause-and-effect diagram

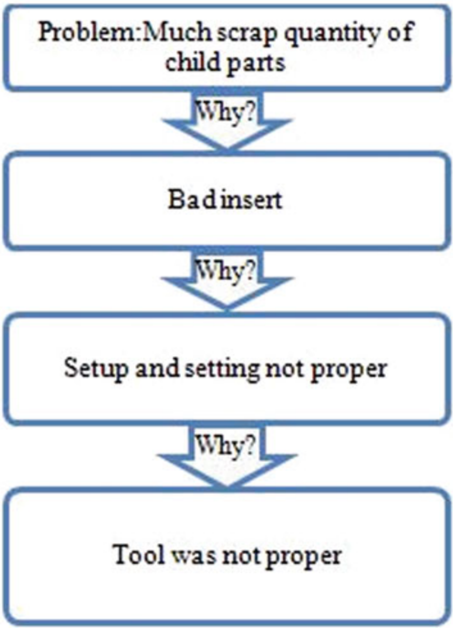

Fig. 4 Why Why analysis—1

4. Servo motor performance errors
5. Tolls damage or loose.

3.5 Why Why Analysis

The causes such as dimensional errors, improper fitment, and brazing defect were discussed. The root causes for this problem identified and corrective actions such as modification of program, fin chute issues, jamming and cutting problems, or problems related to alignment of fin, etc., and rework process at core builder was discussed as shown in Figs. 4, 5, 6, 7 and 8.

4 Improvement in Quality

After find the root causes and taking corrective actions, cost saving approx. Rs. 1 lakh to 1.10 lakhs per month happened. Due to zero rework, customer complaints gets reduced. It helps to save process cost, rework reduction, and customer complaint reduction.

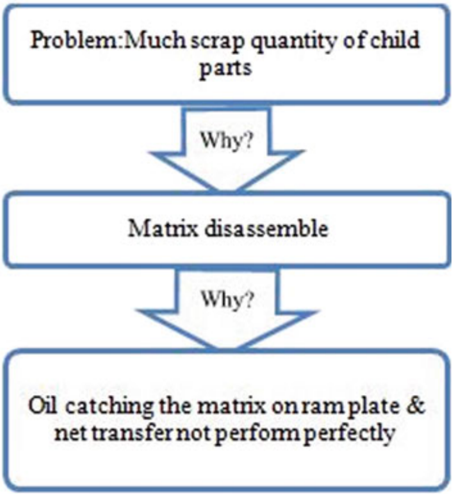

Fig. 5 Why Why analysis—2

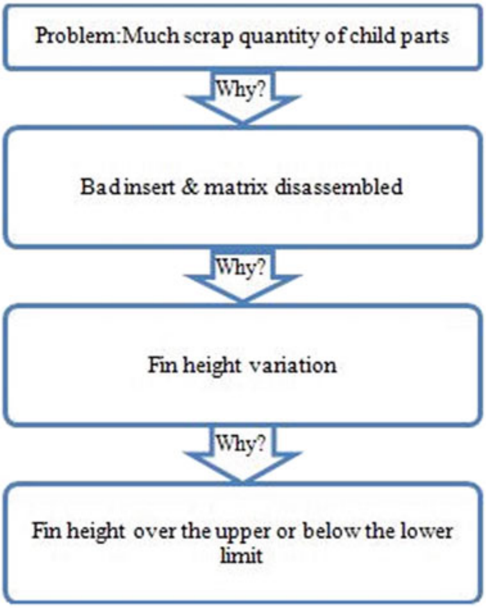

Fig. 6 Why Why analysis—3

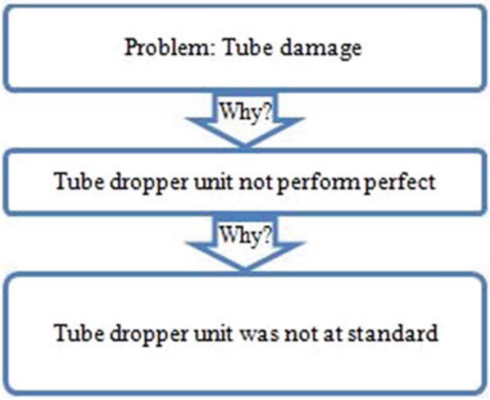

Fig. 7 Why Why analysis—4

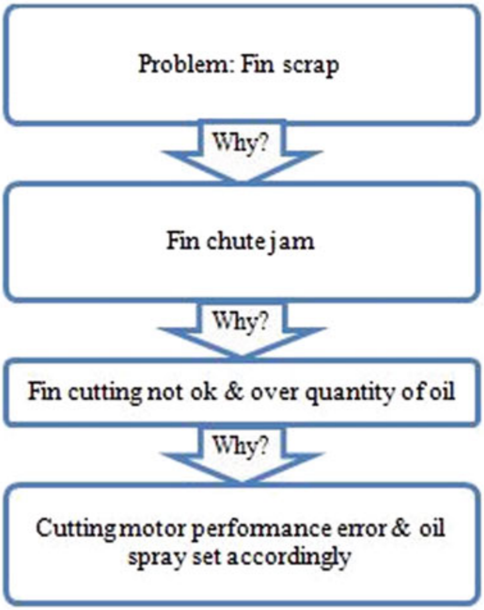

Fig. 8 Why Why analysis—5

Defect reported after core manufacturing as shown in Fig. 9.
Before implementation: 245 nos. reported of defects/month.
After implementation: 158 nos./month.

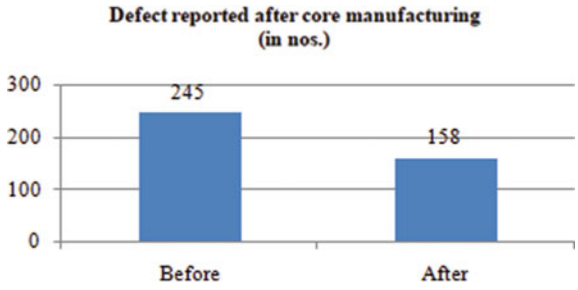

Fig. 9 Defect comparison

4.1 Rework Reduction of Condenser

The condenser if it is not found as per specification will be reworked. At present, there was 420 condenser/month (bad insertion, baffle open, tube damage, side support damage) which are reworked. After implementation, this was reduced significantly around 40% of present.

Rework core reduced by 420 nos. to 250 nos.

4.2 Reduction in Child Part Rejection

From six months' history, it was observed that the child parts scrap cost is Rs. 304,085/- and average cost of condenser at core builder is Rs. 800/- (800 /piece in average including fin, flat tube manifold, oil, manpower, and machining processes) that is 380 condensers in the month are rejected. This is up to 70% of the total rejection. After implementation of this research, these rejections were reduced by more than 50% and accordingly its contribution in the total rejection gets reduced as shown in Fig. 10.

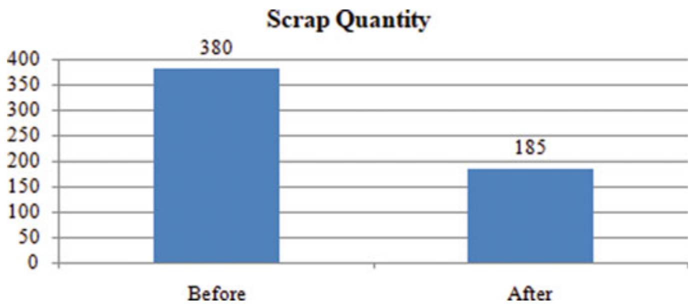

Fig. 10 Scrap quantity comparison

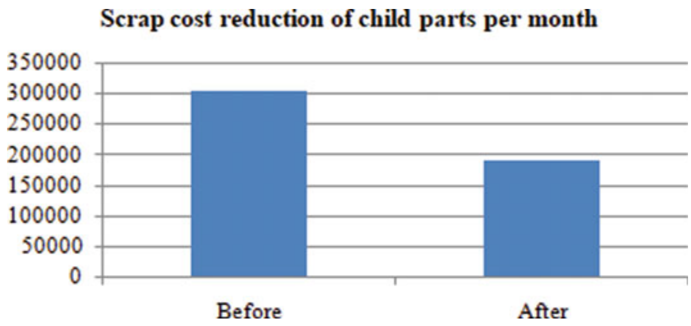

Fig. 11 Scrap cost comparison

4.3 Reduction in Cost of Rejection

The cost of rejection is Rs. 3 lakhs at present. This cost is on account of fin, tube, and manifolds rejection during the fitment. After implementation, the rejection of these parts reduced, and accordingly, the cost of rejection of child parts get reduced. As shown in Fig. 11, the average cost before implementation was Rs. 304,000/- which was observed Rs. 191,000/- after implementation.

It means Rs. 113,000/- saving, i.e., 33% of total scrap cost, reduced after this implementation.

5 Results and Discussion

This research has reduced the cost of child parts scrap as well as increased the productivity of the condenser core manufacturing. Previously, time required for rework is 84 h per months. After this research, the rework time reduced by 84–51 h that means 34 h saving per months. Child part scrap cost was 3 lakhs per month; after this research, it reduced to 1.91 lakhs per month. And scrap quantity was 1460 kg per month; after this research, it reduced to 960 kg per month. The cost of implementation of this research is Rs. 2.5 lakh which is one-time investment keeping in mind the payback period of the investment is 1.5 months.

Efforts required during implementation of this research include decision making, analysis, finding out alternatives, training and observations, staff training, and cooperation from team.

5.1 Overall Results of the Research

Table 3 shows the overall results of the research.

Table 3 Overall results

Area	Before	After
Scrap cost saving per month	302,000 lakhs/months	191,000 lakhs/month
Reworks hours per month	84 h/month	51 h/month
Oil consumption per month	120 L	80 L
Net profit from this research	1.1 lakhs/month	13 lakhs/month
Cost of this research	2.5 lakhs	
Duration of this research	1 month	

Table 4 Economical benefits

Area	Before	After	Result
The child part scrap cost	Rs.304000/month	Rs.191000/month	Rs. 110,000/month saving
Oil consumption	Rs. 25,000/month	Rs. 20,000/month	Rs. 5000/month saving
Core cost	Rs. 1360/core	Rs. 980/core	Rs. 380/core saving

5.2 Overall Benefits

Economic benefits from this research are Rs. 1.91 lakhs per month which accounts Rs. 23 lakhs in a year through saving child parts scrap at condenser core manufacturing. This benefit takes into account cost of saving from process feed materials, additional cost of labors, and time and cost of rework as shown in Table 4.

Other non-economical benefits include customers' satisfaction, business growth, and scope for horizontal deployment.

6 Conclusion

Overall results showed the improvement in the scrap cost reduction in condenser manufacturing process. This has done through saving consumables such as oil. Reduction of scraps, such as bad indention, fin height variations, was the leading reason for more scrap when the reasons reduced scrap of fin, flat tubes, manifolds, and other child parts scrap reduced.

Overall, this research reduced the child parts scrap and reduced consumables as well as improved the quality of product and reduced the rework time and save more times for production.

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Innovativeness in Indian Defence Sector: An Academic Strategy Perspective and the Way Ahead

Anup Chawan and Hari Vasudevan

Abstract The defence sector has been widely recognized as the sunshine sector by many developed and developing countries. India has started shifting its gear in this sector very rapidly, particularly in terms of design, manufacturing and testing facilities. The extant research work in the field throws light on the latest reforms in the defence sector, conducted from different perspectives. The reforms made in the defence sector show elite level of innovativeness happening in the Indian way. This study is inspired by the various reforms happening in the Indian defence sector that too in the midst of COVID 19 challenges. It is important to understand these reforms, so that various strategies can be formulated further to boost innovations in the defence sector, so as to make the experience of Atmanirbhar Bharat and Make in India a reality. This paper further comes out with strategic contributions and identifies key enablers for Atmanirbhar Bharat from an academic perspective, so as to expedite its contribution in making India a global manufacturing destination in the defence sector. This study also concludes with some suggestions and provides for future directions in the country's efforts towards achieving autonomy in the defence sector.

Keywords Defence · India · Manufacturing · Innovativeness

1 Introduction

Defence sector in India has been identified as one of the champion sectors with focus on improving India's defence manufacturing capabilities [1]. In this context, innovativeness in solutions to improve manufacturing capabilities is expected to lead to

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better firm performance, thereby meeting the needs of the Indian defence establishment. Therefore, there is sufficient reason, as to why it is important to study innovativeness in this key area. Innovativeness is generally defined as a firm's tendency and ability to introduce innovations [2, 3]. Society of Indian Defence Manufacturers (SIDM) has carried out different types of studies to explore the capabilities of the Indian industries to manufacture various defence products. Current policies for defence sector in India have also encouraged SMEs as well as academia to be a part of the indigenization process.

India is one of the third largest defence spenders in the world, where USA stands first and China ranks second among them [4]. Manufacturing in the defence sector is complicated due to rapid changes in the cutting edge technologies [5]. Self-reliance in this sector has been the key basis of India's defence production policy [6]. In the interest of self-reliance in defence manufacturing, as a part of Atmanirbhar Bharat, a second list of weapons/platforms/systems/ammunition has been released with timelines recently [7]. Around 108 items would be procured from the Indian Industry as per the indicated timelines [8]. Innovations for Defence Excellence (iDEX) framework have also been implemented by the Ministry of Defence (MoD) [9]. This framework was formulated, so that the MSMEs, start-ups and innovators could get ample of opportunities to provide innovative and indigenous technological products and solutions to the Indian military base from time to time [10].

1.1 Innovativeness

Innovativeness in organizations and governments has been widely studied in different contexts by several scholars [11]. Firms, which have affiliations with the higher level of governments, enhance firm innovativeness [12]. The Indian government has currently come up with policies to enhance firm innovativeness. The role of government plays an important role in advancing the technology for SMEs' innovativeness. Around 8000 Micro, Small and Medium Enterprises (MSMEs) are actively involved in the defence production sector, currently [13]. In this study, innovativeness is defined in terms of the reforms done in the defence sector.

This study is structured into six sections. The first section describes the significance of innovativeness from a defence perspective. The second section gives a brief overview of the defence sector in India. The third section describes various reforms, happening in the Indian defence sector. The fourth section describes the strategic contributions towards Atmanirbharta in defence sector, from an academic perspective. The fifth section describes the key enablers for Atmanirbhar Bharat again from an academic perspective. In the sixth section, conclusions and recommendations for future are discussed.

2 Indian Defence Sector: Background

The Ministry of Defence consists of total five departments, which include the Department of Defence, Department of Defence Production, Department of Ex-Service Welfare, Defence Research and Development Organization, and Department of Military Affairs [14]. There are various Defence Public Sector Undertakings (DPSUs) in India, which work under the administrative control of the Department of Defence Production, MoD [15]. Ordnance factories in India are operated under the guidance of MoD. There are total 41 ordnance factories in India [16]. They offer different types of products to the Indian Army, such as small arms, systems and platforms, ammunitions, explosives and propellants, troop comfort items, materials and components, civil trade arms & ammunitions and optical devices and parachutes [17]. SIDM is the apex body of the Indian defence industry [18]. SIDM plays a key role in terms of growth and capability building of the defence industry in India. Currently, there are more than 500 members of SIDM [19]. SIDM in its span of 5 years has so far made phenomenal changes for the growth of Indian defence industry. SIDM has provided further outlook to other professional bodies/industries/academia in India, as to how they can contribute to defence sector, thus aiming for self-reliance. It can be noted that these professional bodies are now stepping up the activities towards contributing to the defence sector.

3 Reforms in Indian Defence Sector

Various reforms have taken place in the defence sector with the aim of increasing the share in Indian defence procurement, providing access to critical technologies, initiatives for encouraging investment, enhancing indigenization, tapping the world market, easing the business, exhibitions as well as outreach programmes [20].

The government has been proactive in making several reforms in the defence sector during the year 2020 [21]. These reforms are discussed in this section, which include various aspects, such as technological, administrative and innovation. Recently, the ordnance factories have been restructured into seven new Public Sector Undertakings (PSUs) [15]. This has been done to make India self-reliant in the defence sector. A chief of defence staff has been appointed as per the recommendations of Kargil Review Committee [22]. In order to improve civil and military integration, the department for Military affairs was formed [23]. Import has been stopped on 108 defence items with subsequent timelines [24]. 74% FDI has been permitted in the defence sector [25]. 87% of all the defence acquisition proposals were taken from domestic vendors [26].

New defence acquisition procedure has been approved, which promotes Make in India and Indigenous materials for defence and aerospace applications [27]. Transfer of Technology (ToT) for materials is being done through offset policy [28]. In order to boost start-up's provision for procurement from them as "buy Indian Indigenously

Designed Developed and Manufactured (IDDM)" has been initiated [29]. The new cyber security policy for MoD LAN has been brought out to address various security threats [28]. In order to boost the MSME sector, procurement up to 100 crores has been reserved for them [30]. In order to boost innovation in defence, five R&D labs with young scientists have been launched [28]. Recently, MoD has set up Defence Testing Infrastructure Scheme (DTIS) with the aim to push up defence and aerospace manufacturing [31]. Recently, many international alliances have also taken place in the defence sector to boost manufacturing.

4 Strategic Contributions from the Academic Perspective

Academicians have always played a transformational role by promoting innovations and entrepreneurship in various industrial segments. However, achieving autonomy in defence sector requires special efforts, especially in developing countries. Various schemes and initiatives have been launched to promote indigenization in the defence sector in India. Since privatization has been encouraged in the defence sector, OEMs, SMEs, private institutions, research & technological institutes and premium institutions like NITs and IITs have a plethora of opportunities to explore. The army design bureau has already established mechanisms to mentor and support academia and industry to foster indigenous technologies [32].

The authors of this study have found that there is an opportunity to achieve complete autonomy in the defence sector, and in order to achieve that, there is a need to create an operational strategy and functional mechanism at the national level to enable more contributions of academia with OEMs, SMEs and other institutions of repute. The proposed strategy drives its ethos and motivation from the promulgation of "Make in India" and "Atmanirbhar Bharat". It was also observed that the process of indigenization has been started, but only to a limited extent in the context of academia, due to various challenges. In the context of the above as well as based on wide interactions with various authorities in the defence sector, a detailed strategy is proposed here, and this strategy is inspired by the market entry framework developed for the automotive industry to assist in entering the aerospace and defence market [33].

Table 1 below describes the steps, strategy as well as detailed guidelines to achieve the same, as recommendations and contributions of the current study.

Step 1: There is a need to create awareness about various defence related products, which have been banned for import by the Ministry of Defence.

Step 2: The next step is to understand the current capabilities of Indian defence manufacturers and to identify new product development opportunities by interaction with key personnel from the defence industry.

Step 3: There is also a need to identify the technologies associated with the design, development and testing of defence related products.

Step 4: It is also needed to familiarize with the different government schemes for financial aid.

Table 1 Strategy from an academic perspective

Steps	Strategy	Guidelines
Step 1: Create awareness	To create awareness on defence items, which has been recently banned for imports by the MoD	Refer the recent list of banned items for import (Available on Srijan Defence Portal) [34]
Step 2: Identify opportunities	To understand the manufacturing capabilities of defence components/systems/equipments Identify product opportunities by interacting with the key resource persons/organizations/exhibition partners To understand problem definition statements published by Army Design Bureau	To become member of Society of Indian Defence Manufacturers To participate actively in the events organized by Society of Indian Defence Manufacturers To actively participate in various defence exhibitions In India, we have Defence Exhibition Organisation (DEO), which machinates defence exhibitions in India and abroad. Example Defence Pavilion, Aero India, Defexpo and India Pavilion To develop contact with currently working and superannuated armed forces to understand the gaps in the existing product performance and knowledge on subjects, such as systems and platforms, warfare, simulations and strategies, advanced engineering, mathematics, rockets and missiles fundamentals The contact details of the superannuated senior scientists from DRDO have been listed in syllabus of M. Tech in Defence Technology Army Design Bureau (Refer official website of India Army), where army make projects details are available

(continued)

Table 1 (continued)

Steps	Strategy	Guidelines
Step 3: Identify technologies	Key technologies for defence Applications include, quantum computing, drive by optics, IoT, machine learning, artificial intelligence, 5G & 6G, block chain, Industry 5.0 and 6.0 Identification of technologies for design, manufacturing and testing of defence systems and their level of application	To identify labs/institutes for accesses and learning these technologies
Step 4: Know-how of government schemes	SPARK Support for Prototype and Research Kick-start (In Defence) Framework was initiated by Defence Innovation Organization in partnership with Atal Innovation Mission [35] The framework provides grant up to 1.5 crores for producing functional prototypes. The spends are encouraged on research and development, prototyping, pilot implementation and market assessment [35] Individual innovators (Research and Academic Institutions can apply) [36] Technology Development Fund (TDF): In order to promote self-reliance in defence technology, Ministry of Defence initiated this scheme to encourage participation of public/private industries, specially MSMEs and start-ups to provide cutting edge technologies for defence [37] Non-Profit Research Institutions are only eligible in collaboration with an Indian Industry only [38]	Know more about SPARK and technology development fund to visit their official website
Step 5: Product/process development	Making technological alliances as per the requirements for product/process development	Universities/Colleges in India may sign MoU/look for technological alliances with other universities/colleges of the nations having friendly relationships

Step 5: Further, the product and process development through technological alliances have to be initiated.

5 Key Enablers for Atmanirbhar Bharat

Though, Atmanirbharta has been acknowledged by the industry associations and industries, its essence from an academic perspective is not much addressed. Various enablers for Atmanirbhar Bharat from an academic perspective are addressed in this section, which include KM strategies, reforms in ED cells, FDPs, competitions, alliance strategies, awareness and academic credits. Knowledge management in the defence sector is complicated, as compared to the other sectors. Only the required information needs to be shared, that too on a secured and trusted platform, when it comes to sharing knowledge. However, when it comes to open innovation practices in the defence sector, more platforms are required to disseminate knowledge related to design, manufacturing and testing of defence-related products.

Entrepreneurship development cells are required to encourage start-ups in defence sector. They are expected to invite the start-ups engaged in the defence sector to motivate the engineering students. Competitions should be thrown up and should focus on fuelling frugal innovations in the context of problem definitions coming for Indian Defence Organizations. Academic institutions are to be encouraged to focus on forming MoUs with universities from India and abroad to disseminate knowledge pertaining to various defence technologies. Cyber security is also a major concern, when it comes to sharing of confidential information related to the defence systems, and this is required to be addressed on a priority basis. There is also a need to create awareness on different schemes for making the market entry for defence sector. Due weightage must also be given to the educational institutions, contributing to the defence sector.

6 Conclusion and Recommendations for Future

Recent happenings in the Indian defence sector have been explored and discussed in this research work, wherein the study discoursed the recent reforms happening in the Indian defence sector. The strategic contributions from an academic perspective have also been discussed. The study has identified some of the key enablers for Atmanirbhar Bharat from an academic perspective. In order to scale up the indigenization process in the defence sector, this study comes with some policy implications as well as future directions.

In the future, a committee could also be formed by the senior officials of the MoD, industry associations, DRDO, OEMs, etc., to decide on how a defence-related project could be structured. From an academic perspective, the indigenous defence projects could be divided into three parts, i.e. major, moderate and minor. Considering

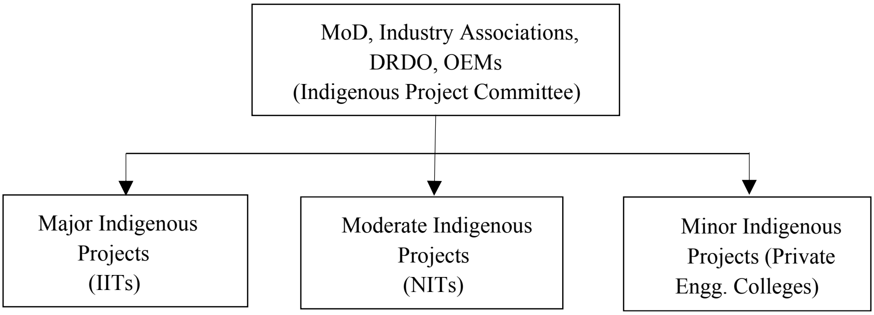

Fig. 1 Projects structurization (authors perspective)

the available technology infrastructure, talent pool and other facilities, the projects could be structured in terms of offering opportunities to IITs, NITs and private engineering colleges, in terms of various possible contributions. Figure 1 below shows the proposed project structurization.

There has also been an increase in cyber espionage operations by hackers in India [39]. A threat group called "RedFoxtrot" in collaboration with People's Liberation Army (PLA) Unit 69,010 has been targeting defence, government and telecommunications sectors, across Central Asia, India and other nations, and this has been confirmed by a renowned cyber security firm Recorded Future [40]. It is found strategically important to emphasize on innovativeness in developing product/system/subsystem architectures and cyber security solutions. Innovativeness from cyber security solutions also include focusing on encryption breaking algorithms and developing tools to fight against ransomware attacks, and this was also found imperative to be taken up in the defence sector.

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Work Centre Productivity Analysis for Making the Manufacturing Lean: A Case Study on Glass-Lined Pressure Vessels

Turvasu Amin and Meeta Gandhi

Abstract Any organization to be lean should have tools and techniques which can be deployed and maintained easily to achieve targeted productivity. The study was carried out at GMM Pfaudler, a leading process solutions supplier for agro, pharma, chemical, and other industries in their glass-lined pressure vessels division. The objective of the study was to make the manufacturing cycle leaner and more productive. Hence, work centre productivity analysis was carried out. Process bottlenecks were carefully examined at each step of the operation, and data for machining processes, downtime of shifts, and daily targets was gathered. It was found that there was a lot of inconsistency in the data which resulted in faulty reporting of machine downtime. Another bottleneck observed was the forming process which is performed on the swaging machine, 150, 300, and 600 Ton Press. To make the manufacturing process leaner, dashboard displays were designed which help not only in understanding the process better but also helped in setting focus on points which otherwise go unnoticed. In the forming process, torch heating of jobs was replaced by induction heating which reduce the time and the labour required to finish the job substantially.

Keywords Lean manufacturing · Productivity · Visual dashboard display · Induction heating

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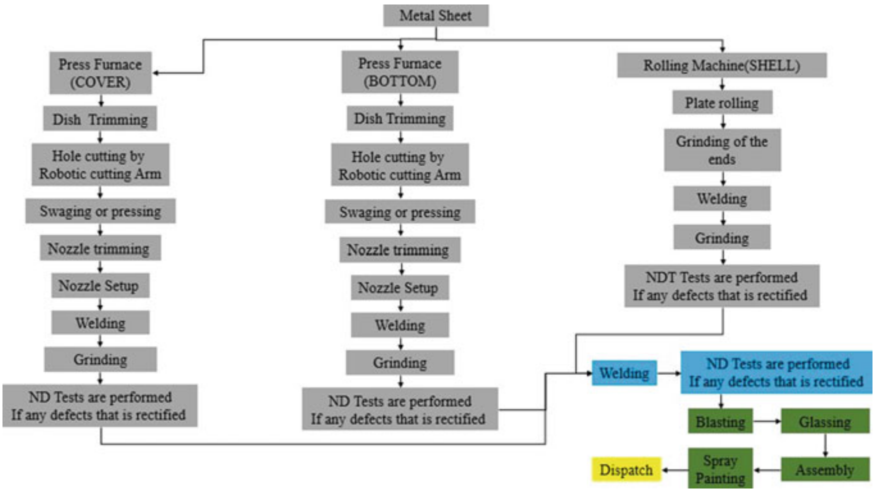

Fig. 1 Process flow chart

1 Introduction

GMM Pfaudler is a leading process solutions supplier for agro, pharma, chemical, and other industries. PFAUDLER, NORMAG, MAVAG, MIXION, INTERSEAL, EQUILLOY, and EDLON are the business lines of the company depending upon the services. The majority of the operations are at the Karamsad facility in the district of Anand in the state of Gujarat are related to the core glass-lined pressure vessels (Original equipment, OE) industry. This study was carried out in the glass-lined technology (PFAUDLER) in Fabrication department where pressure vessels are manufactured. Figure 1 describes their process flow chart for the capacity ranges from 100 to 63,000 lit for reactors and up to 80,000 lit for tanks. The job starts with a long metal sheet. The metal sheet is cut according to the requirement by PUG cutting or plasma cutting. Then, the sheet is divided into three sections such as shell, cover, and bottom. After the fabrication is done, these three sections are welded together and then the job is sent for the blasting process after which the glassing process takes place. Finally, the job is taken to the assembly station to assemble the required parts and then dispatched.

2 Literature Review

Mostafa et al. [1] have strongly advocated implementation of an advanced learning approach in order to serve the organization's vision, mission, objectives, goals, and targets. Studies of Kulkarni et al. [2] have shown that lean manufacturing tools can be effectively and efficiently be paired with work study methods to create a leaner system that can serve as the general remedy for any industry experiencing productivity issues of any kind. Kovács [3] has discussed the benefits of the performance-based lean concept, which manufacturing businesses can apply to gain a competitive advantage. The author has listed the most common wastes and highlighted the importance of applying lean manufacturing, lean tools, and lean methodologies. Okoh et al. [4] have described a visual dashboard design technique for visualizing maintenance and repair data. They created a single view page of maintenance tasks which makes it easier to get accurate and pertinent information for better decision-making through visualization and helps in identifying the root cause. The work of Luica et al. [5] explains the benefits and the development of induction heating techniques.

3 Methodology

Researched the OE Fabrication process and the technological advancements made to streamline the process. The OpEx department's primary goal is to streamline the process, so the initial strategy was to locate the process bottleneck by carefully examining each step of the operation. Then, data analysis was done for all the workstations in order to identify the bottleneck. In order to get better insight of the procedures done and their limitations, an informal interview of the workstation personnel was also conducted. Also the department's data was examined for possibility of technical changes or process modification to make the process leaner. Finally, a few adjustments were done in the procedure to improve its efficiency and debottleneck the congested process.

3.1 Problems Faced

While studying the process and brainstorming sessions, a lot of inconsistency and bottlenecks were discussed. These problems were affecting the productivity of the company. Many processes are happening simultaneously in three shifts for 24 h a day for 6 days in a week. On an average, 200 pressure vessels are fabricated collectively. Many different types of machines are used during the process. As processes are happening simultaneously, maintaining a track of each and every process gets difficult. In order to improve the productivity, company has adopted one of the QC tools where they maintain data and do analysis for the required output.

Every work station is given a data sheet book for entering the data daily. The data is updated on a daily basis in an Excel sheet. These sheets help in collecting the data for the working shifts, downtime of a shift, and daily targets as shown in Figs. 2 and 3. On performing data analysis for every workstation, namely nozzle trimming machine (NT), swaging machine, 300 Ton Press, 600Ton Press, dish trimming machine (DT-01, DT-02), a lot of inconsistency in the data sheet was found such as incorrect entries, data manipulation, multiple mentions of the same reasons, spelling mistakes, and no mention of the data even if the job is performed.

On careful observations of the data collection sheets, it was found that there was a lot of duplication and wrong entries as seen from Fig. 3. The reason being, these data sheets were manually filled from the data given by the work station operator's data sheet book. For preparing a visual dashboard, this data was significantly inadequate, and hence, modification in the data sheets was done.

Operator	Shift	Capacity/LOT	Start Time	End Time	Duration (Hrs)	EU s	Day of month	Month	Year	EU s MTD	Daily target
VIPUL VAGHELA	2	25000/159	16:45	00:52	08:07	2.6	1	Apr	2022	2.6	7.7
LALIT PARMAR	1	2000/433	08:40	11:50	03:10	1.0	2	Apr	2022	9.3	7.7
LALIT PARMAR	1	2000/432	12:40	16:15	03:35	1.0	2	Apr	2022	9.3	7.7
VIPUL VAGHELA	2	2000/234	16:40	20:15	03:35	1.0	2	Apr	2022	9.3	7.7
VIPUL VAGHELA	2	2000/235	21:05	00:50	03:45	1.0	2	Apr	2022	9.3	7.7
MANISH PRAJAPATI	3	5000/719	16:40	20:20	03:40	1.4	2	Apr	2022	9.3	7.7
MANISH PRAJAPATI	3	5000/718	21:10	00:50	03:40	1.4	2	Apr	2022	9.3	7.7
LALIT PARMAR	1	2000/431	12:00	16:15	04:15	1.0	4	Apr	2022	12.6	7.7
VIPUL VAGHELA	2	16000/632	16:40	00:50	08:10	2.3	4	Apr	2022	12.6	7.7
LALIT PARMAR	1	25000/157	08:40	11:55	03:15	2.6	5	Apr	2022	18.7	7.7
LALIT PARMAR	1	3000/1973	12:40	16:15	03:35	1.1	5	Apr	2022	18.7	7.7
VIPUL VAGHELA	2	5000/721	16:40	20:20	03:40	1.4	5	Apr	2022	18.7	7.7
VIPUL VAGHELA	2	2000/436	21:05	00:50	03:45	1.0	5	Apr	2022	18.7	7.7
LALIT PARMAR	1	3000/1974	08:40	11:55	03:15	1.1	6	Apr	2022	27.1	7.7
VIPUL VAGHELA	2	16000/628	16:50	00:40	07:50	2.3	6	Apr	2022	27.1	7.7
VIPUL VAGHELA	2	12500/873			00:00	2.0	6	Apr	2022	27.1	7.7
VIPUL VAGHELA	2	10000/1126			00:00	2.0	6	Apr	2022	27.1	7.7
VIPUL VAGHELA	2	1600/2826			00:00	1.0	6	Apr	2022	27.1	7.7

Fig. 2 Data collection sheet

Row Labels	Count of Description of downtime
⊞1 - Material non-availability	1
⊞10 - Cleaning	3
⊟2 - Labour non-availability	207
ALL LABOUR ABSENT	1
ALL LABOUR GATE PASS	1
ALL TEAM 150 T & 300 T PRESS	1
ALL TEAM 150 T & 300 T PRESS	5
ALL TEAM 150 T & 600 T PRESS	4
ALL TEAM 150 T PRESS	134
ALL TEAM 150 T& 600 T PRESS	1
ALL TEAM 150 T,300 T PRESS	2
ALL TEAM 300 T & 150 T PRESS	1
ALL TEAM 300 T PRESS	10
ALL TEAM 300 T PRESS (SWAGING OPERATOR ABSENT)	1
ALL TEAM 600 T & 150 T PRESS	2
ALL TEAM 600 T &150 T PRESS	1
ALL TEAM 600 T PRESS	33
ALL TEAM 600 T PRESS (SWAGING OPERATOR ABSENT)	1
ALL TEAM 600 T,150 T & 300T PRESS WORK	1
ALL TEAM 300 T PRESS	2
ALL TEAM ABSENT	5
ALL TEAM GEAT PASS	1
⊞5 - Machine breakdown	16
⊞7 - Crane breakdown	1
⊞8 - Crane doing other work (starvation)	4
⊞9 - Others	12
Grand Total	244

Fig. 3 Downtime reasons

Operator	Shift	Capacity/LOT	Start Time	End Time	Duration (Hrs)	EU s	Day of month	Month	Year	EU s MTD	Daily target	Week
LALIT PARMAR	1	5000/720	13:10	17:30	04:20	1.4	8	Apr	2022	37.7	7.7	Week-1
VIPUL VAGHELA	2	5000/210	22:10	00:50	02:40	1.4	8	Apr	2022	37.7	7.7	Week-1
LALIT PARMAR	1	20000/434	09:45	16:25	06:40	2.6	9	Apr	2022	47.7	7.7	Week-1
VIPUL VAGHELA	2	5000/207			00:00	1.4	9	Apr	2022	47.7	7.7	Week-1
VIPUL VAGHELA	2	10000/1130			00:00	2.0	9	Apr	2022	47.7	7.7	Week-1
VIPUL VAGHELA	2	10000/1135			00:00	2.0	9	Apr	2022	47.7	7.7	Week-1
VIPUL VAGHELA	2	10000/1132			00:00	2.0	9	Apr	2022	47.7	7.7	Week-1
VIPUL VAGHELA	1	5000/209	10:10	14:25	04:15	1.4	11	Apr	2022	57.1	7.7	Week-2
VIPUL VAGHELA	1	5000/208	14:50	16:18	01:28	1.4	11	Apr	2022	57.1	7.7	Week-2
VIPUL VAGHELA	1	10000/1131			00:00	2.0	11	Apr	2022	57.1	7.7	Week-2
MANISH PRAJAPATI	2	2000/443	18:40	22:50	04:10	1.0	11	Apr	2022	57.1	7.7	Week-2
MANISH PRAJAPATI	2	2000/442	22:55	03:10	04:15	1.0	11	Apr	2022	57.1	7.7	Week-2
LALIT PARMAR	3	25000/34	03:25	04:50	01:25	2.6	11	Apr	2022	57.1	7.7	Week-2
VIPUL VAGHELA	1	2000/1065	08:35	11:50	03:15	1.0	12	Apr	2022	69.6	7.7	Week-2
VIPUL VAGHELA	1	10000/1127			00:00	2.0	12	Apr	2022	69.6	7.7	Week-2
VIPUL VAGHELA	1	10000/1129			00:00	2.0	12	Apr	2022	69.6	7.7	Week-2
VIPUL VAGHELA	1	10000/1133			00:00	2.0	12	Apr	2022	69.6	7.7	Week-2
VIPUL VAGHELA	1	10000/1136			00:00	2.0	12	Apr	2022	69.6	7.7	Week-2
LALIT PARMAR	3	25000/35	01:10	06:55	05:45	2.6	12	Apr	2022	69.6	7.7	Week-2

Fig. 4 Modified sheet

Modifications in the data sheets

Three shifts make up the 24 h throughout the course of six days a week. So, a column for week was added as shown in Fig. 4 in order to create a weekly report and for better data interpretation. According to the business, the first week of a given month is from the first through the tenth. The second week of that month is from the 11th to the 17th, the third week is from the 18th to the 24th, and the fourth week is from the 25th to the day the month ends. So, as seen in Fig. 1.5, a new column was applied for the week. The following formula was created in Excel to fill up the Week column in the data sheet.

Formula:

= IF(O10 < = 10, "Week-1",IF(AND(O10 > = 11,O10 < = 17), "Week-2", IF(AND(O10 > = 18,O10 < = 24), "Week-3", IF(O10 > = 25, "Week-4")))))

In the formula, "O10" means the column "O" of the Excel sheet which has the Day of the Month and "10" is the first row for filling the data. This formula was applied to the "Week" column to generate a standard data in order to prevent manual errors while filling the data sheets. So, when the day of the month is mentioned the week column will mention the respective Week of that month.

3.2 *Output*

After making the necessary modifications to the data sheets for the errors and reasons mentioned above, a brainstorming session was held with the manufacturing personnel to familiarize them with the changes made and to discuss the next course of action, which was to create a visual dashboard display on the production floor so that employees could monitor their performance and visitors or stakeholders could view the machine data when they visited the facility. Similar idea was implemented to monitor the worker performances and downtime.

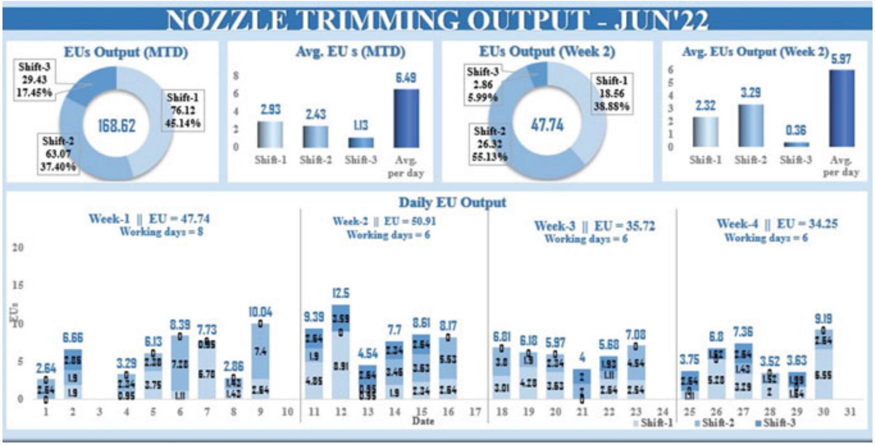

Fig. 5 Dashboard display

The dashboard display was prepared by the data collected in the data sheets. The coding of dashboard display was done in Excel for all workstations. As soon as the person in charge adds data, the software calculates the process output and simultaneously auto-generates/updates the charts also. Based on the information required, multiple charts for the same workstation can be prepared at the click of the button.

Company uses engineering unit (EU) system for division of jobs on and monitoring the progress of the job so that every job can be delivered on due date, and the output can be maximized. Hence, dashboard was configured in such a way that this objective could be met and each dashboard would display weekly and monthly output. The value and the calculation depend on the capacity of the job, i.e. depending on the number of nozzles and the time taken to finish the job according to the average time. For each workstation, two dashboards were prepared, one related to manufacturing EU track and the other related to downtime. Figure 5 shows the chart and the format that is displayed on the work floor monitors.

Figure 6 shows the downtime display dashboard. It displays the downtime reason on monthly and weekly basis, shift wise downtime for the month, and similarly for the week. It also displays the downtime for each day. The partitions in the chart show the bifurcation of the weeks and the sum of the downtime in that specific week. It also displays the reason of the downtime. This helps the shop floor in-charge and the mangers to quickly rectify the problem and hence helps in increasing the productivity of the machine and in reducing the total downtime thereby increasing the efficiency of the machine.

On performing the data analysis, it was observed that the swaging machine has a considerable amount of downtime during the process. While studying the process and interacting with the people concerned it was found that the forming process is the bottleneck of OE Fabrication. This forming process is performed on the swaging

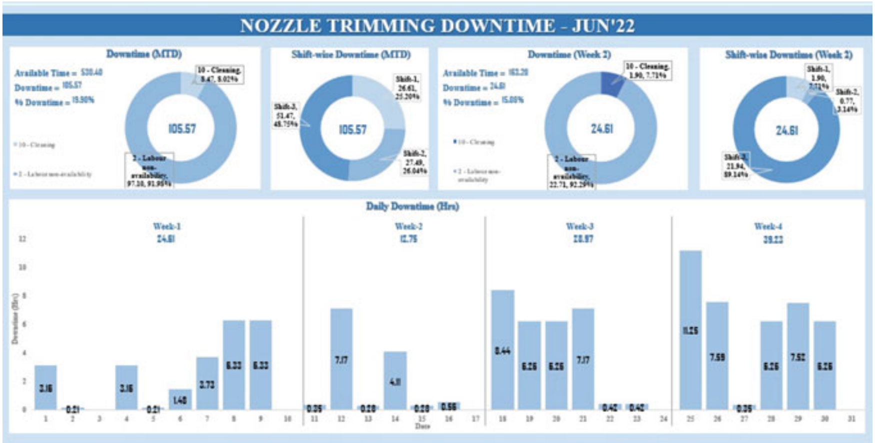

Fig. 6 Downtime dashboard display

machine, 150, 300, and 600 Ton Press. Data analysis revealed that the major downtime of the swaging machine was due to labour non-availability as the helpers associated are routinely taken to work on other forming machines.

Problem

Swaging process is a type of forming process. In this process, a hole which is supposed to be swaged is heated up till the heated area is red hot. This process is carried out to extrude the holes of the nozzle opening. The job is placed on a stand and placed on the machine. The process is carried out by performing swaging in the descending order of the diameter of the hole. The heating of the job is done by heating torches. It takes 7–12 min depending upon the size of the hole. After heating, once the hole is red hot and the required temperature is obtained, the punch is swaged and the swaging for one hole is done. After the swaging for one hole is done, the punch is set up for the next hole and in the meantime the workers take rest. Similarly, diameter holes are swaged together before changing the dye punch. To calculate the time taken per hole is 7–12 min heating period and 5–10 min of rest before starting the next nozzle. So, the total time taken per nozzle is 12–22 min. Five workers are assigned to the machine to heat the job. The most downtime of the process is because the labour is being called to help out on other workstations. This leads to staking of the job near the swaging machine. So, to reduce the downtime and increase productivity, an alternate method for heating the holes was implemented.

Implementation of Induction Heating

To make this process more effective and leaner, an automated induction heating idea was pitched to the people in charge. By implementing the induction heating method, the holes will heat up faster compared to the manual heating process. The 5–10 min rest that the workers were taking was eliminated as the process is automated and does not require lot of labour. The need of the five workers on this machine was reduced to one single worker. Hence, the workers were free to help out on the other machines where more labour was required. The only drawback was increased consumption of power which can be squared off by increased productivity and reduced labour requirement.

4 Conclusion

Visual dashboard display and modified data sheets made the data analysis process more accurate and efficient and gives more information about the process in a single slide, where all the data related to the machines are displayed graphically. The visual representation of the data makes it easy to comprehend the production entry and give an overview of the machine and the work rate of the machine. The dashboard displays are accessible to everyone and the authorities could therefore easily help the workers in interpreting the work to be done and the downtime hours to be covered up. Thus, visual data display aided in understanding the process better and helped in focusing on the certain points which otherwise go unnoticed.

Implementation of induction heating reduced the time taken to finish one job and also reduced the labour requirement. This freed up the labour time which can now be effectively utilized on the other machine besides reducing labour fatigue. This helped in increasing the productivity.

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Improvement in Productivity of Assembly Line by Cycle Time Reduction: A Case Study

Devanshi Vaghela, Hari Vasudevan, and Rajendra Khavekar

Abstract This study was undertaken in a biomedical equipment manufacturing organization, situated in Mumbai, so as to improve the assembly process using various ways to reduce cycle time as well as by applying other productivity-oriented methodologies. The primary motive was to generate a lean solution and calculate the value added to the overall production. Installation of automated tools in order to enhance the cycle time reduction of subassemblies, gathering individual worker efficiency data, and usage of jigs in photometer assemblies was involved in the study. After this study, total cycle time was reduced from 52 h per machine to 43.3 h per machine approximately. The organization achieved a saving of Rs. 3.2 LPA and also more number of machines were delivered to the markets per year.

Keywords Cycle time reduction · Automation · Worker efficiency · Process improvement · Jigs · Productivity

1 Introduction

A variety of methodologies may be used to define the term "cycle time" in organizations. For instance, when describing it in the manufacturing sector, it may be described in terms of the average time required to produce a product, beginning with the receipt of raw materials and ending with the completion of the product. Cycle time is composed of two components: process time, which occurs when a workpiece is treated or machined to bring it closer to its final shape or size and delay time, which occurs when the workpiece remains idle waiting to move to the

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next stage. Cycle time is a widely used and straightforward concept that incorporates both variable and fixed activities, such as order entry, inspection, processing, storage, transportation, and waiting [1]. These activities include time spent on non-productive pursuits and time spent on productive ones. Production time can be broken down into technological time, production time, and setup time, as well as non-technical time, control time, transportation time, and packaging time. Cycle time helps in the sustainability and competitiveness of an industry. Similarly, reduced cycle time durations are reported to have a substantial impact on "operational planning in production" and also contribute to improving "customer order fulfillment" efficiency and thereby productivity. Productivity as a measure can be enhanced in industries by decreasing the cycle time and also by controlling the process statistically.

Photometers, as part of a biomedical equipment, are widely used in the industries and that depends on the type of business, industry, firm, or organization. In order to enhance the productivity of photometers, it has been found that it is very important to test each lamp supplied with the photometer. This study is an attempt to improve the productivity of an assembly line, involved the manufacturing of photometers, by cycle time reduction.

2 Literature Review

In biochemistry, a photometer uses proportionality of the color of the sample with the concentration of the parameters being tested. When a beam of light passes through the colored sample, the test material absorbs energy with a particular wavelength. By measuring the transmission or absorption, the photometer determines the sample's color. Interference filters of superior quality accurately restrict the wavelength and get high-precision measurement results [2]. The lamp or the light source plays a very important role in the same. A minor difference can change the end result, which eventually gives incorrect readings to the consumers. Therefore, it is very important to test each lamp supplied with a photometer and enhance their productivity of the process [3]. Christopher [4] expressed that the success in any competitive context depends on having either a cost advantage or a value advantage, or ideally both. Today's business environments are reaching a point, where competition for survival and market share is considered an obligation. Upon exploring the global economy, it shows that being good is not sufficient; therefore, every organization really tries for transcendence, if it wants to remain in the competition [5, 6].

In an effort to remain competitive in world market, industries must not only design and offer better product and services, but also are required to reform their manufacturing processes and operations [7]. Vasudevan et al. [8] attempted to improve the productivity of blow molding process using energy saving. It was noted that the manufacturing industries are constantly on the lookout for newer ways to enhance the process continuously, so that rework could be minimized.

Productivity is a measure of an efficiency with which the resources are modified into useful goods and services [9]. Productivity can be enhanced by decreasing the cycle time and controlling the process statistically [10]. Focus is necessary on efficient use of capital, and a suitable environment is necessary in the organization to enhance the productivity [7].

3 Case Study

This study was conducted in a biomedical equipment manufacturing organization, situated in Mumbai. It was decided to study the cycle time and try to enhance the same using automation, development of jigs, and implementation of worker efficiency. All these are explained in detail below.

3.1 Cycle Time Before Study

It takes roughly 52 h to assemble one XL200 biochemical analyzer machine that includes a photometer. The organization, wherein the case was conducted, has a monthly target of 100 machines, but due to higher orders and processes, it slows down and the target wasn't met many a times. As a result, the management of the organization decided to investigate and reduce the cycle time, wherever possible. Before the study was conducted, it was decided to calculate the cycle time and observe the assembly process of the firm. In order to investigate and reduce the cycle time, it was observed that each and every process that happens on the production line be noted down with multiple possibilities of reducing cycle time at the respective stations. For the same, multiple tools and studies were used. Table 1 shows the detailed cycle time required for the assembly of the machine.

Table 1 Cycle time of assembly before study

Process	Cycle time in hours
Assembly of chassis	4
Wiring and looping	16
Hydraulic connection	9
Mounting of subassemblies	4
Inspection and testing	8
Paneling	3
Final quality check	4
Packaging	4
Total	52

Table 2 Process flow in assembly line

Process no.	Description
10	Assembly of chasis
20	Wiring and looping
30	Hydraulic connection
40	Mounting of sub-assemblies
50	Inspection and testing
60	Panelling
70	Final quality check
80	Inspection

3.2 Process Cycle Efficiency

The Process Cycle Efficiency, often known as the "Value Added Ratio," is a ratio that indicates the amount of time spent, adding value to a process. The greater the value, the more efficient the procedure is. Often, material spends 95% of its time waiting. This is owing to the time delays introduced by less than 20% of workstations, dubbed "time traps." Value stream mapping enables companies to discover and eliminate time traps. Cycle efficiency quantifies the proportion of value-added time. A lean process is one, in which the time spent on value-added activities exceeds 25% of the overall lead time.

3.3 Observation

First step was to map the entire main assembly line during the first few days of the study. Table 2 highlights the flow of the processes on the main assembly line. In the start, each and every process was minutely observed and later using a stopwatch, it created a preliminary data. A time study was conducted and it is defined as a work measurement approach for documenting the times and rates of work for the elements of a certain project, performed under specific conditions and analyzing the data to determine the time required to complete the project at a certain level, in terms of performance.

4 Methodology

After studying the assembly process minutely, it was decided to implement the automation as well as development of jigs and implementation of employer's efficiency data sheet to reduce the assembly cycle time.

Fig. 1 Manual tubing cutter

Fig. 2 Automatic tubing cutter

4.1 Implementation of Automation

Automated Tubing Cutter: Biomedical machines have a lot of hydraulic plumping and piping, which require trimming and cutting for the same. Pipes carry all the water, cooling, and reagents throughout the machine. Each one has to be of a set length and is cut using a manual cutter and a ruler (Fig. 1).

An automatic bench top tubing cutter was ideal for medical and flexible tube processing. Since these machines require a lot of tubes to be cut, automation was incorporated in the line (Fig. 2). Automating process reduced the risk of contamination by human contact and increased the accuracy, speed, and productivity. The tubing was indexed by a dual drive tractor belt system for high accuracy. For easy operator use, the indexing motor was controlled by the touch screen, as it was to simply enter the length and the number of pieces.

4.2 Development of Jigs

Reference Jigs: Jigs were designed for barcoding and RGT calibration, which eventually helped in reducing the time required for barcoding the stickering process and improving the accuracy of the operations as well. The computer-aided design of the jig is shown in Fig. 3.

Lamp Optics Holder: A new test jig was implemented (Figs. 4 and 5) for lamp light as cross light reflection would lead to improper voltages and waviness in graph. To avoid this, the lamp was previously aligned and fitted on lamp mount of photometer casting. This new lamp optics holder helped in getting accurate voltage readings as well as less efforts in alignment and calibration process was required, which reduced in time requirement and that finally led to productivity improvement as well as material rejection.

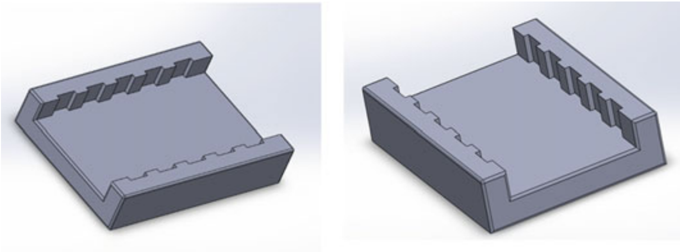


Fig. 3 Reference jigs

Fig. 4 Lamp optics holder jig (CAD model)

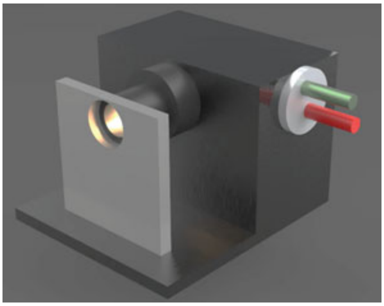
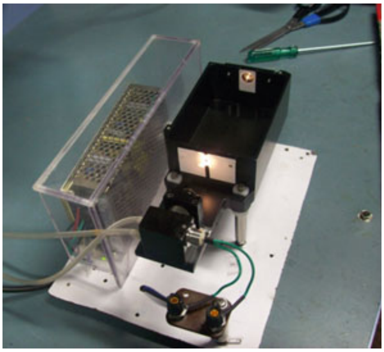


Fig. 5 Lamp optics holder jig (actual)



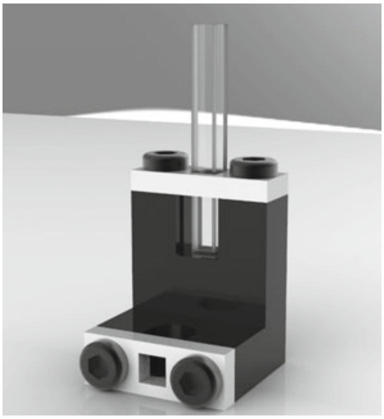


Fig. 6 Neutral density testing jig (CAD model)

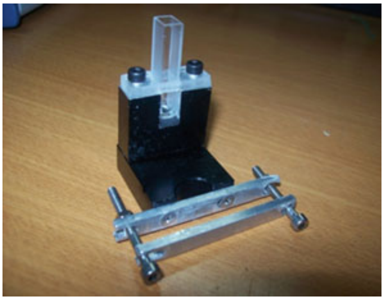


Fig. 7 Neutral density testing jig (actual)

Neutral Density Testing Jig: To conduct the procedures on all neutral density filters and subtract the water, outer diameter was measured initially. A new testing jig (Figs. 6 and 7) was developed to make this process accurate and simple. It helped in reducing the assembly cycle time.

4.3 Implementation of Worker Efficiency Data

Worker efficiency sheet was introduced (Fig. 8) to find the idle time of each worker. After implementing the same, idle time in the assembly was reduced. The graph (Fig. 9) highlighted the times of a subset of employees before and after implementing the worker efficiency sheets for their respective task. The worker efficiency sheets clearly highlighted as to where the wastage was occurring. As a result, the organization was able to save the time from the non-redundant processes by eliminating excess motion/processes or just cut down on wastage done by the process operators.

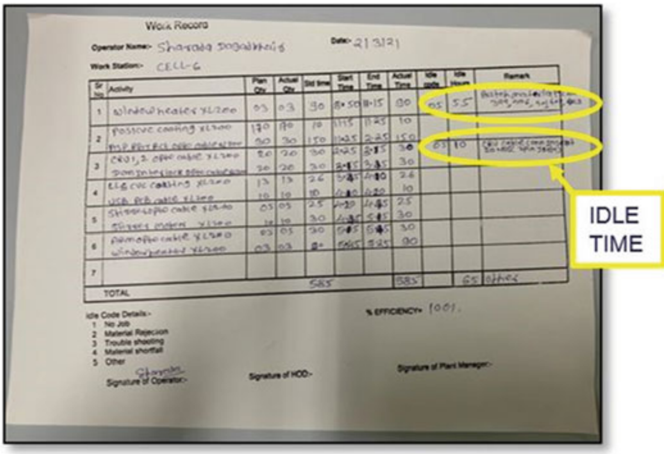


Fig. 8 Worker data sheet

Fig. 9 Graph of time requirement of the "before implementation of data sheet versus after implementation"

5 Conclusion

This study was conducted to improve the productivity of a photometer in an organization in the biomedical equipment arena, using various productivity methodologies, particularly cycle time reduction. Barcoding, labeling, and stickering alignment jigs used were found cost effective and also it reduced the waste. Figure 10 shows the reduction of time in each activity of the assembly of photometer after implementing this study. By automating the manual processes, additional idle time was created, which was used for more complicated production processes. By replacing the conventional adhesives in complex hydraulic (laundry) assemblies, it was also found possible to save money and time. The study found that it was possible to reduce

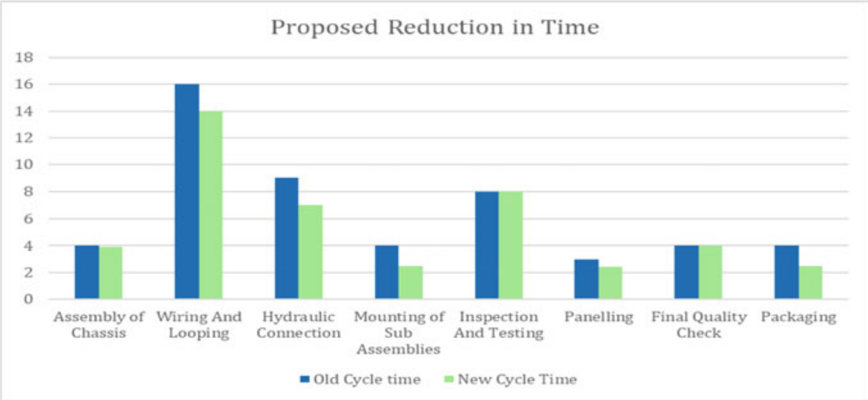


Fig. 10 Graph highlighting the cycle time reduction

the cycle time required in the assembly process per machine from 52 to 43.3 h, which saved Rs. 3.2 LPA to the organization. It also further enhanced production of more machines and customer satisfaction.

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A Challenging Future of Industry 4.0—New Technologies and Lean Production Systems

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Abstract In current years, the industrial system has experienced significant changes as a result of additional advancements known as Industry 4.0 (I.4.0), particularly in the fields of digital automation and production. Industry 4.0, the fourth industrial revolution, was first proposed in Germany and has received a lot of attention in current research. The Internet of Things (IoT), information and communications technology (ICT), Enterprise Integration (EI), Cyber Physical Systems (CPS) and Enterprise Architecture (EA) and are all tightly linked to it. Industry 4.0 is the downfall of the standardized. The purpose of this article is to delve into this new domain and provide the current state of research on I4.0 and lean production systems along with the definition and framework, with the use of novel and key technologies used in I4.0 such as cloud computing, additive manufacturing, industrial Internet of things, cybersecurity and autonomous robots and then tried to find out the correlation between lean manufacturing and Industry 4.0.

Keywords Industry 4.0 (I4.0) · Industrial Internet of Things (IIOT) · Lean production systems · Cloud Computing (CC)

1 Introduction

The concept "Industry4.0" was introduced by Henning Kagermann, a physicist, and former head of the SAP board of directors, in 2011 and then Industry 4.0 has grown into a scheme for the growth of German industry [1]. Since the first Industrial Revolution, which was sparked by the creation of steam engine, multiple revolutionary

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developments have emerged, including digital machines and an automated production system, all of which have had a substantial impact on productivity. Customization of need, waste minimization, and rapid product development times are the major factors and catalysts for the extreme shifts [2].

Industry 4.0 is a manufacturing system that integrates information technology (IT) with operational technology (OT). The conception of Industry 4.0 is the outcome of the fourth industrial revolution's technical advancements [3]. Industry 4.0 ushers in a new era of digitalization. Business models, settings, automation systems, equipment, operators, goods and services are all automated. Everything is linked together within the automated environment and its virtual depiction. The physical movements would be continuously tracked via internet technology [4]. Industry 4.0 comprises a vast variety of principles, including advances in automated machinery, digitization, connectivity and downsizing.

Furthermore, Industry 4.0 is based on a combination of dynamic value-creation networks in terms of the physical fundamental system and software system with other departments and areas of the economy, as well as other manufacturers and industry types [5]. The Industry 4.0 idea is increasingly being adopted in businesses through segmented investment initiatives in certain sectors of operation. In the literature, the methods for applying Industry 4.0 in businesses have not yet been detailed in depth in a complete and accurate way. There are no articles that describe pre-made examples and procedures) for implementing specific capital projects based on the Industry 4.0 idea. In both manufacturing sectors and particular industries, the selective implementation of advanced analytics of Industry 4.0 happens [6, 7]. Despite of this kind of uncertainty this paper has tried to explain in detail about some of the key technologies that can be used in the I4.0. Different sectors of industries such as FMCG, transportation, automotive, aircraft, have begun to implement concepts and methods of Industry 4.0. These industries have distinct features, resulting in varied digital transformation routes and applications [8].

This article also tries to give relation between I4.0 and lean production systems along with their definitions and frameworks. Lean has grown in popularity as a method for achieving high-efficiency operations in businesses. It is demonstrated that a process-oriented organization, and hence Lean Production Systems, may aid in the effective and long-term deployment of Industry 4.0 in the manufacturing environment. To allow for a thorough examination of the interdependencies between Lean Production Systems (LPS) and Industry 4.0 [9]. Customers may pick from a wide range of items with a lot of options due to the growth long list of rivals and the shift from a seller to a buyer's market. This raises the demand for items, which must maintain a consistent pricing and quality level.

As a result, the necessity of cost-effective producing in lot size 1 for manufacturing firms will grow in the future. Because of this the concept of mass customization started trending and to survive in this kind of competitions industries have to manufacture smartly with lean production system and do to it in efficient way I4.0 can be used this kind of collaboration or interdependency can be very beneficial for the seller as well as customer [10]. The key contributions of this paper are as follows:

- Definition and framework
- Key technologies of I4.0
- Correlation Between Industry 4.0 and Lean Production System.

2 Definitions and Frameworks

This section introduces and exclusively focuses over definitions and frameworks in the field of lean manufacturing.

2.1 Industry 4.0

Davies (2015) defined Industry 4.0 as the overall revolution and transformation of all industrial manufacturing by the integration of communication technologies, information and Internet with traditional manufacturing processes [11] (Fig. 1).

It is a broad term that refers to a variety of perspectives, industries, corporate functions, technologies and fields. Because of the high level of activity and continuous development of new approaches, concepts and solutions on the part of solution providers, hardware manufacturers, businesses, research institutions, the focus and understanding of Industry 4.0 are constantly evolving. Industry 4.0 entails a pattern shift away from automated manufacturing, which was pioneered during the industry 3.0 revolution, moving toward intelligent manufacturing concept. It is a strong combination of information technology (IT) and operational technology (OT) in production, and it would heavily rely on and use concepts such as the Internet of Things (IoT),

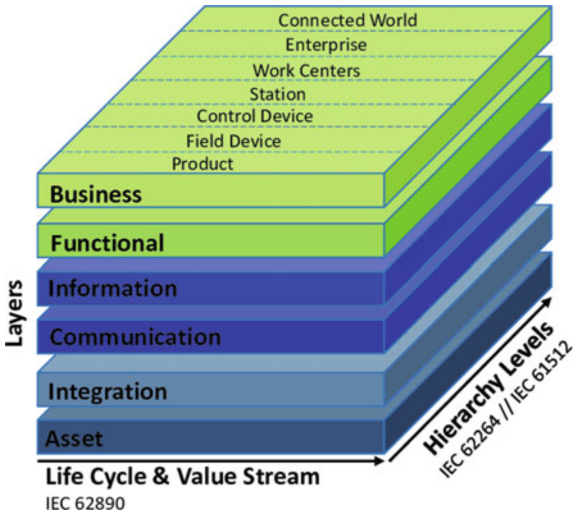

Fig. 1 Reference architecture model for the Industry 4.0 approach in Germany (RAMI4.0) [12]

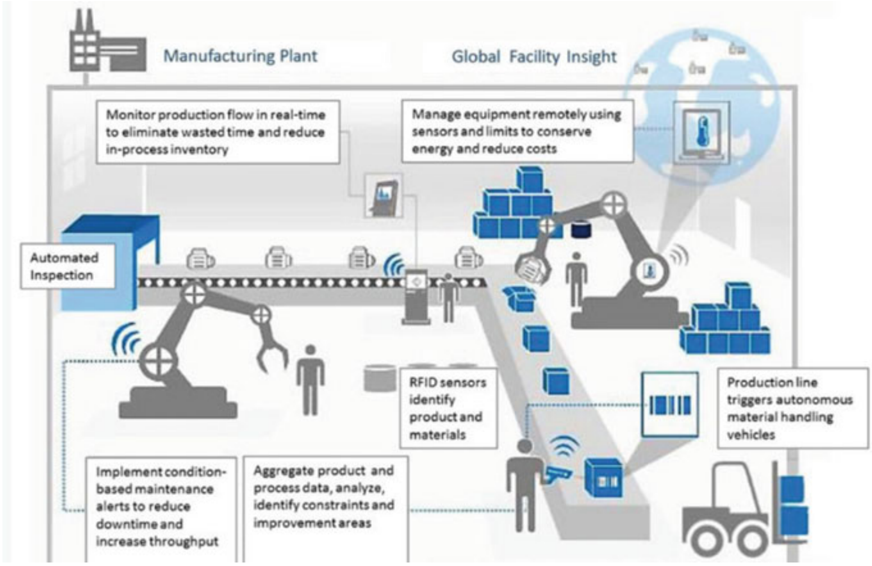

Fig. 2 Manufacturing plant utilizing CPS for Industry 4.0 [14]

Cyber Physical Systems (CPS) to facilitate this change [12]. The establishment of state-of-the-art technology relies on businesses remodeling newer systems that take into the account on how the technology will optimize departments to allow company employees do what they excel at. [source] Thereby, Hermann et al. identified six design principles that firms should adopt in order to reap the benefits of Industry 4.0 [13] (Fig. 2).

2.1.1 Interoperability

Interoperability could be defined as the capability of people, machines and other IoT device in a business to interact, co-ordinate and share data. This capacity to link everything "through open nets and semantic descriptions" in the organization with everyone and everywhere is critical for leveraging data insights to optimize operations and boost efficiencies.

2.1.2 Virtualization

In Virtualization, a virtual copy of a physical world is created with data from sensors which would monitor various real-time physical processes in the firm, which allows one to understand their equipment better, extend the lifespan of components, expose operation inefficiencies, and reduction in maintenance costs.

2.1.3 Decentralization

The increased demand for specific items makes it more difficult to centrally control systems. However, with Industry 4.0, all technology involved is decentralized, which allows the firm to establish decentralized systems across all industries on a worldwide scale. For, quality assurance and traceability purposes, it should be mandated to have track of the whole system with failure in tasks performed being reported to higher level.

2.1.4 Real-Time Capability

Real-Time capability could be defined as the compilation and evaluation of data real-time, which allows the firm to take decisions immediately at any moment. It allows the firm to inspect the daily-operations and check out for potential opportunities to increase productivity. It also enables one to analyze micro trends, respond instantly to breakdowns and problems with production line and take a proactive approach to inefficiencies and abnormalities.

2.1.5 Service Orientation

To separate the firm from the competition through a service-oriented model, it should leverage data insights to give unique services to the consumer base. Additionally, it should begin to identify repetitive, non-core operations that may be minimized or eliminated via the use of technology so that employees can focus on key business responsibilities.

2.1.6 Modularity

Modularity could be defined as the firm's ability to flexibly adapt to dynamic requirements and needs of the industry by substituting or developing individual modules. Identifying the company's own primary differentiators is the greatest place to start when deciding how to use a modular business structure. Modules can be easily adapted in case of periodic or changed product characteristics.

2.2 Lean Production Systems

The Lean Production System (LPS) has a rich history of providing efficient and target-orient processes to overcome hurdles faced by firms. Originated from Toyota Production System, it can be defined as "an enterprise-specific methodical system of rules for the continues orientation of all enterprise processes to the customer in order to achieve the largest by the enterprise management", which strives to achieve the goal of systematic and continual elimination of non-value-added tasks in order to give the best level of customer satisfaction [9]. Lean Production System has now been established in almost all the industries and has become a mandatory industry standard to be followed [14]. The procedures strictly follow lean principles, however with company-specific methods and tools involved [15].

3 Key Technology of I4.0

I4.0 is distinguished by advanced automation and digitalization processes, electronics and IT for production and assembly [1]. I4.0 focuses on the production of smart and informative systems such as mechanical and human machine interactions which are concerned with the flow of data via smarter and dispersed interaction between the systems from the operations and manufacturing management perspective [2]. I4.0 encourages connectivity, adaptability, flexibility, strategic planning, productivity and cost savings among other things [16] In mutually dependent sectors, the execution of I4.0 should be multidisciplinary. In this section the various key technologies are discussed that are mainly used in I4.0 [3].

3.1 Cloud Computing

Cloud Computing (CC) is an eco-friendly technological advancement for industries who would like to invest in IT infrastructure. Cloud Manufacturing (CMfg) has been developed to employ CC technology in industrial applications with a view to improving present-day production techniques [4]. CC in the production line as a CC manufacturing version-employing directly cloud apps for manufacturing, web-based apps or computer-aided machining are illustration of feasible CC system implementation [17]. These softwares are executed in two CC network service tiers corresponding to Software as a Service (SaaS) and Platform as a Service (PaaS) [5]. Benefit of the entire innovative form of cloud service, CMfg systems are built on the Service-oriented Architecture (SoA) around the cloud and offer manufacturing infrastructure. The Infrastructure as a Service (IaaS) layer on CC system is reflected.

The new CMfg computing, and service-oriented production approach comes into this with the integration of technological advances [18]. A technology like CMfg allows users to request for services at all stages of a product's life cycle, from ideation to production to management, etc. [6]. CMfg is an information production model. Information performs the essential part in the execution of a process. CMfg's approach utilizes CC, Big data, Internet of Things, Cyber Physical Systems, the interconnected production industry, service-oriented production, virtual production and virtual business [7]. CMfg platform integrates 3D printing services and resources, Mai et al. Figure 3 shows how the CMfg can be used in various services,

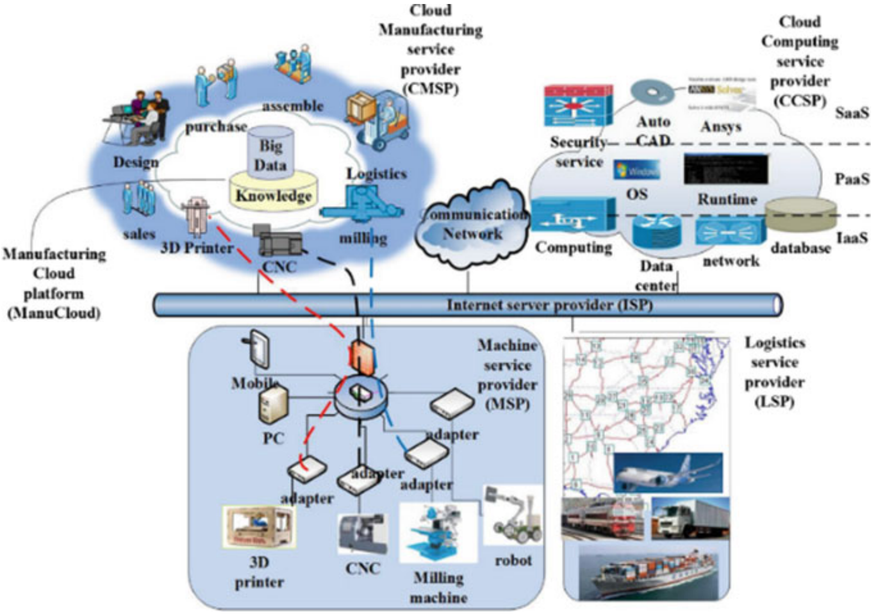

Fig. 3 Various services in cloud manufacturing [8]

e.g., design, 3D printers, assembly, simulations, modeling, software, etc. [19, 20]. Because of the strong relationship among 3D printing and 3D models the model management and the integration of online equipment in the building of the CMfg 3D printing service platform [8].

3.2 Additive Manufacturing

The concept of additive manufacturing (AM) is continuously getting adapted and delivers very viable implementations into engineering industry. Jian et al. stated about AM's capability for replacing several traditional industrial techniques was addressed [21] AM is a technology that allows new goods, operating models and new supply—chain to be supported. The aggregate term AM includes a series of technologies that allow the "3D printing" of actual items [9]. Shin et al. discussed how AM processes cover geometry design, computer tools and interfaces development, material design, process mapping and control tools, AM applications such as nanoscale (biological), micro scale (electronics), macro (personal goods, automotive) and large scale applications were discussed [11]. In addition, AM processes covered the topics (architecture and construction, aerospace and defense) [10]. Chang et al. suggested that in order to manufacture complex 3D component in high resolution, multi materials or multi-functional characteristics for the next generation AM operations, new technique such as micro/nano printing of the 3D scale, bioprinting (biomaterial AM) and 4D printer (combining AM with smart materials (stirring responsive that changes its form or functional properties) [11].

3.3 The Industrial Internet of Things

Industrial Internet of things (IIoT) describes the connections to the Internet of industrial equipment such as components and/or machines [22]. Higher production efficiencies with the big data analysis, for example, by combining the acquired detection of data in an installation with IoT network [23]. With the development of smart phones, IoT has been developed. As the most important technologies presenting linked Intelligent systems, IoT may be done through connecting Radio Frequency Identification (RFID), Wireless Sensor (WSN), middleware, cloud computing, IoT application software and Software Defined Networking (SDN) [12]. The Industrial Internet of Things (IIoT) connects industrial machinery such as components and/or machinery to the internet in order to possess real-time data accessibility and high dependability in industries Fig. 4. shows how IIOT is involved in industries [24]. For example, integrating the sensing data gathered inside one plant with IoT platform improves process efficiency through big data analysis [13].

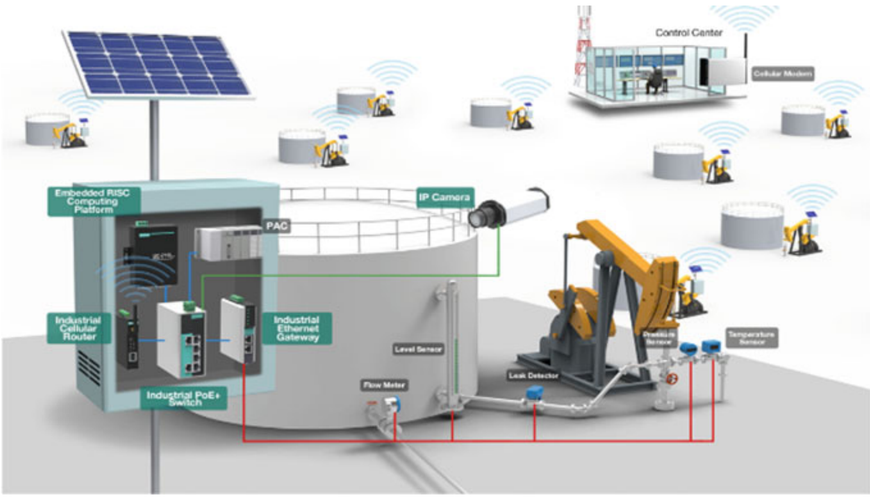

Fig. 4 Use of IIOT in industries [15]

3.4 Cybersecurity

IoT, virtual workspaces, remote monitoring, cloud-based data, etc. are several accessible options that increase vulnerability that result in exposed data for individuals and businesses. The danger scenario is realized by the ambiguous and dissolving corporate borders [15]. IoT must be developed on the basis of secure connections at every step in the production framework, and connectivity between installations as essential aspects of the quality of the supply chain must be ensured [25]. The growth of connected technologies means more cyber attacking risks. I4.0 technologies must make it possible to create a cyber-based security environment that will benefit CS [26]. I4.0 contains essential, protected information. The success of the sector is crucial to information and data security. It is vital that only authorized individuals have data available [2]. Industries could stop working by a cyber-attack, so industries lose extra money, but the major problem are cyber-attacks aimed at systems needing security and posing a massive risk to the employees' safety. It is necessary to determine integrity and sources of information. These all threats can be reduced by always continuously updating the antivirus, keep maintaining firewalls, installation and implementation of multi-factor authentication, the system must be end-to-end encrypted, should not connect any external unprotected or unknown device such as hard disk, pen drive, etc. to the system [17] (Fig. 5).

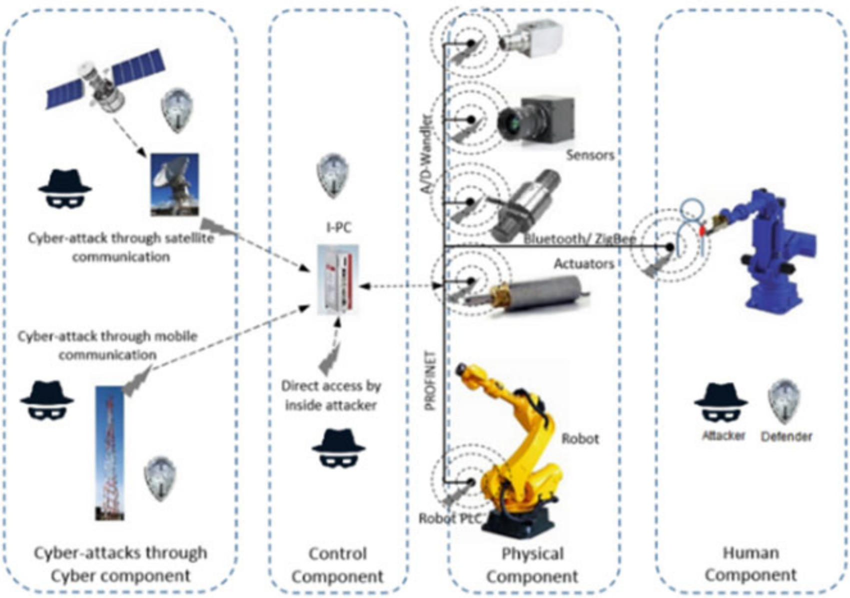

Fig. 5 Cyber-attack paths for human–robot in an industry connected production [20]

3.5 Autonomous Robots

The production framework moves swiftly from mass production to custom—made production that requires, for example, robots as a reconfigurable automated system [27]. This trend leading to production adaptability for a broader product variety focuses ideally on lot size one and has an influence on the production technologies of manufacturing organizations. It is vital to note that completely independent robots decide to handle the surroundings constantly fluctuating without the intervention of technicians [28]. An Autonomous Industrial Robot (AIR) or numerous AIRs working together can enhance messy or dangerous industrial applications in unpredictable conditions. Hassan et al. mentioned that it is feasible to have a wider range of industrial operations with the implementation of many autonomous robotic systems functioning as unit. As a result, the human–robot barrier is segmented for industrial firms, allowing for better cost and flexibility for operations [14].

4 Correlation Between Industry 4.0 and Lean Production System

The current scenario of competition and need of market, the efficient production is now become necessary and for that the industry must use lean production system along with the current technology more precisely that indicate for the use of I4.0 [29] (Fig. 6).

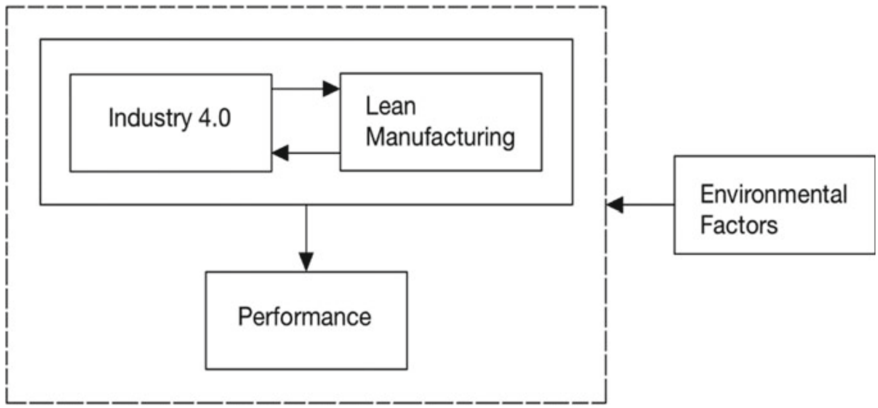

Fig. 6 Framework of I4.0, lean manufacturing, performance and environmental factors [16]

4.1 Lean as a Facilitator for Industry 4.0

The creation and execution of efficient processes with specified standards and a strong customer focus is a significant feature and pursued goal of Lean Production Systems. Before organizations begin to automate certain production processes, lean procedures must be defined in an efficient manner [9]. Hence, it requires a high level of management strategy with well-defined procedures, suppliers, customers, tasks and deadlines. Thus, Industry 4.0's adoption of horizontal and vertical networking into Lean Production System allows for greater integration of consumers and suppliers into the value-addition process [15].

4.2 Industry 4.0 Progresses Lean Progression System

This section shall focus over current literature on how Industry 4.0 can benefit lean manufacturing, both during the introductory phase and for existing lean systems. Value stream mapping (VSM) is a fundamental lean principle that is frequently used as the first step in the lean implementation process [30]. It is used to map the current process and identify areas for increasing efficiency in the value chain. Traditional Value Stream Mapping (VSM) is a traditional "pen-and-paper" process, and data collection can be complex and prolonging. Not to further mention, it only provides a "snapshot" of the process, and minor changes could drastically alter the picture taken in consideration. Industry 4.0 can improve Value Stream Mapping process by collecting data in real-time [31, 32]. It can be contended that smart manufacturing may help firms attain a greater level of leanness, as they explore the influence of data collecting, big data analysis and integrated processes on lean manufacturing [33]. The rise of Industry 4.0 has broadened Jidoka's application range and proposes a smart Jidoka system based on Cyber Physical System concept [33]. It is observed that additive manufacturing methods like 3D Printing can help with several lean manufacturing goals, such as one-piece flow and just-in-time delivery [34].

Employing Industry 4.0 technologies, processes developed according to lean principles can be further optimized to deal with increasing complexity [35]. Furthermore, various authors in their research present multitude of ideas on transitioning to much smarter and leaner manufacturing methods [36].

5 Conclusion

In this paper, the concept of "Industry 4.0" was reviewed thoroughly where the study conducted on the topic covered via various sections and the concluding remarks regarding this paper are as follows:

- The study reveals and focuses about the newly defined concept of "Industry 4.0" the fourth industrial revolution which was introduced in 2011 for the first time which promotes the use of computed manufacturing as well as Lean production system.
- Industry 4.0 utilizes many latest technologies that were discussed in this paper which were cloud computing, additive manufacturing, the industrial Internet of things, cybersecurity and autonomous robots. Although there is no predefined structure or blueprint to implement I4.0 but the main moto is to reduce the unskilled manpower and increase the efficiency with perfection in each product manufactured in industry.
- Further, the paper tried to link I4.0 and lean production system and one cannot thing of these easiness and efficiency without correlating them with each other in that section the paper tried to explain about different facts that can support the section that I4.0 and lean production systems are correlated with each other, and one cannot think to implement I.40 without lean production system.

Future Scope

According to the paper I4.0 is in its early developing stage so there is a lot of scope in development and because of this I4.0 has plethora of things that can be done to improve it:

- With some further research, one can find the most efficient way of using technology for I4.0 for different domain of industries as every industry has different processes so restricting I4.0 to only one method would not be a great idea, this would provide a broader scope of study in industrial engineering field.
- The automation provides the future scope in correlating I4.0 and lean production systems.
- The developing countries should work on promoting I4.0 by this way these countries can grow.

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Productivity Improvement Using Principles of Kaizen

Krutik Panchal and Atul Dhale

Abstract Today's technologically driven environment where the business landscape shifts rapidly, forces many industries to face challenges and complexities be it manufacturing or service-oriented. And thus, to respond to these challenges, adopting lean methods has become important for organizations to sustain their business. Producing or delivering good quality products at higher productivity using minimum resources is the primary objective of any organization. The application of Kaizen, one of the pillars of the lean methodology helps accomplish this purpose.

Keywords Lean manufacturing · Kaizen · 5S · Productivity improvement

1 Introduction

Kaizen is a Japanese lean production methodology whose aim is to improve the productivity and efficiency of a workplace through continuous improvements. It specifically looks to optimize the resource utilization of an organization by eliminating or reducing different forms of waste present in the industry. The concept of Kaizen states that Small incremental changes amount to extraordinary results in long term. Another lean technique that complements Kaizen is 5S, which is also a Japanese management philosophy that delineates a structured approach to achieving a clean and orderly workplace by fixing places for everything, to improve productivity and efficiency.

We have discussed steps to achieve positive results using the methodologies of kaizen and 5S. A detailed illustration of four different projects (cases) undertaken

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during the In-plant training at one of the world's leading providers of industrial sealing technology, where the application of kaizen improved the existing processes leading to the reduction in cycle time and manufacturing costs thereby increasing the output and productivity.

2 Literature Review

Continuous improvement using kaizen as an element that is driven by the management, it brings about a change that is aimed at reducing failures and increasing successes [1]. Unlike dramatic and impressive innovations that depend on huge investment in new technologies and equipment, kaizen involves achieving process improvement goals using small steps and their continuity. Therefore, leads to a few radical changes that are the outcome of innovative ideas which take place over time without consuming huge capital [2].

Seven categories of waste are discussed along with a case study at a core shop of a foundry wherein the efficiency of the workplace was improved by the elimination or reduction of different types of wastes associated with the manufacturing processes [3]. Kaizen activities helped a small-scale manufacturing company to enhance their productivity, safety, and efficiency. These objectives were accomplished by the application of semi-automation in manufacturing processes which helped in eliminating human errors [4]. Application 5S methodology at scientific equipment manufacturing company by adopting the Plan, Do, Check and Act (P-D-C-A) approach emphasized on creating awareness among the employees to use 5S as a tool that makes a difference and not just a philosophy [5].

Six steps of continuous improvement kaizen which was taught at Toyota intends to simplify by removing as much of the mystery in the process as possible enabling the kaizen practitioners to better their skills and confidence [6]. Research is focused on the less successful kaizen events; Understanding these less successful cases plays a vital role in organizational learning. Few methods have been suggested that engineering managers and researchers can utilize to measure and examine the performance of a kaizen event [7]. For kaizen of continuous quality improvement (CQI) and its role in healthcare organizations. A web-based application tracked and gathered the kaizen initiatives for over four years which resulted in over four hundred improvements in the emergency department system. The authors, however, concede that the impact on patient outcomes remains unknown [8].

3 Methodology

The Kaizen philosophy stresses that to achieve higher productivity and efficiency, a workplace requires a clean atmosphere, protection, and discipline. Kaizen is a Japanese word that stands for "Continuous Improvement". These Continuous improvements are usually a large number of small improvements that progress over time leading to exceptional results. With kaizen, an organization's resistance to change weakens. This methodology enhances all the business functions of an enterprise and includes all the staff from the top management to in-line workers.

The implementation of the Kaizen methodology involves a few simple yet effective steps that are elaborated below:

Step1: Involve your employees.

Incorporating the employees in the kaizen activities will not only empower them but also make the kaizen more effective. Employees should be the driving force of the change that leads to continuous improvement. The process occurs slowly but with time, it will lead to tremendous success.

Step 2: Analyze the process.

The second step to kaizen suggests that everything can be improved and should be improved. To do this, the overall feedback from all the staff is necessary, and make sure that every business process involved within the organization is surveyed.

Step 3: Think and find solutions.

The kaizen teams consisting of innovative employees must concentrate on problem-solving by devoting time and effort to brainstorming the solutions to the issues faced by the organization.

Step 4: Implement the solution.

To experiment with new theories and ideas, select a pilot environment for small-scale implementation. This is effective, especially in larger companies as there may be multiple developments going on and it should disturb or restrict the routine work environment. Patience is the key, taking small steps at a time will gradually lead to significant outcomes. The applied practices must be planned properly and monitored so that the effects after the kaizen implementation can be tracked.

Step 5: Study the results.

The results obtained after the implementation of the kaizen must be reviewed thoroughly. Compare the results with the conditions prior to implementation of kaizen. Also, discuss the situation of the area where kaizen is implemented and obtain feedback from employees who work there.

Step 6: Standardize the solution.

If the implementation of kaizen yields positive results and has improved the process, then standardize the kaizen in all divisions wherever it is applicable to ensure a smoother and efficient operation of the organization. However, if this is not the case then move back to step 3.

4 Implementation of Kaizen

Kaizen 1: Cycle time reduction by sourcing a new tool.

The purpose of this project was to test and compare the machining performance of the existing tool (HSS cutter) against the proposed tool (Index-able Carbide cutter) (Fig. 1). The tools were tested on a VMC machine for milling the Eccentric Grove

(Spiral groove) (Fig. 2). For the given eccentric groove milling operation, the cycle time for machining was noted for both the tools. The cycle time of the existing tool was found to be 6 h and for the proposed tool it was 1 h and 45 m. That is a significant difference. Further on, both the tools were tested on regular jobs in the machine shop and their respective average tool life was noted (Table 1). The results found were very positive and to arrive at a conclusion, a cost analysis was carried out (Table 2). For the existing cutter, the cutter is sent for regrinding after the completion of its life so that the same cutter can be reused again, after regrinding it can machine up to 2 components. The cutter can be reused up to 2 regrinds after which it cannot be used again. In the case of the proposed tool, since it is an index-able cutter, the inserts need to be changed after the completion of its life. Here, it takes around one minute to change one insert.

Further on, a cost–benefit analysis was done to ensure that the changes made are indeed beneficial to the organization in the longer run (Fig. 3).

Kaizen 2: Waste reduction by Trepanning.

For manufacturing the components of a mechanical seal, the central core of the raw material needs to be removed by machining as per the design requirements. To

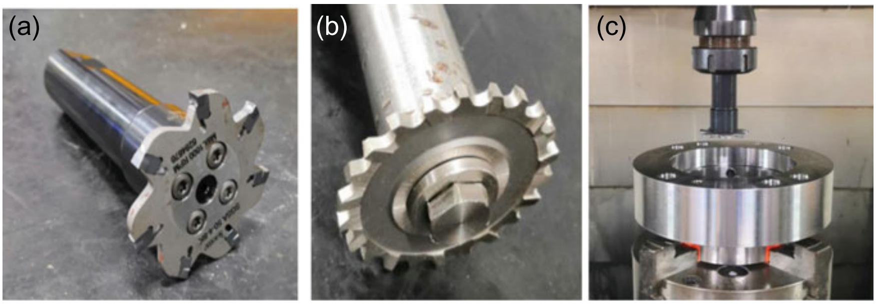

Fig. 1 **a** Proposed Index-able Carbide cutter **b** existing HSS Slit cutter **c** machining operation is done with the proposed tool

Fig. 2 Finished component after machining

Table 1 Cycle time—tool life comparison

	Existing	Proposed
Average life (nos.)	18 h	9 h
No. of components produced	3	5
% Increase in output/life	66.67%	
Total cycle time (h)	6 h	1 h 45 m
Insert contact time (h)	6 h	1 h 45 m
% Time reduction	71%	

Table 2 Cost per part comparison

	Existing	Proposed
Tooling cost/part (Rs.)	1073.81	1360.8
Machining cost/part (Rs.)	7200	2100
Total cost/part (CPC) (Rs.)	8273.81	3460.8
% reduction in CPC	58.17%	
Cost saving/part (Rs.)	4813.01	

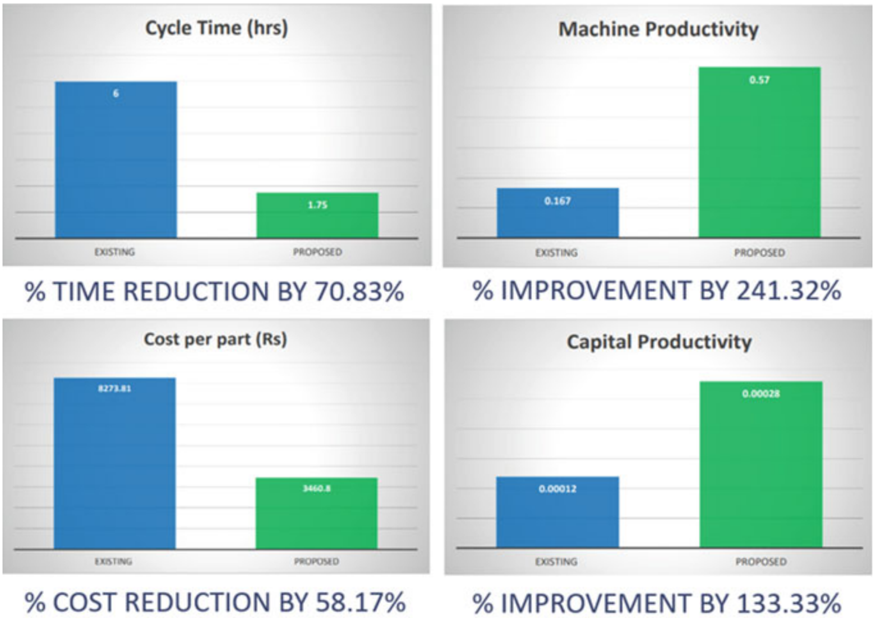

Fig. 3 Key results achieved

Fig. 4 Conventional methods versus trepanning

achieve this, the old practice involved machining operations like drilling and inner diameter turning. The maximum diameter which can be drilled is 50 mm which is subsequently followed by a turning operation along the inner diameter up to the desired dimensional limit. During these conventional machining processes such as drilling and turning, a large quantity of raw material is scrapped in the form of chips. To counter this, we replaced the conventional machining processes with an alternative machining process called “Trepanning” to reduce raw material wastage (Fig. 4).

Trepanning is a process in which deep circular grooves are machined such that it leaves a solid inner core behind. This method is not as power-consuming as solid drilling. Using this method, we can save raw material in the form of round bars which can be further reused to manufacture seal components. Three trepanning tools were developed for different diametrical ranges. Using these tools, raw material in form of round bars ranging from Ø 50 mm up to Ø 580 mm can be retained. Process comparison (Table 3) was done to assess both methods from a financial perspective. For this purpose, a pre-machined SS316 round bar of diameter 100 mm and length 110 mm is taken, on which a central hole of diameter 75 mm is to be machined. After leaving a machining allowance of 5 mm for finishing, core of Ø 70 mm × 110 mm is to be machined. The cost of an SS316 round bar is Rs. 450 per Kg whereas for SS316 scrap chips is Rs. 200 per Kg. Both the operations are done on the CNC machine for which the machine cost per hour is Rs. 1500.

A data sheet was maintained to monitor and track the amount of raw material which was retained using trepanning. During the months of January, February, March, and April, a total of 3050 kg of raw material was saved (Fig. 5).

Kaizen 3: Elimination of unproductive machining by employing a Customized tool.

In certain designs, there is a requirement of machining a radial curve of 5 mm on the inner as well as the outer diameter of the components. To perform this operation, the operator had to grind the regular turning insert to give it the required radial form (Fig. 6). Using the radius gauge, operators checked the curvature on a timely basis until the desired dimension is achieved (Fig. 7).

Table 3 Process Comparison and Cost Analysis

	Drilling + turning	Trepanning
Material allowance left (mm)	5	5
Setup time (m)	45	30
Operation time (m)	75	55
Total cycle time (m)	120	85
% Time reduction	29%	
Machining cost per hour (Rs.)	1500	1500
Machining Cost for operation (Rs.)	3000	2125
Savings (Rs.)	676	1521
Effective cost (Rs.)	2324	604
Cost saving (Rs.)	1720	
% Cost reduction	74%	

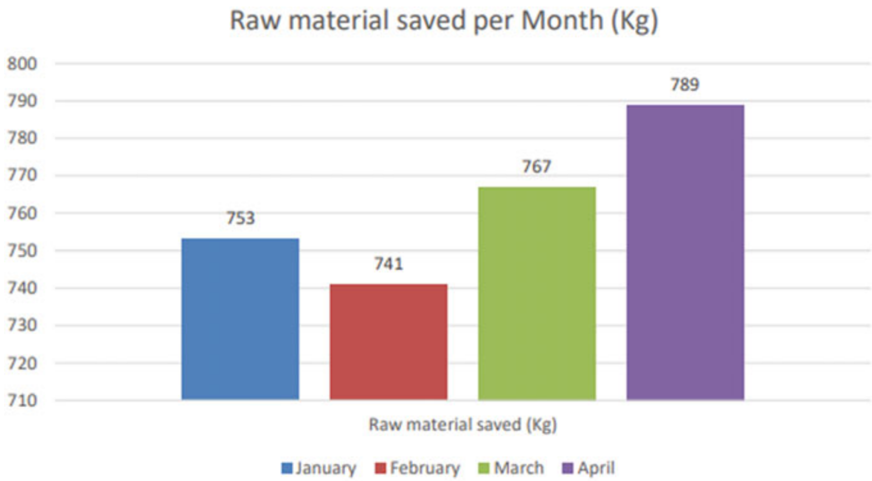

Fig. 5 Graphical representation of raw material saved

We looked to eliminate the grinding operation. We aimed to find a way with which we can achieve better machining quality and develop a simpler yet effective method to machine the components. For this purpose, a customized tool was designed and manufactured which serves the required purpose and fulfills the scope of project objectives. The tool is designed in such a way that only a single tool holder is required for machining along both inner diameter as well as the outer diameter (Fig. 8). Moreover, a special provision was made for the insert slots such that a round insert of a radius 5 mm can be used for machining. The use of customized tool eliminated the grinding operation leading to a reduction in machining time for the operation.

Fig. 6 Process flow for giving the radial form

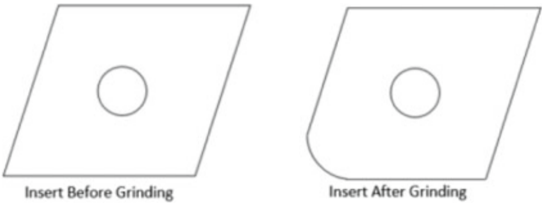

Fig. 7 Insert Form before and after grinding

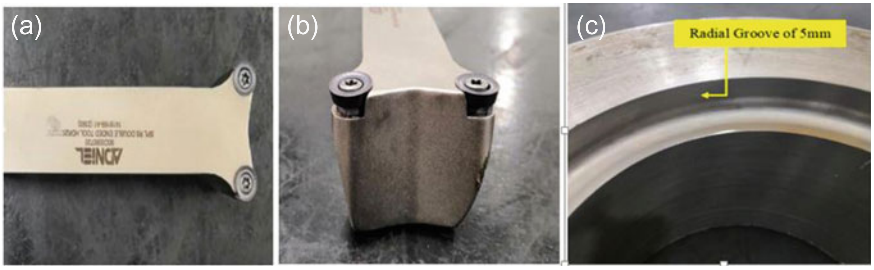

Fig. 8 **a** and **b** Customized tool **c** result achieved using customized tool

Kaizen 4: 5S Implementation.

In the Finished Goods (FG) Stores, cartons of packed products were found misplaced and not organized, workers were wasting time in search for cartons required for processing. It was observed that there was no standardized way or method which was followed to keep the FG cartons, they were placed randomly with no segregation or marking (Fig. 9). These cartons could fall and get damaged or broken resulting in a loss. The 5S methodology was implemented to control this, main objective of this project was to clear the path for movements, create a more organized and systemic inventory, and Standardization for the placement of FG cartons

Fig. 9 Finished goods section before and after implementation of 5S

Table 4 Time comparison—5S activity

Time taken to locate FG boxes		T (m)
Before application of 5S	(Atleast)	45
After application of 5S	(Atmost)	10

to reduce the time involved (Table 4) in locating them for dispatch and their proper storage to avoid damage.

5 Conclusion

In the case of eccentric milling operation, the proposed tool outperforms the existing tool. The figures indicate that there has been a significant improvement in machine shop productivity, rate of production (output), quality & surface finish. Along with a large amount of reduction in cycle time and manufacturing costs. The machine and capital productivity increased by 241.32% and 133.33%, respectively.

The implementation of the trepanning operation eliminated raw material wastage. The process comparison proved that it is not only cost efficient but also time-saving. Moreover, the saved raw material can be reused further.

The use of the customized tool for form radial machining eliminated unproductive machining activities and brought down the total cycle time by 30 m. Furthermore, it ensures a safe working environment, and the chances of accidents are also reduced.

By implementing the 5S methodology, the time required for locating a particular carton was reduced from 45 to 60 m to just 5–10 m. This has decreased the time delays for the dispatch of finished goods thus improving the overall productivity. The percent reduction in time achieved was 77.78%.

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Application of Work Measurement to Reduce the Cycle Time in Manufacturing Firm: A Case Study

Tejaswini Sapkal, Hari Vasudevan, and Rajendra Khavekar

Abstract One of the factors affecting the productivity of any manufacturing firm is the Cycle time. Lesser the cycle time required, the more production is obtained. Motion and time study techniques are used as productivity improvement techniques in many manufacturing firms. This case study was conducted in a manufacturing firm, situated at Satara, western India, which is engaged in the manufacturing of machines used for construction work. In this study, an attempt was made to reduce the assembly time of crusher machine, using time and motion study. After conducting this study, assembly time was reduced by 9 m, i.e., 10.71% reduction in cycle time was achieved. Work measurement also helped in proper planning of various tasks and scheduling, in order to reduce the indirect costs like electricity bill and rent, etc.

Keywords Work measurement · Time study · Cycle time · Indirect cost · Idle time · Tasks

1 Introduction

The definition of productivity, represented in some way, is the effectiveness of the production of commodities or services. Partial Productivity refers to productivity metrics that only consider one aspect. Labor is a typical partial productivity indicator. Since it provides an essential gauge of economic development, competitiveness, and living standards within a country's economy, labor productivity is a leading indicator of several economic variables. In general, the ratio of an output volume metric to an input use measure represents labor productivity.

Modern manufacturing firms are required to produce the products that are available at competitive prices and with less lead-time. Reducing cycle time that is required

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for manufacturing of products will have a significant impact on a company's bottom line. This study looked at production-related issues from a work-study perspective. Implementing work-study would help to reduce the production time and decrease unwanted costs in manufacturing firms.

Stopwatches, "Predetermined Motion Time Systems or Synthetic Time Systems," and "Work or Activity Sampling" are all used in time studies. However, only the time study utilizing a stopwatch was used in this study to assess the passage of time. The stopwatch was lapped as the particular task was completed or the worker was changed of an assembly under study and the study considered the timings required for each movement involved in the job.

2 Literature Review

Singh and Brar [1] concluded in their research that Single Minute Exchange of Die (SMED) is the best way to reduce the changeover time and alter it into production time. Gujar and Moroliya [2] discussed the advantages of work-study implementation in manufacturing firms. Singh and Yadav [3] used work-study method in reducing the cycle time in a battery manufacturing firm. Desai and Warkhedkar [4] used SMED techniques for productivity improvements. Kulkarni et al. [5] concluded in their research that work-study techniques tend to improve the productivity of the operator and helps in enhancing the profitability of the firm. Yusoff et al. [6] employed time study in their research work to benchmark the time required in car seat manufacturing line. They concluded that work measurement method is a very adaptable research instrument that could be applied for measuring tasks in any firms. Sai Nishanth Reddy et al. [7] used time study in their case study to improve the productivity in solar industries and concluded that motion and time study is an empirical analysis method, designed to find the prime way to execute a repetitive task and to measure the time taken by an average worker to finish an allocated task in a fixed workplace. Wilson [8] summarized in his research that Gantt chart remained an accepted management tool, although dating back over a century. Presently, these tools are used in projects to provide effective means for displaying important information. Duran et al. [9] concluded in their research study that work and time study are scientific approaches to enhance the efficiency of utilization factors of production process used in manufacturing firms.

3 Methodology

3.1 Case Study

The case study was conducted in a manufacturing firm, which manufactures machines for construction work. This study focused on reduction of cycle time of crusher machine and its sub-assemblies. Before conducting this study, the time required for assembly of crusher machine was 85 m. An attempt was made to reduce the cycle time, using work measurement technique, i.e., time study.

3.2 Data Collection

Primary data: The data was collected from the shop floor and was collected on a data sheet or plain paper. This data included the number of workers required for the particular task and their exact timings required to complete the task. Stopwatch was used to record the timings cumulatively.

Secondary Data: The primary data was entered in different Click up, Excel, etc. Data were collected and recorded on a daily basis, which were based on the actual production. Subsequently, a Gantt chart was plotted to monitor and analyze the problems.

3.3 Data Analysis

Gantt chart (shown in Fig. 1) was drawn based on the secondary data. This method helped to detect the main donor to high time loss and help visualize and better understand. For instance, an assembly of "Platform" (Data shown below) was studied and analyzed. Table 1 shows the secondary data created using the primary data. It helped to calculate the exact time the worker as well as specific machine as required in the assembly stage.

3.4 Time Study to Reduce Indirect Costs

From the Gantt Charts and time charts, the idle time or waiting time was found. Simultaneously working could increase the production obtained in the same amount of time, with same workforce. This led to exact proper utilization of the manpower. The indirect costs like rent, electricity costs and water bills could also be calculated using this work-study data.

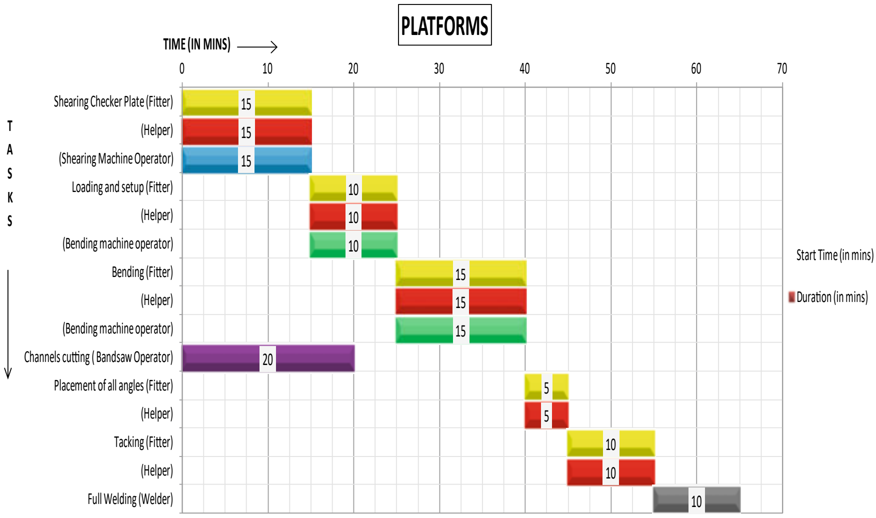

Fig. 1 Gantt chart based on the secondary data

Before this time study, the total cycle time required for crusher machine assembly (shown in Table 2 and Fig. 2) was 85 m. After the time study, unnecessary idle time was removed. Hence, the time required for task 2 and task 4 were reduced (shown in Table 2 and Fig. 3) by 9 m.

As seen in the Gantt chart, the Band saw worker ends the task early and is then free. Other workload, therefore could be given to that worker. The study highlights similar tasks that have free time and makes the supervisor/authorities aware of the free time slots of the worker.

4 Conclusion

Time study is a scientific method used in industries to reduce idle time of the workers. It helps in enhancing labor efficiency. After conducting time study in the manufacturing firm, there was reduction of assembly cycle time required for crusher machine from 85minutes to 74 minutes (i.e., 10.71%). This firm approximately saved Rs. 1.87 lakhs per annum as a result of conducting this case study.

Reduction in unnecessary expenses, such as rent, electricity bills and cost of idle workers, etc. were calculated from the available data and budget was set accordingly. Maximum production using minimum workforce was achieved. This study also helped the firm in reducing the lead-time required for delivering the machine to customers as well as the energy bill.

Table 1 Secondary data for assembly of a sub part

Sr. No.	Task	Worker 1	Worker 2	Worker 3	Worker 4	Machine 1	Machine 2	Machine 3
Assembly name						Date: dd/mm/yy		
Break timings: 11.00 (10 m), 12.30 (30 m), 16.00 (10 m)								
Platforms								
1	Shearing checker plate	Shearing m/c operator 15 (0–15)	Fitter 15 (0–15)	Helper 15 (0–15)	–	Shearing m/c 15 (0–15)	–	–
2	Bending checker plate loading and set up	Bending m/c operator 10 (15–25)	Fitter 10 (15–25)	Helper 10 (15–25)	–	Bending m/c 10 (15–25)	–	–
	Bending	Bending m/c operator 15 (25–40)	Fitter 15 (25–40)	Helper 15 (25–40)	–	Bending machine 15 (25–40)	–	–
3	Channels cutting (4 nos.)	Bandsaw machine operator	–	–	–	Bandsaw m/c 20 (0–20)	–	–
4	Ass-placement of all angles	–	Fitter 10 (40–45)	Helper 5(40–45)	–	–	–	–
	Assembly-tracking	–	Fitter 10 (45–55)	Helper 10 (45–55)	–	Arc m/c 10 (45–55)	–	–
5	Full welding	Welder 10 (55–65)	–	–	–	MIG welding m/c 10 (55–65)	–	–
Total cycle time: 65 m								

Table 2 Reduction in cycle time of the assembly

Task number	Cycle time before time study (in min.)	Cycle time after time study (in min.)
Task 1	15	15
Task 2	25	18
Task 3	20	20
Task 4	15	13
Task 5	10	10

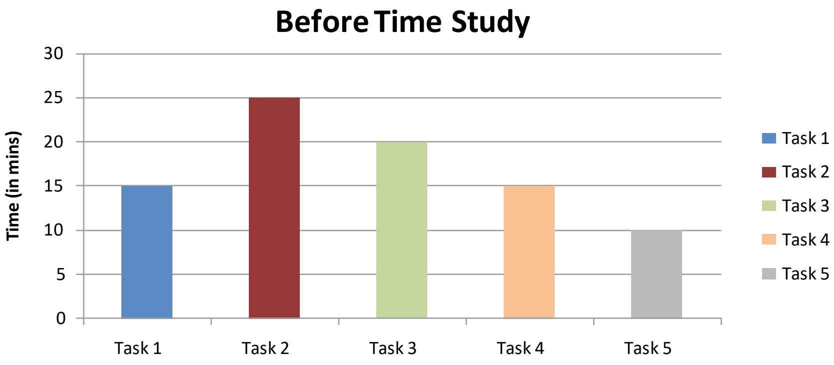

Fig. 2 Task durations before time study

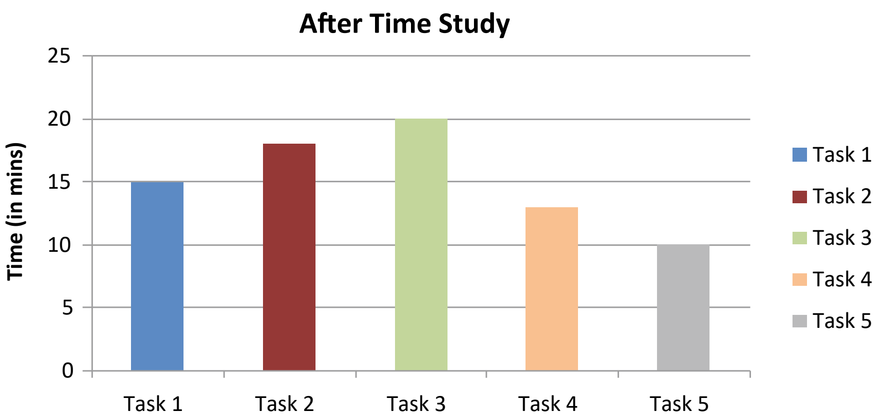

Fig. 3 Task durations after time study

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Rapid Tooling Technologies Based on Additive Manufacturing: A Comprehensive Review

Ganesh Borikar, Varun Velankar, Sanjana Joshi, Parth Dandawate, and Sachin Deshmukh

Abstract This study aims to give an overview of additive manufacturing-based rapid tooling technologies. Rapid tooling is a pre-production segment where AM technologies truly shine, as the tools to be manufactured are less in quantity, and each component should be custom-made according to the process requirements. Therefore, a case study to compare the two manufacturing processes for the production of components based on cost and time constraints is showcased. According to the case study analysis, we can infer that FDM technology offers better cost when it is to be produced in small quantities and when the requirement for customization is very high. In injection molding, the flexibility is significantly compromised, but it yields better results when the component is to be produced in large quantity. In conclusion, it has been shown that the FDM process is advantageous for small businesses or luxury automakers that produce small-scale components.

Keywords Additive Manufacturing (AM) · Rapid tooling · Time-cost analysis · Fused Deposition Modeling (FDM) · Injection Molding (IM)

1 Introduction

A modern manufacturing technique called additive manufacturing has completely changed how we prototype things for the manufacturing sector. The most widely used additive manufacturing techniques include wire arc additive manufacturing, fused deposition modeling, stereolithography equipment, selective laser melting, selective laser sintering, and binder jetting. These manufacturing technologies for tools are outlined together with the materials employed. Also, utilized as an example

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is a case study on the cost-time analysis of the "filter media" portion of the oil filter used in the automotive sector.

2 Literature Review

Tools are produced swiftly using techniques like FDM and SLA [1, 2]. Less lead time to market and the removal of several traditional production procedures, such as tooling, assembly, transportation, etc., will result from the development of additive manufacturing. It will make feasible to produce the same product in many ways. Supply chains will be more affordable, compact, and flexible [3]. We must consider two crucial requirements before using a 3D printed component in real-world applications: Any Von-Mises stress applied to a fixture component should be less than the component's yield strength, which was obtained by 3D printing the component. Moreover, the factor of safety should be at least 1.5.

These conditions can be determined or calculated by any computer-aided engineering (CAE) software. If the above two conditions are satisfied, then the material (used for additive manufacturing) can be used to manufacture that component [4]. But, there are various other factors, for example, evaluation methods to determine whether a jig or fixture has to be produced using additive manufacturing or conventional methods [5]. We can determine whether a hybrid welding jig system with AM functional elements and interfaces can provide technical and economic advantages for different types of welding jigs in the automotive sector [5–7]. Here are some examples of quick tooling processes: Selective laser sintering (SLS) is used to create location components for free-form part indexing [2].The manufacture of semi-auto insertion jig components such as baseplates, connections, E-bits, base plate supports, and LR jigs uses a AM [4]. Robotic goods that are lightweight and extremely precise have several applications [8]. While pieces were being positioned during welding, the disk support sub-assembly of the agricultural machine stubble cultivator was put together [9]. To prevent deformations in the scanned model, fix the component securely in place before scanning [10]. Developed measuring fixture, checking fixture, or climatic fixture to conduct tactile and visual measurements [11, 12]. Employed additively manufactured jigs and fixtures in automotive applications when lead times are greater and items are needed immediately [13].

3 Types of Rapid Tooling Processes

3.1 Fused Deposition Modeling (FDM)

It is a solid material-based system that uses an extrusion nozzle and material in the form of filaments to print parts (Fig. 1) of every complexity and nature at a less cost

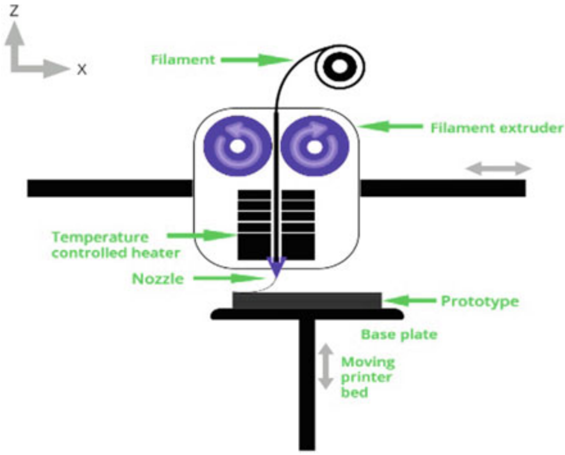

Fig. 1 Fused deposition modeling (solid-based system)

and good accuracy. FDM is one of the most affordable and convenient processes for quick and time-bound applications like pattern making, prototyping, and fabrication of jigs and fixtures. This technology mainly uses various thermoplastic materials in the form of wire filament, which is then melted and extruded onto the build platform to create the model layer by layer.

Preferred materials used for the FDM process: *Polylactic Acid (PLA)*: It has low melting point, low thermal expansion, high strength, brittle, and high flexural strength. *Acrylonitrile butadiene styrene (ABS)*: low melting point, high strength, ductile, and high thermal stability. *Thermoplastic Polyurethane (TPU)*: low melting point, high elasticity, abrasion-resistant, brittle-ductile phenomenon, high chemical resistance. *Polyether ketone (PEEK)*: creep resistance, dimensional stability, high strength, crystalline nature. Tooling developed—a welding fixture used in the automobile industry using ABS as material [9].

3.2 Stereolithography Apparatus (SLA)

In order to solidify the liquid resin monomer into polymers and create the required model, the liquid-based additive manufacturing (Liquid-based AM) technique, as seen in Fig. 2, requires a laser beam. SLA is a kind of vat photo-polymerization that relies on photochemical curing to function. The procedure, however slow, is appropriate for intricate, high-quality goods. A full setup of the SLA is shown in Fig. 3. Preferred materials used for the SLA process: *Standard resin*: It gives good surface finish, brittle, high accuracy. *Clear resin*: transparent, brittle, dynamic optical clarity, good surface finish. *Tough resin*: high stiffness, min. wall thickness of 1 mm, brittle. *Heat resistant resin*: good surface finish, high heat deflection temperature,

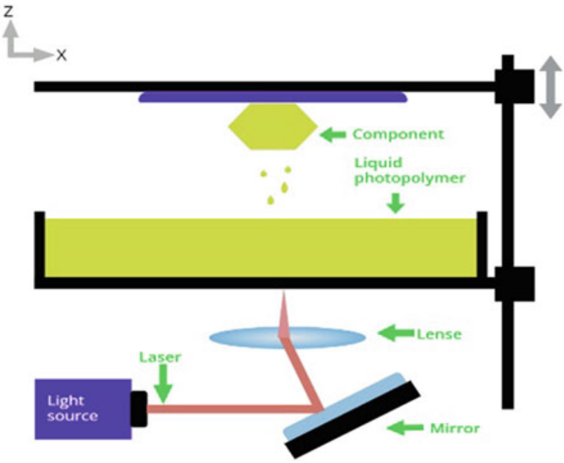

Fig. 2 Stereolithography apparatus (liquid-based system)

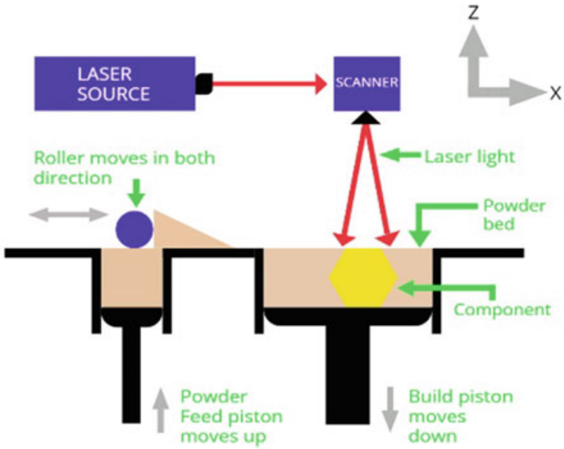

Fig. 3 SLS/SLM (powder-based system)

brittle, minimum wall thickness of 1 mm. Tooling developed—skull models were developed using the SLA method [14].

3.3 *Selective Laser Melting (SLM)*

Powder-based system that uses a laser as a heat source to selectively melt the metal powder to create the desired components (Fig. 3). SLM is an expensive and energy-intensive process as it requires a specialized laser for melting. The metal laser system consumes a greater magnitude of energy. This method can be employed to fabricate complex and specialized products with higher accuracy, functionality, and minimal post-processing. Preferred materials include Al, SS, Ti, and Cu alloys.

3.4 Selective Laser Sintering (SLS)

It is a technology that is similar to SLM in working (Fig. 3) and with main difference of SLM makes use of a full melting mechanism in which particles are completely melted and then fused, whereas SLS makes use of solid-phase sintering or liquid-phase sintering in which particles are sintered in solid-state completely.

Preferred materials (non-metal powders) used for the SLS process: *Polyamide 12 (PA 12)*: high strength, high chemical resistance, and surface roughness. *Aluminum-filled nylon (Alumide)*: high stiffness, lustrous. *Glass-filled nylon (PA-GF)*: high wear resistance, high-temperature resistance, high stiffness, anisotropic. *Carbon-fiber-filled nylon (PA-FR)*: high weight-to-strength ratio, high stiffness, anisotropic. Tooling developed lightweight robotic exoskeleton and lightweight metallic lattice structures developed using AlSiMg [8].

3.5 Binder Jetting (BJ)

Binder jetting is a powder-based system that uses a material binder that is selectively deposited onto the powder bed. Here, the binder acts as an adhesive to cure the component into the desired shape, layer by layer. The binder Jetting process has a unique feature in which two different materials can be combined to form a multi-color model. Binder jetting is very accurate. It is also the medium cost metal printing process. Figure 4 shows a detailed description of the binder jetting process. Different materials used for the BJ process: Binders: *Furan Binder*, *Silicate Binder*, *Phenolic Binder*, *Aqueous-Based Binder* Powders: *Metals*. Tooling developed—reactor packing material which is ceramic support is employed in the heterogeneous catalysis process [15].

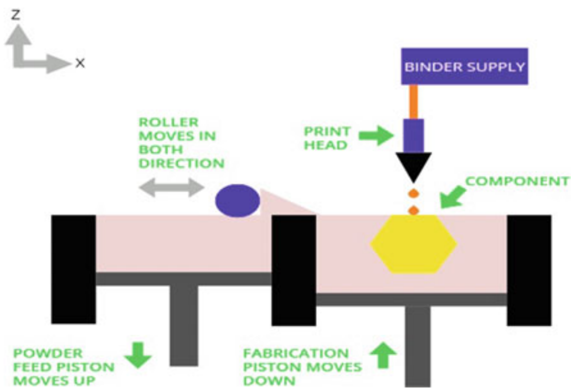

Fig. 4 Binder jetting (powder-based system)

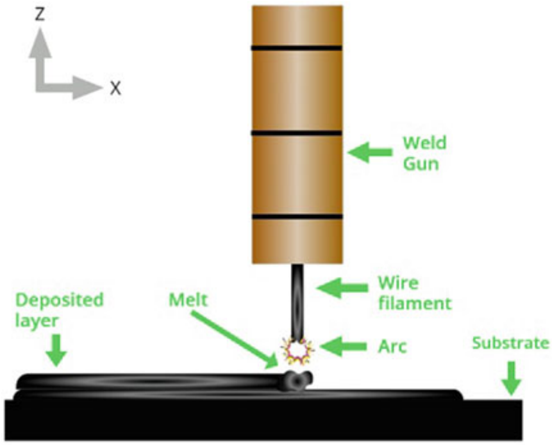

Fig. 5 Wire and arc additive manufacturing (DED process)

3.6 Wire and Arc Additive Manufacturing (WAAM)

WAAM, also now known as the direct energy deposition-based process, uses a metal wire electrode and melts and fuses it with another material to form a composite structure as shown in Fig. 5; the materials used are titanium, chromium, aluminum, Inconel, and Ti-6Al-4A. WAAM has a low cost and higher efficiency [16].

This technology has now evolved into a more accurate and efficient technology due to the use of 6 DOF robotic manipulators since welding is a contour application. Applications: Metal components in automotive, aerospace, and steel industries and also maintenance in welding companies. Common materials used for the WAAM Process: *Aluminum*, *Carbon steel, Copper, Stainless steel, Magnesium.* Tooling developed—Fabrication of complex metal parts in general.

3.7 Laminated Object Manufacturing (LOM)

It is a solid-based technology that uses sheets as material. The materials are usually coated with an adhesive layer that is heated by a moving roller to apply pressure and heat the sheet and adhesive. In this way, each layer can be glued to the previous one to build up an object. This process is still under research and development, and very few firms across the world use it as a mainstream technology. Figure 6 shows the process of LOM technology. Preferred materials used for the LOM process: *Paper, Metal Sheets, Ceramics.* Tooling developed—patternmaking in sand casting, investment casting, and injection molding [17].

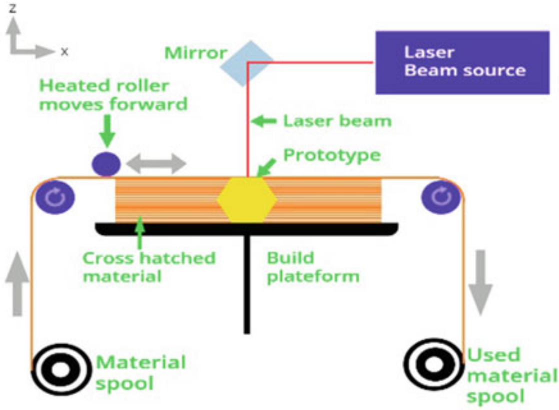

Fig. 6 Laminated object manufacturing (powder-based system)

4 Tooling for Manufacturing

In any production process, it is essential. These include numerous machine tools, including as production, bridge, and prototyping equipment. It takes a lot of time and effort to create investment casting patterns, which might take several months in various metal sectors. Due to lengthier lead times and increased corporate competition, this causes issues in the supply chain. Therefore, using FDM technology, these designs may be 3D printed in a couple of hours. Jigs and fixtures, which are often created specifically for a component's size and manufacturing process, are the most crucial instruments in the manufacturing sector. FDM, SLM, SLS, and WAAM technologies can be used to 3D print these tools. They shorten lead times while improving precision and finishing. Phases were established throughout the entire approach. Phase 1 entails topic study and knowledge; Phase 2 entails analysis; and Phase 3 entails conclusions. Finding the time-cost analysis of FDM vs. injection molding technology was the methodology's ultimate aim. Tools like patterns, jigs and fixtures, molds, and frames may be produced more quickly and more cheaply by using additive manufacturing technologies [2].

5 Case Study: Time-Cost Analysis of Filter Media Used in the Automobile Industry

Phase 1 Examine Current AM Technologies: Extensive study was conducted about AM technologies to understand the topic more in-depth. Various types of research papers, projects, reviews, etc., were studied to get an idea about the same. From the above research materials, it was observed that for the production of industrial components, AM technologies have proven beneficial in terms of cost, with respect to time, cost, and accuracy. Components that are generally complex to manufacture using conventional technologies can be manufactured using different AM technologies depending on their application. The researchers brief more about the industrial component that will be additively manufactured, as well as the quality, cost, and time that can be reduced. Radhwan et al. [4] give a study of the additively manufactured welding fixture. The FDM process is used to manufacture the welding fixture. ABS was the substance employed in the procedure. A unique welding fixture was constructed for a particular acute angle weld using FDM technology, which decreased cost, lead time, and weight. 3D scanners were investigated by Kampker et al. [5]. A extremely complicated component can be exceedingly time-consuming to develop as a whole and may not be as precise as the original product. As a result, the component is completely scanned using 3D scanners before being printed, eliminating any possibility of error or subpar quality. In order to carry out a successful scanning process, a fixture was scanned and created to hold a component.

Phase 2 Analysis: An essential part of the car industry that is created using injection molding technology is filter media. If the component is to be produced in small batches (i.e., 250 components in this example), the FDM technique may easily beat the traditional injection molding process, according to the full time-cost analysis of these components. Conventional production techniques are ineffective in this situation since there isn't a vast volume of product to be produced. Due to their significant machinability challenges, these components can only be produced via injection molding technique.

Hereby, we have studied two technologies: FDM and injection molding. We have used FDM technology considering its demand in the industry and for conventional processes. We have considered injection molding since the conventional machining of these products is difficult. We have considered Ultimaker 2+ FDM printer to print this component and also calculate costs and lead time for the FDM technology using Ultimaker Cura software (Figs. 7 and 8). But, for the injection molding process, we have considered approximate costs provided by local business owner. (Refer to acknowledgment).

A time-cost analysis for the individual components is completed for the aforementioned two procedures after taking into account the quantity of components to

Fig. 7 Design of filter media in Ultimaker Cura

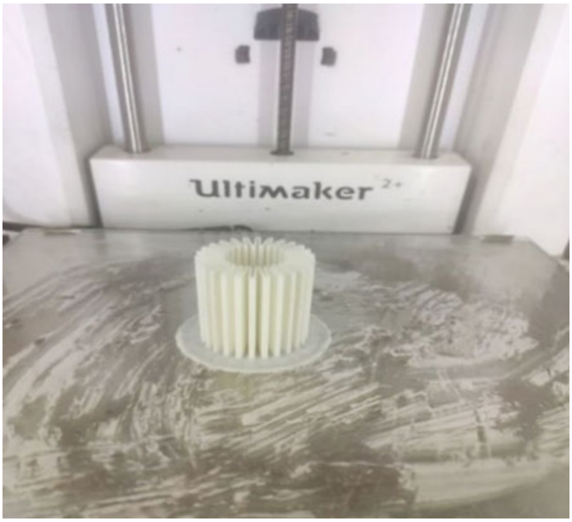

Fig. 8 3D printed filter media

be made. With the aid of the analysis, the cost of the first five components was determined rather than the next ten, raising the values. This cost was computed using factors including the cost of the spool (1 kg, 1.75 mm), the pattern ($266.6), and the speed (1 product/15 s). As the number of components changes, Table 1 compares the time and cost of the FDM and Injuction molding (IM) procedures. After 250 pieces, it is not advised to use the FDM technique since it wastes time and would add additional manufacturing days.

Phase 3 Findings: The two processes are compared for the manufacturing of filter media used in the automobile industry, which was manufactured in small batches.

The results of our analysis are as follows:

Table 1 Time-Cost analysis (FDM versus IM)

Quantity (the no. of components)	Cost (in US $)		Time (in days)	
	Fused deposition modeling	Injection molding	Fused deposition modeling	Injection molding
1	0.13	270	0.083	21
100	13	271	8.3	21
250	32.5	272.5	21	21
500	65	275	41.5	21
1000	130	280	83.33	21
2000	260	290	166.6	21
2250	292.5	292.5	186.75	21
2500	325	295	207.5	21
3000	390	300	249	21

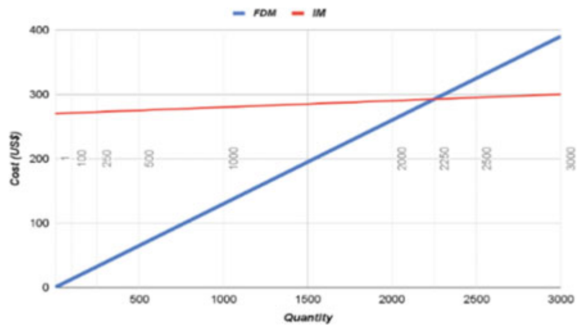

Fig. 9 Cost analysis

1. *Inflection point for cost*: When components are manufactured individually by both the processes, the inflection point is obtained at the 2250th piece, where the cost of both the processes is almost equal. FDM is not a cost-efficient process if we want to manufacture more than 2250 pieces in this case. Therefore, injection molding should be employed to cater to the mass production requirements, considering 'cost' as a parameter (Fig. 9).

2. *Inflection point for time*: After manufacturing the 250th component, the inflection point is obtained where the time required to manufacture the same component using both processes is equal. To manufacture more than 250 components, FDM will take more time as compared to injection molding. Analysis shows that injection molding can produce up to 5500 components per day (without breakdowns); hence, the time taken will only be 21 days for quantities given in the above table. It will be detrimental for the company to use FDM processes for quantities greater than 250 even though the costs are lower as compared to injection molding as tooling is a time-critical process. Hence, we can safely conclude that for large quantities, injection molding has no alternatives, but for small quantities, FDM offers better prospects (Fig. 10). An *important point* to note in this analysis is that consumer automotive companies that produce cars in a huge quantity may have less possible use of AM processes.

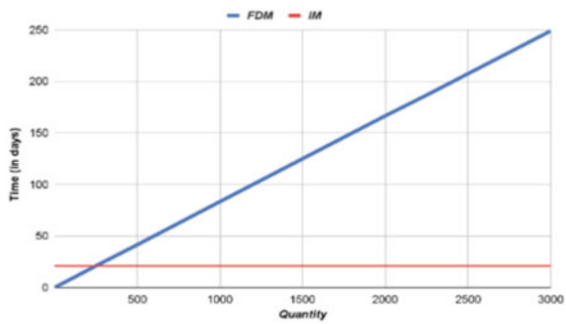

Fig. 10 Time analysis

5.1 Sustainable Development Goals

Additive manufacturing contributes significantly to the 8th, 9th, 12th goals of the UN SDG's which are to be fulfilled by the year 2030. Additive manufacturing as a technology also reduces material wastage, overall energy consumption contributing to the sustainability values that are needed to ameliorate the effects of climate change on society.

6 Future Scope

Additive manufacturing is a relatively new technology; it is still in its formative stages, and there is tremendous scope for research and development on the technology. Major industries benefiting from this technology are automotive, aerospace, and health care since there is a huge demand for new tooling processes in these industries that can reduce lead time and cost. These AM processes need to be more efficient in order to compete with traditional manufacturing processes, and they should be able to provide a better cost-benefit ratio. Although this technology is only limited to prototyping and limited customized segments of manufacturing, in the future, we can expect it to be as a consumer product which will be able to print things on demand.

7 Conclusions

The additive manufacturing (AM) processes that are currently used in the industry as *FDM, SLA, SLS, SLM, WAAM, BJ,* and *LOM* are reviewed from the perspective of rapid tooling technologies, key features and their associated applications. According to the current study, the FDM technique of rapid tooling is the best one for batch manufacturing/tooling but is ineffective when mass production is taken into consideration. In the present case study it shows, it is incredibly cost-effective and has shorter lead times than injection molding (IM) when producing filter media in quantities of fewer than 250 pieces. When the required output exceeds 2250, it becomes clear that FDM is no longer a time- and cost-efficient technique. For items with comparable sizes and quantities, this connection could be similar. The key finding is that AM tooling technologies/procedures work best for applications with characteristics: complexity, small batch needs (preferably less than 200), and are having specific requirements of product and tooling. These qualities may be ideal for luxury automakers, who typically modify their component designs and produce very few number of vehicles in a batch. These characteristics call for a high degree of flexibility, which AM technologies possess.

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Role of Drivers, Barriers and Critical Success Factors for Lean Readiness in Indian Manufacturing Industries

Dhaval Birajdar and Hari Vasudevan

Abstract Manufacturing sector in India is currently geared up to increase its competitiveness, lower production costs and make goods up to par with industry standards, in the era of Industry 4.0. They are reviewing their manufacturing processes, as a result of increased market rivalry as well. Many industries have adopted lean in recent years to increase their firms' competitiveness due to the competition's recent escalation. Lean is a corporate approach that seeks to increase efficiency throughout the organization by removing waste, enhancing quality & service and reducing costs. Lean manufacturing has been recognized as one of the critical approaches to enhancing the performance of an organization. The Indian Manufacturing Sector's readiness to adopt lean tools is a challenge in the current environment. In this context, a review of lean manufacturing, covering drivers, barriers in lean implementation, critical success factors, organization readiness for lean and the intention to adopt lean was carried out to build a theoretical framework. The research aimed to identify the critical success factors required to implement lean tools successfully. This study also sheds light on contextual factors, such as organizational culture, which can be used to investigate the link between critical success factors and organizational readiness for lean, leading to the intention to adopt lean tools in Indian manufacturing industries.

Keywords Drivers · CSF · Organizational culture · Lean readiness

1 Introduction

The notion of lean was born when the Japanese manufacturers realized that they could not afford the enormous expenditure required to rebuild their destroyed facilities, following World War II. Since then, lean manufacturing (LM) has been put into practice by many productivity conscious manufacturers. Manufacturing processes have been developed at the Toyota plant to reduce waste. In the 1980s, automobiles were made with half the human labour, half the manufacturing area, half the

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expenditure and half the engineering hours, as compared to mass production at the time. The efficient Japanese management of manufacturing and human resources was primarily responsible for making this possible [1]. The lean system comprises of general management guidelines that can be used by any organization [2]. LM approaches are now widely recognized as having high cost and quality advantages over traditional mass production methods by enterprises of all sizes [3]. The goal of LM is to reduce waste in human labour, inventory and manufacturing space, to be incredibly responsive to consumer demand and produce things of the highest calibre, most effectively and affordably. According to the Lean Enterprise Research Centre at Cardiff Business School, just 5% of production activities provide value, 35% contribute to non-value added processes, and 60% do not add any value to the finished product. They demonstrate the importance of every size company in eliminating waste and increasing profit or return on investment (ROI).

Literature also shows that, when a company's leadership can collect data from within the organization and use it to develop actionable data that may help shape decisions, strategy and direction, as the company begins on the lean journey, and also, it is possible that the destination can be achieved much sooner. Analysis of the correlations between components crucial to the effective adoption of lean has been done using statistical techniques [4]. Numerous studies have examined critical success factors for lean implementation. It is believed that a comprehensive study of the critical success factors with lean readiness and intention to adopt lean in Indian manufacturing industries is still missing.

As a result, the primary research question is: What effect and role do drivers and barriers have in implementing lean in the Indian manufacturing sector as well as what role does the organizational culture play in implementing lean in the manufacturing sector?

In this context, this research study focuses on three objectives: (1) To discuss the critical success factors (CSF) for implementing lean tools from the literature review and analysis of literature. (2) To examine the relationship between the organizational readiness of lean and the intention to adopt lean tools and (3) To examine the moderating variable and its association between critical success factors and intention to adopt lean tools in Indian manufacturing industries.

2 Theoretical Background

A framework for describing LM was offered by [2], which included the specification of a value, identification of the value stream and creation of a flow, pull and perfection. Lean implementations can be made broader, using this approach. LM adoption and erroneous application of lean practices are common problems for most enterprises.

Many lean practices were included in the framework developed by [5]. They were broken down into various categories: principles and concepts, competitive priorities, stakeholders and operational department functions. Reference [6] reviewed the existing lean roadmaps (studying 80 relevant publications) for similarities. The examined roadmaps, identified several "lean" steps, and three significant stages were identified (planning, design and implementation). The following section covers drivers of LM pertaining to Indian manufacturing industries.

2.1 Drivers

Numerous studies have identified various drivers or enablers of lean manufacturing. When it comes to lean techniques, [7] separated them into six categories: manufacturing, planning and control, manufacturing, human resources, product design, supplier connections and customer connections. According to [8], the success of lean manufacturing adoption depends on four key factors: leadership and management, financing, knowledge and a supportive company culture. Researchers in India examined the level of lean awareness and implementation in Indian enterprises [9]. According to them, inadequate lean training and a lack of lean awareness initiatives for employees, poor use of statistical tools for process improvement and uncertainty about the most effective lean tool are the key obstacles to lean practises in Indian companies. Higher levels of dedication, more fervent confidence in the system being implemented, increased communication and improved work practices can all raise the possibility that workers perceive the change to be effective. According to the [10], following factors contribute to successful lean implementation: employee awareness (EA), top management commitment (TM), continuous improvement (CI), visual management (VM), standardization (ST), supplier relationship (SR), inventory leanness (IL), communication (CO), waste elimination (EW) and lean tools (LTS). The drivers assisted the researchers in identifying the critical areas that needed to be addressed.

Production scheduling and optimal resource use are two essential drivers that aid in the deployment of LM [11]. Production scheduling allows for the standardization of production activities throughout the manufacturing processes [12]. Improvements in shop-floor management are typically achieved through reducing cycle durations, set-up times and making setup checklists available [13]. Integrating these drivers allows all shop-floor movements to be efficiently synchronized, potentially enhancing the production system's total productivity [9]. Quality product design and network-aligned distribution management are critical to efficient and effective production [14]. It entails striving for zero flaws by deploying adequate equipment capable of detecting defects and delivering remedies for the root causes of the problems. In this context, many questions remain unanswered about the drivers used in manufacturing industries, despite these efforts having been carried out and reported in the literature.

2.2 Barriers

Review of the extant literature shows that although many companies have learned from Toyota's success stories, there is a low rate of successful lean adoption in the workplace. [9] discovered that less than 10% of companies have successfully implemented lean. Although lean ideas, processes and tools constitute the foundation of the lean manufacturing system, there are other barriers to overcome. Lean implementation is impossible if only tools are implemented without an integrated system that works as a forerunner to lean implementation [15]. According to them, the lack of an integrated system before lean deployment does not assist in transforming organizations into learning organizations. However, it did not bring the kind of success these companies expected through lean implementation. [16] aimed to identify the cultural challenges that could hinder the implementation of continuous improvement methodologies and the problem of resistance to change. [16] surveyed Fortune 500 manufacturing plants in the Eastern USA and reported that these companies are thoroughly committed to continuous improvement, and plants have achieved only partial success due to the persistence of legacy attitudes on the part of unionized and high senior employees.

2.3 Critical Success Factors

Reference [8] investigated the level of lean usage in 10 small and medium-sized businesses (SMEs) in England. The majority of the data for the study came from semi-structured interviews with essential employees, which were subsequently evaluated using Delphi methodology. According to the findings, the most crucial critical success factors (CSFs) were organizational culture, leadership, finances, skills and knowledge. Reference [17] used a survey that was distributed amongst two international firms to research the CSFs for lean deployment. A general list of success characteristics was created from the survey responses, and it was then broken down into categories, such as a corporation, factory size, stage of lean implementation and national culture. The study discovered that the stage of lean implementation may influence a worker's assessment of a factor's efficacy.

Another study, conducted by [18], looked into lean success in IT services, mainly focusing on IT outsourcing links. Semi-structured interviews were conducted at six IT companies to identify the CSFs. There were 16 CSFs detected, when the interviews were evaluated. The most significant CSFs, according to the study, were corporate culture, internal expertise and worker skill. Further, lean business models have been proposed to enhance lean implementation in a variety of industries, such as health care. In addition, [19] found that organizational culture was a significant component in the actual deployment of lean in Indian manufacturing businesses. Reference [20] emphasized the importance of cultural factors in implementing lean in a Canadian aerospace company. Research on determining CSFs for lean adoption is currently being conducted although the scope of these studies is limited. As a result, to properly comprehend the CSFs for lean deployment, an international research study spanning numerous industries is required.

2.4 Lean Readiness

The term "readiness factor" refers to any behaviour or feature that facilitates organizational change by removing or neutralizing potential barriers to success or by supplying the skills and competencies needed to successfully implement change [21]. According to [22], lean readiness elements are those fundamental components that will boost the likelihood of achieving any lean effort, before investing significant resources (financial, people) in the initiative. Additionally, readiness factors are any action or trait that facilitates organizational change by removing or negating potential barriers to success or supplying the skills and competencies needed to successfully implement change. Processes, planning and control, human resources, top management and leadership, customer and supplier relations and supplier relations are all variables that contribute to lean readiness.

3 Research Model and Hypotheses

There are currently no pertinent variables or restrictions in the literature on organizational readiness for lean. By evaluating the significance of critical success criteria for lean, assembled from relevant literature and put to the test, lean readiness and practice may be evaluated. Implementing LM is not a simple process; sadly, no method can ensure a successful deployment, if applied. Furthermore, unsuccessful implementation can significantly impact the organization's resources, affecting employees and their confidence in lean philosophy. Several "roadmaps" are available to help a business transition from its current operation to one that fully embraces the lean mindset.

As a result of the descriptive and content analysis of the theoretical background, relating to drivers, barriers and critical success factors of lean and organizational culture, a research framework is proposed, as shown in Fig. 1, towards the lean readiness and intention to adopt.

Few studies on the failures of LM implementation are made public, mostly because companies desire to protect and not make public their failed investments. Lean suppliers, leadership and business processes are the most prominent root causes of failed implementations in the few research reported. Implementing LM can be obstructed by poor management, lack of resources and a general unwillingness to adapt. Lean deployment might be hindered or aided by management. A lack of focus on supporting lean manufacturing projects, lack of urgency and lack of long-term vision are just a few of the attitudes and behaviours that might be cited as

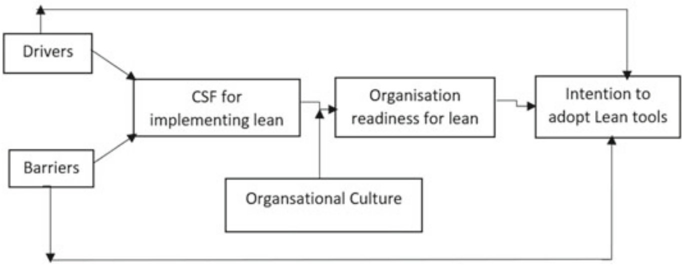

Fig. 1 Research model

organizational barriers. Many firms rely on consultants to implement lean; therefore, consulting resources are essential. Confusion regarding LM and obstacles to its adoption can originate from consultants with superficial knowledge of the subject and little experience in its application. When it comes to implementing lean, a lack of familiarity with the philosophy and the various technologies can be a significant barrier. Employees' reluctance to change is also a common roadblock. The dread of the unknown, the fear of failure and complacency, etc. could play a role in this reluctance.

Based on theoretical background, the drivers play an important role for implementation of LM. The following list summarizes the primary drivers for a company to engage in LM, as identified by most researchers. • Increased market share. • Increased flexibility. • Need for survival from internal constraints. • Development of key performance indicators. • Desire to employ world's best practices. • Part of the organization's continuous programme. • Drive to focus on customers. • Customer requirement/motivation and Mother company requirement.

Researchers have found that a lack of knowledge about lean, the need for investments and employees' fears of losing their jobs are some of the barriers that make it hard to put LM into place.

Based on the literature review, which covers the importance of drivers and barriers of lean manufacturing, it is hypothesized that:

H1: Drivers of lean Manufacturing will have a positive effect on critical success factors of lean Manufacturing.

H2: Barriers of lean Manufacturing will have a negative effect on critical success factors of lean Manufacturing.

When it comes to determining the information needs for managers, [23] demonstrated the notion of critical success factors (CSFs). For any programme or technique, CSFs are those factors that must be met in order for it to succeed; if they are not, the programme or technique will most likely fail catastrophically [24]. In the same way that other productivity-enhancing initiatives are difficult to implement, the LM is no exception. To facilitate its implementation, experts and researchers have suggested several success factors.

There is a lack of an appropriate methodology to assess lean readiness level or preconditions and organizational readiness for change in manufacturing processes, which creates a significant gap in lean research [22]. This has resulted in several deployment failures and unsatisfactory lean implementations due to the lack of a robust methodology for evaluating and assessing organizational preparedness for change, before implementing LM inside manufacturing industries. As a result, most previous studies have only measured preconditions or lean readiness factors, such as processes, planning and control, human resource, leadership, commitment, supplier relations and customer relations and have ignored the willingness and acceptance of those preconditions to organizational readiness to change to lean. A recent study on the impact of quality management practices on change readiness due to new quality implementations was undertaken by [25], and it was found that those practices positively affected change readiness. Future research should investigate and design an appropriate framework for manufacturing industries to promote the deployment and implementation of QM practices, like LM in emerging economies. As a result, it is hypothesized that:

H3: Critical Success factors of lean promotes organization readiness for lean.

An important topic in academic research, organizational theory and managerial practice is the role of organizational culture, which has been acknowledged as a crucial and influential aspect in various circumstances. According to [26], sociology and anthropology have long examined culture to define social groupings, whether nations or tribes, by their differences in essential values. However, these investigations led to the development of organizational culture.

These assumptions are considered valid, and new members are taught to apply them correctly, when confronted with these issues in the future. Values, underlying assumptions, expectations and definitions that characterize organizations and their people are all included in the concept of "culture." Reference [26] defined organizational culture as an umbrella word for a mode of thinking that places a high value on cultural and symbolic phenomena. Consequently, organizational culture encompasses an organization's whole attitude and behaviour since it depicts how members of the firm conduct everyday tasks with internal and external clients. Favourable culture is essential to lean environments because it stresses teamwork and cooperation, which may considerably strengthen the cohesion between diverse departments, thereby enhancing the employee satisfaction level of the organization's personnel. To eliminate waste from a company's systems and processes, the concept of continuous improvement, as stated by [27], often entails a culture of perpetual development. As a result, it is hypothesized that:

H3a: Organizational culture mediates the relationship between critical success factors and organizational readiness for lean.

H4: Organizational readiness of lean promotes the adaption of lean tools.

A framework was proposed by [28] to assess lean readiness in South African organizations. Process activities and facilities, such as operations planning and control; patient/customer interactions; top management's commitment; human resources, supplier relations were are all considered. Readiness considerations included lean principles and practices with technologies. The literature review highlighted that drivers and barriers affect readiness for lean. Hence, it is hypothesized that:

H5: Perceptions of higher drivers for lean promote the adaptation of lean tools (a) directly and (b) indirectly by increasing organization readiness for lean.

H6: Perceptions of higher barriers for lean decrease the adaptation of lean tools (a) directly and (b) indirectly by increasing organization readiness for lean.

4 Conclusion

Today, manufacturing organizations face a slew of new and complex issues. Implementing lean offers a promising approach to meet the high complexity in the production environment and simultaneously focus on customer benefit. As the elements of lean tools are challenging to implement, developing a reference implementation strategy for manufacturing companies is essential. This study explored the relationship between drivers, barriers and critical success factors required for implementing lean tools that lead to organizational readiness for lean and adopting lean tools.

A severe shortcoming found is a dearth of studies conducted on the readiness and actual implementation of lean in India's manufacturing industries. This study reviewed the literature to find the drivers and barriers of lean implementation and recommends an integrated and thorough implementation strategy, incorporating CSF and the desire to adopt and readiness for lean. Furthermore, organizational culture is examined in this study to evaluate the link between critical success factors and lean readiness, leading to the deployment of lean tools in the Indian manufacturing sector. According to the findings in the study, CSF of lean tools could lead to adopting lean tools in the Indian manufacturing industries.

It is recommended that the hypotheses developed by this study be tested quantitatively, as it is based on theoretical recommendations. The critical success factors selected for this study were limited due to few considerations of drivers and barriers, and additional critical success factors could be considered in the future. Future studies might focus on how manufacturing firms can employ design investments to adopt I4.0 technology. Other factors, such as employees' technical and soft skills, could also help the manufacturing industry move towards I4.0. Adopting lean tools may be facilitated by using normative, mimetic and coercive methods in the form of institutional pressures. Finally, future research could focus on endogeneity as well.

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Investigation of Quality of Clean-Cut Surface for Sheet Metal Blanking Using Decision Tree

Pradip Patil and Vijaya Patil

Abstract In case of sheet metal blanking, inadequate trimmed condition of such a blanked material may produce fit concerns in the assembly. Cracks may form due to uneven surfaces, leading to a loss of exterior smoothing and improved efficacy. Four underlying parameters are selected after punching: shear angle, punch penetration, burr height, fracture angle as decision-making input parameters to measure quality of clean-cut surface. The fracture depth is determined by gradually increasing the punch penetration. Experiments are conducted with uni-punch tool on the power press, and sheet metal material is IS277GI. This research aims to assess the cut surface quality using surface roughness value, which is categorized into three groups. To measure the efficiency of the cut surface, a classification model is developed adopting the machine learning decision tree classifier technique. The model's reliability is 93% of the Gini and Entropy index.

Keywords Quality of clean-cut surface · Decision tree classifier · Sheet metal blanking

1 Introduction

The metal forming business is facing challenges worldwide due to new materials and processing processes. Because the process necessitates the employment of several resources, a computerized method for assessing the blanking procedure is required. Improved approaches for studying the behavior of the sheet metal forming sector are in high demand.

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Automation is required to increase production. Given the automation level, deploying software applications in the sheet metal processing industry is advantageous. Different sensing techniques for fault diagnosis and the re-use of damaged component replace systems rapidly appearing as automation develops. However, a suitable process model is required to manage the complexity of sheet metal.

The next industrial revolution is being ushered in by advancements in automation. There has been growing research in sensing systems for defect detection and identifying significant parameters. The intricacy of the sheet metal working method, on the other hand, makes building a self-learning model challenging. With advent of mechanization, the industrial positioning in assessing defect is rapidly moving toward developing self-sustained systems. However, a suitable process model is required to manage the complexity of sheet metal processing.

While studying the process parameters in machining, research is conducted utilizing ANN modeling to increase the precision of intellectual structures [14, 21, 23] and as well as sheet metal blanking [11, 16, 17, 19]. The approach has been influenced by sheet thickness and tool wear [6, 7].

Classification model is proposed using decision tree modeling in current work, for IS277GI material for predicting fracture surface quality.

2 Literature Review

2.1 Blanking Process Setup

The process model of blanking consists of blanking die, sheet metal, blank holder, and punch as shown in Fig. 1. Suitable clearance is selected between blank and punch for obtaining smooth fracture surface. A punch with velocity shears the work-piece placed between blank holder and die. In this way, a slug, called blank, separates from the work-piece.

Figure 2 depicts blank part after shearing and the clean-cut surface. Strain at rupture is the most crucial element in determining when a fracture will begin and the propagation circumstances. From the inside die corner to the punch corner, a fracture line develops as a result of shearing. As per literature, the clearance is defined in terms of percentage of sheet thickness. Figure 3 shows mechanism of metal fracture at punch and die. Smooth sheared surface is obtained when the crack path joins the fracture line.

The previous studies on clearance identification for sheet metal employed FEM [9, 11] and FEM simulation findings were consistent with experimental investigations. They concluded that surface roughness improves when the cracks beginning at the punch and die coincides [9]. However, punch velocity and heat production during processing have a significant role on metal behavior [16]. Investigations were done into how the punch geometry affected the features of the cut surface and the cutting forces [21].

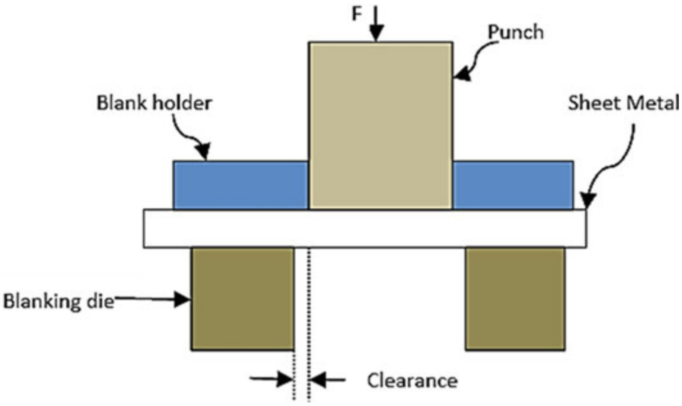


Fig. 1 Blanking procedure system [18]

Fig. 2 Slug work-piece [18]

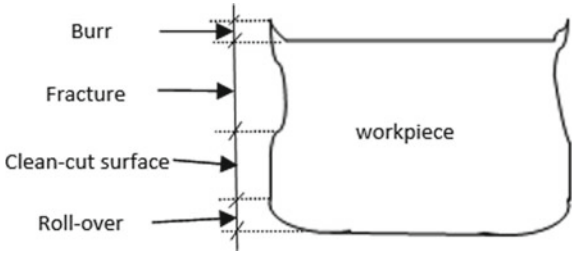
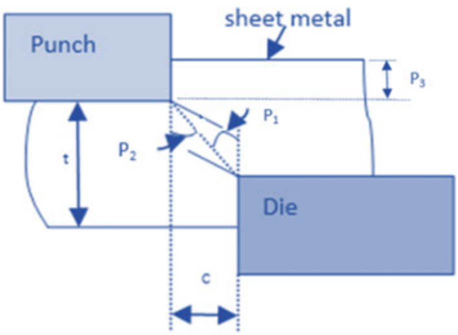


Fig. 3 Diagonal fracture line diagram [16]



$$c = 100\frac{D_m - D_p}{2t}(\%) \quad (1)$$

where D_m—die diameter, D_p—punch diameter, t—sheet thickness.

ANN is powerful methodology for studying the behavior of the turning process [12, 23], as well as the bending of sheet metal [3, 23]. The simulated system uses an algorithm that replaces the conventional judgment system. The NN is chosen to construct suitable model for predicting optimal punch-die clearance. A backpropagation neural network was used for the prediction of optimal clearance [16–18]. The data on experimental fracture angles was utilized to train the algorithm, and model is developed for a given data. While assessing the defects in sheet metal forming, [5] uses a CART, MLP, SVM, RF techniques for predicting the coil back, and utmost thinning result achieved the accurateness varying from 87.39 to 94.98%.

2.2 Decision Tree Classifier (DTC)

The decision tree (DT) algorithm is a supervised machine learning technique to solve classification and regression problems. This approach aims to develop a model that predicts the value of a targeted variable; for that, the decision tree solves the issue using the tree representation, where the leaf node belongs to a class label, and characteristics are expressed on the inner node of the tree. A classification strategy continually separates data using decision rules. Data is classified at each node for optimization of decision-making for information gain:

$$\text{Gain} = \sum_{j=1}^{m} \frac{n_j}{N_j} H\left(D_j\right)$$

where N represents the total number of data points for node j, n represents the number of data points for node j of the expected class, D represents node values, and H represents impurities [5]. The formula for impurity Gini Index is as follows:

$$I_{\mathrm{G}} = 1 - \sum_{i=1}^{C} p_i^2$$

where p_i share of sample for node.

$$I_{\mathrm{H}} = -\sum_{i=1}^{C} p_i \log_2(p_i)$$

where p_i—the proportion node fitting to a class [2]. If all node samples are of the same kind, then entropy is zero. This step is followed until the same label remains in a sample from each terminating node. A stop condition can also be established to avoid over fitting.

3 Methodology

For investigating the quality of surface, decision tree classifier is employed. The independent factors dependent, and categorical variable is chosen. Figure 4 depicts a correlation analysis using Python code to investigate the association between the independent variables through heat map generation.

The control factors are derived though literature and total of 140 data points (training and testing) and 42 (validation) data points. This study develops a DTC model by splitting data: 70% for training and 30% for testing. An estimator with a variable maximum depth is used to train the resulting model, while parameter adjustment is applied. At the depth of 5, we obtained highest accuracy for accuracy measurements in terms of training and testing, recall, precision, f1-score, and confusion matrix. At each node, we employed Gini and Entropy as impurity indices, with a maximum depth of 5 and minimum sample leaf 5. The research flowchart is shown in Fig. 5.

During training phase, progressive categorization of samples and visualization of the decision tree is developed using Python code for the detailed functioning of the Gini and progressive calculation Entropy indexes.

Figure 6 shows gradual classification of samples based on Gini index, and Fig. 7 shows iterative steps till samples are classified based on entropy.

The outcome of classification is approved if the validation (experimental) provides consistent results; the findings are directed to the DTC model training and testing for parametric optimization.

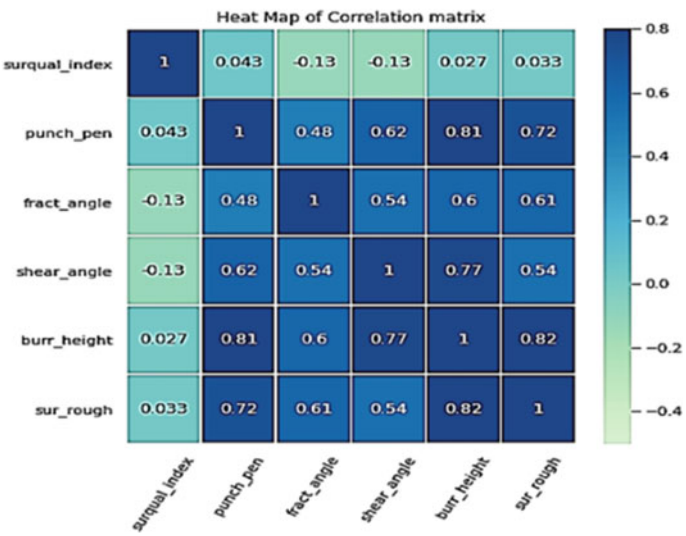


Fig. 4 Analysis of correlation

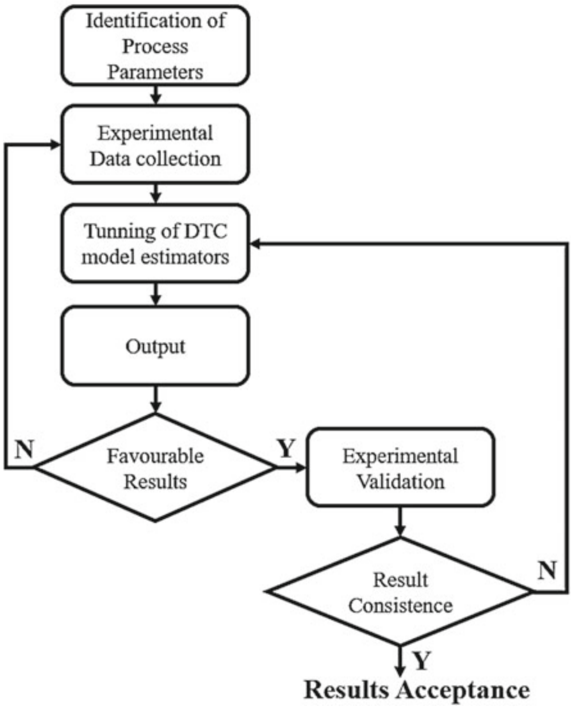


Fig. 5 Research chart

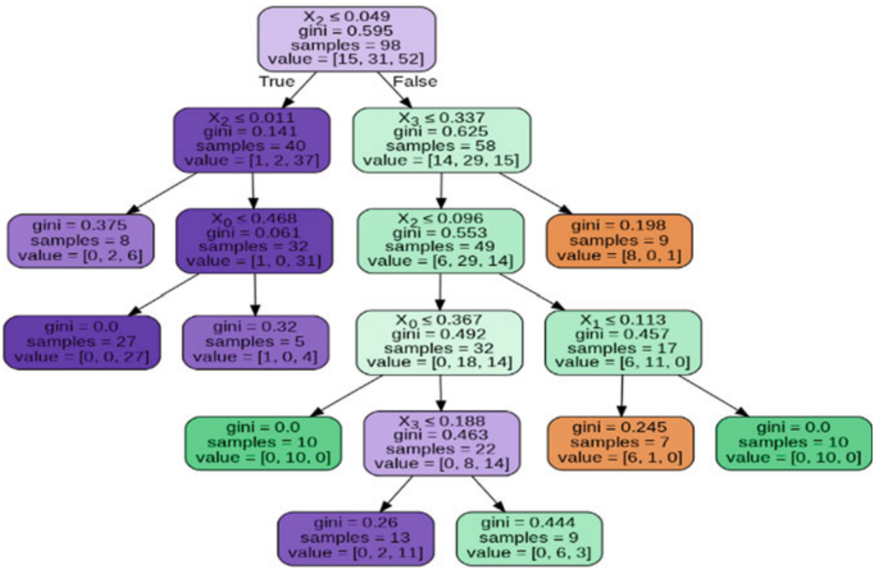


Fig. 6 Functioning of Gini index visualization

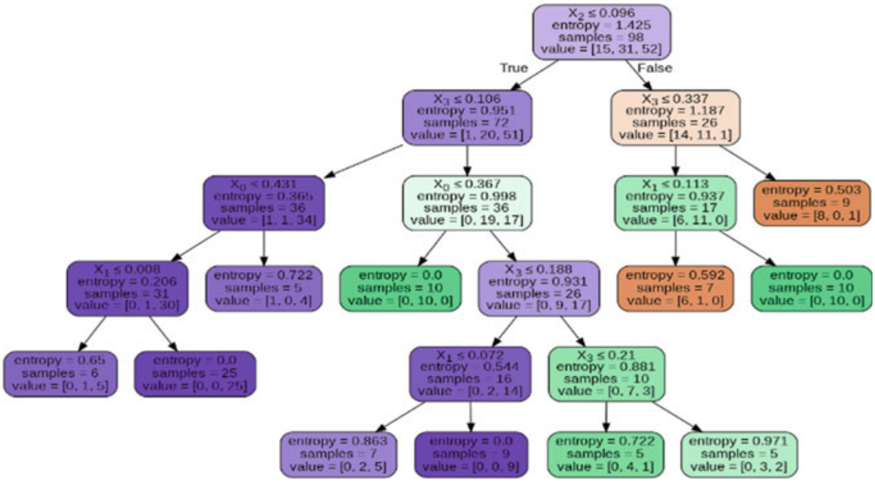


Fig. 7 Functioning of Entropy index visualization

4 Discussion and Result

Experiments are carried out for blanking operation using power press with a punch (hallow circular). Table 1 displays the input parameter and properties of 'IS277GI' for the experiment. Engineering strain and real strain are calculated using material characteristics [5].

We trained the DTC model using the Gini and Entropy index of impurity criterion, and both models obtained 93% accuracy. Figure 8 depicts a comparison of prediction performance with various classes.

Confusion matrix is an another approach employed for measuring the accuracy of model as shown in Fig. 9, to validate the performance of DTC model. During the testing phase, class 3 has all of its sample points properly identified; however, classes have a deviance of sample points (one and two).

One more performance measure for the model is receiver operating characteristic (ROC), which presents graphically performance of classification. Two variations are

Table 1 'IS277GI' mechanical properties

Properties	Percent clearance (% of sheet thickness)	Clearance (mm)	Thickness (mm)
Material elongation (%) = 48.19 Tensile strength = 301.46 True strain = 2.3 Engineering strain = 6.025 Reduction area (%) = 49.43 Yield stress = 315.43	20	0.2	1.0
	13.33	0.2	1.5

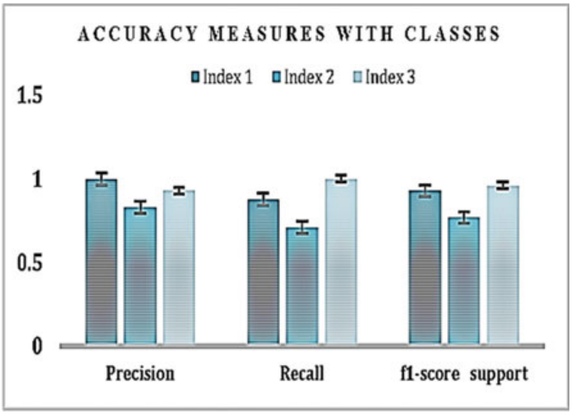


Fig. 8 Accuracy measures for different classes

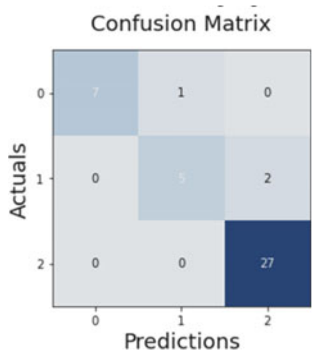


Fig. 9 Confusion matrix

plotted: the true positive rate (TPR) and the false positive rate (FPR), as shown in Fig. 10. The probability for the ROC curve of class 2 is 0.85, which is less than the probability for classes 1 and 3, which are 0.93 and 0.92, respectively.

5 Conclusion

The machine learning approach (decision tree classifier method) is used to estimate quality of the fracture surface. The result shows that punch penetration has a direct impact on burr height creation and surface roughness. When employing DTC, we discovered that both the Gini as well as Entropy index impurities provide precise model correctness for the training, testing, and validation sets. The precision metric for class one is 1, whereas the recall measure for class two is 1. With k-fold cross-validation, additional sample points would imply greater model accuracy. Other classification models, such as support vector machines and random forest, can also be investigated using the significant data points.

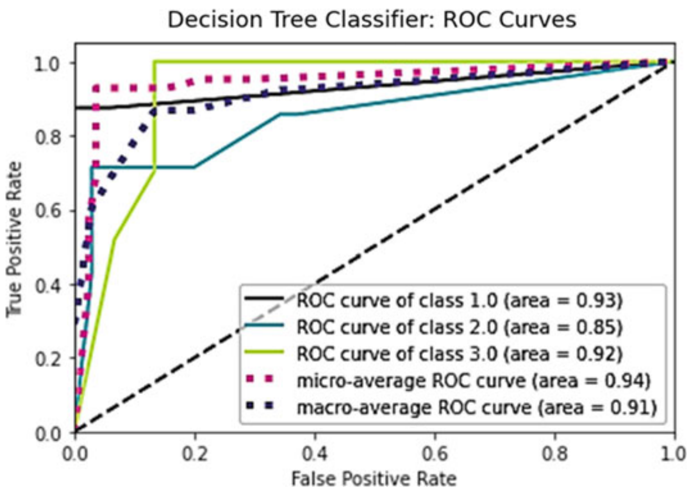


Fig. 10 ROC curve

Current study provides sheet metal production engineers with a decision-making solution for selecting the underlying factors for calculating precision for right fit requirement for processing IS277GI.

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Increasing Time Efficiency in Jewellery Industry Using Lean Manufacturing Principles

Rishi Dasgupta, Deepak Jain, and Dharam Ranka

Abstract In the increasingly dynamic and competitive world of jewellery manufacturing, it is extremely important to be updated with the current industry trends and emphasize a policy of continuous improvement to be able to consistently improve and innovate on the production processes and be competitive on a global stage. The paper aims to increase time efficiency in multiple departments in the company by applying lean manufacturing principles which involves the utilization of innovative industry trends to improve the established manufacturing practices, managerial logistics, and promote better working conditions through higher shop floor to executive integration, streamlined manufacturing processes, and focus on value to customer. This paper aims to address errors and bottlenecks which the company faces during regular operation and suggests solutions for the same. It describes lean principles implementation to decrease tool idle time and improve working practices, reduced overall non-value-added time by 50 min/worker daily and thereby improving time efficiency. Several tools like Kaizen, Kanban, and 5S were used to optimize value-added time in product manufacturing.

Keywords Lean manufacturing · Runner system · Jewellery

1 Introduction

Lean manufacturing is a systematic method used to minimize waste in a manufacturing system whilst ensuring a neutral or positive change to productivity. This

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system was pioneered in the Toyota Production Systems (TPS) in Japan, wherein the emphasis was put on minimizing waste within a manufacturing operation by identifying appropriate value generation streams [1].

The paper aims to utilize and integrate several lean manufacturing tools like Kaizen, Kanban, 5S, Poka-Yoke, and visual management systems to improve the operational efficiency in the shop floor of a jewellery manufacturing company—V.D. Jewels and Artisons Pvt. Ltd. located in Mumbai, India. Several time study analyzes were performed on the shop floor, and operational bottlenecks were identified. Solutions for improvement were suggested and implemented after successful trial runs; including the design and construction of a 5S toolbox for tool storage and sorting in the repair and setting department and the implementation of a runner system for more efficient product flow between departments.

2 Literature Review

The majority of open-source studies on the benefits of lean manufacturing skew towards opinion pieces from industry leaders or as anecdotal evidence from lean practitioners which may be prone to biases without quantifiable evidence. However, there also exist many specialized literatures on the benefits of lean manufacturing in various industries with detailed analyzes of LM tools for process improvement, which can be appropriated to the jewellery industry as well. One study highlights the importance of the management accounting system in the process of adopting a lean production strategy [2] and argues for greater transparency in the design, cognition, and functionality of the account (order) management system. Several studies of the benefits of lean manufacturing in the automobile sector [1, 3–5] show quantifiable improvements in performance after following lean principles, with one of the studies [3] showing an improvement in the production cycle time from 11 to 7 s after using lean manufacturing tools (MUDA-automation). In another study of an automobile sector assembly process, a new loop layout was implemented for the work stations in order to improve the production process. It was concluded that the productivity at the shop floor could be improved by 10% in this company [6].

One study also emphasized the importance of visual management systems to improve overall efficiency. This study was conducted in the advanced manufacturing laboratory at the University of Stellenbosch; it concluded that the overall time efficiency can be improved by using visual management tools [7]. In another study, the implementation of tools such as 5S and visual management generated an average decrease of 47% in setup time and resulted in greater staff involvement [8]. In a study undertaken by means of questionnaires presented to workers, the improvement of ergonomically enhanced conditions to perform operations resulted in less absenteeism and consequently, to the greater productivity and quality of the manufactured goods [9]. One study which pertains specifically to the jewellery industry demonstrates the need for an MES interface in addition to improvements in the account management systems [10].

Therefore, from the above, we can say that it is important for the lean philosophy to penetrate all layers of the organization and lean manufacturing tools be applied to all levels of operations in the shop floor as well as the logistics and management sectors. There needs to be greater transparency in the account management and logistic systems as well as higher shop floor visibility. Specialized software can be appropriated for this purpose and create a smart operation apparatus in the company. With all these implementations, the company can progress into the lean philosophy.

3 Methodology

The methodology followed was an initial review of literature and further research to narrow down the tools and principles which can be implemented at the grassroots level in the company, followed by time study analyzes in various departments in the company to determine the overall scope for improvement.

The team identified a lack of visual management systems in the repair and setting department of the company, which often lead to miscommunication and significant idle time due to tool disarrangement. As a countermeasure, a 5S toolbox was ideated, designed, and tested in the department with successful results. Another major inadequacy prevalent throughout the shop floor was the lack of efficient product flow methods which lead to several bottlenecks at various departments in the company. For this purpose, a runner system was tested which was successful in removing the said bottlenecks and reducing the overall batch idle time.

Research was also conducted on the MES-ERP integration system, traceability, and visual management tools which can be designed and appropriated for use at the shop floor level. The major bottlenecks were identified, and solutions for the same were ideated keeping into consideration minimal gestation and capital investment from the company. Finally, several solutions were proposed with few being implemented after successful demonstrations in trial runs conducted in the company.

4 Results and Discussion

Various 5S systems were implemented along with Kanban principles to facilitate efficient storage and accessibility for the workers who are handling various tools during the production process. Initially, the team surveyed the hand-setting and repair departments and identified a disorganization in tool storage from workstation to workstation. Considering that most of these employees are contractual and often change workstations, adjusting to disorganize workspaces can cause additional confusion which is an avoidable time wastage. Therefore, the workstations required a regulated storage system. 5S principles were used to design a sorting tray in which the toolsets would be stored in colour-coded compartments.

The toolbox with various stages as shown in Fig. 1 is constructed from MDF boards which are cheap and commonly available, with rectangular high-density XPS foam slabs placed in smaller compartments to hold the thinner tool-bits. A separate section for the Dremel tool and smaller subsections for other tools will create a compact storage space which will be portable enough. Additional shelves and handles to carry the box can be attached if required. The toolbox design has been presented to the project in-charge, and deliberations about its utilizations are being conducted.

The toolbox has been designed in SolidWorks CAD Software and has a base dimension of 20 cm x 15 cm with height 7 cm. It has three compartments—one compartment for storage of Dremel tool and two compartments for storage of tool-bits. The Dremel compartment contains MDF holders which follow the contour of the tool surface, whilst the tool-bit compartments have XPS foam slabs for attachment. Identifiers can be placed in the two compartments for tool-bit identification. A hinged lid is also provided for enclosure.

One of the more recurring problems in the shop floor was the need for workers to move away from their workstations to operate on a separate workstation or deliver work pieces themselves, thereby leaving the remaining batches idle. This was observed during the time study analyzes conducted, that during such situations, jobs would be completed at an average of 250–300% of their usual time which is a significant markup from their ideal completion times.

Even though this glaring wastage can be compensated by hiring more workers, often it is counter-intuitive to do so especially during the slow months where the company can afford to delay product completion as long as it ships in time, owing

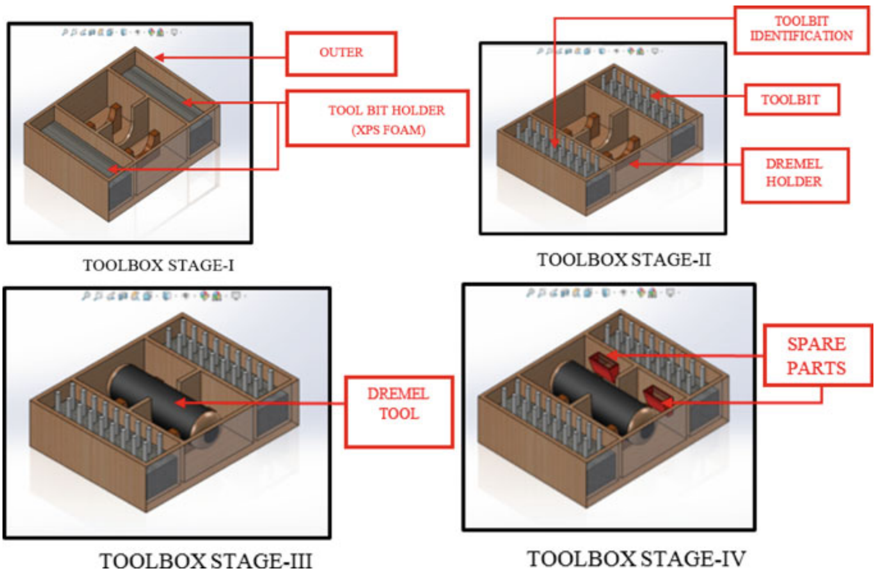


Fig. 1 Toolbox design

to lower order volume. However, this does not exempt the contrary situation when the worker has to physically deliver the product(s) themselves. In this case, the team observed an average 150% increase in completion times, with 50% idle time which translates to 2–5 min accounting for separate product categories.

The red lines as shown in Fig. 2 denote the usual product flow within the company, room no. 4 which is the laser department has the highest inflow at any given time, with items coming in from almost all the departments simultaneously. This causes a long queue and immensely contributes to idle time, thereby becoming a major bottleneck within the company. The direct solution to this issue is to order another laser welding machine or repair the secondary laser machine which has been non-operational for a long time. Both of these solutions will require significant capital investment; however, a solution having runner arrangement is proposed.

A runner system can be established where each worker is provided with a two-sided stand, with one coloured GREEN and the other coloured RED to signify the QC and laser departments, respectively. These are the two most frequently visited areas where high numbers of batches pass continuously. An independent runner will be hired to deliver these batches to the required department, as signalled by the worker at the repair/setting workstation.

Once the worker pulls up the stand (which is hinged on the side wall of the workstation cubicle and facing towards the door), the runner collects the batches and updates the batch status in a tasks software or app similar to Google tasks. They then bring it to the required department as per the colour of the flag. At the same time, the worker can keep working on the next batches rather than wait in line for access to the laser department. This is expected to save an average of 2–4 min per batch and a cumulative of 1–1.5 h per worker daily. A weekly saving of 7–8 h equates to one full day of productive work for each worker. Considering 20 workers at a time, this equates to 160 h of cumulative savings weekly.

The runner system has been proposed, and trial runs have been conducted which corroborated the above findings. The workers themselves have responded positively

Fig. 2 Shop floor layout with product flow lines

to this idea and seem to be happier and more focussed in their work. Physical exhaustion is minimized for the worker, and they have shorter working hours at the end of the day. This suggests that hiring the extra worker is worth the time saved.

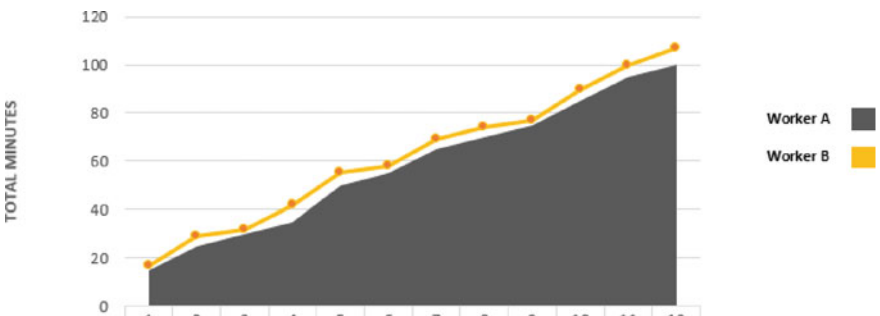
A dry run was conducted with the previously discussed improvements to evaluate their efficacy. For this purpose, a day was selected in which a similar kind of ring was ordered in bulk so that there would be enough units for the workers to operate on in independent workstations at the same time.

The workers were chosen at random in sets of two, and time study was conducted as shown in Fig. 3 such that one worker was placed on the improved workstation and the other in the control workstation (which has not been changed from original). The trial was conducted three days after the workstations were improved so that the worker may be able to adjust to the new changes.

Both workers began with 12 unworked metal base pieces on which setting is to be conducted. One worker (A) is at the workbench with 5S improvements (GREY), and the other (B) is at an unchanged workbench (ORANGE). We can notice the benefits of having the sorting system and other 5S principles at workbench A, as even at the very first piece, he saves 2 min on the whole operation as compared to worker B. Now, overtime, this number cumulates, and we can see that worker A finished with all 12 pieces 7 min earlier than worker B.

However, this trial run by itself was insufficient to conclusively establish the benefits of the 5S system since there was no parameter to consider the variation in the efficiency of the workers themselves, or guarantee the conformity of every metal piece which may contribute to the adulteration of actual data.

The only way to understand the trend is to generate multiple trial runs using many worker pairs and also iterating between workers within those pairs. The time study data was collected as shown in Fig. 4. Here also, we can see a similar trend wherein worker at bench A completes the same set of workpieces faster than worker at station B. Similar trends were obtained for three other pairs; however, one trial was of particular significance as it establishes the necessity of the runner system. Figure 5



	1	2	3	4	5	6	7	8	9	10	11	12
Series1	15	25	30	35	50	55	65	70	75	85	95	100
Series2	17	29	32	42	55	58	69	74	77	90	100	107

Fig. 3 Time study–setting and repair department

is the cumulative average of time study data collected over 10 days at workstations, where the runner system was on trial. Data was collected using a stop watch, and the runner motions were identified to locate high product flow workstations. The graph shows the comparative time study of two workers, A and B with worker A provided with a runner, and worker B is operating in original conditions.

Here again, we find a similar trend as the above two graphs. However, we can see that in this instance, the time saved by worker A is almost 35 min, which is very high. The reason for this was that both the workers were provided with one defective piece which required a laser welding operation. However, only worker "A" was provided with the runner, so when worker "B" reached the defective piece (no. 5), he had to physically leave his workstation and queue at the laser department, whereas "A" had the service of a runner who did this task for him whilst he worked on the remaining units. So, by the time the runner returned with the piece around 30 min later, "A" was already finishing up with workpiece no. 7 and could smoothly change over to

Fig. 4 Time study 1—setting department

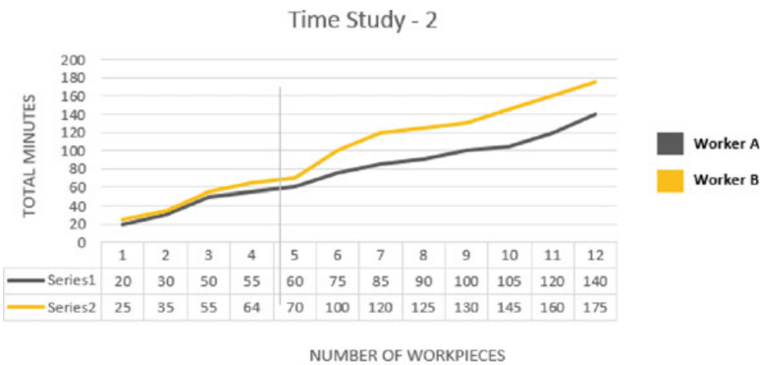


Fig. 5 Time study 2—setting department

workpiece no. 5. At the same time, worker "B" returned after 30 min of having left the workstation and then resumed from workpiece no. 5 onward.

In the end, the runner system saved approximately 35 min for worker "A" which can be utilized to perform operations on two extra workpieces. Situations like this occur approximately 30% of the time during rush hours as per observation, so a system like this may save 50 min at maximum. Calculation = 0.3 * 35 min * 8 h * 60 min / (Approx. 100 min cycles) = 50 min/day saved.

The above evidence suggests that the lean manufacturing principles, 5S improvements, and the runner system have proved beneficial to improving the time efficiency in the company.

5 Conclusion

This paper presents multiple strategies for increasing overall manufacturing efficiency and describes how lean principles were utilized to decrease tool idle time and improve working practices, reducing overall non-value-added time by 50 min/worker daily and thereby increasing time efficiency. Several tools like Kaizen, Kanban, and 5S were used to optimize value-added time in product manufacturing. The suggested improvements of including the 5S toolbox design and the runner system to aid product flow were implemented with encouraging results and shall remain beneficial to the company under the varying demand cycles.

6 Future Scope

VD Jewels and Artisons Pvt. Ltd. are a relatively new company with tremendous scope for improvement. Along the course my tenure at the company, it was observed that various areas in which the company can improve on the systemic level as well as on the micro-level within departments. Additionally, there is scope for further streamlining the manufacturing pipeline by trimming off non-value-added times and reduces/recycles the various wastes and by-products resulting from the manufacturing processes. Some suggestions for the company to implement in the future are as follows:

- Improve and develop the existing ERP system which should be adapted to business processes and other supporting data, such as the mapping of the skills and abilities of each worker.
- Creating a notification system, in the form of health check notification system (COVID specific), due to lack of automation within the production processes.
- Reuse the wax utilized during the casting process to make candles and other wax products as a high turnover side business.

- Resell the gold and silver dust by-product directly to the paint industry where gold dust is used as a primary material in high-end edible paints.
- Utilizing a barcode system on product batches to ensure traceability from producer to end customer.
- Experimenting with electroplating using thiourea in the polishing department.
- Increasing machine redundancy, especially the laser welding machine to control product flow traffic on the shop floor.
- Performing TOPSIS analysis of all departments to find ideal solution with given alternatives.

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Productivity Improvement by Applying Lean Tools for Manufacturing of Mechanical Seal

Aayush Shah, Sanket Sane, and Mehul Prajapati

Abstract Lean tools aid engineers and organization, to identify problems and various losses, waste and to reduce or eliminate them. Overall equipment effectiveness (OEE) is a successful lean tool to increase the productivity of the existing manufacturing process flow in a plant. The placement of various machine equipment, facilities for providing services, and staff amenities within a facility affects how effectively production is carried out. The paper gauges the OEE tool and plant layout to know the availability of the machines for manufacturing the seals, its efficiency, and overall quality of the product.

Keywords Lean tools · Productivity · Overall equipment effectiveness (OEE) · Plant layout

1 Introduction

Lean tools are grouped into three categories: just in time (JIT), waste elimination (WE), and flow management (FM). The lean tools can also be divided into improvement and exploration categories. Exploration tools are the lean tools used to systematically gather data and compile figures to determine the scope of improvement. Improvement tools for lean manufacturing include Andon, value stream mapping (VSM), overall equipment effectiveness (OEE), and Yamazani charts. The lean tools that are applied to change or improve upon the product or process fall under improvement tools such as 5S, heijunka, Jidoka, Kanban, Poka yoke, and single minute die

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exchange. The improvement tools are used to change the situation after the exploration tools have been used to comprehend the current situation. The classification of the lean tool as an exploration and improvement tool further justifies the order in which lean tools are implemented in organizations. A study found that most of the industries, 90% tend to implement exploration and improvement tools to find out and eliminate unnecessary non-productive time and waste [2].

2 Overall Equipment Efficiency

Overall equipment effectiveness (OEE) is a way to monitor and improve the efficiency of manufacturing process. OEE has gained acceptance as a management tool for monitoring and assessing plant floor productivity. Three indicators used to measure OEE (availability, performance, and quality). These metrics assist in determining the plant's effectiveness and efficiency as well as in classifying significant productivity losses that occur during the manufacturing process. The setup and adjustment time that is lost due to downtime is minimized by the work study. Work study is the methodical evaluation of activity implementation strategies with the goal of enhancing resource utilization efficiency and establishing performance benchmarks for the activities being carried out. There are a number of work study techniques such as ergonomics, operations research, work study, and time and motion study to minimize setup and adjustment time to improve overall equipment effectiveness. It measures both efficiency (doing things right) and effectiveness (doing the right things) with the equipment's [3, 4].

OEE is a function of the three factors availability, performance, and quality. Availability is proportion of the time the machine is actually available out of the time it should be available. Performance efficiency is the portion of the OEE metric which represents the speed at which the machine runs as a percentage of its designed speed. Quality refers to quality rate, percentage of good parts out of total produced. The quality metric is a pure measurement of process yield that is designed to exclude the effects of availability and performance [3].

Based on the data collected, OEE is calculated by

$$\text{OEE }\% = \text{Availability x Performance} \times \text{Quality }\% \tag{1}$$

2.1 World Class OEE

A benchmark is used to compare the company's OEE to world class OEE. Table 1 below provides the world class OEE percentage.

OEE factor values are generally acknowledged, but they vary for various industries. For manufacturing, the value of world class OEE is 85% but for Paper Industry

Table 1 World class OEE [1, 4]

Factors in OEE (%)	OEE world class
Availability	90.0
Performance	95.0
Quality	99.0
OEE	85.0

and Cement Industry, the value is 95% and 80%, respectively [1, 4]. The sections that follow discuss OEE technique applied in a manufacturing firm and the proposed plant layout to increase the efficiency. The project was carried out on the shop floor of the Chemseals Engineering Pvt. Ltd.

2.2 Data Collection

On the shop floor, two CNC machines operate continuous. After observing the manufacturing process, various unnecessary downtime losses were observed. To study more about them, the previous three months data is listed for two machines given in Table 2.

As seen in the above data, the performance of the three months is good which means that machine is running at maximum speed. Quality is also good, but availability every month is low, and because of this, OEE is reduced. Availability is the percentage of time that machine is available for scheduled production compared with the amount of time they were actually producing. Figure 1 depicts the average down time loss due to factors like machine breakdown, no tooling available, power cut, inspection, rework, and CNC programme unavailable for three months which reduce availability.

Table 2 Data for CNC lathe machine and CNC milling machine

Elements of OEE	Data					
	CNC lathe machine			CNC milling machine		
	Oct 20 (%)	Nov 20 (%)	Dec 20 (%)	Oct 20 (%)	Nov 20 (%)	Dec 20 (%)
Availability	87.98	90.27	89.02	82.98	83.27	82.63
Performance	81.66	83.06	82.41	74.66	75.06	74.21
Quality	96.75	96.84	96.11	98.05	97.94	98.41
OEE	68.5	72.60	70.50	60.74	61.21	60.34

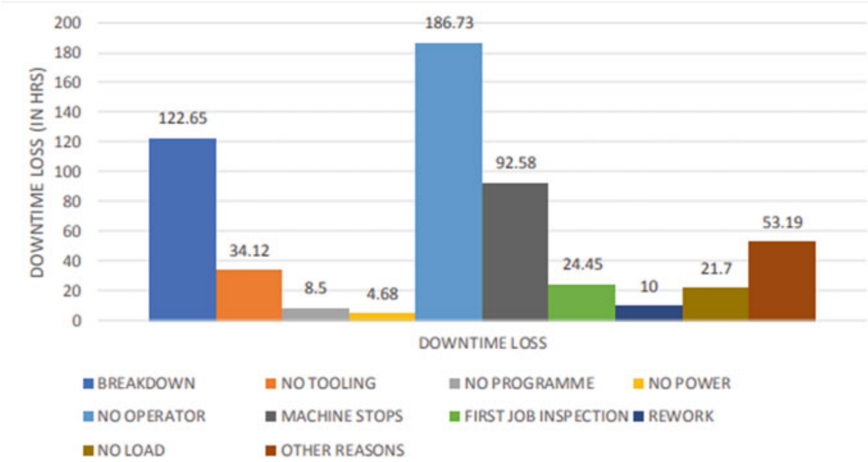

Fig. 1 Graph of average downtime loss of three months

2.3 OEE Metric Calculation

To find out more about the causes for low availability, OEE is calculated for the month of January 2021. After implementation of 5S, Table 3 records the shift data collected for month of January 2021 for two machines CNC lathe and CNC milling machine.

Gross available hours for production include 365 days per year, 24 h per day, and 7 days per week which is an ideal condition which excludes holidays and vacations. A shift's mandatory breaks (tea break, lunch break) are not included in the planned production time.

Table 3 Observed data of CNC lathe machine and CNC milling machine

Entities	Data for January 2021	
	CNC lathe machine	CNC milling machine
Shift length	10 h = 600 min	10 h = 600 min
Lunch break	30 min	30 min
Tea break	2 @ 10 min = 20 min	2 @ 10 min = 20 min
Total break	50 min	50 min
Downtime	60 min	86 min
Idle run rate	1 piece/4 min	1 piece/ 2 min
Total piece produced	98 pieces	176 pieces
Rejected pieces	4 piece	2 piece

Table 4 OEE for January 2021

Elements of OEE	Formula	Jan 21	
		CNC lathe machine	CNC milling machine
Availability	$\frac{\text{Operationtime}}{\text{Plannedproductiontime}}$	$\frac{490}{550} = 89.09\%$	$\frac{472}{550} = 84.36\%$
Performance	$\frac{\text{Partsproduced} \times \text{idlecycle}}{\text{Availabletime}}$	$\frac{94\text{x}4}{490} = 80.00\%$	$\frac{176\text{x}2}{464} = 80.00\%$
Quality	$\frac{\text{Goodpiece}}{\text{Totalpiece}}$	$\frac{94}{98} = 95.91\%$	$\frac{174}{176} = 95.91\%$
OEE	Availability x performance x quality	68.35%	63.26%

$$\text{Planned Production Time} = \text{Shift Length} - \text{Breaks} \quad (2)$$

The downtime and the speed losses are also ignored by the planned production time available. The down time includes equipment failures, machine changeover, tool damage, material shortage, and process warm up. The speed losses include product misfed, component jam, equipment aged, tooling wear, product flow stoppage, and level of maintenance of operator.

$$\text{Operating Time} = \text{Planned Production Time} - \text{Down Time} \quad (3)$$

The overall goal of OEE is to maximize the final machine run time which also includes the quality or the goodness of total parts produced. Quality losses refer to the situation when the line is producing, but there are quality losses due tolerance adjustment, warm up process, and part incorrect.

$$\text{Good Piece} = \text{Total Piece} - \text{Reject Piece} \quad (4)$$

To find OEE, use the data collected for the month of January 2021 from Table 3 with the above equations.

Table 4 gives OEE for the month of January of CNC lathe machine is 68.35%, and CNC milling machine is 63.26%. There is an enough scope for improvement in OEE.

2.4 Solution for Low OEE

To further increase the availability and OEE, below suggested points must be implemented.

(1) Machine breakdowns: Preventive maintenance programme must be implemented, and training should be given to operators, so that minor breakdowns can be avoided. Alternate tooling, enough manpower, sophisticated measuring

instruments and gauges, and work holding devices should be made available to reduce downtime.

(2) CNC machines should be integrated with the CAD software's to generate programme of any job immediately after loading job on machines. Instead of using SDN software for transferring programme from computer to machine use flash card wherever possible, so there will not be time loss due to programme transfer or computer hang.

(3) Time require for rework should not be considered as a part of OEE because these parts are made as per drawing before sending it for assembly.

(4) 5S Activity: 5S should be applied and practised in the industry. Necessary and unnecessary parts, tools, and equipments should be sorted and set in order. Tag should be attached, so that the operator will not spend more time in finding required parts. And the unnecessary downtime will be reduced.

3 Redesigning of Plant Layout to Increase the Efficiency

The simple flow of materials through a manufacturing facility can be significantly altered by small changes in the positioning of machines and equipments. The effectiveness of the entire manufacturing process is also impacted along with production costs. Designing a functional plant layout from the beginning is important because layouts are quite expensive. Using string diagrams and systematical layout planning, a plant layout can be redesigned to increase efficiency. String diagram provides basic details about the flow of material through the shop floor and the inter-relation of various activities [5].

3.1 Existing Layout

A measurement was taken of the space taken up by the machines, aisles, work-in-progress, storage area, raw material areas, and finished goods areas. In order to depict the overall picture of the manufacturing activities, flow process charts, outline process charts, and string diagrams were used. Figure 2 depicts the scaled drawings of the floor plans for the building [5].

The manufacturing process flow and the distance travelled in between the machine are mentioned in the below Table 5.

The job requires a total of 62 m of travel distance under the current plant layout. The prescribed travel length proposed by the company management is 35 m. Longest travel distance in the plant is the distance between the grinding machine and the quality control department, i.e. 13 m.

$$\text{Efficiency of current plant layout} = \frac{\text{Prescribed travel length}}{\text{Actual travel length}} = \frac{35}{62} = 56.45\%$$

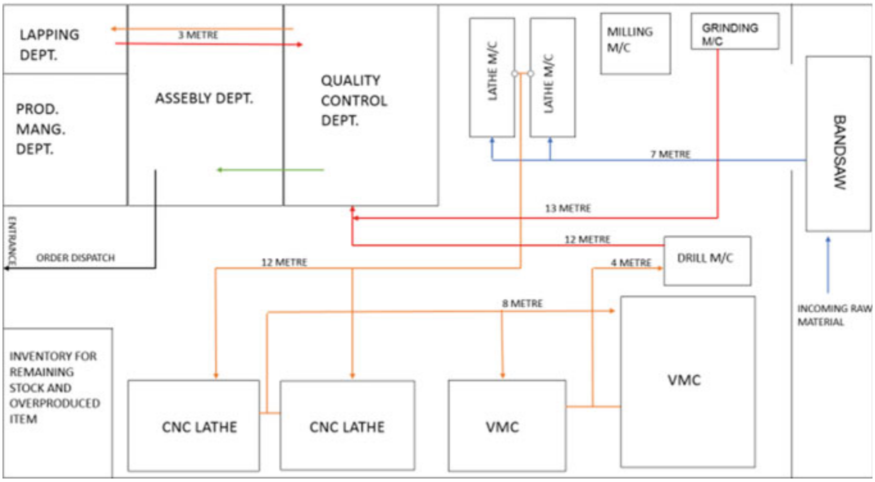

Fig. 2 Current plant layout

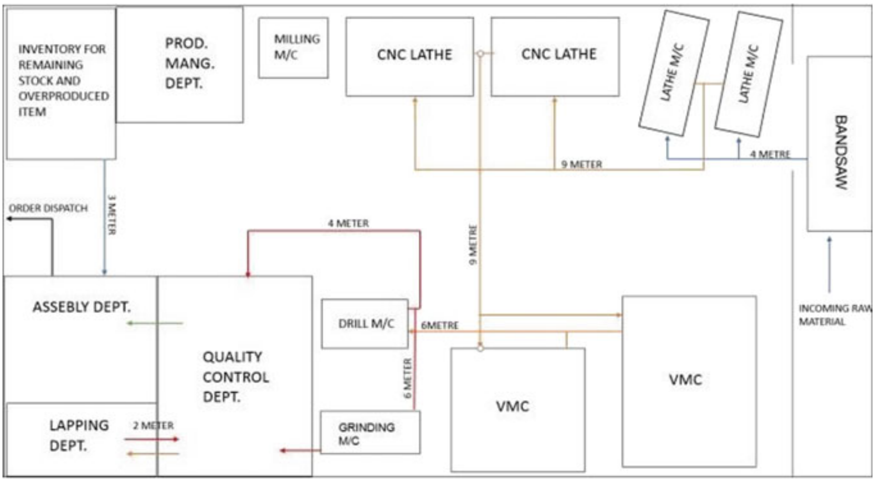

Fig. 3 Proposed plant layout

The main objective is to reduce the actual travel length of the material. By observing and studying the current material flow of the work piece right from the raw material to the finished product, a new plant layout is proposed.

Table 5 Distances travelled between machines

S. No.	From	To	Distance travelled (metre)	
			Current layout	Proposed layout
1	Material cut on the bandsaw	Conventional lathe machine	7	4
2	Conventional lathe machine	CNC lathe machine	12	9
3	CNC lathe machine	CNC milling machine	8	9
4	CNC milling machine	Drilling machine	4	6
5	After drilling on drilling machine	Quality control department	12	4
6	After final check in the quality dept	Assembly room	1	1
7	Grinding machine	Quality control department	13	6
8	Quality check department	Lapping department	3	1
9	Lapping department	Quality control department	3	1
Total distance travelled =			62	46

3.2 *Proposed Plant Layout*

String diagram indicates complex movements, back tracking, congestion, bottle necks, and over and underutilized paths on the current shop floor layout. By understanding the string diagram of the proposed plant layout, the material travelled distance between the machines and department is reduced as mentioned in Table 3. The location of quality control department, CNC lathe, and lathe machines was moved. Figure 3 depicts the proposed plant layout with the total travel length of the job as 46 m.

$$\text{Efficiency of current plant layout} = \frac{\text{Prescribed travel length}}{\text{Actual travel length}} = \frac{35}{46} = 76.00\%$$

A firm's long-term success can be adversely affected by the percentage increase (Eq. 5) and percentage decrease (Eq. 6) in transportation length when choosing which type of facility layout to use.

$$\%\ \text{improvement in plant layout} = \frac{\text{Proposed layout} - \text{Current layout}}{\text{Current layout}}$$

$$= \frac{76 - 56.45}{56.45} \times 100 = 34.63\% \tag{5}$$

$$\% \text{ reduction in transportation length } = \frac{\begin{array}{c}\text{Difference in proposed plant}\\ \text{layout material movement}\end{array}}{\text{Difference in current plant layout}} \times 100$$
$$\frac{(62 - 27)}{(46 - 35)} \times 100 = 40.74\% \tag{6}$$

The most effective manufacturing facility layout is chosen based on its adaptability to change in product demand and product mix in the future. Minimizing distance travelled is not always practical for all manufacturing industries. Whilst keeping the bare minimum of distance between machines and departments, it might be necessary to tolerate congestion in a particular area.

4 Conclusion

Productivity of the company is increased after applying lean tools and improving the design of the plant layout. After implementing 5S, downtime was reduced to 15–20%. After applying overall equipment effectiveness (OEE), various problems and unnecessary downtime losses were identified which are affecting the productivity. Redesigning of plant layout reduced the material travelling distance and minimizes unnecessary moment of material and workers on the shop floor.

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A Conceptual Framework Involving Barriers in the Integration of Additive Manufacturing with Industry 4.0 Practices

Trupti Markose and Hari Vasudevan

Abstract Industry 4.0 (I4.0) has drawn a lot of attention internationally over the past several years, because of its potential to boost the manufacturing sector's sustainability and competitiveness in future. For example, additive manufacturing (AM), advanced robotics, AI and ML, big data analytics, cloud computing, smart sensors, Internet of things, and augmented reality are all examples of advanced technologies that are currently referred to collectively by the term "I4.0". Transitioning from the current centralized production processes and further toward digital and decentralized one, significantly increases flexibility, quality, productivity, cost, and customer satisfaction. Despite the potential advantages of I4.0, firms are still having trouble embracing new technologies and successfully integrating them into their business strategies. I4.0 is thought to have been significantly influenced by AM, and other cutting-edge technologies are now supporting AM's productive operations in several industries. And therefore, integrating AM with I4.0 technologies is the need of the hour. Although technically feasible, a number of significant obstacles prevent its execution. Very few publications in the extant literature discuss the barriers in the readiness for the integration of AM and I4.0. In light of the above, this study makes an effort to pinpoint these obstacles and comprehend the impact they have on the advantages brought about by this integration. A literature analysis was done on AM and I4.0, covering the obstacles preventing their integration, in order to develop the conceptual framework, while also presenting the constructs chosen and hypotheses made toward attaining the integration. The study's objective was to identify the obstacles that must be overcome for AM to successfully integrate with I4.0 technologies. According to the study, it is hypothesized that the barriers and organizational factors negatively moderate the benefits of the integration of AM with I4.0.

Keywords Additive manufacturing · Industry 4.0 (I4.0) · Barriers for integration · Organizational factors

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1 Introduction

The creation of different manufacturing paradigms can be traced back to the historical relationship between technology advancements and industrial revolutions. Industry 4.0 (I4.0), also called the fourth industrial revolution, is a new idea that involves building a high-tech structure that is more connected and smarter [1]. The objective of I4.0 is to automate production of even the most complicated parts, while keeping batch size to a minimum. The goal is to get the benefits of mass production even when making just one complex part by using I4.0 tools [2]. A tool for Industrial Revolution 4.0, additive manufacturing examines the most recent advancements, underlying mechanisms, difficulties and potential for 3D printing in a digital manufacturing environment [3]. In order to maximize the benefits from one to the other, I4.0 and AM both share common goals, and hence to take advantage of AM's competitive edge in the I4.0 environment, the time has come to rewrite the manufacturing industry's business model [2]. Many researchers have identified and prioritized the barriers for AM implementation as well as I4.0 implementation. However, only few researchers have so far identified the same, and very few have ranked the challenges/barriers for integrating Industry4.0 with AM [4–8]. Also, various studies indicate that these barriers play a moderating influence on the benefits due to this integration [9–13].

Therefore, a few research questions arise, such as what are the barriers to the integration of AM and I4.0? How do they affect the benefits reaped out of this integration? What is the mediating and moderating factor that will affect the integration and its benefits? In this context, this research study has attempted to explore the following:

1. Identify and examine the potential barriers for integrating AM with Industry 4.0 from the extant literature.
2. Examine the moderating factors and its effect on the benefits of integrating AM with I4.0.
3. Develop a research model showing the relationship between barriers and readiness for integration of AM and I4.0 and test various research propositions.

There are four parts to this paper. Introduction is covered in Sect. 1, and then, theoretical background is covered in Sect. 2, which also provides the most recent literature review on the barriers of AM and I4.0. Additionally, it provides literary backing for the moderating elements. The research model and the created hypotheses are presented in Sect. 3. The conclusion and recommendations for further study on the same are presented in Sect. 4.

2 Theoretical Background

2.1 Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing, being a game changer, offers flexibility in the manufacturing process and strengthens the supply chain through localized manufacture. In contrast to the conventional manufacturing process, AM makes it possible to produce accurate geometric shapes by layering the material onto a digital design without the need for human interaction [14]. AM has established itself as the industrial sector's answer to Industry 4.0. This cutting-edge technology's versatility has transformed the industrial world from what it formerly was. Another intriguing aspect of additive manufacturing is the ability to produce a product, employing both composite and functionally graded materials in a single manufacturing run. This is significant to Industry 4.0, because it demonstrates how IoT, one of the technologies driving Industry 4.0, makes it possible for a product to be developed in one area and manufactured in a different location. Remote management of a production process is also seen possible from anywhere in the world.

Five fundamental steps in the additive manufacturing (AM) process enable the features of Industry 4.0, making AM the foundational technology for the fourth industrial revolution [15]. Despite being prepared to implement AM technology; Indian industries are still in the early stages. In this regard, the spread of this technology and research into the significant barriers hindering its adoption will aid in understanding the dynamics of this industry and competitiveness. Few researchers identified and analyzed some critical barriers, like compatibility, initial cost, and lack of talent. Among other factors affecting AM implementation, organizational factors are also known to affect production competence and firm competitiveness [10, 16, 17].

2.2 Industry 4.0

Advances in German Industries have given birth to the origin of the fourth industrial revolution, often known as "Industry 4.0 (I4.0)" in the manufacturing sector, and it aims to achieve intelligent autonomous production. In the manufacturing scenario known as I4.0, connected machines will work together to perform certain tasks. Utilizing a range of information and communication technologies, it enables system integration [18]. The cause group barriers, like lack of management support, lack of knowledge about Industry 4.0 concept, training cost and availability of trainer, lack of digital operations, vision and strategy, lack of organizational and process changes, implementation cost, lack of Internet-based networks and Internet connectivity, etc., relevant to Industry 4.0, and their cause and effect relation were explored and identified [19]. There are a number of technological, organizational, and environmental elements that could affect as to how SMEs are now positioned in relation to Industry

4.0. Depending on their characteristics, these factors might serve as either barriers or drivers [20].

2.3 Integration of AM with Industry 4.0

Additive manufacturing (AM), the most innovative production tool, is a crucial Industry 4.0 technology. The manufacturing sector needs the support of all other I4.0 components, with AM playing a key role. Flexibility in manufacturing is one of I4.0's objectives. Manufacturing can easily adjust to change in product design or product mix with little to no influence on how it is now set up and AM is a great solution to address this. When a product's design is changed, additive manufacturing (AM) can be used to build the item without affecting the production setup. AM is crucial for continuous development, because it can swiftly generate new parts, whenever a design change occurs [2].

Integrating Industry 4.0 and additive manufacturing makes it easier to control multiple manufacturing processes and allows for fewer iterations with less time and waste creation, resulting in a higher benefit-to-cost ratio. Every part of AM is controlled by a computer, and a computer is capable of managing the number of machines simultaneously. Industry 4.0 consists of computer-driven machinery with extensive programmability and information technologies. These gadgets contain many computer-controlled AM machine kinds, and the operations can be altered online using a single controller. Therefore, this technology makes it possible to integrate and control a wide range of manufacturing equipment online. The creation of a product that is customized for each user inside each machine is made possible by this combination. Due to their versatility in creating several products at a time and practically infinite levels of complexity, AM machines can be used as a crucial element of the modern industrial age [7, 15, 21]. The factors that must exist for AM to effectively integrate with Industry 4.0 technologies were identified in another research. According to the study, organizational characteristics have a moderating effect on whether AM is ready to be integrated with Industry 4.0 [22]. Bibliometric data on the barriers through a systematic review in two key areas: business model innovation and sustainability in AM from Industry 4.0 perspective were analyzed [23]. The main obstacles of implementing AM technology are the expense of integrating the AM setup into the manufacturing system and the additional cost associated with materials and post-processing [5].

Based on the above discussions, it is vital that the barriers of AM and I4.0 be investigated and analyzed. Ranking and analyzing the barriers assist managers in creating risk mitigation strategies as well as in assessing risks associated with manufacturing, supply chains, and business initiatives [24].

Few of the potential barriers are the implementation of additive manufacturing (AM) in operations, its productivity limitations and economic and social sustainability, high investment cost, organization transformation, unpredictable value and risk as well as lack of know-how. Whereas, few potential barriers in implementing

Industry 4.0 are lack of understanding and knowledge, inadequate digital culture, employee flexibility required to learn and adapt, implementation cost, integration of physical systems with cyber systems data and information security, etc. [19, 25].

3 Research Model and Hypotheses

A moderated mediation model, depicted in Fig. 1, was developed following a thorough description and content analysis of the theoretical background to demonstrate the relationship between barriers and readiness for AM and I4.0 integration as well as the moderating effect of the barriers on its advantages. The next section proposes research hypotheses based on the conceptual framework, covering the main elements of the research agenda. Another research explored the difficulties associated with integrating Industry 4.0 and additive manufacturing (AM) to change the way manufacturing is done in future [26].

A model based on the TISM technique was established after analyzing 20 factors, which included challenges related to the integration of AM and I4.0 [4]. The dominant factors identified were sensor integration, resolution, small build volumes, Internet of things, and lead time. The function of additive manufacturing (AM) for maintenance engineering in Industry 4.0 (I4.0) was discussed. Additionally, a case study highlighting these crucial aspects of AM that make it a vital technology for Industry 4.0 was also covered. Further, the potential barriers that prevent firms from adopting AM technology and their potential solutions are briefly discussed [5]. While AM is

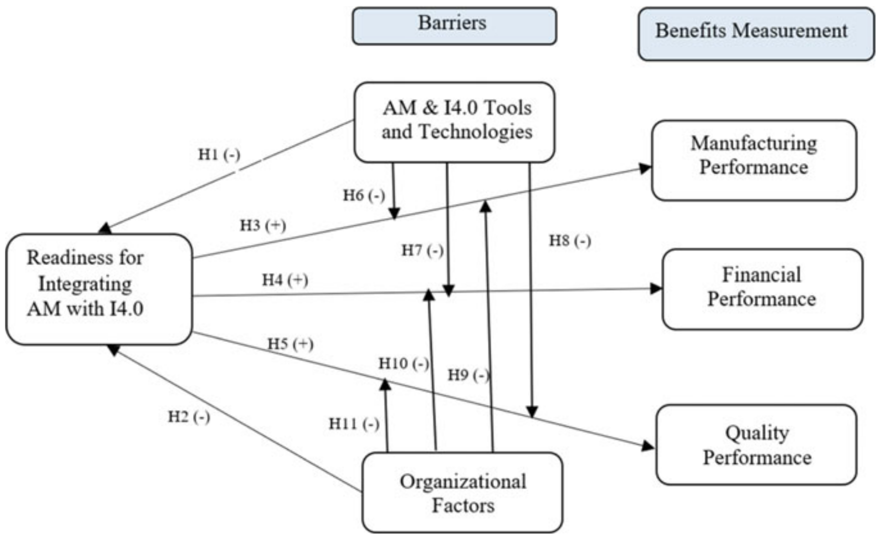

Fig. 1 Conceptual framework

a cutting-edge technology that is gaining popularity in a variety of industries due to its multiple benefits, its rapid growth is impeded by a number of obstacles [8]. The various technological, organizational, and environmental factors that might determine the current positioning of SMEs against Industry 4.0 was described [20]. The I4.0 poses significant challenges to manufacturing companies from the technological, organizational, and management points of view. They further explored as to how the top executives interpret the concept of Industry 4.0, the driving forces for introducing new technologies and the main barriers to Industry 4.0 [12]. The relationship between environmental dynamism and I4.0 is mediated by technological and organizational variables. The insights would help managers create unique I4.0 transition strategies, support sustainable development, and boost market performance. There are five global challenges that AM is currently dealing with and which has to be overcome. These include technical aspects, supporting technologies, management of operations, supply chain configuration, and legal innovation [27]. The following hypotheses are proposed as a part of this study, based on the review and analysis of the extant literature:

H1: Barriers related to AM and I4.0 tools and technologies have a negative impact on the readiness to integrate AM & I4.0

H2: Barriers related to organizational factors have a negative impact on the readiness to integrate AM and I4.0

H3: Readiness to integrate AM and I4.0 positively affects manufacturing performance.

H4: Readiness to integrate AM and I4.0 positively affects financial performance.

H5: Readiness to integrate AM and I4.0 positively affects quality performance.

H6: Barriers related to AM and I4.0 tools and technologies negatively moderate manufacturing performance achieved due to integration.

H7: Barriers related to AM and I4.0 tools and technologies negatively moderate financial performance achieved due to integration.

H8: Barriers related to AM and I4.0 tools and technologies negatively moderate quality performance achieved due to integration.

H9: Barriers related to organizational factors negatively moderate manufacturing performance achieved due to integration.

H10: Barriers related to organizational factors negatively moderate financial performance achieved due to integration.

H11: Barriers related to organizational factors negatively moderate quality performance achieved due to integration.

4 Conclusion

A thorough analysis of the extant literature shows that there is a need to integrate AM with I4.0. Literature also indicates that there are various reasons for the said integration. AM is regarded as the most disruptive tool ever developed in the domain of manufacturing. Additionally, AM is customizable and has a significant potential for lowering the production costs in industries.Despite the potential advantages of I4.0 and AM, firms are still having trouble implementing new technologies successfully into their business models and are encountering the typical barriers and difficulties. This study, therefore, seeks to identify potential obstacles in the integration of AM and I4.0 deployment in manufacturing enterprises.

Along with the technological barriers, consideration of organizational barriers as a moderating variable is also of prime importance for this integration. In order to address the above-mentioned barriers, a conceptual framework is proposed and hypothesized in the study. Managers would eventually be able to use this framework to assess their own readiness for integration and take the necessary action.

Future research could focus on testing the suggested hypotheses, which would give the study's findings more statistical robustness and validity. The investigation and ranking of integration barriers for AM and I4.0 are required to be researched in future. In addition, given the limited amount of research that has been done in this area and the necessity for potential researchers to have access to relevant literature, future research might concentrate on understanding how the adoption of integration impacts sustainability parameters and how it affects the manufacturing performance of the industry.

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A Case Study to Control Welding Defects in Pressure Vessels

Krishnan Kaushik, Turvasu Amin, and Meeta Gandhi

Abstract Welding is the most critical and important process in the Glass-lined technology as any defect in welding could affect the Glassing process which directly impacts the profit margins. The study was carried out at GMM Pfaudler facility at Karamsad in the district of Anand in Gujarat. GMM Pfaudler is a leading provider of process solutions to the chemical, pharmaceutical, agricultural, and other allied industries. The majority of the operations at the Karamsad facility is related to the core Glass-Lined Pressure Vessels (Original Equipment, OE) industry. The aim of the study was to examine the work center productivity and the reduction of welding flaws to make the manufacturing cycle more efficient and leaner. A new kind of weld edge preparation was suggested to control and reduce weld faults. The company's digital management software was also debugged to remove the inconsistency in the data observed. These modifications helped in monitoring welder wise performance also. This led to the reduction in number of welding defects with improved quality of the job.

Keywords Work center productivity · Welding defects · Ultrasonic test · Radiographic test

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1 Introduction

Leading provider of process solutions to the chemical, pharmaceutical, agricultural, and other industries is GMM Pfaudler. The company's business lines that depend on the services are PFAUDLER, NORMAG, MAVAG, MIXION, INTERSEAL, EQUILLOY, and EDLON. The company has several business lines. The study was carried out in Fabrication's Glass-lined Technology (PFAUDLER), where pressure vessels are made. These pressure vessels are used for reactors with the capacity ranging from 100 to 63,000 litres, and for tanks, it can reach upto 80,000 litres.

Welding is the most critical and important process in the Glass-lined technology as any defect in welding could affect the Glassing process. Rework during the glassing process is very tedious and long process for rectifying and decreases profitability as glassing process is very expensive. Majority of the rework jobs have a problem in welding. Different types of welding are done depending upon the position and requirement of the welding. Submerged Arc Welding (SAW), TIG Welding, MIG Welding are the types of welding performed. The weld butt joints which are used are square butt joint and single v butt joint. Square butt joint is used for thickness less than 25 mm and is quite strong but it should not be used when metals are subjected to impact and fatigue pressures. Single v butt joint is used for thicknesses between 16 and 30 mm, it expensive and calls for a special beveling equipment or cutting torch. The weld defects that usually occur are Slag inclusion, Porosity, Lack of Penetration (LoP), Lack of Fusion (LoF), Cracks and Undercut.

The Non-Destructive Tests (NDT) are performed on welded joints to check the welding defects. Usually, Radiography Test (RT) and Ultrasonic Test (UT) are performed.

Radiographic Testing (RT):

The X-rays or gamma rays produced by an X-ray tube or a radioactive isotope are used in this form of weld testing. By observing the treated film's shape and density variations, all discontinuities can be found. A permanent film record of the weld quality can be produced by radiographic testing, which is reasonably simple for qualified persons to interpret. This testing technique often works best when both sides of the welded joint can be accessed. Although this non-destructive testing technique is time- consuming and expensive, it is effective at finding defects within welds.

Ultrasonic Testing (UT):

The mechanical vibrations used in this testing technique are similar to sound waves but have a higher frequency. The thing being tested is struck by an ultrasonic energy beam. Except when it is intercepted and reflected by a discontinuity, this beam passes through the object with minimal loss. The fact that sound travels at almost constant speed through a given material makes it possible to measure distances, and that the relative amplitude of a reflected pulse is roughly proportional to the size of the reflector makes it possible to detect, locate, and evaluate discontinuities. The capacity of ultrasonic testing to pinpoint the precise location of a weld dis-continuity is one of its most helpful features.

2 Literature Review

A review of the research studies that are based on welded joints, welding flaws and work center productivity was done. Many software process approaches and tools assume the presence of a formal model of a process, according to the justification from Cook and Wolf [2]. Unfortunately, developing a formal model for an ongoing, complex process can be difficult, expensive, and prone to mistakes. They came to the conclusion that this barrier can be reduced by automating the process. Teng et al. [9] described a mathematical model to predict the effects of significant butt weld geometry parameters and residual stresses on the fatigue crack initiation (FCI) life of butt-welded joints. These parameters include weld toe radius, weld bead flank angle, preparation angle, and plate thickness. It is shown that estimations of fatigue life produced using the novel method closely matched the outcomes of experiments. Additionally, the suggested method is used to calculate the fatigue life of butt-welded joints that have been exposed to simulated residual stress fields brought on by preheating temperature conditions. The effects of weld joint design and post-weld thermal ageing treatments on the metallurgical, intergranular, and pitting corrosion behaviour of AISI 304L stainless steel welded joints were investigated experimentally by Singh and Shahi [7]. Gas metal arc welding was used to create single-V and double-V shaped linear weld joints that were 10 mm thick. This study demonstrates that single-V joint designs, as opposed to double-V joints, can be a crucial component of manufacturing processes when service requirements necessitate higher corrosion qualities of these welds. According to Jeffus [4], the book "Welding and Metal Fabrication" uses a special hands-on, project-based learning approach to efficiently teach welding techniques and skills.

3 Methodology and Results

The OpEx department's main goal is to make the process more efficient, so the initial strategy was to locate the bottleneck by meticulously examining each step of the operation. To gain clear understanding of the process and its limitations the data that the department had collected was thoroughly examined and also had de-tailed discussion with personnel in charge of the respective workstations.

As mentioned above, welding process has a lot of reworks. To maintain a hard-copy of every single joint detail and the job, takes up a lot of space and a lot of pa-per. In order, to reduce the use of paper and have an easy accessibility to the data, a software was developed by the company called Digital Quality Management System (DQMS). This software collects all the data related to fabrication. Workers provide the data sheet to the respective in charges who then enter the data in the software.

UT tests is carried out for every single job to check the welding defects before it is approved for glassing. Pre inspection of job is done by the quality control department

Sr.No.	Capacity UT	Type	LOT NO	Joint Details	Size	Inside for C&L.S Welder (TIG)	Outside for C&L.S welder (co2)	Weld Length	UT Date	No. of Repair	Length of Repair	Repair %
								7222			485	7.52%
318	40000	MB/BE	37	SB3	150	W-671	W-962	471	03/01/2022	6	30	6.37%
318	40000	MB/BE	37	D	150	W-253	W-962	471	03/01/2022	5	25	5.31%
318	40000	MB/BE	37	S	150	W-253	W-962	471	12/01/2022	24	120	25.48%
318	40000	MB/BE	37	R	150	W-253	W-962	471	12/01/2022	6	30	6.37%
318	40000	MB/BE	37	N2	150	W-253	W-962	471	12/01/2022	5	25	5.31%
318	40000	MB/BE	37	SB1	150	W-253	W-618	471	03/01/2022	5	25	5.31%
318	40000	MB/BE	37	B	150	W-253	W-618	471	12/01/2022	3	15	3.18%
318	40000	MB/BE	37	G	150	W-253	W-618	471	03/01/2022	3	15	3.18%
318	40000	MB/BE	37	TE2	400	W-253	W-228	1256	03/01/2022	6	30	2.39%
318	40000	MB/BE	37	C	150	W-253	W-618	471	12/01/2022	21	105	22.29%
318	40000	MB/BE	37	SB2	150	W-253	W-618	471	27/12/2021	1	5	1.06%
318	40000	MB/BE	37	H	150	W-253	W-618	471	12/01/2022	9	45	9.55%
318	40000	MB/BE	37	M1	250	W-253	W-618	785	12/01/2022	3	15	1.91%

Fig. 1. Screenshot of data collection technique

before ultrasonic testing. Once the test is performed, a manual entry of the defects is done in the software. Production team then checks the data uploaded in the software and makes provisions to rectify those welding defects. The reworked job is again sent back to verify if the defects are eliminated. Figure 1 shows a sample data sheet.

As seen from Fig. 1, data related to the type of joint, lot number, number of repairs and the repair% along with the welder and the welded length is recorded. Here a single repair is counted as 5mm as the tool required to dig the weld for checking and rectifying the defect is 5 mm wide. Thus, the 'Length of Repair' is obtained by multiplying the 'No. of Repair' with 5. The Repair % and Total Repair % are calculated as follow: For 40,000 Litres as shown in the Fig. 1.

Repair% for a joint detail= (Length of Repair/Weld Length) x 100 Total Repair % = Average of Repair%.

3.1 RT Reports

Radiographic Testing of welded joints is also carried out. The UT is performed for every job but the RT is performed for only a few jobs as it is expensive compared to UT and injurious to the health. RT is done for the inside and the outside of the weld whereas UT is done only for half the thickness from the inside as that is the critical area for the Glassing process.

In Fig. 2, the highlighted rows show the errors and the inconsistency in the data. For example, the first highlighted row has 5 Repairs but no entry is done for the type of defect. Other example is the second highlighted row where 9 Repairs are detected but the total type of defects shown are only 4. Such inconsistency in the data sheet were observed and hence there was a need to modify the data sheets.

Seam No.	Thick mm	TOTAL SPOT	OK Spots	Repair	Repair Length	Slag/Inclusion	Pors.	Crack	L/F	L/P	Dress up & R/s	RESHOOT	Film Size (inches)			Film Quantity (No.s)	TOTAL LENGTH (MM)	Repair %
3N1,1N6	20	10	0	4	126	4						6	3	X	15	10	3810	3.31
3N1,1N6	20	10	4	4	181	4						2	3	X	15	10	3810	4.75
LS1,LS1A,CS1,CS1A,CS2	32	12	4	7	564	7					1	0	4	X	15	12	4572	12.34
LS1,LS1A,CS1,CS1A,	32	9	3	3	126	3						3	4	X	15	9	3429	3.67
DLS2A	18	15	11	2	38	2					1	2	4	X	15	15	5715	0.66
DLS1	36	16	4	5	159							7	4	X	15	16	6096	2.61
DLS2A	18	6	5	1	18								4	X	15	6	2286	0.79
LS1,LS1A,CS1,CS1A,CS2	32	8	2	6	236	5		1					4	X	15	8	3048	7.74
LS1,CS1,CS1A,CS2	32	6	1	3	105	2		1				2	4	X	15	6	2286	4.59
CS1,CS1A,CS2	32	9	4	2	72	2					3		4	X	15	9	3429	2.10
1N2	16	4	3	1	20		1						3	X	12	4	1219.2	1.64
1N10	16	4	4	0	0								3	X	12	4	1219.2	0.00
3A	16	6	6	0	0								3	X	15	6	2286	0.00
1N2	16	4	4	0	0								3	X	12	4	1219.2	0.00
1N10	16	4	4	0	0								3	X	12	4	1219.2	0.00
3A	16	6	3	3	93	3	1						3	X	15	6	2286	4.07
LS2,LS2A,CS3,CS3A	18	75	53	9	258						4	9	4	X	15	75	28575	0.90
3A(MW)	18	6	5	1	16	1							4	X	15	6	2286	0.70
LS1,LS1A'CS1.CS1A	32	9	6	3	58	3							4	X	15	9	3429	1.69
CS1,CS1A	32	5	4	0	0							1	4	X	15	5	1905	0.00
LS1,CS1,CS1A	32	5	3	2	28	1		1					4	X	15	5	1905	1.47
3	25	9	2	4	171		1				1		3	X	15	9	3429	4.99
1N1,1N2,1N13,1N14,1N15	25	20	13	0	0							7	3	X	12	20	6096	0.00

Fig. 2. Screenshot of RT sheet

4 Modification to the Data Sheets and the Software

4.1 UT Report Modification

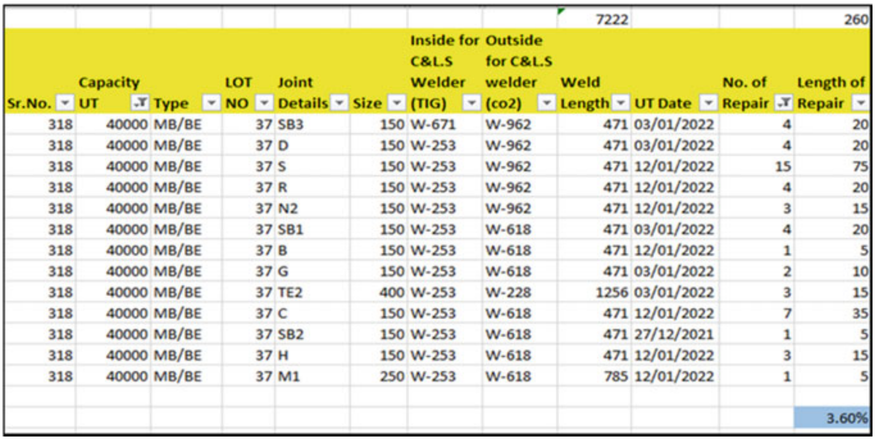
Upon analysis of the UT report few more defects were identified. Table 1, shows the UT performed for the job. In order to calculate the actual defects of the jobs only the sum of 'R0' should be counted. 'R0' means the first time the job was offered for UT and the numbers next to it indicates the number of times the job has been reoffered. Instead, the software was summing up every single repair that was reoffered along with the offered repairs. Due to which the Repair% were higher than the expected and calculated output.

In the Table 1, the difference between the number of repairs is a lot leading to high repair%. The method to calculate the repair% was also making a difference in the repair%. After a brainstorming session the conclusion was that the Repair% column is not required as there is no need to calculate repair% for every joint detail. So, the repair% column was removed and the formula used to find one joint detail was applied for the sum of those columns giving the desired output as mentioned below in Fig. 3.

The changes and the modifications were made in the software. These modifications helped in monitoring the welder wise performance. So, after the changes the welder performance charts showed the correct output which assisted in analyzing welder performance. This helped in finding out the welder with more defect percentage for whom the required measures can be taken to reduce this defect percentage.

Table 1 UT report

Weld joint	R0	R1	R2	R3	No. of repair (In report)	No. of repair (Actual)
SB3	4	2	0	0	6	4
D	4	1	0	0	5	4
S	15	6	3	0	24	15
R	4	1	1	0	6	4
N2	3	1	1	0	5	3
SB1	4	1	0	0	5	4
B	1	1	1	0	3	1
G	2	1	0	0	3	2
TE2	3	3	0	0	6	3
C	7	7	7	0	21	7
SB2	1	0	0	0	1	1
H	3	3	3	0	9	3
M1	1	1	1	0	3	1



								7222			260
Sr.No.	Capacity UT	Type	LOT NO	Joint Details	Size	Inside for C&L.S Welder (TIG)	Outside for C&L.S welder (co2)	Weld Length	UT Date	No. of Repair	Length of Repair
318	40000	MB/BE	37	SB3	150	W-671	W-962	471	03/01/2022	4	20
318	40000	MB/BE	37	D	150	W-253	W-962	471	03/01/2022	4	20
318	40000	MB/BE	37	S	150	W-253	W-962	471	12/01/2022	15	75
318	40000	MB/BE	37	R	150	W-253	W-962	471	12/01/2022	4	20
318	40000	MB/BE	37	N2	150	W-253	W-962	471	12/01/2022	3	15
318	40000	MB/BE	37	SB1	150	W-253	W-618	471	03/01/2022	4	20
318	40000	MB/BE	37	B	150	W-253	W-618	471	12/01/2022	1	5
318	40000	MB/BE	37	G	150	W-253	W-618	471	03/01/2022	2	10
318	40000	MB/BE	37	TE2	400	W-253	W-228	1256	03/01/2022	3	15
318	40000	MB/BE	37	C	150	W-253	W-618	471	12/01/2022	7	35
318	40000	MB/BE	37	SB2	150	W-253	W-618	471	27/12/2021	1	5
318	40000	MB/BE	37	H	150	W-253	W-618	471	12/01/2022	3	15
318	40000	MB/BE	37	M1	250	W-253	W-618	785	12/01/2022	1	5
											3.60%

Fig. 3 Screenshot of modified UT report

4.2 *RT Report Modifications*

To improve the inconsistency in the sheet as mentioned above, a suggestion for an additional column was added, rearranged and removed a few columns to reduce manual entries leading to errors. In the Fig. 4, the green highlighted areas are the new columns added along with the sum formula on top of each row to have an idea about the number of defects and to make the visual chart. So, the modification gave an accuracy of 100% for the process. The error in the sheet apart for manual and faulty entries was that while performing the RT, one film would have multiple defects. So, according to the old sheet the number of films were mentioned but the type of the defects would mention the quantity of the defects leading to inaccuracy in the data. After the required changes made in the report, in the Fig. 4, it is observed (yellow highlighted cell) that the repair spots are 4, but the quantity of the repair is 3 which is mentioned in the adjacent column with the Repair spots giving a clear idea of the defects.

After making the necessary changes a pie-chart Fig. 5, was prepared for easily identifying the types of defects and the frequency of the types of defects in the jobs as mentioned.

			176605.2	613	459	98	104	2426	57	14	11	0	0	22	60				
Seam No.	Thick Mm	size	TOTAL LENGTH (MM)	TOTAL SPOT	OK Spot	Repair Spot	Repair Qty	Repair Lengt	Slag/Inclusion	Por	Crac	L/	L/	Dress u	RESHOOT	Film Size (Inches)			Repair
LS2, CS3T, CS3A	18		2286	6	4	1	1	100	1						1	4	X	15	4.37
TDLS			4191	11	11	0	0									4	X	15	0.00
LS3	18		1143	3	0	2	2							2	1	4	X	15	0.00
LS2, CS3T, CS3A	18		2667	7	7	0	0									4	X	15	0.00
LS3	18		1143	3	3	0	0									4	X	15	0.00
TDLS			5715	15	11	4	3	152	3							4	X	15	2.66
TDLS			5334	14	14	0	0									4	X	15	0.00
Patch			228.6	1	1	0	0									9	X	9	0.00
DLS2 (Top Dish)	32		6096	16	11	2	2	195	2						3	4	X	15	3.20
DLS2 (Top Dish)	32		6096	16	8	1	1	100	1						7	4	X	15	1.64
N4LS	25		190.5	1	1	0	0									4	X	7.5	0.00
1AN4	25		1256	5	5	0	0									4	X	15	0.00
N8LS	25		190.5	1	1	0	0									4	X	7.5	0.00
1AN8	25		1256	5	3	1	1	10		1					1	4	X	15	0.80
DLS2 (Top Dish)	32		3866	16	13	1	1							1	2	4	X	15	0.00
DLS1 (Bottom Dish)	36		3866	16	9	3	6	113			6				4	4	X	15	2.92

Fig. 4 Screenshot of RT data sheet modification

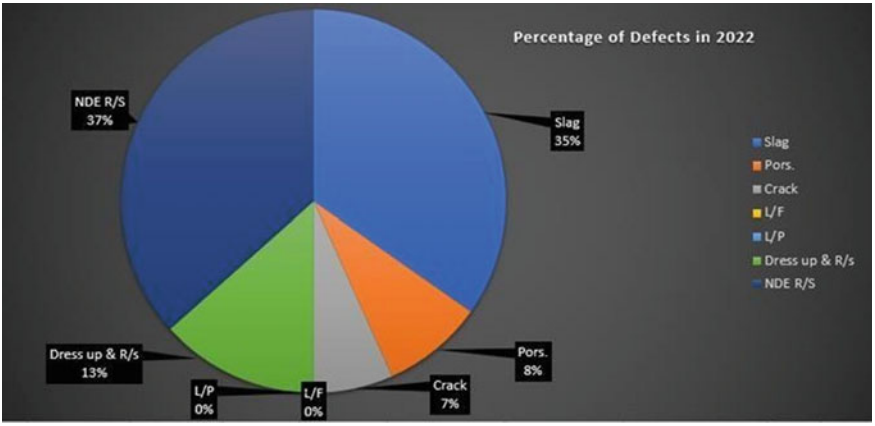


Fig. 5 Percentage defects

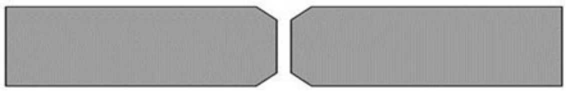


Fig. 6 Modified weld edge preparation

5 Modified Weld Edge Preparation

Welding is the most important and critical process in the fabrication process as any kind of discontinuity and defect in welding can affect the glassing process. Glassing is the most important and a very expensive process in the Glass-Lined Technology. Depending upon the type of joint to be used for welding, the metal sheet is cut accordingly before rolling the job and setting up the area to be welded. As mentioned above the 3 different types of welding are performed according to the position and different type of weld edge preparation are used. While doing the analysis, it was found that the job with 25 mm thickness were giving the most defects. A few jobs had a 100% weld defects like Lack of Penetration (LoP) whereas a few jobs had other weld defects.

While doing the analysis, came across a lot of defects in the Long Seam (LS) for the job of 25 mm. Initially it was thought to implement square butt joint, but the number of defects observed were many. After multiple brainstorming sessions and a lot of research, a modified square butt as shown in the Fig. 6 was proposed. It is a mixture of a double 'V' butt joint and a square butt joint which would eliminate the drawbacks of the two V and square butt joint. The 25 mm thickness sheet was made into a 22 mm square butt setup and an additional 3 mm on both sides are cut at an angle to form a 'V' so that better penetration could be achieved. The SAW welding process is used to weld the LS, the small 'V' kind of an opening is welded perfectly.

After proposing the change in the weld edge preparation, three jobs each of capacity 20KL, 40KL, 16KL with a thickness of 25 mm were allowed to perform the trial on. The complete process of welding was monitored. The Repair% for the trials for capacity of 20KL, 40KL, 16KL were 0.72%, 1.10%, 0.63% respectively. The number of defects had decreased and the company criteria of achieving Repair% of less than 2.5% was satisfied. Due to decrease in the number of defects, the trial was a success and the new weld edge preparation was approved and implemented for the required jobs.

6 Conclusion

Fixing inconsistencies in the software led to 100% accurate results, eliminating the need for manual computations and the time required to prepare a defect percentage table. The program displays data linked to welds at any given date range. In order to fix software issues, cross-departmental interactions were necessary to check for defects. However, due to the correctness of the data, this requirement was eliminated as well. By decreasing the need for human calculations and analysis to get the desired outcome, the software advancements made to the program allowed the other data that were relevant to the UT analysis to also begin providing reliable data output.

The changes made to the RT sheets provided the necessary data to two the distinct departments, thereby clearing up any ambiguity regarding the number of flaws or the number of spot repairs. All welding-related data could be now verified in one sheet without any complications. This also led to developing a visual display for easy identification of the welding defects.

By bringing in the modification in the weld edge preparation, the job that previously needed three rounds of welding and one round of back gauging was replaced by only two rounds of welding and that too with decreased defects. Implementing the modified weld edge pushed the repair percentage to less than 2.5%, thus satisfying the company target. The productivity of the welding machine also increased because of fewer rounds of welding and significantly fewer repairs. This led to timely completion of jobs with enhanced quality, fewer faults, increased productivity and optimal material use.

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Managerial Insights into the GSCM Practices in the Indian SME Manufacturing Firms

Meeta Gandhi and Hari Vasudevan

Abstract This research work involved an extensive study on various green supply chain management (GSCM) practices in the Indian SME manufacturing firms. The research also investigated the impact of GSCM practices on business performance and defined in terms of environmental performance, operational performance, and financial performance. Scope of this study was restricted to the broad domain of Indian manufacturing firms, especially the SMEs in India's western region. Researchers studied the correlation between GSCM practices and environmental, economic, operational, and overall business performance of Indian manufacturing SMEs and also compared them across the three sectors of SMEs (chemicals, textiles, and rubber/plastics). This research work provides useful insights into the GSCM practices in the Indian SME manufacturing firms, which has not been covered and reported by any of the previous studies. Managerial insights resulting from this research could be potentially used to identify key performance parameters of GSCM practices, particularly in sectors, like textile, chemical, and rubber/plastics covered in the study.

Keywords Green supply chain management practices · Business performance · Chemical · Textile · Rubber/Plastic · Managerial insights

1 Introduction

Climate change and global warming are two of the burning issues of the twenty-first century. Supply chain and energy security are also considered two major game changers for the world economy as well as human welfare. Moreover, from the supply chain management point of view, sustainability is important as consumers demand

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eco-friendly products, thus increasing market competition. Production as well as consumption, which ultimately have to take care of the environment is necessary for improving the health and working conditions, reducing poverty and rebuilding environmental quality to bring about economic growth. Therefore, evaluating the impact of green supply chain practices on the triple bottom line has been progressively becoming significant for firms [1]. This drives the firms to not only evaluate their traditional financial bottom line but also appraise their social and environmental performance. This is also imperative for the planet's unpretentious care in future. With it, the environmental and organizational performance bring numerous prospects, driving to higher profitability and better competitive advantage [2]. The fact that firms who understand and value their impacts on ecosystem, dependency, and holdings will have a foremost advantage over their competitors was highlighted by the World Business Council for Sustainable Development [3].

Inorder to meet these goals, a significant change is required in our production and consumption approach. Therefore, to have a sustainable pace of consumption, our products and processes must change, keeping in mind the competitive pressures and challenges that our manufacturing firms face today. These environmental concerns have created new customer requirements, which are beyond conventional functionality, quality, and cost and related to product manufacturing, product life, and product disposal at the end of its life [4]. This gives rise to a new challenge of building greener products and environmental strategies to direct a firm's growth toward a sustainable future. Thus, GSCM practices promise to a long-term future of the planet. Hence, firms that understand and act on this will have a major advantage over its competitors as well as on greater profitability [3].

Asian Emerging Economies (AEE) have seen a rise in manufacturing bases and production facilities coming from developed nations [5, 6]. The principal reason behind this is the availability of cheap labor and low cost of material [7]. The awareness about the effect of production processes on the environment has put tremendous pressure on manufacturers of both developing as well as developed countries. The emerging economies index 2014, reports that 10% of world market capitalization is represented by the emerging markets. Hence, there is a significant need to green their supply chain in all aspects in the emerging markets, like China, Taiwan, India, Malaysia, Indonesia, Thailand, and South Korea [5, 8]. Moreover, as India is attempting to become a global manufacturing hub through its initiatives, such as 'Make in India', 'Startup India', and 'Skill India' programs, the manufacturing sector is compelled to address the GSCM challenges in an enthusiastic way for the long-term sustainability of the environment [9].

Today, India is one of the emerging markets among the BRICS nations, but it lags behind in the healthy environment. (South Africa is ranked at 72nd, followed by Russia 73rd, Brazil with 77th place, and China at 118th). India is not only announced its National Action Plan on Climate Change (NAPCC) in June 2010 but has also signed the association of Kyoto protocol and carbon credit system to make an effort on the path of green. Also under the Paris Agreement by 2030, India has to reduce its carbon footprint by 33–35% from its 2005 levels. Thus, India's environmental challenge is formidable, if the country has to be in the league of fastest growing economy, as compared to other emerging economies. This would encourage the industries to start their journey toward a greener future, by implementing GSCM practices, in order to maintain their competiveness, especially taking into account the regulations being put. However, it is observed that the implementation of this concept is restrained mainly due to economic reasons. Hence, this necessitates the need to show the proof of economic benefits and the direction, which would help in the broader application of the concept. India, therefore, presents a model research context to explore the impact of green supply chain management practices on a firm's performance.

GSCM practices especially in the AEE in manufacturing have received tremendous attention from industry, academia, regulatory bodies, and customers [7]. This clearly points to the academia, highlighting the need to identify and establish, if the GSCM practices bring in higher business performance [10]. Reported results have been non-conclusive for the empirical studies on impact of GSCM practices on firm's performance. Researchers such as Zhu and Sarkis [11] in their studies in Chinese manufacturing industries found that the GSCM practices did not contribute to increased economic performance. This may be due to the reason that GSCM practices were in its infancy stage in China. In the initial stages of GSCM practice adoption, a higher investment is required, which may increase a firm's operational costs and thus undesirably impacting the economic benefits. More recent studies in contrast have found GSCM practices and firm's performance to be positively related. Authors intend to explore and deliver generalizations observed between the GSCM practices and the business performance relationship.

2 Literature Review

The following conclusions have been reached after reviewing research studies that use GSCM and have a particular interest in manufacturing in India. Mudgal et al. [12] investigated and ranked barriers against GSCM adoption. Luthra et al. [13] analyzed important barriers to GSCM adoption from an Indian perspective and identified contextual relationships among 11 barriers. Toke et al. [14] ranked interactions and evaluated critical success factors for GSCM adoption in the Indian manufacturing sector. Mathiyazhagan et al. [15] analyzed the relationship between 26 barriers and identified the most influential in GSCM adoption in the automobile industry from an Indian perspective. Diabat and Govindan [16] analyzed drivers for GSCM implementation in the Indian perspective through a case study, involving a manufacturing firm in south India. Surjit Bag et al. [17] designed a GSCM strategy for Indian manufacturing firms. They stressed how GSCM can help organizations get a competitive edge by enhancing their environmental performance. Paramanik et al. [18] have created a conceptual framework with multiple performance indicators for GSCM deployment performance measurement of a company. Additionally, researchers have not conducted the analysis from many industrial perspectives within the setting of India.

It is obvious that very little research has been done on the examination of GSCM implementation and its impact on business performance in the Indian context.

Several parameters for examining the influence of GSCM techniques on business performance were selected in this study based on the published studies and existing literature as well as input from experts in the industry and academia. They are as follows. Environmental performance parameters represent reduction in the following, such as air emissions, waste water, solid waste, energy consumption, consumption of hazardous/harmful/toxic materials, total flow quantity of scrap, frequency of environmental accidents, and improvement in a company's environmental image [19–27]. The cost per operating hour, manufacturing costs, operating expenses, cost of purchasing environmentally friendly materials, cost of scrap/rework, disposal costs, recycling costs, transportation costs, cost of avoiding environmental actions, increased revenue from green products, fines and penalties, and cash rewards/subsidies for using renewable/alternative energy sources are among the economic performance parameters cited by these researchers. Additionally, they listed operational performance indicators such as an increase in the quantity of goods delivered on time, a decrease in customer complaints, better after sales service efficiency, a better ability to respond to urgent deliveries, a decrease in inventory, an improvement in product quality, a decrease in customer reject rates, a decrease in in- plant defect fallout rates, a reduction in cycle times and delivery lead times, an expansion of the product line, and an improvement in capacity utilization.

The impact that the government initiatives/regulations can have on greening the sup- ply chain is also included in the study. These parameters are reward for buying renewable energy, relief on capital gains and tax, providing information on what to measure and how to measure, low interest loans for buying waste disposal/treatment equipments, awards for greening the process, heavy fine/penalty for wrong disposal of waste, heavy fine for using excess energy, popularize knowledge of environmental management, and building infrastructure for facilitating green supply chain initiatives.

3 Methodology and Results

A structured survey was created to examine the adoption of green supply chain practices and assess their effects on business performance, as measured by environmental performance, economic performance, and operational performance, in small and medium scale manufacturing industries (SME) in the western region of India. A pilot study was initially carried out, based on responses received from 25 firms to check for the reliability and validity of the instrument. Satisfactory values of the Cronbach Alpha (0.860) and KMO (0.811) were obtained as part of the pilot study. The questionnaire was subsequently deployed as part of an extensive survey, covering more than 300 firms, out of which data from 256 manufacturing firms were included in the final analyzes. These forms were grouped separately as Group I and Group II. Data was analyzed using both descriptive and inferential statistics (Z test, correlation, factor analysis, regression analysis, and ANOVA), and they were carried out using SPSS.

4 Results and Discussion

The results of the study show that there is a good awareness and willingness for implementation of green supply chain management (GSCM) practices in SME manufacturing firms. Moreover, it is found that there exists a strong relationship between GSCM practices and environmental performance as well as the operational performance. In the case of Group I firms (GI), having either ISO9000 or ISO14000 or environmental management system (EMS), the environmental, economic, operational, and total business performance was significantly higher than that in case of the Group II firms (GII), which did not have any certification or EMS. The firm's environmental reputation, fewer environmental accidents, lower energy use, cash rewards, or subsidies for using renewable energy, cost avoidance from environmental actions, higher revenues from green products, more goods delivered on time, lower rates of customer complaints, and better after sales efficiency were identified as factors significantly contributing to their higher performance.

The results also show that there exists a significant difference in the environmental and economic performances of the chemical, textile, and rubber/plastic firms, whereas there is not much of a difference in their operational and total business performances. Across the three sectors, GI firms have higher environmental and operational performance, whereas there is no significant difference seen in their economic performance. It can also be concluded that, though some measures are taken to green the supply chain, it is still in its early stage of implementation in the SME sector. Economic reasons predominantly govern a firm's decision to mitigate their impact on the environment. However, from a sustainable and long-term perspective, educating the SMEs is so crucial and is very much needed to ensure that by implementing the green practices, benefits achieved are waste reduction, higher operational efficiency, continuous improvement, and higher profits. In the contemporary manufacturing scenario, especially in the SME sector, this is really the need of the hour in a country, like India.

5 Managerial Implications

SMEs dominate the economic landscape of India. They contribute substantially to employment, exports, and the GDP of the country. Their individual contributions are responsible for building flexibility and robustness into the economy. SMEs are driven by the successful recovery of expenditures and the prospects of generating profits. In India, it is found that SMEs do not collaborate with academics and hence are not aware of the latest developments and thus become less enthusiastic to incorporate them and struggle to adopt and make use of them to their advantage. Indian business is currently witnessing a rise of entrepreneurs, who are willing to take risks and drive innovations in the markets. India is at the cusp of a start-up boom and is among the world's fastest growing start-up economies. It is this entrepreneurial spirit of the SME sector, which plays a major role in driving the economic growth of India.

From the results of the study, it can be stated that the SMEs want government authorities to put a significant thrust on legislation and regulation to enhance the green practices. Indian SMEs today are faced with problems like, low value addition, lack of access to timely and affordable credit, low level of technology adoption, lack of innovation, poor branding and packaging, lack of awareness on IPR issues and International Trade Agreements, lack of quality database on exports, and high transaction costs. To address these problems, a number of schemes are announced by the Development Commissioner of Medium and Small Manufacturing Enterprises (MSME). One such flagship program is the National Manufacturing Competitiveness Program (NMCP), in which SMEs could enroll and benefit themselves. Also, firms have to realize that by tailing the low cost policy, it not only hampers their ability to invest in green practices and its associated benefits, but in due course of time, it would make them vulnerable to legislations and regulations.

The findings of this study are also coherent with some of the observations of Mohanty and Prakash [28] that the SMEs only adopt green practices, when they face strict regulatory measures. In this context, government should strictly enforce regulations for SMEs as well as encourage firms to go in for ISO certification, create techno-parks to disseminate sustainability knowledge, develop research centers catering to green practices as well as enhance the awareness of various sustainability schemes announced time and again. Government could assist SMEs in their green journey, by playing the role of information providers and awareness raisers, who signals market opportunities as well as give directions for green industrial revolution and consumer behavior related to manufacturing of green products. Strict regulatory measures help improve product quality as well as manufacturing processes and at the same time, negate the adverse effect of industrialization on health, environment, and safety. Thus, government should adopt a 'carrot and stick' approach to enhance the adoption of GSCM practices in the SMEs. Government can formulate a policy for remanufacturing in formal business activity, create awareness about the myth of quality of remanufactured products, and develop markets for the same. Cooperation between the manufacturer and remanufacturer, if created could also mitigate the impact on environment.

The results of this study suggest that the manufacturing firms covered have understood the significance of implementing GSCM practices and that they positively reduce the environmental impact and increase the business performance. Inspite of their awareness in the GSCM practice-performance relationship, the SMEs are still in the nascent stage of implementation of GSCM practices. It has been found that the SMEs lack human and financial resources with expertise on the adoption of GSCM practices. To improve this, SMEs may employ resourceful engineers to meet the environmental and social standards. To achieve the competitive advantage in business management through eco-innovation, firms could also think of industrial symbiosis, which is an innovative method to promote the green economy [29].

Information Technology Systems are a good avenue to drive the environmental footprints and sustainable practices [30]. The system applications like digital media, e-commerce, smart buildings, and intelligent transport systems could help in reducing carbon emission and also help to optimize the overall energy consumption. SMEs could also adopt IT functions, which would lead to better customer and employee experience, lower cost of operations, improved profitability, increased collaboration and interaction, and enhanced environmental, economic, and operational efficiency.

Firms could also benefit from the low cost of solar energy or biodegradable energy sources, compared to traditional sources of power by adopting the rooftop solar solutions that can reduce their price of power by 10–50%, depending on their scale and location. In the near future, off grid, standalone energy generation, storage, and consumption will become imperative for SMEs. Carbon will certainly become a parallel currency to money in coming future. Firms will then be required to work within that carbon cap or else pay for that excess carbon. Also, simply monitoring the carbon foot print offers a good amount of control on the reduction in manufacturing cost and the overall energy consumption as well as it enhances a firm's green image.

During the study, it was found that quite a few firms feel that EMS, ISO9000, and ISO14000 are mere documents. There is a need for them to understand that these standards focus on the processes in the supply chain, and they help the management to identify the controlled and uncontrolled environmental concerns. They also help in developing targets and plans to achieve significant as well as incremental environmental improvements and thus help in building the green image. SMEs can develop an effective customer relationship, which can help them in environmental cost reduction, improve responsiveness to customer's environmental worries, increase customer satisfaction, and reduce business wastage [31]. Several activities recommended to boost the employee morale and customer satisfaction are increasing the environmental awareness through training and education, integrating environmental function into strategic decision-making process and investing into the pollution preventive solutions.

Hence, it can be concluded that, once the GSCM practices have a strategic focus, and systems are identified to monitor efforts to become green, firms can begin to implement the GSCM practices with some certainty, expecting that these practices will improve the branding and business performance. Thus, the SMEs should adopt innovative approaches with a global view point and build strong technological base, have an aggressive competitive spirit and at the same, be willing to restructure when necessary. Also, firms that are in the evolutionary stage could simply base their performance measurement on government's environmental regulations, while those ahead in the development could include information related to the greenness of a product or process and green supplier evaluation metrics.

Slowly, 'green' is changing from being viewed as a 'necessary evil' to a 'positive business practice'. Businesses that implement green initiatives stand to benefit from brand development, political traction, and regulatory compliance. It will also help the firms gain greater ability to attract and retain talent as well as enhance customer retention and potential cost savings.

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Waste Reduction of Molded Plastic Parts by Applying Principles of Six Sigma

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Abstract Six Sigma is a method that provides organizations tools to improve the capability of their business processes. This increase in performance and decrease in process variation results in defects reduction and improvement in profits, employee morale, and quality of products or services. The main objective of this research is to minimize the non-confirming products that are manufactured using plastic injection molding and reduce the waste using Six Sigma. Using statistical techniques to quantify variation, the Six Sigma Philosophy offers a step-by-step methodology for quality improvement. The study focuses on the application of Six Sigma in plastic injection molding to enhance the quality of the finished products by removing significant flaws that occurred utilizing low-cost techniques. In this case, mostly, the focus was on reducing shrinkage defects, which accounted for almost 39% of the overall non-confirming products manufactured. Another goal was to eliminate the root causes of product rejections, by using Six Sigma's define, measure, analyze, improve, and control (DMAIC) methodology. To achieve desired results, the proposed Six Sigma approach effectively integrates quantitative and qualitative tools such as control charts (p-chart), Pareto charts, histograms, Ishikawa diagrams, measurement system analysis, and checklists. The results show that by implementing the proposed Six Sigma approach can significantly reduce the rejection rate. It was observed that the final product quality had significantly improved, primarily in terms of defects per million opportunities (DPMO) and sigma level, which increased from 4.60 to 4.74.

Keywords DMAIC · Control charts (p-chart) · Ishikawa diagram · DPMO

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1 Introduction

One of the most challenging processes for producing high-quality and cost competitive parts is plastic injection molding. It is most widely used method because of its high rate of output. In this process, the part is made by injecting a molten material into the mold. Granular raw material is fed into the machine through a hopper that pre-heats the material. After that, the substance is heated in a barrel and maintained at ideal temperatures throughout various zones. The molten polymer is then injected into the mold at the required pressure from the nozzle. Once the part is cold enough to be expelled, the mold opens, and the part is taken out with the help of an ejector pin.

2 Literature Survey

Six Sigma may be summed up as an approach for reducing errors in processes that adds value for the customer by identifying sources of variation and removing them. Naumann and Hoisington [1] have pointed out that the concept of Six Sigma is the development of a regular way to measure and monitor the performance, set extremely high expectations, and improvement targets [1]. Hild et al. [2] stated three main goals of Six Sigma are to increase customer satisfaction, profitability, and productivity [2]. De Feo and Barnard [3] focused on Six Sigma's two main methodologies, define, measure, analyze, improve, and control (DMAIC), which is used for existing processes and define, measure, analyze, design, and verify (DMADV), which is used for designing new processes [3]. Brady and Allen [4] stated that Six Sigma has permeated most business disciplines since its introduction in the industry by Motorola's Bill Smith, two and a half decades ago, depending on the philosophy, principles, and techniques of overall quality management [4]. Radha Krishna and Dangayach [4] presented a case on implementation of Six Sigma at an auto-component manufacturing plant [5]. Falcón et al. [6] discussed Six Sigma methodology used to improve energy efficiency in a distillation unit of a naphtha reforming plant. The results revealed a significant annual savings of around 150,000€. [6]. Wyper and Harrison [7] focused on the application of Six Sigma being expanded to include service-provider organizations, additionally, in human resource roles [7]. Vijay [8] discussed on reduction in patients discharge cycle time in a multidisciplinary hospital process using the Six Sigma DMAIC model [8]. Gutierrez et al. [9] conducted a search based on analyzing the application of Six Sigma framework for supporting continuous improvement (CI) in logistics services which resulted in significant improvement and positively influenced company's annual income [9]. Uluskan [10] focused on increasing interest of Six Sigma which led to an extensive study of its tools, both statistical and managerial [10].

Fig. 1 Shrinkage example

3 Methodology

3.1 Define Stage

During the define phase, three steps were undertaken: determining a feasible project scope, establishing project goals, and defining project conditions. Due to resource constraints, the duration of this Six Sigma project could not exceed six months. It was observed that out of total products produced by the company each month, 8% were defective. The occurrence of shrinkage and short shot was maximum among the defective products. Other frequent defects found were flash, silver streaks, and flow marks. The primary goal of this project was to ensure a stable and robust manufacturing process with a low number of non-conforming parts. Figure 1 shows a sample with a shrinkage defect. Figure 2 shows injection molding process diagram.

3.2 Measure Stage

To identify the issues, data for output line reject that happened during the 550 tons and 180 tons injection molding part production, which concentrated on the manufacturing of diverse parts, were continuously gathered for three months. These numbers were used to determine the defect per million opportunities (DPMO) and Six Sigma level for each month. Readings for production done in entire 1st month were taken. After taking the readings, the non-confirmed (rejected) products were taken for further

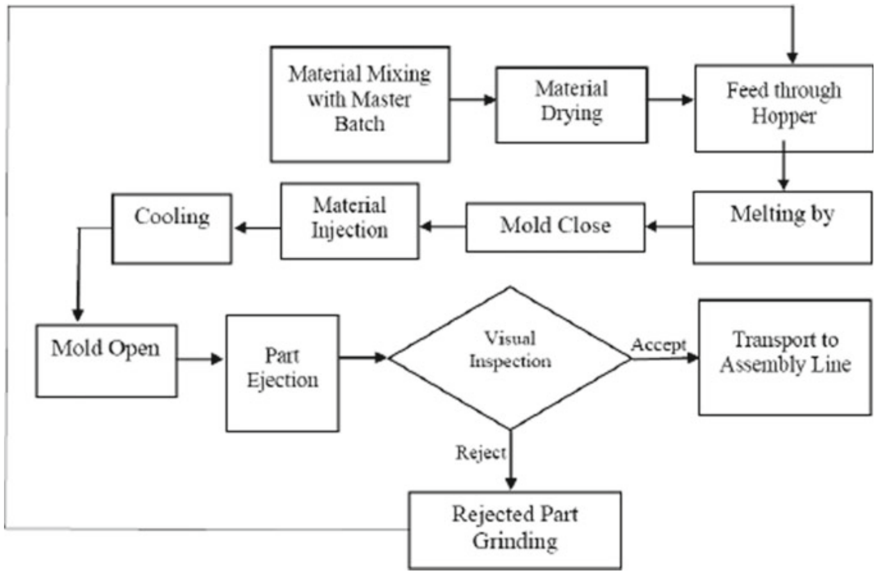

Fig. 2 Process diagram of injection molding production

analysis and segregated into defects, which lead to rejection of products. Table 1 shows the rejection quantity under different heads for 9 molds.

Based on Table 1, all the non-confirming products along with defects that led to their rejection are added in a cumulative fashion, and percentage wise calculations are shown in Fig. 3.

Defects per Million Opportunities (DPMO): This ratio demonstrates the number of defects per every million opportunities. In other words, how many times did you

Table 1 Overall production in the 1st month

Mold no	Total Qty	Accepted Qty	Rejected Qty	Shrinkage	Short shot	Flash	Silver streaks	Flow marks
668	3125	2878	247	93	62	34	32	26
50,200	1451	1325	126	48	36	17	14	11
91,653	4235	3933	302	113	104	41	31	13
2154	592	520	72	37	21	9	5	0
1301	1734	1587	147	61	43	18	14	11
50,203	1682	1526	156	61	44	18	21	12
202	2005	1780	225	104	75	24	16	9
625	2265	2055	210	85	59	27	23	16
188	1570	1420	150	31	37	29	29	21
Total	18,659	17,024	1635	633	481	217	185	119

Defects	Occurrences	Cumulative	Percent
Shrinkage	633	633	39%
Short Shot	481	1114	68%
Flash	217	1331	81%
Silver streaks	185	1516	93%
Flowmarks	119	1635	100%

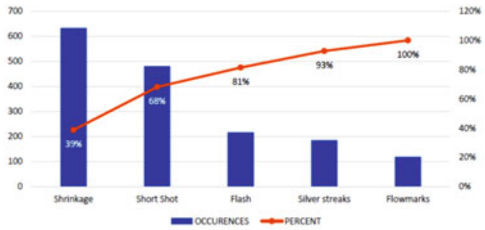

Fig. 3 Pareto chart of overall defects for the 1st month

make a mistake or have a flaw (defect) for each opportunity that presented itself. Can below Eq be written.

DPMO calculation for 1st month	Six Sigma calculation for 1st month
$\text{DPMO} = \dfrac{\text{No. of defects}}{\left(\begin{array}{l}\text{No. of}\\ \text{units}\end{array}\right) \times \left(\begin{array}{l}\text{No. of defect}\\ \text{opportunities}\\ \text{per unit}\end{array}\right)} \times 1000000 = \dfrac{1635}{5 \times 18659} \times 1000000 = 17525.05493$	$\text{Sigma level}(Z) = 0.8406 + \sqrt{29.37 - 2.221\ln(\text{DPMO})} = 0.8406 + \sqrt{29.37 - 2.221\ln(17525.05493)} = 3.6096$

Similar method was followed, and readings for production done in the 2nd and 3rd month were taken. After that, the non-confirmed products were taken for further analysis and segregated into defects which lead to rejection of product. Pareto charts were made, DPMO and Six Sigma level calculations were done. Six Sigma level for 2nd month was found to be 3.6020, and for 3rd month, it was 3.6111.

3.3 Analysis Stage

Choosing which defects to start with during this phase was the first step. The Pareto chart for the sorts of defects that occurred in the study's 3 months demonstrates that shrinkage defect, and short shot is the biggest factor in the rejection. When compared to other problems, shrinkage accounts for about 39% of all rejects each month. Figure 4 shows few reasons for production of defective products.

Overall defects in 3 months were added to get a gist of how much rejections were each of the defects responsible for, which is shown in Fig. 5.

Root cause analysis for shrinkage defect

A depression that forms in a casting during the solidification process is known as a shrinkage cavity. Unlike gas porosity, which has rounded surfaces, shrinkage porosity has angular edges. Dendritic fractures or cracks may coexist with cavities in some cases. All the causes and significant variables were visually represented on a cause-and-effect diagram during brainstorming sessions. There are five main variables that contribute to the defective component defect: the machine, mold, operator, procedure, and material. Figure 6 shows the Ishikawa diagram for shrinkage defect.

Large shrinkage cavities might compromise the castings integrity and potentially lead to its eventual failure under stress. A die casting alloy has a lower density while it is liquid than when it is solid. As a result, when a substance changes from the liquid state to the solid state, its size always decreases. When the casting is solidifying inside a die casting die, shrinkage occurs. This shrinkage can result in numerous tiny spaces, or "shrinkage porosity," toward the center of thick parts of a casting. It can, however, seriously weaken a casting if it is bigger or connected. It is apparent that an operator would produce more defects than the others when they lack sufficient experience and

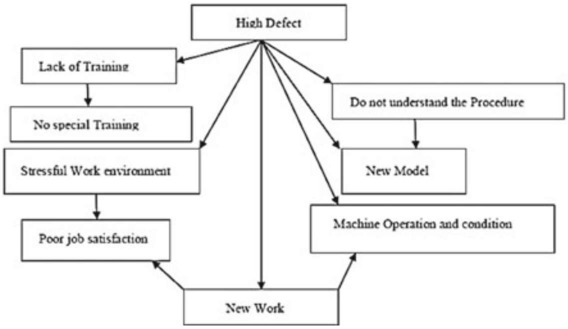

Fig. 4 Some reasons for production of defective products

DEFECTS	OCCURANCES	CUMULATIVE	PERCENT
Shrinkage	1980	1980	39%
Short Shot	1524	3504	68%
Flash	684	4188	82%
Silver Streaks	525	4713	92%
Flowmarks	425	5138	100%

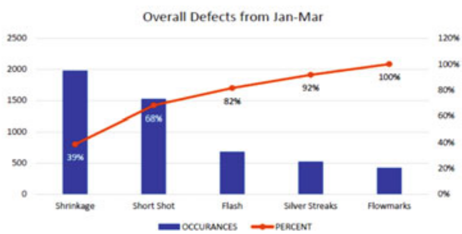

Fig. 5 Pareto graph for overall defects between 1st and 3rd month

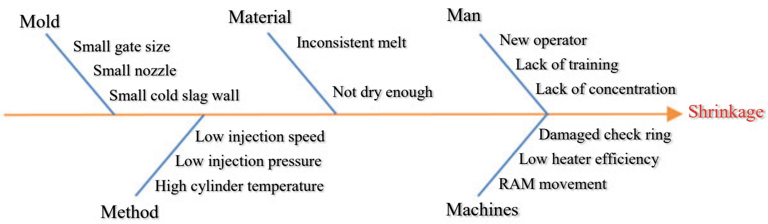

Fig. 6 Ishikawa diagram for shrinkage

practice. In addition, when a material contaminated with foreign particles is used, the part's quality will be affected, which can result in serious flaws.

3.4 Improve Stage

An action plan is made and executed to eliminate the root causes that led to the shrinkage defect and to increase the ability to detect them as quick/early as possible. The fundamental technique for improvement centers on the idea that we should be able to anticipate when the shrinkage will occur. As a result, this process will reduce the faulty rate. The root cause analysis serves as the foundation for the countermeasures. The following arguments were presented to machine operators and are supported by research papers.

3.4.1 Countermeasures for Tackling Defects

Countermeasures against shrinkage in simple terms:

- Use a commercial decontamination product to clean the machine or take out the screw and clean the barrel.
- Store the raw materials in dry areas away from moisture.
- Check the cooling system to ensure that the mold temperature is consistent.
- Lower the temperature of the cylinder and increase the holding force.

Countermeasures against short shot in simple terms:

- Increase the charge.
- Increase injection speed.

Countermeasures against silver streaks in simple terms:

- Preheat the powder to be used in production properly.
- Increase back pressure and reduce the barrel temperature.

Countermeasures against flow marks in simple terms:

- Adjust injection pressure and holding time.

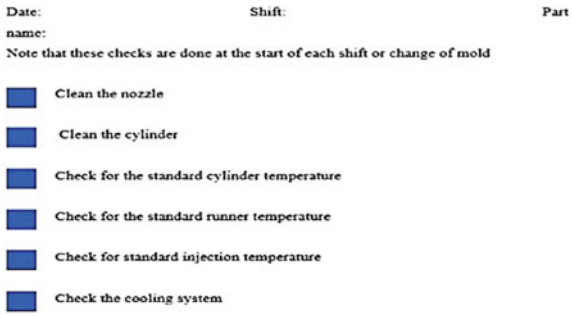

Fig. 7 Suggested checklist

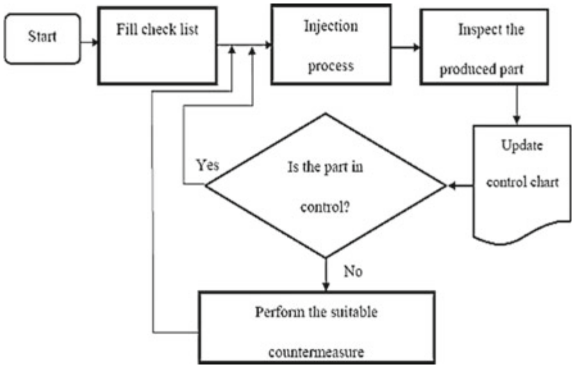

Fig. 8 Suggested process flow

Figure 7 shows the checklist to be followed before starting every production, and Fig. 8 shows the flowchart during every production.

3.4.2 Control Chart (p-chart)

A graph used to examine how a process evolves over time is the control chart. Data are plotted according to time. An average line in the middle, an upper line for the upper control limit and a lower line for the lower control limit are always present on a control chart. In statistical quality control, the p-chart is a type of control chart used to monitor the proportion of non-conforming units in a sample with data collected in subgroups of varying sizes, where the sample proportion non-conforming is defined as the ratio of the number of non-conforming units to the sample size. Figure 9 shows the p-chart for 3rd month, and Fig. 10 shows the p-chart for 4th month, which were made using the Minitab software for the data gathered with various sample sizes.

As seen in Fig. 9, the test failed at 5 points that are 6, 7, 9, 10, 11 and one point more than 3.00 standard deviations from center line which shows how important it was to implement a specific methodology like Six Sigma to reduce overall waste produced and hence boost the productivity.

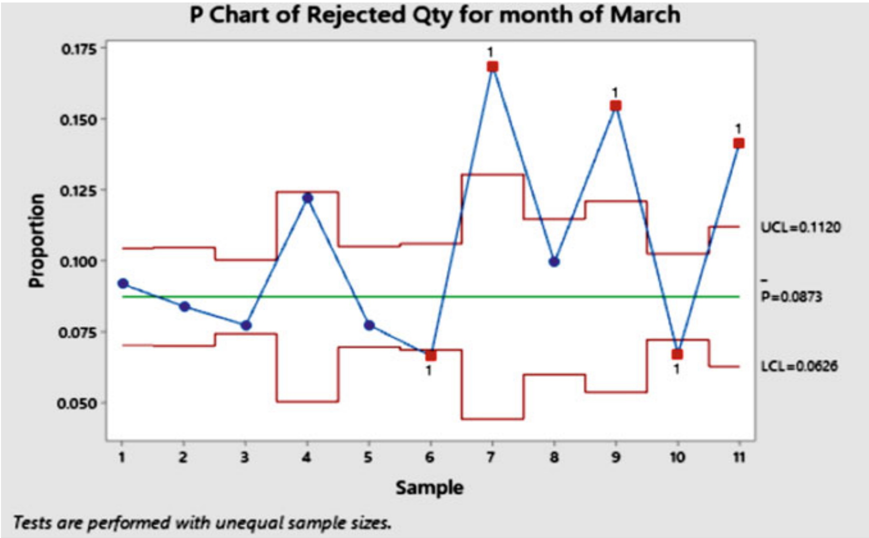

Fig. 9 P-chart for the 3rd month

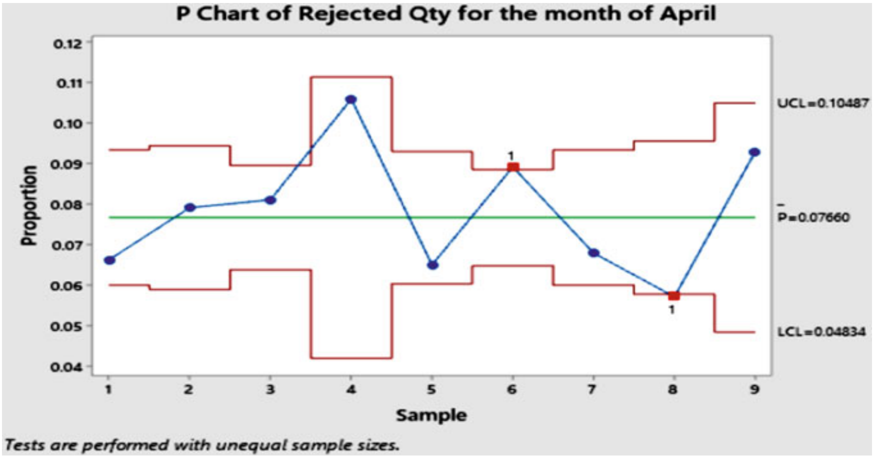

Fig. 10 P-chart for 4th month

As seen in Fig. 10, the test failed at merely 2 points that are 6 and 8 and one point more than 3.00 standard deviations from center line. This indicates that after following standard operation procedures that are implemented, Six Sigma methodology helps in reducing waste generated and thereby boosting overall manufacturing productivity.

3.5 Control Stage

This phase is to make sure that the upgraded conditions can be sustained and kept up in future. The following are some surveillance practices and suggested enhancements:

- Establishing a maintenance checklist sheet and keeping track of the production procedure so that it can be used as a guide in future. The next control involves routinely doing thorough maintenance on the machine by setter.
- Strengthen work inspection and monitoring. To reduce the creation of defective products brought on by human factors, this control can be achieved by strengthening the leader's oversight of the operators' adherence to discipline.
- Improving workspace and surrounding. This type of control can be accomplished by decreasing the amount of noise the engine of crusher machine makes while being reworked, shutting the doors, and installing a silencer in the crusher room.

4 Results and Discussion:

Table 2 shows overall observations of production for month 6, after implementing Six Sigma.

Table 2 Overall production in month 6 (for first 15 days)

Mold no	Total Qty	Accepted Qty	Rejected Qty	Shrinkage	Short shot	Flash	Silver streaks	Flow marks
668	1209	1120	89	23	21	25	8	12
50,200	1091	1000	91	17	22	29	9	14
91,653	2341	2210	131	61	39	17	8	6
31,625	1098	1020	78	19	21	17	8	13
2218	2320	2218	102	35	24	11	14	18
2107	569	510	59	22	18	9	6	4
898	1514	1420	94	25	24	20	14	16
Total	10,142	9498	644	202	169	128	67	83

Post Six Sigma implementation, readings for production done in month 6th (partially) were taken. After taking the readings, the non-confirmed products were taken for further analysis and segregated further into defects which lead to rejection of product.

Based on Table 2, all the non-confirming products along with defects that led to their rejection are added in a cumulative fashion, and percentage wise calculations are shown in Fig. 11.

Defects	Occurrences	Cumulative	Percent
Shrinkage	202	202	31%
Short Shot	169	371	57%
Flash	128	499	77%
Silver streaks	67	566	87%
Flowmarks	83	649	100%

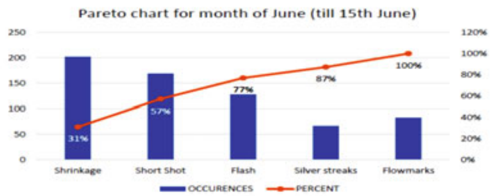

Fig. 11 Pareto chart of overall defects for the month 6 (For 1st 15 days)

DPMO calculation for month 6	Sigma level calculation for month 6
$\text{DPMO} = \dfrac{\text{No. of defects}}{\left(\text{No. of units}\right) \times \left(\text{No. of defect opportunities per unit}\right)_{gathered}} \times 1000000 = \dfrac{1635}{5 \times 18659} \times 1000000 = 17525.05493$	$\text{Sigma level}(Z) = 0.8406 + \sqrt{29.37 - 2.221\ln(\text{DPMO})} = 0.8406 + \sqrt{29.37 - 2.221\ln(17525.05493)} = 3.6096$

4.1 *Comparison of Waste Before Versus After Implementing Six Sigma*

As clearly seen in Fig. 11, shrinkage and short shot defects, which accounted for almost 68% (refer Fig. 5) of total non-confirming products manufactured in the 1st month, have been reduced and brought down to 57% (by the 6th month), over the course of six months after application of Six Sigma Principle. Figure 12 shows comparison of individual defects occurred in first and sixth month.

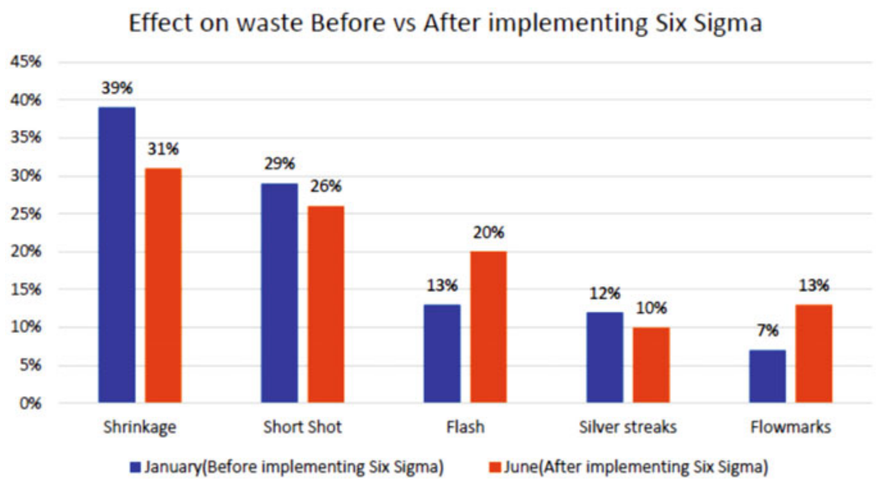

Fig. 12 Bar graph comparing individual defects occurred in 1st and 6th month

5 Conclusion

Based on results of data collection, processing, and the analysis, it was concluded that:

- Defects per Million Opportunities (DPMO) decreased from 17,500 (approx.) which was observed in 1st month to 12,700 (approx.) which was observed in 6th month.
- The sigma level increased from 3.60 to 3.74 during the span of six months.
- The overall defectives rate dropped from 9 to 6.3%.
- Talking in terms of products, 360 more confirming products are manufactured each month now using same amount of raw material.
- A checklist was made which contains specific set of instructions that are to be followed before starting every production.

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Influence of Digitized Transforming Enablers on Manufacturing Performance in the Context of Social Dimension of Sustainability

Dharam Ranka and Hari Vasudevan

Abstract Every manufacturing revolution has so far been progressively developing toward sustainability goals, considering the environment, social, and economic pillars. Impacted by the new technologies, the manufacturing sector, globally, is on the wheels of Fourth Industrial Revolution "I4.0". The umbrella keyword "digitized transforming enablers (DTE)" discussed in the study encompasses the digital technologies of the I4.0. To date, research on the impact of DTE on manufacturing performance in the context of the social dimension of sustainability has been scant and scattered, especially in the case of small and medium-sized businesses (SMEs). The discussion available in the literature reflects both positive as well as negative results. Due to the lack of relevant literature and inconsistent results, there has been a demand for further research on the subject. The objective of this study was to synergize the DTE implementation and manufacturing performance through the lens of the social dimension of sustainability within the SMEs segment. The study presents a mediation research model developed with the help of theoretical background, based on descriptive and content analyzes. This was done, while also describing the constructs selected and the hypotheses developed by collaborating DTE implementation, indicators of social sustainability as well as manufacturing performance.

Keywords I4.0 · DTE · Social sustainability · Manufacturing performance

1 Introduction

Manufacturing ecosystem is on the wheels of Fourth Industrial Revolution (I4.0), the first giant in itself, targeted toward optimized performance across every value creation stage. This study introduces an umbrella keyword "digitized transforming enablers (DTE)", defined as the digital technologies of I4.0 for transforming reporting processes, acquiring and analyzing data in real time as well as applying insights to limit risk and enhance efficiency. The digital technologies of I4.0 are expected to

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enable manufacturers choose the optimal facilities and employees, reduce operating expenses, increase productivity, better utilize resources, and identify process bottlenecks that can be closed [1], leading to enhanced overall manufacturing performance. The role of social capital is always at the focus for the successful implementation of DTE [2], which would require life-long safe work places, social well-being, and equality. This brings the second giant, sustainability, into action.

The intersection between the two giants, i.e., DTE and sustainability, is growing leaps and bounds, endorsing positive as well as negative remarks in the extant literature. Multiple study reports that the link between DTE and sustainability is in its early stage of research [3], and much more attention is required [4, 5]. But, as reported in [6], there is strong evidence that reflects the intersection between DTE and sustainability goals. Also, as reported [7], effective DTE implementation ensures sustainability. From the findings of [3] and [8], mostly, DTE positively supports the sustainable practices of firms, emerging especially for the literature focusing on manufacturing. For small and medium-sized enterprises (SMEs), research shows that DTE implementation is still below the expectations [9, 10].

The association of employees with a specific job category will end, and they need to coexist in the same space as intelligent robots [11]. The key elements of digital work culture will be information and data. Hence, continuous skilling and reskilling would be essential to develop the skills required for the digital technologies of I4.0. Since employees are in the middle of action, it brings forth social dimension of sustainability (SDS) in the frame of our study. The growth of physical and digital network integration into industrial production processes signals the progress toward achieving the objectives of social sustainability [10]. Technology benefits workers [12], but it also has inherent restriction that makes it difficult to use it in many manufacturing applications. The results from [13] reveal that the attention on human being is lost, in the quest for productivity, performance as well as competition and sustainability was left as a secondary consideration with its social dimension being undervalued and understudied. The extant literature linking the impact of DTE on SDS is still young, underdeveloped, and further, research is required, and this has also been corroborated in [3, 14, 15]. The concerns and gaps raised above have motivated to the efforts articulate and compose this study. The research agenda conceptualized as part of this study was

(1) To identify the indicators relating SDS from the extant literature.
(2) To explore the influence of DTE implementation on manufacturing performance through the lens of SDS, and
(3) To develop the research model and research propositions collaborating DTE implementation, SDS, and manufacturing performance.

The paper is structured as follows: Sect. 1 covers the introduction, and Sect. 2 offers the theoretical background along with the current review of the literature linking DTE implementation, SDS indicators, and manufacturing performance. Section 3 presents the research model, describing the constructs and the hypotheses developed.

2 Literature Review

The following section presents a theoretical background on the indicators of social dimension of sustainability, collaborated with the digital technologies of I4.0, and its influence on the parameters of manufacturing performance.

2.1 Social Dimension of Sustainability (SDS) and Its Indicators

Human-centered work is related with the social attribute. Social sustainability encompasses features that guide towards life-long social development of human beings. The indicators representing social dimension of sustainability are job satisfaction, quality of life, health and well-being, safety, social integration in communities, equity and justice in the distribution of goods and services and equal opportunities in education and training, and these have been reported in the literature [16–18]. Table 1 represents the list of SDS indicators reported in the extant literature.

The manufacturing-social sustainability pillar, which is concerned with the stakeholder's well-being and the community in which a manufacturing value chain functions, is the least well-defined and accepted component of manufacturing sustainability [30]. Social risks have been identified as being the most harmful to an organization's health, out of all the constituent risks taken into account in the study [31]. The importance of the workforce should be recognized through upskilling, counseling,

Table 1 List of SDS indicators reported in the extant literature

Indicators	Source
Worker's health and safety	[19–24]
Resistance to change	[19]
Employee turnover	[23, 25, 26]
Working conditions	[22, 23, 25, 26]
Accident rate	[22, 23, 25–27]
Gender ratio/gender equity	[23, 27]
Training opportunities	[23, 24, 27, 28]
Employee satisfaction	[20, 23, 27, 29]
Salary and benefits	[18, 23]
Full time/part time employee rate	[23, 25]
Customer satisfaction	[22, 28]
Participation of employees in business decisions	[25, 28]
Workforce diversity	[24, 28]
Stakeholder collaboration	[23, 25]

training, and mentoring by practitioners [31]. In terms of the social dimension of sustainability, highly educated and skilled workers are required to keep up with technology advancements [32].

Based on the above insights, the first research agenda was addressed, identifying the indicators for social dimension of sustainability (SDS).

2.2 Influence of DTE on Manufacturing Performance Through the Lens of SDS

The extant literature has reported positive as well negative findings of the influence of DTE implementation on SDS and further its impact on manufacturing performance.

The findings from the study [7] show that effective DTE implementation boosts a company's revenue earnings, i.e., financial performance, which is because of improved manufacturing performance. This has also been corroborated in the study [33]. Hence, it can be concluded that DTE implementation boosts manufacturing performance. Several other manufacturing performance indicators reported in literature are process and turnover rate optimization, product consistency, production quality, and dependability as well as production flexibility [19]. It also promotes the use of natural and renewable resources, reduces resource consumption, and improves social well-being, which affects SDS. The conclusion from [34] suggests that a more effective and optimized production process is one of the advantages of DTE. Along with that, it benefits the social systems by providing improved employee working conditions and enhanced function of the worker on the assembly line. The study [35] remarks positively on the influence of DTE adoption on sustainability and further, significant impact of sustainability on organizational performance. The research [36] demands to raise consciousness of the opportunities occurring from DTE to promote sustainability and corporate performance indicators. As a result, a huge need for activities to facilitate knowledge transfer in future can be foreseen.

Digital divide is raising social inequality [4]. The digital transformation changes human habits and would affect quality of life of the future generations. The emerging social digital culture indicates that social sustainability has become paramount in the digital shift [4]. Findings from [37] confirm that manufacturing needs to pay greater attention to the social side, which is frequently ignored. Technology adoption has resulted in job losses in the manufacturing sector, due to the automation of routine labor [38]. For SMEs to help accelerate I4.0 adoption and sustainable transition, governments should strengthen vendor support and expert consultation groups as well as the IT infrastructure [39].

The study [40] reports that smart sensors and actuators, big data analytics and simulation, and additive manufacturing are the technological categories of the sustainability cluster that are most connected, because of their high association with traits like optimized energy use and reduced waste. The work from the authors of [37] has found a beneficial effect of I4.0 technology on sustainability pillars. The existing, positive relationship between the digital transition and social sustainability has been made noticeable by scientific studies [4]. The study [24] suggests that corporate sustainability in case of SMEs is not well-practiced, as compared to big organizations. Also, among developing nations, social practices are grossly ignored in SMEs. Many CEOs believe that DTE implementation will have a positive effect on social issues in society [15].

Based on the above insights, the second research agenda was addressed, exploring the influence of DTE implementation on manufacturing performance, through the lens of SDS.

3 Research Model and Hypotheses Development

The following section proposes a research model, constituting DTE implementation, indicators of SDS as well as manufacturing performance, leading to the hypotheses developed.

3.1 Research Model Development

After a thorough descriptive and content analyzes of the theoretical background, the study developed a mediation model as shown in Fig. 1, proposing the relationship between DTE implementation, SDS indicators, and manufacturing performance. Based on the developed conceptual framework, the study has further proposed research hypotheses in the following section, covering the crux of the research agenda.

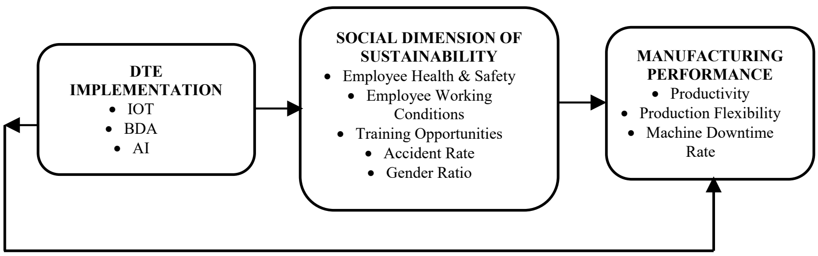

Fig. 1 Research model

3.2 Linking DTE Implementation, SDS, and Manufacturing Performance

The following section identifies key SDS indicators, which mediate the relationship between DTE implementation and manufacturing performance, derived from the extant literature as well as the conceptualization of the research propositions.

The results from [41] show that DTE components improve organizational performance metrics like profitability, sales, production volume, production volume per person, capacity utilization rate, production speed, and product quality. They can also result in significant cost savings throughout production. The study [42] highlights productivity and sustainability as potential outcomes of DTE implementation.

Internet of things (IoT) ecosystem provides improved visibility of the manufacturing execution systems, allowing real-time processing, leading to improved product and productivity [43, 44]. The investigation of the study [45] uncovers that the use of big data analytics (BDA) improves project performance in the manufacturing industry. The study [1] suggests that artificial intelligence (AI) and smart technologies can provide manufacturing alerts, seeing issues before they arise. Thus, operators can plan to turn off equipment before it breaks, preventing potentially hazardous work situations. The investigation from [46] indicates that business earnings and DTE sustainability are linearly correlated. The conceptual framework proposed for Malaysia manufacturing sector in the study [47] and further demands to investigate the relationship between DTE implementation and productivity. This has led to hypothesize the following:

H1a: IoT implementation positively influences manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H1b: BDA implementation positively influences manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H1c: AI implementation positively influences manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

From the extant literature [48–50], the digital technologies of I4.0 frequently mentioned in the sustainability field are IoT, additive manufacturing, cloud computing, big data analytics (BDA), and cyber-physical systems. The study from [16] confirms that DTE implementation encourages sustainability through economic improvements in productivity and product quality, ongoing environmental energy monitoring, safer workplace conditions, lighter workloads, and job enrichment. The research [24] posits positive remarks on the impact of social sustainability performance and business performance indicators, such as sales growth, positive cash flow, profitability, and return on asset. There is a dearth of empirical evidence on the positive as well as negative impacts of DTE on social sustainability as reported in [15].

The findings from theoretical research of [51] indicate that automation, digitization, and robotics would rapidly replace monotonous simple jobs over the next decade, but the impact of the ongoing manufacturing revolution would also lead to new jobs and interesting labor market opportunities. Skilling, reskilling, and upskilling ecosystem for the future-ready workforce of the digital era are the need of the hour [52], which will assure confidence and well-being for the workforce [38]. The research work from [53] recommends investigating the impact of DTE for the worker and the work environment. The review from [3] indicates that social sustainability pillar is the least investigated in the digital context. Further, implication of technological advances for social capital could lead to interesting insights. The findings from [26] reveal that there is lack of theoretical and empirical research on the social sustainability aspect of I4.0. Hence, it recommends future work on providing solutions for enhancing the abilities and skills of workers, in-line with digital manufacturing support. DTE implementation is thought to enhance consumer satisfaction, work environments, and career prospects [54].

From the viewpoint of social sustainability, digital and smart technologies safeguard worker's health and safety by reducing monotonous and repetitive work, which inspires people and raises their level of job satisfaction [7]. Due to increased traceability, the incorporation of Industry 4.0 technologies, namely blockchain, IoT, and big data analytics, can benefit workplace health and safety. Adoption of such technology can replace laborious manual labor, lowering injury risk, and improving workplace environment [55]. Firm's actions can be tracked to stop the misuse of those by the application of technologies like blockchain, big data, and IoT to labor-related concerns, like fair working conditions, wages, and equity [55]. The investigation from [46] validates that with improved I4.0 sustainability, job creation is linear. The research study by [56] recommends exploring how synergy between human and machine boost employee health and safety and simultaneously encourage positive impact in the social dimensions. The research by [57] reflects negative relation of I4.0 with the sustainability pillars. With regard to the social pillar, indicators such as job losses, threats linked with organizational transitions, and employee requalification are reported. The research [58] recommends exploring how I4.0 is poised against the digital divide issue and the threat of social disruptions.

The findings obtained from [36] ratify that, businesses frequently disregard considerations like social and environmental sustainability, in favor of economic sustainability. The demand from extant literature [23, 48, 59–61], recommends further research on the social impacts of I4.0, due to the intricateness of the topic. The research by [23] demands further investigation of factors that drive social attributes associated with DTE to boost market share as well as sales through optimized manufacturing performance. This has led to hypothesize the following:

H2a: Employee health and safety mediate the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H2b: Employee health and safety mediate the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H2c: Employee health and safety mediate the relationship between AI implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H3a: Employee working conditions mediate the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H3b: Employee working conditions mediate the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H3c: Employee working conditions mediate the relationship between AI implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H4a: Training opportunities mediate the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H4b: Training opportunities mediate the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H4c: Training opportunities mediate the relationship between AI implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H5a: Accident rate mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H5b: Accident rate mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H5c: Accident rate mediates the relationship between AI implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H6a: Gender ratio mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H6b: Gender ratio mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

H6c: Gender ratio mediates the relationship between AI implementation and manufacturing performance (i) productivity, (ii) production flexibility, and (iii) machine downtime rate in the SMEs.

The third research agenda of the study is therefore proposed to be addressed, by developing a research model for DTE implementation, SDS with its indicators as well as manufacturing performance, as shown in Fig. 1 and by constructing the research hypotheses posited above.

4 Conclusion

The umbrella keyword DTE discussed in the study encompasses the digital technologies of the I4.0. After descriptive and content analyzes, based on theoretical background, this study has aimed at exploring three research agendas, mentioned in Sect. 1. For the first agenda, study identified the indicators of social dimension of sustainability that are frequently reported in the extant literature. The social indicators are employee health and safety, employee working conditions, training opportunities, accident rate, and gender ratio. For the second agenda, study explored the influence of DTE implementation on manufacturing performance through the lens of SDS indicators. The insights of the study revealed that the digital technologies of I4.0 like IoT, BDA, and AI are repeatedly interconnected with manufacturing performance parameters, such as productivity, production flexibility, and machine downtime rate. On synergizing the above with the indicators of social dimension of sustainability for SMEs, the study found minimal and scattered research in the literature. Further, findings of the study report that the influence of DTE implementation on manufacturing performance of SMEs in the context of social dimension of sustainability has positive as well as negative interpretations. In the third agenda, a mediation research model is developed with the help of a theoretical background, based on descriptive and content analyzes, while also describing the constructs selected and the hypotheses developed by collaborating DTE implementation, indicators of social sustainability as well as manufacturing performance. In all, the study presents eighteen propositions to the research world, guiding toward the influence of DTE implementation on manufacturing performance through the lens of social dimension of sustainability.

Future research work could be aimed at testing of the proposed hypotheses, which would add statistical robustness to the findings as well as significance to the work presented in the study. Other social sustainability indicators, such as stakeholder collaboration, workforce diversity, full time/part time employee rate, employee satisfaction, salary and benefits, and employee turnover could be explored in future. Also, in future, the influence of digital technologies, like additive manufacturing, cyber-physical system, cloud computing, advanced robotics, cybersecurity, and mobile technologies on manufacturing performance of SMEs may be investigated. To further bolster the sustainability goals, future research work could be carried out to establish the influence of DTE implementation on manufacturing performance in the context of both the environment and economic dimensions of sustainability.

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Industry 4.0 Implementation in Indian MSMEs: A Social Perspective

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Abstract The current status of MSMEs in India suggests that medium-sized businesses have more advanced technology compared to their smaller counterparts. Small and medium-sized enterprises (SMEs) cautiously prefer to take baby steps when investing in emerging technologies. Many SMEs are financially constrained and reluctant to implement the digital technologies of Industry 4.0. The organizations need to showcase return on investment before implementing Industry 4.0 technologies. The effect of Industry 4.0 technology on society is a topic of growing interest among researchers. This study aimed to examine these effects using the triple bottom line approach to sustainable development. A model focused on sustainability is offered to assess the impact of Industry 4.0 technology on social sustainability indicators. This study also extends the technical approach that dominates academic literature on Industry 4.0 by identifying the benefits and challenges of its implementation process, assessing the importance of sustainability in Industry 4.0, and analyzing its potential social impact in a developing country like India. This paper considers how sustainable manufacturing research contributes to Industry 4.0 by summarizing present research efforts, highlighting relevant research issues, and evaluating research gaps and future development opportunities.

Keywords Industry 4.0 · Smart manufacturing · Sustainable manufacturing · Social sustainability

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1 Introduction

Lean and green manufacturing has been used and researched for two to three decades, yet sustainability concerns remain. Industry 4.0 could be a tipping point that leads to sustainable growth. This requires defect detection and remedy creation. Triple bottom line (TBL) covers the sustainable use of nonrenewable resources. Sustainable manufacturing requires the integration of goods, processes, and systems due to interdependent sustainability consequences. Every SME tried to survive the epidemic. Every company must adopt new tools and sustainable practices to flourish. The suggested research explores and analyzes the elements affecting Indian MSMEs' long-term viability. Two-tiered bibliometric and content analysis will be used to identify the conceptual framework of sustainable manufacturing literature (SM). This project will explore and deploy Industry 4.0 technologies for sustainable manufacturing. This essay examines the critical success factors for Industry 4.0 in Indian SMEs.

2 Literature Review

Organizations suffer sustainability difficulties if they fail to combine environmental, social, and financial benefits in their business plans [1]. Unbalanced social, environmental, and economic rewards prevent organizations from adopting a sustainable approach [2]. In addition, consumers' concern about the social and ecological impacts of industrial facilities has emerged as further pressure on manufacturers to change the current industrial growth model [3]. Organizations need a strategy to develop sustainable projects; an improper SM strategy won't inspire companies to invest in sustainable projects [4].

Information and automation technologies are combined during industrial transformation to produce new capabilities [5, 5]. Societies are affected by population expansion, resource depletion, land scarcity, environmental degradation, increased food consumption, and waste management. New production and consumption methods are fostered to preserve economic viability over the long term. Due to the challenges, research must be conducted into sustainable practices, standards, assessment systems, and new technologies. Industry 4.0 includes complementary technologies. Assessing the social performance of organizations has to be made the priority [7]. Industry 4.0 facilitates the long-term viability of businesses. Future-oriented, multidimensional procedures [8] will always try to boost sustainability in all perspectives. Rapidly implementing cutting-edge manufacturing processes and technologies to transform, record, distribute, and analyze data from production equipment and other autonomous systems. Companies get a competitive advantage by effectively manufacturing high-quality goods at lower costs and utilizing nonrenewable resources. Modern industrial technology can be integrated into production processes to interact and adapt in real time, enabling businesses to make intelligent goods and services [9].

2.1 Industry 4.0 and Sustainability

Industry 4.0 is an industry transformation that integrates information technologies and automation to improve performance. Financial, social, and environmental performances are examined. Industry 4.0 helps businesses achieve sustainability [10] It is feasible to boost return on investment by 15–20% by introducing BDA technologies [11]. In most businesses, including customer relationship management (CRM) data into analytics is seen as a viable strategy for increasing customer engagement and satisfaction [12]. Moreover, a comprehensive study of data from equipment and processes can increase the productivity and competitiveness of businesses [13]. Few of the Industry 4.0 tools have been discussed here. Table 1 shows list of the factors considered for performance measurement, the literature support from the select research articles, and their ranks based on the number of times the same factor has been used in the research in the context of social sustainability.

A CPS links physical devices and software to share information in various ways [12–14]. A CPS includes cybernetics, mechanical engineering, mechatronics, design, process science, manufacturing systems, and computer science. Embedded systems coordinate and couple physical products with their computational elements or services [6]. A CPS-enabled system uses physical input and output and cyber-twined services, such as control algorithms and computational capacities, to plan and build networked interactions. A CPS relies on many sensors. CPS uses touch displays, light sensors, and gyroscopes for numerous applications.

The IoT is an interconnected world where things are implanted with electronic sensors, actuators, or other digital devices to collect and communicate data [25]. IoT enables object-to-object communication and data sharing by connecting physical things, systems, and services. IoT can automate lighting, heating, machining, robotic vacuums, and remote monitoring. Auto-ID technology can be utilized to develop smart objects in IoT.

Internet and IoT make data more accessible and omnipresent, leading to big data [15]. Big data sources include sensors, devices, video/audio, networks, log files, transactional applications, the Web, and social media feeds. Manufacturing has a "big data environment." IoT (e.g., smart sensors) has accelerated data collecting, but it is unclear if this data can be effectively handled [16]. Traditional data analytics may not work with huge data [17]. Advanced analytics help firms and manufacturers with a lot of operational and shop-floor data find hidden patterns, unsuspected linkages, market trends, consumer preferences, and other relevant business information. Four I4.0 tools have been used to construct a hypothesis based on how often they have been used by researchers.

Kitsis and Chen [26] researched a number of different facets of sustainability and dove deeper into the social issues related to manufacturing to gain a better understanding of the SM domain. Ghobakhloo and Fathi [27] Due to the digital revolution, organizations can enhance productivity by using cutting-edge technology. Industry 4.0 gives firms a competitive advantage by allowing them to produce high-quality goods at cheaper costs and efficiently use nonrenewable resources. Kulatunga

Table 1 Industry 4.0 tools and the respective support from the literature survey

Industry 4.0 tools/Support	[18]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[23]	[10]	[24]	**Rank**
Additive manufacturing	*		*		*	*	*			*	*	*	*	5
Artificial intelligence	*		*	*	*	*	*			*	*	*		6
Autonomous and collaborative robots	*		*		*		*	*	*	*	*	*	*	2
Big data analytics	*	*	*	*		*	*	*	*	*	*	*	*	1
Cloud computing and manufacturing	*		*		*		*	*	*	*	*	*	*	3
Cyber-physical systems			*	*	*	*	*	*	*	*	*	*		4
Cybersecurity	*	*			*		*	*	*		*	*	*	7
Industrial internet	*	*	*		*	*	*		*		*	*		8
Internet of Things	*		*	*	*		*	*	*	*		*		9
Mobile systems and devices	*	*	*			*	*	*	*		*			11
Simulation	*	*	*	*		*	*	*		*		*		10

et al. and Huang [35, 36] The authors investigated small and medium-sized firms' environmental management systems (SMEs).

2.2 Performance Measurement and Its Indicators

A study from [28] shows that there are more than 40 indices and rating systems for sustainability assessment. Even though the topic of sustainability and Industry 4.0 plays an increasingly important role in the scientific discourse. Several metrics were used to evaluate lean manufacturing by Kumar et al. [29] better to understand the process's various stages and features. Organizations reaped the benefits of maintenance-related performance assessments, such as condition-based and reliability–contradance. Miragliotta et al. [30] The authors found that manufacturing businesses favor financial measures above non-financial metrics after classifying 73 indicators into twelve performance domains. Big data-driven supply chain research by Kamble et al. [8] has led to the development of new measures for evaluating manufacturing systems such as predictive quality and real-time defect identification and machine failure forecasting. Sustainability and Industry 4.0 are important organizational elements for sustainable production [7]. Many industrial enterprises lost money because they misunderstood sustainability India has a lower sustainability adoption rate than the U.S and China. The latest business technology includes BDA, blockchain, IoT, AM, and machine learning; if used in manufacturing, these can surely affect positively. Karimi and Walter [31] through case studies, the researchers investigated the use of emerging technology in industries. Industry 4.0 technologies provide significant contributions to social and organizational long-term sustainability. Mathiyazhagan et al. [32] according to the authors, sustainable technologies help minimize energy consumption and waste, increase energy savings, and encourage reuse and recycling. From a social sustainability standpoint, digital and intelligent technologies preserve employees' health and safety by removing monotonous and repetitive activities, encouraging individuals, and increasing job satisfaction. These discussed social sustainability indicators will help achieve greater heights in the manufacturing performance in terms of higher productivity, higher job satisfaction, and occupational health and safety of employees in the context of I4.0 implementation. Table 3 shows some of the factors considered for performance measurement, the literature support from the select research articles, been used in the research in the context of social sustainability and their respective ranking (Table 2).

Based on literature, the following research questions are framed.

- What is the status of social sustainability in the context of I4.0
- What are the I4.0 tools which affects social sustainability?
- What are the social implications of I4.0

Table 2 Manufacturing indicators and the respective support from the literature survey in the context of social sustainability

Manufacturing Performances/Support	[33]	[34]	[35]	[36]	[37]	[38]	[39]	[40]	[41]	[42]	[7]	**Rank**
Pollutant and effluent emission		*	*	*			*	*	*		*	2
Higher productivity	*		*	*	*	*		*		*		1
Smart working	*	*	*		*			*	*	*		1
Higher job satisfaction		*		*	*	*		*		*	*	2
Collaboration between companies	*		*	*	*	*	*	*			*	2
Collaboration between governments		*				*	*	*	*	*		2
Occupational health and safety	*	*		*	*	*	*			*	*	1
Human resources and rights		*	*	*	*		*		*			3
Job creation	*	*	*						*		*	4
Community and regulatory compliance		*		*		*	*	*		*		3

3 Research Methodology and Study Hypotheses

Based on the literature survey, the following hypotheses are proposed (Fig. 1).

H1a: The Industry 4.0 tool BDA has a direct and significant influence on manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H1b**: The Industry 4.0 tool cloud computing and manufacturing (CC & M) has a direct and significant influence on manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H1c**: The Industry 4.0 tool cyber-physical systems (CPSs) have a direct and significant influence on manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H1d**: The Industry 4.0 tool additive manufacturing AM has a direct, positive, and significant influence on the social sustainability of Indian MSMEs.

H2a: The contribution to society mediates relation between the BDA and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H2b**: The contribution to society mediates the relation between the cyber-physical systems (CPSs) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H2c**: The contribution to society mediates the relation between cloud computing and manufacturing (CC&M) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H2d**: The contribution to society mediates the relation between the IoT and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H2e**: The contribution to society mediates the relation between the AM and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs.

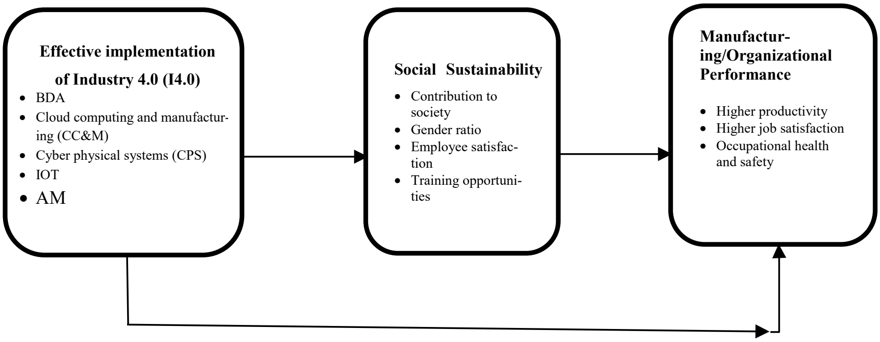

Fig. 1 Research framework

H3a: The gender ratio mediates the relation between the BDA and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H3b**: The gender ratio mediates the relation between the cyber-physical systems (CPS) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H3c**: The gender ratio mediates the relation between cloud computing and manufacturing (CC & M) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H3d**: The gender ratio mediates the relation between the IoT and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H3e**: The gender ratio mediates relation between the AM and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs.

H4a: Employee satisfaction mediates the relation between the BDA and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H4b**: Employee satisfaction mediates the relation between the cyber-physical systems (CPS) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H4c**: Employee satisfaction mediates the relation between cloud computing and manufacturing (CC&M) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H4d**: Employee satisfaction mediates the relation between the IoT and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H4e**: Employee satisfaction mediates the relation between the AM and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs.

H5a: The training opportunities mediate relation between the BDA and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H5b**: The training opportunities mediate relation between the cyber-physical systems (CPS) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H5c**: The training opportunities mediate relation between the cloud computing and manufacturing (CC&M) and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H5d**: The training opportunities mediate relation between the IoT and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs. **H5e**: The training opportunities mediate relation between the AM and manufacturing performance (i) Higher productivity (ii) Higher job satisfaction (iii) Occupational health and safety in Indian MSMEs.

4 Conclusion

This research demonstrates how modern technologies and ideas of sustainable manufacturing may help Industry 4.0 improve its sustainability in a social perspective. The evaluation of relevant literature also created a research agenda and growth projections. This research provides an overview of Industry 4.0 and Indian small and medium-sized enterprises. Both can support environmentally responsible manufacturing. The findings of this study contributed to the development of a research framework and scenario for the future evolution of the field toward normative Industry 4.0 adoption studies. All of the critical success factors that drive I4.0 rollout will guarantee TBL's long-term survival. To enhance the socioeconomic state of the country, local factors must be addressed. Industry 4.0 may benefit all sustainability criteria by applying sustainable manufacturing principles and current technologies, as demonstrated by this study, which enables companies to achieve all Industry 4.0 objectives. Humans at all levels of wealth and education must be made exponentially more aware of the sustainability dilemma. To develop and evaluate products and services in accordance with social sustainability criteria, inventiveness is required. These principles must be introduced to and comprehended by all participants, who are dispersed across the globe and have diverse cultural and educational backgrounds. Current research reveals a dearth of quantitative and methodological analyses of the social implications of Industry 4.0 and its potential contribution to sustainable development. Future studies should aim to bridge this knowledge gap.

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Investigating Critical Process Parameters Using Fuzzy Analytical Hierarchical Process in Casting Process Failure

Amit Chaudhari and Hari Vasudevan

Abstract Productivity enhancement of casting process by optimizing the casting process parameters has been a primary focus area of many researchers. It includes optimization of various process parameters in the design phase, through various DOE techniques and simulation software. There have been major shortcomings in these approaches, wherein the data for casting defects in real time were not considered. Real-time investigation of casting failure for several process parameters is a challenge for the foundry industry. Analytical hierarchical process is a decision support technique through which a hierarchical structural model could be generated. There is subjectivity in the retrieval decision because the primary input of the AHP approach was the opinion of industry experts or practitioners. Additionally, this approach considers the validity of the data with constraints on inconsistency. However, there would be an impact on the accuracy of the data and the results if there was a significant amount of uncertainty and doubt, while making a judgement. This has resulted in the development of fuzzy analytic hierarchy process, an analytic hierarchy process (AHP) approach created with fuzzy logic theory. In this context, this study used a hierarchical model that focuses on the casting failure in industries, and accordingly, the model was tested for various process parameters. The outcome of the study provided the priority ranking of the process parameters for various casting failure, in real time through which the critical process parameters were identified in the order.

Keywords Casting process parameters · Analytical hierarchical process · Fuzzy AHP

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1 Introduction

The productivity of any machine depends on the quality of the components used in its assembly. Casting components are widely used in the assemblies of many capital goods/OEM machines. To sustain the productivity of any such machine, minimizing the casting defects is imperative and is the need of the hour. Chaudhari and Vasudevan [10] brought out few observations on optimizing the casting process using AHP approaches, by using the fuzzy AHP methodology to address the fuzziness of information and human judgement [10]. In order to address the fuzziness of information and human judgement, Zadeh [19] proposed a fuzzy set theory in 1965. It has been demonstrated that fuzzy logic is an effective multi-criteria decision-making technique. Since then, fuzzy set theory has been used in numerous further research publications to handle uncertainty in a variety of fields [17].

Literature shows that the AHP approach has been used to record decision makers' preferences for pair-wise comparison, but it is unable to represent the complexity of human decision-making due to issues with the method's application, such as its limited scale, group decision-making and relativity of choice qualities [18]. To solve the hierarchical problem, fuzzy AHP, which is only an extension of AHP, was developed. Fuzzy AHP is a numerical technique built on Saaty's hierarchical analysis that simplifies and decomposes a complicated issue hierarchically and methodically [20]. This mathematical technique was utilized to incorporate the opinions of experts for a comprehensive examination and methodical problem-solving, while also reducing the chance of a mistake [15]. Chang introduced a triangular fuzzy number for pair-wise comparison and employed an extent analysis for the synthetic extent values of pair-wise comparison to build a unique approach for dealing with fuzzy AHP. Use of a triangle membership function is popular in the literature, despite the fact that the triangular fuzzy numbers are computationally easy and are rarely applied. This current study is an extension of the previous work on optimizing the casting process using AHP approaches, by using the fuzzy AHP methodology [1].

2 Literature Review

Various researchers have utilized numerous techniques to optimize the parameters of the casting process. Some of them have used simulation software, such as Z-cast, AUTO CAST X and MAGMA soft. Various statistical approaches, including the Taguchi method, analysis of variance (ANOVA) and response surface methodology (RSM), are also employed by several researchers for optimizing casting process parameters [16]. Majority of them have mostly concentrated on the design and simulation for optimizing the casting process parameters.

Through the extant literature review, various process parameters considered by different studies are identified. Sushil kumar et al. [1] considered green compressive strength, moisture content, pouring temperature and mould hardness as process parameters for their study [1]. Guharaja et al. [2] considered moisture content, permeability and green strength and mould hardness as process parameters [2]. Datau et al. [3] worked on runner size, mould temperature and pouring temperature as casting process parameters [3]. Pouring temperature, pouring time, moisture content, compressive strength, loss on ignition, mould pressure, volatile content, vent holes and permeability are the process parameters considered for the optimization of sand casting process parameters using Taguchi analysis [4]. Ganganallimath et al. [5] considered pouring temperature, mould hardness, pouring rate, moisture content and permeability of sand and green strength as process parameters to find out the optimum values of parameters to reduce the defects [5].

Pouring temperature, pouring time, sand particle size, mould hardness, moisture content, green compression strength and permeability are the common process parameters considered for the optimization of process parameters, using DOE [6–8]. Casting process parameters, such as riser size, sprue size, clay content, moisture content, grain size and ramming, are also considered by Nekere [9]. Chaudhari and Vasudevan [12] used Markov chain model to identify the critical process parameters and amongst the process parameters considered were mould hardness, pouring temperature, permeability, improper handling, green compressive strength and moisture content [12].

3 Methodology

Methodology employed in the study includes data collection, involving different casting defects and the process parameters from various casting industries. For this research study, various casting industries in the western region of the country were visited for the data collection and defect minimization. Based on the inputs from industry experts as well as extant literature, six casting defects and six casting process parameters were identified and considered for the study.

A hierarchical model was developed that takes into account a number of process parameters and casting defects, while studying the casting failure in industry. Cold shut, inclusion, mould shift, porosity, shrinkage and blow holes were the casting defects and pouring temperature, mould hardness, moisture content, improper handling, permeability and green compressive strength were the process parameters considered in the study. As some of the process parameters are responsible for several defects, the model, depicted in Fig. 1, demonstrates the interrelationship between casting defects and process parameters.

4 Results and Discussion

For this study, inputs from industry experts were used to create a pair-wise comparison matrix, based on a scale of relative relevance for various casting defects and process

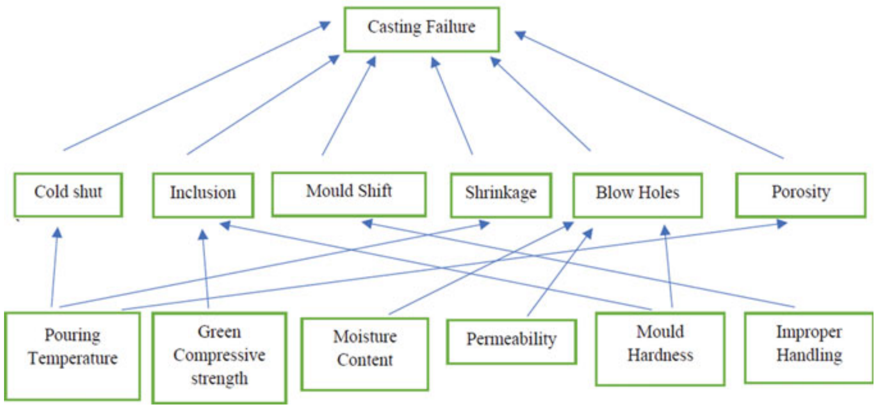

Fig. 1 Hierarchical model for casting process failure

Table 1 Criterion-level judgement matrix for casting defects

Casting failure	Cold shut	Inclusion	Mould shift	Shrinkage	Blow holes	Porosity
Cold Shut	1	1/2	3	2	2	2
Inclusion	2	1	3	2	2	2
Mould Shift	1/3	1/3	1	½	1/2	1/2
Shrinkage	1/2	1/2	2	1	3	3
Blow Holes	1/2	1/2	2	1/3	1	1/2
Porosity	1/2	1/2	2	1/3	2	1

parameters. The pair-wise comparison matrix is depicted in Table 1 for the casting failure model.

Triangular fuzzy number design was used to represent fuzzy comparative judgement in evaluation of priority rankings for various casting process parameters. Table 2 shows fuzzy pair-wise comparison matrix for six casting defects. Weightage/priority of the casting defects was calculated and was shown in Table 3.

A pair-wise comparison matrix was also created for various process parameters, which are associated with multiple defects. Table 4 depicts pair-wise comparison for green compressive strength and mould hardness responsible for the inclusion defect. Table 5 shows the fuzzy pair-wise comparison matrix for green compressive strength and mould hardness responsible for the inclusion defect. Weightage/priority of green compressive strength and mould hardness for inclusion defect was calculated and was shown in Table 6.

Table 2 Fuzzy pair-wise comparison matrix for casting defects using triangular fuzzy

Casting failure	Cold shut			Inclusion			Mould shift			Shrinkage			Blow holes			Porosity		
cold shut	1	1	1	$\frac{1}{3}$	$\frac{1}{2}$	1	2	3	4	1	2	3	1	2	3	1	2	3
Inclusion	1	2	3	1	1	1	2	3	4	1	2	3	1	2	3	1	2	3
Mould shift	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	1	1	1	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1
Shrinkage	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1	1	2	3	1	1	1	2	3	4	2	3	4
Blow holes	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1	1	2	3	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	1	1	1	$\frac{1}{3}$	$\frac{1}{2}$	1
Porosity	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{2}$	1	1	2	3	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	1	2	3	1	1	1

Table 3 Priority ranking of casting defects

Casting failure	Fuzzy Geometric mean value			Priority/weightage
	Low	Moderate	High	
Cold shut	0.933	1.513	2.182	0.221
Inclusion	1.122	1.906	2.620	0.270
Mould shift	0.363	0.490	0.793	0.079
Shrinkage	0.870	1.284	1.906	0.196
Blow holes	0.455	0.660	1.069	0.104
Porosity	0.548	0.832	1.284	0.127
Total	4.293	6.688	9.857	

Table 4 Criterion-level judgement matrix for inclusion defect

Inclusion defect	Green compressive strength	Mould hardness
Green compressive strength	1	2
Mould hardness	1/2	1

Table 5 Fuzzy pair-wise comparison matrix for inclusion defect using triangular fuzzy

Inclusion defect	Green compressive strength			Mould hardness		
Green compressive strength	1	1	1	1	2	3
Mould hardness	1/3	1/2	1	1	1	1

Table 6 Priority ranking of inclusion defect

Inclusion Defect	Fuzzy geometric mean value			Priority/Weightage
	Low	Moderate	High	
Green compressive strength	1	1.414	1.732	0.645
Mould hardness	0.574	0.707	1	0.354
Total	1.574	2.121	2.732	

Table 7 depicts the pair-wise comparison for green compressive strength and mould hardness responsible for the inclusion defect. Table 8 shows the fuzzy pair-wise comparison matrix for green compressive strength and mould hardness responsible for the inclusion defect. Weightage/priority of moisture content, permeability and mould hardness for blow hole defect was calculated and was shown in Table 9.

Finally, in the comparison matrix, priority rankings resulting from various defects and process parameters were allocated. Table 10 displays the priority of the casting process parameters responsible for a variety of casting defects, taken into account in the study. Graph was also plotted for the comparison of priority ranking for various process parameters and is shown in Fig. 2.

Table 7 Criterion-level judgement matrix for blow holes defect

Blow holes defect	Moisture content	Mould hardness	Permeability
Moisture content	1	2	2
Mould hardness	1/2	1	2
Permeability	1/2	1/2	1

Table 8 Fuzzy pair-wise comparison matrix for blow hole defect using triangular fuzzy

Blow holes defect	Moisture content			Mould hardness			Permeability		
Moisture content	1	1	1	1	2	3	1	2	3
Mould hardness	1/3	1/2	1	1	1	1	1	2	3
Permeability	1/3	1/2	1	1/3	1/2	1	1	1	1

Table 9 Priority ranking of blow hole defect

Blow holes defect	Fuzzy geometric mean value			Priority/Weightage
	Low	Moderate	High	
Moisture content	1	1.587	2.080	0.471
Mould hardness	0.691	1	1.442	0.316
Permeability	0.477	0.629	1	0.212
Total	2.168	3.217	4.522	

Table 10 Priority ranking of casting process parameters through fuzzy AHP

Casting failure	Cold shut	Inclusion	Mould shift	Shrinkage	Blow holes	Porosity	Priority
Criteria weights	*0.22*	*0.27*	*0.08*	*0.20*	*0.1*	*0.13*	
Pouring temperature	1	0	0	1	0	1	0.545
Green compressive strength	0	0.65	0	0	0	0	0.174
Mould hardness	0	0.35	0	0	0.32	0	0.129
Improper handling	0	0	1	0	0	0	0.079
Moisture content	0	0	0	0	0.47	0	0.049
Permeability	0	0	0	0	0.21	0	0.022

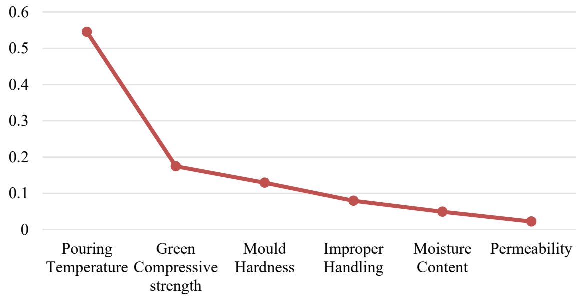

Fig. 2 Comparative analysis of various process parameters

Table 11 Priority ranking of casting process parameters through AHP

Casting failure	Cold shut	Inclusion	Mould shift	Shrinkage	Blow holes	Porosity	Priority
Criteria weights	*0.22*	*0.28*	*0.07*	*0.20*	*0.10*	*0.13*	
Pouring temperature	1	0	0	1	0	1	0.546
Green compressive strength	0	0.67	0	0	0	0	0.186
Mould hardness	0	0.33	0	0	0.31	0	0.125
Improper handling	0	0	1	0	0	0	0.071
Moisture content	0	0	0	0	0.49	0	0.050
Permeability	0	0	0	0	0.20	0	0.020

Priority of casting process parameters was also calculated through AHP for the same hierarchical model. Table 11 depicts the priority ranking of process parameters through AHP.

Figure 3 depicts the probability of failure for casting process parameters using AHP and fuzzy AHP. The graph clearly shows that the probability of casting failure for various casting process parameters was approximately the same in both techniques used.

5 Conclusion

In this work, a hierarchical model focusing on casting failure in industries was designed and evaluated for different process parameters. The model shows the relationship between different casting failures and casting process parameters. Fuzzy

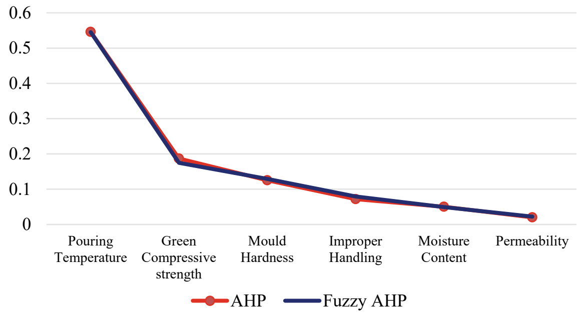

Fig. 3 Comparative analysis of AHP and fuzzy AHP for various process parameters

AHP was implemented on the hierarchical model developed in AHP, so as to reduce the fuzziness in the decision-making. The order for probability of failure of casting process was derived by determining the priority ranking of the process parameters for various casting failures in real time. According to the findings from fuzzy AHP, the pouring temperature was seen as the most critical process parameter for the casting process.

In the study, the hierarchical model was also tested with AHP, and results in terms of priority ranking of the process parameters were also brought out. In AHP, again, the pouring temperature emerged out as the most critical process parameter for the casting process. It was clearly seen in the study that the results obtained through fuzzy AHP were resembling the same results, as in the case of AHP. Hence, it could further be concluded that the fuzzy AHP could be used in investigating the failure of the system through various process parameters.

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Optimization of EDM Process Parameters Using GRA & Taguchi Method

Divij Shah, Kevin Kamdar, and Sandeep Vaity

Abstract EDM devices require input for process variables such as current, pulse-on time and pulse-off time while keeping voltage, work time, jump, servo speed and spark gap values constant. According to the fundamental tenets of the grey relational analysis (GRA) approach, the selected alternative should have the "greatest degree of grey relation" to the positive-ideal solution and the "smallest degree of grey relation" to the negative-ideal option. Using a design matrix developed by Dr. Genichi Taguchi, Taguchi orthogonal array (OA) design is a sort of general fractional factorial design that enables you to consider a chosen subset of combinations of various factors at various levels. Despite the fractionality of the design, the elements can be assessed independently. This paper discusses applications of GRA and OA, to increase material removal rate and decrease electrode wear rate by optimizing the machining parameters of electro-discharge machining (EDM) using P20 tool steel. The factors selected to decrease time and save money are material removal rate (MRR) and electrode wear rate (EWR), and the machining parameters to achieve the same are current-I, pulse-on time-T_{ON} and pulse-off time-T_{OFF}. After using the optimal combination of machining parameters, applying grey relational and Taguchi method, optimal values were determined for improved performance of the machining process.

Keywords EDM · Taguchi method · Grey relational analysis · MRR · EWR

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1 Introduction

Electrical discharge machining, (EDM), is a process that cuts metal with the help of an electric current, with the gap that has to be maintained between the electrode and the workpiece. The connected power supply helps in generating a potential between them as both are good conductors of electricity. An electric field would be established which is dependent on a few factors such as the gap that is present between tool and workpiece and the potential difference applied. The energy from the potential difference applied is able to melt metal due to which the metal is machined. Finally, a crater is formed in the work piece that is almost of the similar shape as that of the tool. The EDM process is able to cut the metals easily and with a set of parameters can provide different levels of finishing as required, with no need for any post-machining process or treatment. In sum, saving time and costs while providing the necessary surface finish.

2 Literature Survey

Nayak and Routara [1], discuss the conclusion of Taguchi method to optimize individual factor selected like MRR and EWR in EDM [1]. Maiyar et al. [2] discusses the optimization of parameters in a milling operation for Inconel 718 alloy by using the combination of Taguchi method paired with the grey relational analysis. Finally, confirmation tests were carried out to compare the results, and the results conclude that the end milling machining performance process can be improved effectively [2]. Seelan and Rajesh [3] discuss about metals having high corrosion resistance properties with higher mechanical properties having their significant applications in modern times. Aluminium alloy LM25, which is having good mechanical properties with combined corrosion resistance properties, is stir cast with titanium and boride salt to get Al-TiB2, which is used for this study with copper as electrode. For optimizing the process parameters, Taguchi method is used, selecting L9 orthogonal array [3]. Jeevamalar et al. [6] concluded that current was major parameter followed by pulse-on and pulse-off time for MRR & EWR [6]. Nadpara, V. J., & Choudhary [4] also concluded that MRR and EWR were mainly affected by current [4]. Singh et al. [5] discuss optimizing multiple performance characteristics such as pulse-on time, pulse-off time, discharge current and gap voltage [5]. Prajapati and Trivedi [7] found MRR was at its highest at 6 amps of current, 100 μs of pulse-on time and 40 μs of pulse-off time. EWR was maximum at current of 4 amps, pulse-on and pulse-off times of 100 μs and 50 μs, respectively [7]. Gaikwad et al. [8] presented effect of control factors on MRR & EWR for die sinking EDM of SS316 [8]. Banker et al. (2014) have focused on optimizing the process parameters of EDM in terms of MMR [9]. Ohdar et al. [10], presented effect of control factors on MRR & TWR for EDM of M.S. using Taguchi's DOE [10].

3 Experimental Setup

Dielectric medium is EDM fluid, i.e. Ipol Spark erosion oil 350. Graphite electrode is used with density of 1.85 g/cc. Table 1 shows array 3 signal levels and 3 factors; therefore, L9 orthogonal array was chosen to optimize the parameters like input current(I), (T_{ON}) pulse-duration, pulse-on time and (T_{OFF}) pulse-off time while keeping other characteristics constant. Tables 2 and 3 illustrate the parametric values arranged and divided into readings based on L9 array.

Table 1 Machining parameters

	Level 1	Level 2	Level 3
Current (AMP)	4	6	8
T_{ON}	80	100	120
T_{OFF}	60	80	100

Table 2 Arrangement into L9 orthogonal array

I	T_{ON}	T_{OFF}
4	80	60
4	100	80
4	120	100
6	80	80
6	100	100
6	120	60
8	80	100
8	100	60
8	120	80

Table 3 Machining time and weight difference for P20 tool steel

Exp. no.	(I)	(T_{ON})	(T_{OFF})	W_B-W_A(g)	E_B-E_A(g)	T (MINS)
1	4	80	60	4.14	2.2	54
2	4	100	80	5.58	1.58	48
3	4	120	100	3.68	1.9	56
4	6	80	80	4.24	1.02	38
5	6	100	100	9.43	2.5	46
6	6	120	60	12.74	1.96	73
7	8	80	100	4.51	1.5	103
8	8	100	60	6.82	1.52	86
9	8	120	80	8.58	1.4	53

Table 4 Calculation of MRR and EWR

Exp. no.	I	T_{ON}	T_{OFF}	MRR	EWR
1	4	80	60	9.77	22.02
2	4	100	80	14.81	17.86
3	4	120	100	8.37	18.34
4	6	80	80	14.21	14.57
5	6	100	100	26.11	29.38
6	6	120	60	22.24	14.53
7	8	80	100	5.58	7.87
8	8	100	60	10.10	9.56
9	8	120	80	20.62	14.28

For calculating **MRR,** we are using the formula:

$$\frac{(W_B - W_A) * 1000}{D * T} mm^3/\min$$

For calculating **EWR,** we are using formula:

$$\frac{(E_B - E_A) * 1000}{D * T} mm^3/\min$$

where W_B/E_B = Workpiece/electrode weight before machining (g)
W_A/E_A = Workpiece/electrode weight after machining(g).
D = Density of P20 steel (g/cc) = 8.96 g/cc and T = Time (mins.)
Results after calculating MRR and EWR are listed in Table 4.

3.1 *Taguchi Method*

Analysis was carried out using Taguchi method by L9 orthogonal array on Minitab 19 software; response tables and graphs were generated for getting optimized values.

3.2 *Inference from Taguchi Method*

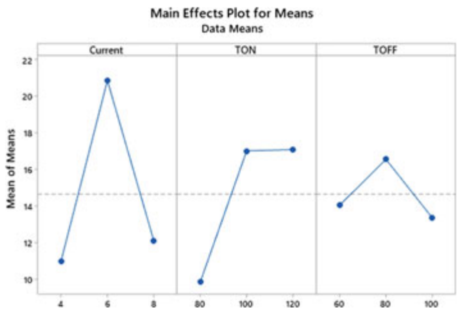
Choose 'Larger the better' option for getting S/N ratio values in Minitab software for MRR. The graph on main effects plot for S/N ratio for MRR and the response table are shown below in Fig. 1.

The graph on the main effects plot for mean is shown in Fig. 2, with the relevance of each process parameters that were rated as per delta value from high to low.

Data for S/N Ratio
Larger is Better

Level	I	T_{ON}	T_{OFF}
1	20.56	19.26	22.28
2	26.11	23.95	24.25
3	20.44	23.90	20.57
Delta	5.67	4.69	3.68
Rank	1	2	3

Fig. 1 S/N ratio larger is better for MRR



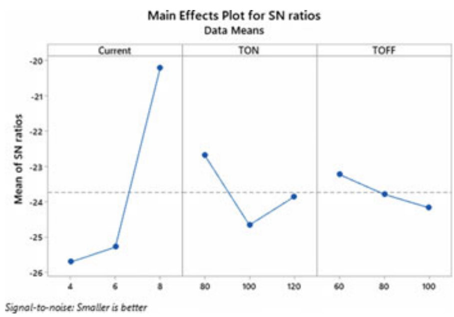
Data for Means

Level	I	T_{ON}	T_{OFF}
1	10.986	9.851	14.036
2	20.853	17.011	16.553
3	12.103	17.080	13.353
Delta	9.867	7.229	3.200
Rank	1	2	3

Fig. 2 Main effects plot for means of MRR

To acquire S/N values for EWR, we would similarly select the "smaller the better" option in the Minitab software, and then generate a main effects plot for S/N values as shown in Fig. 3, as well as a response table.

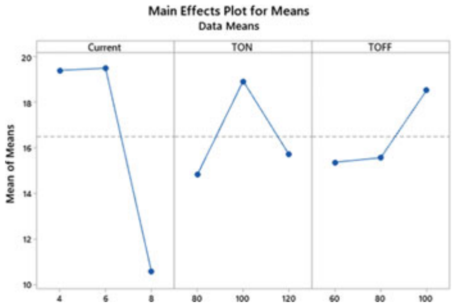
Accordingly, we receive the graph for the mean's primary effects as shown in Fig. 4, along with the relevance of each of the process parameters that were rated in the response table based on their delta values, from high to low.



Data for Means

Level	I	T_{ON}	T_{OFF}
1	-25.72	-22.68	-23.24
2	-25.29	-24.67	-23.80
3	-20.21	-23.87	-24.18
Delta	5.51	1.99	0.94
Rank	1	2	3

Fig. 3 S/N ratio for EWR



Data for Means

Level	I	T_{ON}	T_{OFF}
1	19.40	14.82	15.37
2	19.49	18.93	15.57
3	10.57	15.71	18.53
Delta	8.93	4.11	3.16
Rank	1	2	3

Fig. 4 Main effects plot for means of EWR

Table 5 Normalized values for MRR and EWR

Exp. No.	I	T_{ON}	T_{OFF}	MRR	EWR	MRR normalize	EWR normalize
1	4	80	60	9.77	22.02	0.2041	0.3422
2	4	100	80	14.82	15.29	0.4501	0.5356
3	4	120	100	8.37	18.33	0.1359	0.5137
4	6	80	80	14.21	14.57	0.4204	0.6885
5	6	100	100	26.11	29.38	1.0000	0.0000
6	6	120	60	23.56	12.59	0.8115	0.6904
7	8	80	100	5.58	7.87	0.0000	1.0000
8	8	100	60	10.10	11.94	0.2202	0.9214
9	8	120	80	20.63	14.27	0.7331	0.7025

4 Using Grey Relational Analysis (GRA) to Verify Optimized Values

Data pre-processing is necessary in GRA because the range and unit in one data sequence may vary from the others.

For the MRR, we use 'larger the better' characteristic and can be normalized as: $x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)}$	For the EWR, we use 'smaller the better' characteristic and can be normalized as: $x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)}$

where $x_i^*(k)$ and $x_i^*(k)$ are the sequence after pre-processing data and comparability sequence, respectively, $k = 1$ for MRR/EWR; i = 1, 2, 3,…, 9 for expt. numbers 1 to 9.

Calculations were carried out for readings 1 to 9 for MRR with normalized values are shown in Table 5.

Calculating the deviation sequence for each reading using following formula $\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|$, $\Delta_{0i}(k)$: deviation sequence of reference sequence $x_0^*(k)$ and the comparability sequence $x_i^*(k)$.

Table 6 DEVIATION SEQUENCES FOR MRR AND EWR

Exp. NO	MRR Normalize	EWR Normalize	MRR Deviation	EWR Deviation
1	0.2041	0.3422	0.7959	0.6578
2	0.4501	0.6550	0.5499	0.4644
3	0.1359	0.5137	0.8641	0.4863
4	0.4204	0.6885	0.5796	0.3115
5	1.0000	0.0000	0.0000	1.0000
6	0.8758	0.7807	0.1885	0.3096
7	0.0000	1.0000	1.0000	0.0000
8	0.2202	0.8108	0.7798	0.078
9	0.7331	0.7025	0.2669	0.2975

Table 7 Grey relational coefficient and grade

Exp. No.	MRR coefficient	EWR coefficient	GRA grade
1	0.3858	0.4318	0.4088
2	0.4762	0.5184	0.4973
3	0.3665	0.5070	0.4367
4	0.4631	0.6162	0.5396
5	1.0000	0.3333	0.6667
6	0.7262	0.6176	0.6719
7	0.3333	1.0000	0.6667
8	0.3907	0.8642	0.6275
9	0.6520	0.6269	0.6395

MRR and EWR with deviation sequence values shown in Table 6.

The grey relational coefficient is defined as follows: $\boldsymbol{\xi_i(k)} = \frac{\boldsymbol{\Delta_{min}} + \zeta\ \boldsymbol{\Delta_{max}}}{\boldsymbol{\Delta_{0i}(k)} + \zeta\ \boldsymbol{\Delta_{max}}}$,

ζ distinguishing or identification coefficient. ζ was taken 0.5, as all parameters have equal preference.

The grey relational grade is calculated by: $\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$.

Grey relational coefficient for MRR and EWR and grey relational grades were calculated for each reading, **using above equations**, are shown in Table 7.

4.1 *Inference from GRA*

Based on arrangement of signal values in L9 OA for each parameter, mean of grey relational grade was calculated for each of these signal values. Simultaneously, the difference between highest and lowest mean grade was calculated and that difference

Table 8 Significance of machining parameters through grey relational grade

Process parameters	Grey relational grade			Main effects (Max–Min)	Rank
	Level1	Level2	Level 3		
I (Amps)	0.4476	0.6261	0.6445	0.1969	1
T_{ON} (μsec)	0.5384	0.5972	0.5872	0.0588	2
T_{OFF}(μsec)	0.5694	0.5588	0.5900	0.0312	3

was then ranked from 1 to 3 with highest value given rank 1 and lowest ranked 3 (Table 8).

The difference between the max value and min value for the parameter I is highest, followed by T_{ON} and T_{OFF}. Hence, the ranking level of the parameters is 1, 2, and 3, respectively.

4.2 *Conformation Test*

A verification test is carried out to double check the analysis done previously. A random setting level is chosen from the experiments conducted so as to compare the change with the optimal parameters determined. Here, the setting level is of level 1 of I, level 2 of pulse-on time, T_{ON} and level 2 of pulse-off time, T_{OFF}.

The estimated grey relational grade, using the optimal level of the process parameters, can be calculated as:

$$\gamma = \gamma_m + \sum_{i=1}^{q} (\gamma_i - \gamma_m)$$

where γ_i is the mean of grey relational grade at the optimum level, γ_m is the mean grey relational grade and q is the number of machining parameters (Table 9).

The grey relational grade is increased by 0.1889 or 38%.

The characteristic material removal rate is increased by 6.6 **mm³/min** or 45%.

The characteristic electrode wear rate is decreased by 5.08 **mm³/min** or 28%.

Table 9 Comparison with previous experiment

	Initial machining parameters	Optimal machining parameters
Setting level	A1B2C2	A3B2C3
Grey relational grade	0.4973	0.6862
Material removal rate	14.82	21.416
Electrode wear rate	17.86	12.788

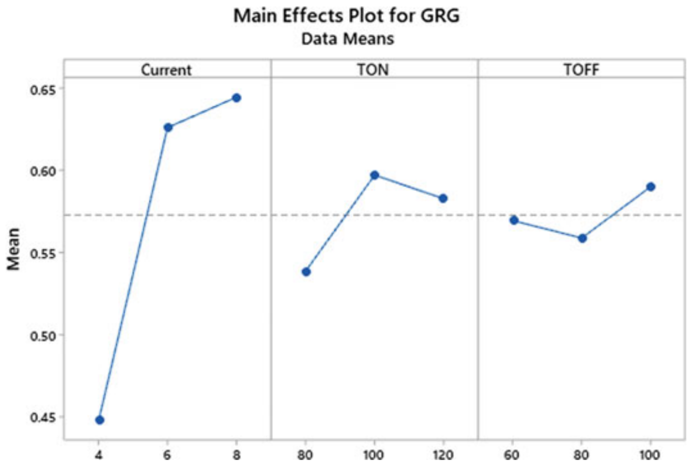


Fig. 5 Main effects plot for GRG data means

5 Result

Taguchi Method:—MRR is affected the highest by I, followed by T_{ON} and T_{OFF}.

MRR is maximized at I-6(amp); pulse-on time-(120 µs) & pulse-off time-(80 µs).

EWR is affected the highest by I(Current) followed by T_{ON} and T_{OFF}.

EWR is maximized at I-8(amp); T_{ON} (80 µs) & T_{OFF} (60 µs).

Grey Relational Analysis:—The analysis had showed that most significant parameters were ranked as 1. current (I), 2. T_{ON} and 3. TO_{FF} (Fig. 5).

6 Conclusion

The results after employing the Taguchi method, Minitab software, grey relational analysis and conformation tests, showed the importance of parameters selected and helped in determining their optimal values, thus improving the efficiency by saving time and saving costs for the company. It was observed that the characteristic material removal rate increased by 6.6 mm^3/min or 45%, and the characteristic electrode wear rate decreased by 5.08 mm^3/min or 28%. The optimal values obtained resulted in overall improvement of the EDM process, and the reduced time can be used for other value adding activities.

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A Model for Integrating Industry 4.0 and Lean Tools Using Critical Success Factors in Indian Manufacturing Industries

Dhaval Birajdar and Hari Vasudevan

Abstract Manufacturing industries in India need to efficiently and rapidly adapt to the changing market conditions, such that it can survive in today's highly competitive industrial landscape. Industries are gearing up for the transition from the Third to Fourth Industrial Revolution (Industry 4.0-I4.0). In terms of performance, I4.0 and Lean manufacturing could be a perfect complement to each other. Adopting Industry 4.0 technologies allows for greater cost control, while enhancing product quality. Integrating these technologies into pre-existing production systems and determining, which processes they can assist are still areas of active research. In this regard, a review was done on Lean Manufacturing & I4.0 enablers as well as the critical success factors & absorptive capacity, as the integration approach was carried out to build a conceptual framework. The research aimed to identify the critical success factors required to integrate lean & I4.0 tools. This study also sheds light on the contextual factors, such as absorptive capacity, which are used as mediating variables, so as to integrate lean and I4.0 tools in the Indian manufacturing industries.

Keywords Enablers · CSF · Lean & I4 · Absorptive capacity

1 Introduction

Lean techniques have benefited several manufacturing industries in the previous two decades. The interaction between lean production and traditional manufacturing is evolving as a result of its enablers and measures. Methodologies known as "lean enablers" help, encourage, and stimulate the use of waste-free systems tools and techniques throughout all value chains, which benefits organization's operational procedures. According to a recent study, Lean manufacturing methodologies are ineffective, when it comes to products with short product life cycles and high customization, because of the difficulty in modifying production lines, buffer stocks, cycle

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times, and other aspects of the manufacturing process. Lean metrics are measurements used to assess the effectiveness of enabling implementation and it facilitates assessing the degree of implementation of initiatives.

To meet the need for customized products and tighter competition, organizations are turning to digital transformation and service-oriented paradigms. This shift has been hastened by cheaper hardware and software options. I4.0 merges numerous upcoming technologies for supply chain integration [1]. I4.0 and Lean production have similar goals, but research into the synergistic relationship between the two is still at an early stage. Numerous studies have examined enablers for lean implementation and few have examined enablers for Industry 4.0 tools. A detailed analysis of the crucial success factors required for integrating Lean manufacturing with Industry 4.0 tools in Indian manufacturing firms is still missing and its effect on the performance parameters is scarce.

As a result, the primary research question is: What effect do enablers of Lean manufacturing and Industry 4.0 tools have in integrating lean and Industry 4.0 tools in the Indian manufacturing sector and what role do mediating factors play, if lean and Industry 4.0 tools are integrated in the Indian manufacturing sector? As a result, this study aims to investigate the new field by first analyzing the current research on the link between Lean implementation and I4.0 technologies. This research study focuses on the following objectives (1) To discuss enablers of Lean and Industry 4.0 tools from literature review (2) To identify critical success factors for integration of lean Manufacturing (LM) and Industry 4.0 tools (3) To examine the relationship between integrative critical success factors and performance factors.

The section of the study is structured as follows: The following sections discuss enablers for Lean manufacturing and I4.0 and its possibility of integration. This is followed by a section titled "Research model and hypotheses," which provides a theoretical foundation for this investigation as well as few research hypotheses. The conclusion section summarizes the contributions of the research study as well as few implications.

2 Theoretical Background

Lean manufacturing practices have been tried and tested for quite some time. It can be described as "an integrated socio-technical system, whose main goal is to get rid of waste by reducing or eliminating supplier, customer and internal variability at the same time". Lean manufacturing is a set of organizational strategies that aims to reduce waste rather than introduce new technologies or plan resources. However, studies have shown that adopting Industry 4.0 technologies can boost performance in a variety of ways, including adaptability, productivity, cost savings, timeliness of delivery and quality. However, the problem at hand concerns the effect on productivity of implementing Lean principles and Industry 4.0 technology simultaneously in various companies. The following section covers the enablers of LM, pertaining to Indian manufacturing industries.

2.1 Enablers for Lean Manufacturing

Anand and Kodali [2] and Garza-Reyes [3] mentioned Sixty-five lean manufacturing elements essential for implementing lean. The main agenda of lean production is to eliminate wastes in a manufacturing process in the form of non-value added activities. Whereas agile manufacturing [4] places emphasis on making the most of what already exists by utilizing relevant data to effect transformations (flexibility) in the manufacturing process. The key elements of lean are centered on the eradication of these wastes.

Lean adoption is mostly driven by internal requirements that originate in the organization's goals. Most lean professionals believe, based on a literature analysis that one of the primary goals of lean adoption is to boost customer satisfaction. [5], speeding up the process by which goods reach consumers [6] as well as to improve quality [7]. Some elements, however, have been found to contradict one another. Panwar et al. [5], who studied lean manufacturing's current state in India's processing sectors, noted that lower costs are a driving element in the sector's increased interest in the method. The survey conducted by Bajjou and Chafi [7] on the advantages of LM adoption in the Moroccan business sector revealed, however, that cost savings are the least valued benefit.

Continuous improvement, total productive maintenance, KPIs, process quality or statistical process quality (SPC), problem-solving, and pull system are the most-cited enablers of lean in the literature. The literature review focused on identifying lean enablers which is a primary component required for identifying critical success factors for integrating lean and Industry 4.0 tools. The following section amplifies the enablers of Industry 4.0.

2.2 Enablers for Industry 4.0

Industry 4.0, also known as the fourth industrial revolution, occurred throughout the last centuries and can be contrasted to the previous three industrial revolutions, which caused major production transformations due to disruptive technology developments. According to the Department of Innovative Factory Systems (IFS) of the German Research Center for Artificial Intelligence, there are four enablers for Smart Factory or Industry 4.0. (DFKI). These enablers are smart products, machines, planners, and operators. The Internet of Things (IoT), cyber-physical systems (CPS), and artificial intelligence (AI) are all integral parts of the visionary framework known as "Industry 4.0.“ [8]. Reliability, scalability, modularity, quality of service (QoS), integration & interoperability, interface & networking capabilities and security have all been recognized as critical features for Industry 4.0 infrastructure [9]. The components of the I4 system for timely gathering and dissemination of information have been highlighted, as shown by a review of the existing literature. While acknowledging the benefits of Industry 4.0, they expressed concern over the lack of a foolproof technical solution to the problems of data security and privacy. There are a number of aspects that can make or break the success of implementing I4 technologies.

2.3 Critical Success Factors(CSFs) for Integrating Lean and Industry 4.0

Businesses must re-evaluate their operations in light of the new realities ushered in by I4 [10]. In order to have smooth rollout of I4.0 tools in the manufacturing sector, critical success factors play a vital role. According to Young and Jordan [11], leadership and top management play a critical role in dealing with the resistance to change that comes with implementing Industry 4.0. The academic literature has paid minimal attention to the critical success factors of Industry 4.0. There are few studies, which discuss about few Critical Success factors of particular Industry 4.0 tools. [12] discussed the CSFs for cloud computing adoption by Indian micro, small, and medium-sized businesses (MSMEs). A study on CSFs in Industry 4.0 was conducted by Sousa Jabbour et al. [13] and the CSFs identified were leadership, organizational readiness for change, leadership role, organizational culture, communication, project management, and natural culture.

CSFs for lean, JIT, TQM, TPM, etc. have long been area of interest in operations management theory and practice. Major success factors for lean have been suggested by other authors [14, 15]. CSFs for JIT has been discussed by [16–18] and others. According to the literature, three of the most important CSFs for lean are "management commitment and involvement," "training and education," and "employee participation & empowerment." Whereas, tools of industry 4.0 CSF will be training & empowerment and teamwork & organizational culture. According to the literature review, the common success factors, which can be used for integrating lean and industry 4.0 tools are (a) Leadership & commitment (b) Firm size and (c) Cultural & technological change.

3 Research Model and Hypothesis

There are currently no pertinent variables or restrictions available in the literature on integrating lean and industry 4.0. By evaluating the significance of critical success criteria for Lean & I4.0, assembled from relevant literature and put to the test, it could explore the integration of lean and industry 4.0 tools. Implementing LM itself is not a simple process and including Industry 4.0 tools will make it even more complicated: sadly, no method can ensure a successful deployment, if applied.

On a thorough descriptive and content analysis of the theoretical background relating to enablers of lean, enablers of I4.0 as well as critical success factors of lean & I4.0, a research framework is proposed, as shown in Fig. 1.

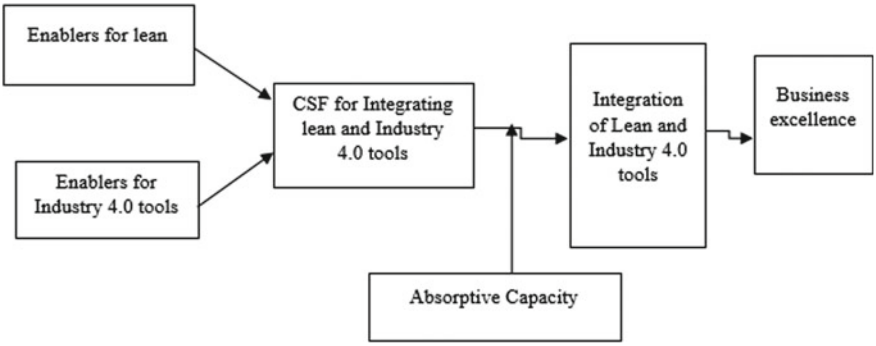

Fig. 1 Research model

The Lean approach treats every worker as a process expert and encourages everyone to be self-critical. As a result, initiatives for making things better start coming from the ground up, with employees taking the lead (intrinsic). As its name implies, Lean is primarily concerned with streamlining and standardizing processes in order to cut down on waste. According to Hermann et al. [19], as Industry 4.0 merges traditional manufacturing with ICTs, it can be compared to other forms of technological progress. Companies in developing countries like India may struggle to fully embrace the benefits of Industry 4.0. Firms in developing countries lag behind their developed-world counterparts when it comes to the adoption of new technology because their economies are centered on the extraction and sale of commodities. I4 is a novel notion in India, having been presented very recently by [20]. Limitations for both methodologies come from the actual implementation and the associated expenses. I4.0 as an innovation paradigm has garnered a lot of attention from all over the world. Based on the theoretical background, the enablers of lean play a vital role in the implementation of LM. Similarly, enablers of Industry 4.0 tools play an essential role in the implementation of I4.0. The enablers of both paradigms will lead to critical success factors, which are essential for integrating Lean and Industry 4.0.

Based on the literature review, which covers the importance of enablers of Lean and enablers of Industry 4.0, it is hypothesized that.

H1: Enablers of lean Manufacturing will positively impact the CSFs required for integrating lean and I4.0 tools.

H2: Enablers of lean Manufacturing will positively impact the CSFs required for integrating lean and I4.0 tools.

I4.0 and Lean production emerged independently in recent years, efforts to merge the two are still in their infancy. However, just a few recent studies have begun to explore as to how I4.0 and lean production might interact with one another. For instance, one seminal article [21] proposed that companies in India might improve their supply chain sustainability by adopting Industry 4.0 manufacturing technologies. Additionally, [13] discussed how big data, a leading Industry 4.0 tool, might help foster a circular economy. Industry 4.0 and Lean manufacturing have yet to find synergy. Future research could investigate and design an appropriate framework for manufacturing industries to promote the deployment and implementation of LM and Industry 4.0 in emerging economies. Hence, it is hypothesized that.

H3: Critical Success factors of lean and industry 4.0 promote the integration of Lean & Industry 4.0 tools in Indian Manufacturing industries.

The term "absorptive capacity" (AC) refers to a company's prowess in collecting, analyzing, synthesizing, and using information from both internal and external sources to improve its performance in the marketplace. (AC). The prior firm's expertise and the efficiency of its internal communication systems both contribute to the development of absorbent capacity. According to [22], Companies with a higher absorptive capacity are better able to adopt new technologies since they already have an established foundation of knowledge and channels of communication for doing so. Organizational processes and communication must be reworked and employees' ability to work together must be tested, when a company embarks on the process of adopting a new technology. In reality, studies have shown that enterprises' absorptive capacity increases their knowledge and skills, which in turn improves their capability to support the adoption of new technologies and manufacturing methods among their staff and with external players. According to [23], organizations with more capabilities to absorb new information will be more likely and more widely embrace e-supply chain management. In [24] it was demonstrated that the amount of adoption of time-based manufacturing processes is predicted to benefit from the absorptive capacity. In conclusion, businesses that are better able to learn from others and apply that knowledge can boost the effectiveness of their partnerships and the rate at which new technologies are adopted. Following these considerations, the following hypotheses are proposed.

H3a: Absorptive capacity mediates the relationship between CSFs and the integration of Lean & I4 tools.

Chiarini and Kumar [25] explored and shown how combining Industry 4.0 and Lean production may provide companies a competitive edge. This is an original result, and it adds to the scant literature on the subject of Lean production and I4 tools integration [26]. Most literature on integrated approach is conceptual or employs surveys to explain Lean and Industry 4.0 [27]. Using grounded theory [25], researchers studied how one manufacturer achieved operational excellence using a holistic strategy. Integration patterns from the two phases of study shed information on challenges and pitfalls in the final stage of the process. According to them, after using the Lean practices to streamline and reduce variation in business processes, manufacturers may begin implementing Industry 4.0 technologies. Only then Industry 4.0 can be deployed to increase performance. This leads to the following hypothesis,

H4: Integration of Lean and Industry 4.0 tools will have a positive impact on the business excellence of an organization.

4 Conclusion

The lean manufacturing and I4.0 production paradigms are promising developments for the future of manufacturing, especially if the organizations are able to combine them with the aim to create efficiency enhancing synergies. Implementing lean and Industry 4.0 tools together offers a promising approach to meet the high complexity in the production environment and simultaneously focus on the customer. This study explored the relationship between enablers for lean & Industry 4.0 tools, CSFs required for combining lean & Industry 4.0 tools & the effect of an integrated framework on business performance of an organization. As a result of the extensive literature survey, a severe shortcoming found is a dearth of studies conducted on the integration of lean & I4.0 tools in India's manufacturing industries. This study reviewed the literature to find the enablers of lean implementation and I4.0 tools separately. The study recommends an integrated and thorough implementation strategy, incorporating CSF and its effect on business performance of an organization.

Furthermore, Absorptive capacity is examined in this study to evaluate the link between CSFs and integration of Lean & I4 tools, which might lead to improvement of business performance of a manufacturing firm. According to the findings of the study, CSF of lean tools and CSF of Industry 4.0 tools together can lead to integrating two different paradigms, namely, Lean & Industry 4.0. It further analyses the effect on the performance of the firm. It is recommended that the hypotheses developed by this study be tested quantitatively, as it is based on theoretical recommendations. The critical success factors selected for this study were limited due to few considerations of enablers of Lean & Industry 4.0 and additional critical success factors could be considered in the future. Future studies could focus on how manufacturing firms can employ design investments to integrate I4.0 technology & lean manufacturing tools. Other factors, such as employees' technical and soft skills, could also help the manufacturing industry move toward I4.0. Utilizing normative, mimetic, and coercive approaches in the form of institutional pressures could also help accelerate the adoption of Lean techniques in conjunction with Industry 4.0.

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A Survey of Existing Maturity Models for Implementation of IoT in SMEs

Sanket D. Parab and Ashish Deshmukh

Abstract To fully realize the potential of the Internet of Things (IoT), it will be necessary to overcome the significant obstacle of ensuring the participation of small and medium-sized businesses (SMEs) in the implementation of IoT. IoT is critical for ensuring SMEs' manufacturing competitiveness; however, little is known about the implementation stages for IoT in SMEs, as well as the resources required to reach the next stage. The analysis of readiness factors is essential to encourage IoT adoption in SMEs. Few researchers, however, have proposed a readiness framework that takes into account technological forecasting to assess the rate of IoT adoption and, in turn, lay out a plan for its introduction in SMEs. The purpose of this research was to examine the current Maturity Models (MMs) so that a new MM could be proposed to address their shortcomings.

Keywords IoT · SMEs · Maturity models

1 Introduction

Economic development in developed countries would be impossible without a robust manufacturing sector. In today's fast-paced business environment, manufacturers face the daunting task of meeting the demands of a wide range of customers. Humanity has reaped huge benefits from each of the three industrial revolutions that have occurred, each of which brought about significant changes in various aspects of the industry. The fourth industrial revolution is being ushered in by the integration of the Internet of Things (IoT) and Services into production environments today. Every

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country has its own distinct industrial improvement plan, based on its vision, values, and culture.

The digitalization/transformation of an entire business is a big challenge that firms are currently facing. New fundamental paradigm shifts will be triggered by the merging of the physical and digital worlds as a result of cheap and easy-to-use worldwide digital infrastructure, including computers, mobile devices, broadband network connections, and powerful application platforms. To remain competitive, even small and medium-sized enterprises (SMEs) must be prepared to deal with and handle emerging information and communication technologies. As the adoption of IoT in SMEs has gotten increasingly sophisticated, it is imperative that businesses fully grasp and utilize the benefits that IoT can provide.

2 Literature Survey

2.1 IoT Concept and Its Enabling Technologies

An organization's competitiveness can be improved by new concepts such as mass customization and business servitization as well as the digitization of equipment, goods, and processes. Machines, warehouse systems, and production resources will all be part of the fourth industrial revolution because of the introduction of IoT in manufacturing contexts. Cyber-Physical systems (CPS) will let equipment and systems communicate, generate activities, and self-manage themselves [1].

Product individualization, resource efficiency, and product launch time are all issues that industries are grappling with as they strive to meet the needs of today's consumers. Digitization and Information & Communication Technology (ICT) use are frequently linked to these challenges; the IoT, in particular, has a significant role to play in enabling these kinds of challenges [2]. The increasing demand for customized products has led to a shift in the configuration of mass production, from the manufacture of standardized items to the configuration of mass customization, where customers may discover exactly what they need and want [3]. CPS, machine-to-machine (M2M), industrial automation, autonomous and intelligent equipment, Big Data analytics, products and processes digitalization, visual computing technologies (such as virtual and augmented reality and 3D images processing and human–machine interaction interfaces), cloud computing, additive manufacturing, and virtual reality are all enabling technologies of IoT [4].

2.2 IoT Assessment Tools

Maturity/readiness models are used to determine whether or not a company qualifies as involved in the Internet of Things, as well as the level to which that engagement has progressed. These types of models are made up of dimensions that include sequential stages of development (and their characteristics) as well as the rational connection between them. Jorge et al. argues that the current maturity models are inadequate for determining the IoT readiness of small and medium-sized enterprises. The majority of SMEs struggle to embark on the IoT because they lack an understanding of MMs and the Digital Readiness Index [5].

2.3 Maturity Models

A maturity model is a conceptual structure that specifies a field's maturity or development. Some of these documents define the methods an organization must follow to attain its goals. MM's can be used for internal analysis, competition analysis, and comparison with domain reference points (benchmark). Models include dimensions and levels [6]. MM's are used to measure a company's or process's maturity. According to these theories, people, organizations, functional areas, and processes mature in stages. From a certain model level, you can plan and implement a higher maturity level. Models measure and mature actions. Content for each dimension can be derived through qualitative research methods such as literature reviews, case studies, focus groups, and the Delphi method [6]. Dimensions show a domain's capabilities, whereas levels mark stages. Maturity is the consolidation of general and specialized practices that increase an organization's performance or a specific goal [7]. IoT requires an increase in manufacturing's digital capabilities and other changes. A full planning and execution process will take years, with incremental stages, so efficiency advantages can be realized gradually. Not all business operations, industrial systems, manufacturing lines, or production cells in a plant are synchronized.

Each organization must select which stage of growth balances the costs and benefits of a transition while keeping an eye on the end goal [8]. This evaluation as to where the SME is currently standing can be done by evaluating the digital readiness index which is described in the next section.

2.4 Digital Readiness Index

The degree to which an organization's workforce is prepared to make the transition to digital workflows enabled by software and technology is known as "digital readiness." An organization's investment in IT assets is only one part of a three-part technology transformation: culture, process, and technology.

Workers are the building blocks of any business, when a company decides to realign its goals and strengthen its infrastructure with new technology, it must begin the transition with its employees. More quickly employees can adopt these new technologies smoother will be the path to digital transformation. To make this journey a success, the entire workforce must be involved.

An organization's readiness for and ability to handle a transformational process or change can be measured and assessed systemically. When new processes, procedures, organizational structures, etc., are implemented in a real organizational context, a readiness assessment seeks to identify any risk factors as well as potential opportunities and challenges [9].

2.5 Digital Maturity and Operational Performance

Small and medium-sized enterprises (SMEs) are extremely risk-averse, so the operational benefits of digital maturity are essential if SMEs are to actively pursue it. New digital technologies offer new tools for promotion, marketing analysis, and communication, which may help to explain the positive correlation between digital maturity and sales performance discovered in the paper by Eremina et al. [10]. In contrast, this same paper discovers an inverse relationship between revenue expansion and digital advancement; this is in part because of the high upfront costs associated with adopting the latest digital solutions. According to the paper's findings, there is a correlation between a company's level of digital maturity and its bottom line. When we focus closer, we see that authors who discuss the implementation of more specific technical aspects of digital maturity tend to agree with this. It is argued by Parra et al. that businesses that can make use of data in their decision-making and analytics see significant gains in performance [11]. From a strategic standpoint, data analytics systems are crucial, as they can make a major impact on the success of a business [12]. According to Buer et al., businesses that have adopted lean manufacturing practices to a high degree find that digitalization improves their operational performance. This suggests that an organization's operational performance will improve in proportion to its level of digital maturity [13]. There's also widespread agreement that Big Data and Business Analytics' analytic capacities improve operations across an organization. Investments in Business Analytics, according to Pasteur et al., boost supply chain efficiency. Lastly, sectors where digital pioneers are performing better than their peers, are ones where digitalization is most evident in its positive effects [14].

In conclusion, businesses, especially SMEs, will need to boost their adoption and integration of digitalization for IoT initiatives to remain relevant and competitive in the future. Investments in this direction will eventually yield performance by extension of financial benefits. SMEs tend to be risk-averse and frequently lack the financial capability to invest in long-term, non-immediate value-adding investments. This results in a divide between academic goals for digitalization and business objectives.

3 Analysis of Existing Maturity Models

3.1 Issues with Existing Maturity Models

A review of the literature on various MMs from practitioners and academics revealed that there is no agreement on how to describe digital maturity levels, even in specific domains such as manufacturing. Also, Minonne et al. looks at 15 digital MMs and points out that they all look at "maturity" in very different ways, they further conclude that the models they looked at are not good enough to fully judge a company's digital maturity. Also, a review of 6 digital MMs by Williams et al. concluded that it is hard to compare digital MMs because their definitions and terms are not the same. They also show that MM have several problems when it comes to generalization and collecting data. According to these authors, there are only one or two ways to gather data, and companies often rely heavily on self-reporting, which raises questions about the validity of the data [15]. There also seem to be some problems with figuring out which factors have the most impact on digitalization. The literature review by Teichert shows that "Culture" is an important domain. This is because the reviewed articles describe "Culture" as one of the biggest problems with digitalization. This shows that organizational factors are usually the most important, which makes the case for a top-down approach. But A. Amaral et al. says that technology is the key to getting the benefits of IoT to work and that a bottom-up approach is best [16]. Also, Pulkkinen et al. say that IT technologies are a big part of making sure that efficiency and effectiveness are at their best [17]. But many digital MMs don't look at technology. Instead, they focus on organizational areas like strategy, business, and applications. This shows that there is a mismatch between technology and organizational factors. This is also shown in a paper by Sundberg et al., who surveyed 123 manufacturing companies in Sweden to find out how digitally mature they were. In this case, the people who answered the survey seem to value organizational capabilities more than their "basic enablers," or how they use technology. This seems to show that the companies have a high opinion of themselves, but they don't do well with IoT activities [18]. So, they conclude that most of the companies surveyed haven't done anything that looks like what the literature says IoT is.

3.2 Comparison of Existing Maturity Models

The MM measures maturity in different areas known as dimensions, and each dimension is described by a set of transformation capabilities. The degree to which each transformation capability, and thus each dimension, is implemented is used to assess IoT maturity. A comparative analysis was performed on the models to gain a better understanding of their dimensions and maturity levels. Table 1 displays the dimensions, maturity levels, and disadvantages of each model. We tried to evaluate the pros and cons of existing MMs in the literature to establish whether or not they are adequate for gauging a company's preparedness to adopt IoT technologies. We found a total of eight distinct MMs, and our reviews of them are as follows:

1. **Industry 4.0(I4.0)/Digital Operations Self-Assessment**: The digital preparedness for I4.0 is the focus of this online self-assessment tool-based MM. This model operates in six dimensions. However, neither the dimensions used in their research nor the items themselves are made available to users [19].

Table 1 Comparison of Existing Maturity Models

Sr. no	Model/readiness index	Maturity levels	Dimensions	Drawbacks
1	Industry 4.0/digital operations self-assessment [19]	Three maturity levels (Vertical Integrator; Horizontal Collaborator; Digital Champion)	6 dimensions	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions
2	Industry 4.0/digital operations self-assessment [19]	Likert-scale maturity levels (from rating 1 = not imp to rating 4 = very imp)	9 dimensions	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions
3	Industry 4.0/digital operations self-assessment [19]	Five maturity stages (assessment; secure, upgraded network controls; defined analytics; collaboration)	4 dimensions	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions
4	Industry 4.0/digital operations self-assessment [19]	Six maturity levels (outsiders; beginner; intermediate; experienced; expert; top performers)	6 dimensions	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions
5	Industry 4.0/digital operations self-assessment [19]	No information regarding MM	Not defined	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions

(continued)

Table 1 (continued)

Sr. no	Model/readiness index	Maturity levels	Dimensions	Drawbacks
6	Industry 4.0/digital operations self-assessment [19]	Value-based development stages presented in the model	Not defined	This online self-assessment tool measures I4.0 digital readiness. The study and users are unaware of the model's six dimensions
7	Industry 4.0/digital operations self-assessment [19]	Five maturity stages (basic digitization; cross-departmental digitization; horizontal and vertical digitization;)	3 dimensions	Business maturity is determined by software and technological aspects. MM doesn't consider organizational and environmental factors
8	Industry 4.0/digital operations self-assessment [19]	Contains nine dimensions: product innovation, IT, product innovation, strategy, etc.	3 dimensions	The assessment has nine dimensions but no levels or items. This research lacks model structure

2. **MM for Assessing I4.0 Readiness and MM**: This MM suggests nine criteria for evaluation: customer, products, people, operations, leadership, culture, technology, strategy, and governance. The evaluation is conducted using a rating system based on a Likert-scale. The convenience of this model for judging maturity levels is contrasted by the fact that it provides only a generic ranking and no specific recommendations [20].
3. **Connected Enterprise MM**: Connected Enterprise MM is evaluated across five stages of development, no information was provided about the model's dimensions or the items that make-up each stage [21].
4. **IMPULS**: The level is affected by the level of development of similar businesses. In other words, responses from other companies operating in the same market are only considered when determining the level of market maturity; otherwise, they are disregarded [22].
5. **Empowerment and Implementation Strategies for I4.0 MM**: The analysis of the I4.0 revolution is only partially comprised of the maturity assessment of a company. Nothing is fully explained about the MM's make-up, its dimensions, or its contents [23].
6. **ACATECH I4.0 Maturity Index**: Stages of value-based development are presented in this model, and the dimensions are named transparency, capacity, predictive adaptability, computerization, connectivity, and visibility. However, information about items or difficulty levels is lacking [8].
7. **System Integration Maturity Model Industry 4.0(SIMMI 4.0)**: To assess a company's level of development, we look at how advanced its software and

technology are. In the MM, neither the organizational (such as company vision and employees) nor the environmental (such as market structure and competitors) factors are taken into account [24].

8. **Digital Maturity and Transformation MM**: There are nine dimensions in this evaluation, but details about levels and items are unavailable. There is no description of the model's internal structure in their study [24].

Our literature review's MMs are summarized in Table 1. Moreover, we can assert that none of them meets all the criteria for accuracy, thoroughness, clarity, and objectivity.

4 Conclusion

The paper adds to the existing literature by conducting a detailed systematic review of eight MM for SMEs. Furthermore, to enable IoT implementation in SMEs, readiness factors must be investigated, which most models fail to do. Although case studies have frequently been used to conduct research in maturity models, the validity and potential generalizability of the findings are highly questionable because data from SMEs who have used these maturity models to implement IoT is still limited, implying that the MM may not be generalizable. In our review of the literature, we did not find MM providing a comprehensive guide to a self-administered assessment in SMEs, as well as guiding them throughout their journey of implementing IoT. In general, the Digital Readiness Index determines whether an SME is ready to implement IoT, the Maturity Model compares companies to benchmarks in implementation, and the framework provides guidelines for implementing IoT. However, an ideal model should be a combination of these three, so we can conclude that a framework is required that combines the above three to drive IoT implementation in SMEs, and SMEs also require a holistic view, not just focused on hardware and software improvements, to fully embrace IoT.

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Sustainability Benefits and Barriers in the Integration of Additive Manufacturing with Industry 4.0 Practices—A Conceptual Framework

Trupti Markose and Hari Vasudevan

Abstract The sustainability crisis is a developing problem that all business sectors need to address, if they want to continue to be responsible, relevant and competitive. Manufacturing companies have embraced the idea of sustainable manufacturing to manufacture goods and processes that are more environmentally friendly. Industry 4.0 (I4.0) technologies are currently finding applications in many industrial sectors. I4.0 may be able to reduce excessive manufacturing, material mobility and energy consumption, when supported by intelligent devices. The development of additive manufacturing (AM) technology opens up a number of possibilities that might be very advantageous to designers and accordingly improve the sustainability of products. AM is a key component in the context of I4.0. It has the ability to completely transform the current state of manufacturing and pave the way for the development and widespread implementation of sustainable, circular business models. According to several studies, this technology has the potential to improve material use, produce novel shapes, personalize designs and reduce production times, all of which have the potential to significantly alter some of the current business models. In light of the above discussion, a literature review on AM and I4.0 was conducted in order to develop a conceptual framework, covering the sustainability benefits of AM & I4.0 integration as well as to identify the barriers resulting from their integration. The study's goal was to pinpoint the sustainability benefits derived from integrating AM with I4.0 technologies as well as the challenges that must be overcome. According to the study, the integration of AM with I4.0 is believed to have a positive effect on both the sustainability benefits and the barriers caused by the integration.

Keywords Sustainability benefits · Sustainability barriers · Additive manufacturing · Industry 4.0 (I4.0)

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1 Introduction

Industry 4.0 (I4.0), also known as the Fourth Industrial Revolution, has undeniably changed the manufacturing sector by promoting significant gains in efficiency and flexibility by improving strategic and operational decision-making as well as strengthening the overall industrial performance. Three-dimensional (3D) printing, also known as additive manufacturing (AM), has been regarded as one of the key forces propelling I4.0 [1]. Research demonstrates as to how combining the Internet of Things (IoT) and AM research might lead to a paradigm shift in production and supply, thereby lowering the ecological effect of industrial systems and product life cycles. The future of manufacturing may change as a result of the convergence of AM with I4.0 [2]. Several studies have looked at the factors for integrating AM and I4.0 and have come to the conclusion that adopting this model systematically will help the organization get sustainable benefits [3]. Mass customization can be done effectively with AM, which satisfies the key demands of Industry 4.0. By keeping the product in digital form and using different design software to produce innovative designs, it reduces the cost of inventory, while achieving the objectives of the smart manufacturing system. This technology has a big effect on the environment, because it cuts down on the waste of materials and makes the best use of the workplace to get the job done [4].

Manufacturing companies put a lot of effort into implementing new technologies to meet consumer wants. Adapting to industrial processes while keeping in mind sustainable development strategies such as, using less energy, fewer resources and producing waste and exhaust emissions at low levels, is another challenge they face [5]. AM is a major technological breakthrough for the supply chain of spare parts, because of various advantages like improved design freedom, the ability to produce bespoke goods in both small and large quantities, the opportunity for topology optimization and part consolidation. The manufacturing cost and time to market both can thus be greatly decreased [6]. In an I4.0 environment, AM has the ability to manufacture high-quality goods. In situ monitoring, processing using a digital twin and modeling & simulating throughout the design stage are all supported by I4.0. High-quality product production is a component of sustainable manufacturing. Tools of I4.0 tracks additive manufacturing (AM) components, utilizing cutting-edge tools like RFIDs and other sensors over the course of the product's life cycle, enabling reuse, refurbishment and recycling operations that are crucial for sustainable manufacturing [7].

A few research issues emerge as a result, including: what sustainability benefits are realized as a result of integrating AM with I4.0? Are there any barriers that must be overcome for the integration to be successful? In this context, this research study has attempted to explore the following as a result of the review and analysis of extant literature:

1. Identify and examine the potential sustainability benefits arising due to integrating AM with Industry 4.0.

2. Identify and examine the potential sustainability barriers arising due to integrating AM with Industry 4.0.
3. Develop a research model showing the relationship between these benefits and barriers resulting due to the AM and I4.0 integration and test the research propositions.

The remainder of the paper is organized as follows. Section 2 covers the theoretical background, which provides the most recent literature review on the sustainability aspects in AM and I4.0. The research model and the conceptualized hypotheses are presented in Sect. 3. The conclusion and recommendations for further study are presented in Sect. 4.

2 Theoretical Background

2.1 Sustainability in Additive Manufacturing

Changes in technology require the AM processes to be smart and sustainable. Additionally, the AM technique is anticipated to be economical and have better ability to handle difficulties in product development. Environmental, economic and societal sustainability areas are the subjects of in-depth analyses and insights [8]. A framework was developed and the significance of sustainable AM was highlighted by the study. Based on a review of the literature, factors impacting sustainable AM were identified and a TISM model was created [9]. Big data analytics, AM and sustainable smart manufacturing technologies were combined to create a framework that benefits additive manufacturing businesses [10]. It concluded that sustainability is a very important part of the life cycle of a product made with additive manufacturing. Therefore, it has been felt necessary to identify a number of barriers before additive manufacturing techniques may be implemented. The literature has identified and compiled 11 obstacles to the adoption of sustainable additive manufacturing [11]. Literature also show that the AM techniques still have many sustainability problems, such as slow processing speeds and inconsistent performance of parts. Analyzing the challenges encountered when implementing Sustainable Additive Manufacturing (SAM) techniques is crucial from this perspective [12]. From the perspectives of reduced material usage, reduced operational costs, less handling and so on, AM techniques are becoming more sustainable. A study was conducted to determine the drivers of SAM, using the Best Worst Method (BWM). Eco design, green innovation and energy reduction were cited as key drivers [13]. With the aim of reducing energy consumption and printing time and ensuring lightweight ABS component creation through FDM additive manufacturing, the effects of various printing settings were examined [14].

2.2 Sustainability in Industry 4.0

Industry 4.0 promises to introduce a new production paradigm to meet the rapidly growing need for customization and personalization. According to the insights derived from the literature, there is a strong correlation between I4.0 and sustainability. "Sustainable Industry 4.0" is the name given to this combination. Therefore, there is a need to thoroughly identify and examine the forces behind this integration and propose a sustainable Industry 4.0 framework [15–17]. The most significant Industry 4.0 initiatives that aid in enhancing the CE performance metrics are cyber-physical systems and IoT [18]. The deployment of Industry 4.0 is encouraged by the strategic, operational, environmental and social opportunities, but is hampered by issues with competitiveness, future viability, organizational and production fit [19, 20]. A framework was developed by the authors, wherein ten major contributors toward the ethical sustainable manufacturing were discussed. Few researchers also analyzed the challenges of Industry 4.0 driven sustainable manufacturing [21, 22].

In order to establish a sustainability-driven business model in a (eco)system as well as the sustainability practices framework, I4.0 and sustainability issues must work collaboratively [23, 24]. The transition to Industry 4.0 resolves urgent concerns related to sustainable development objectives, particularly those involving the manufacturing-economic development. I4 technologies assist in creating a successful CE environment, which results in the accomplishment of long-term business objectives. Additionally, managerial, economic and environmental drivers have a significant impact on the adoption of sustainability [25–27].

2.3 Sustainable Integration of AM with Industry 4.0

Over the past 30 years, the research trend in additive manufacturing (AM) has developed from patents, design advancements and layer-by-layer materials to technologies. But there are several obstacles in the way of this evolution, including the adoption of additive manufacturing (AM) in production, the latter's productivity restrictions and the sustainability of the economy and society [28]. Rich potentials have been identified in the four characteristics at the AM process level: speed, sustainability, agility and customer centricity. AM can quickly produce any customized prototype for a specific consumer. By analyzing market demand and lowering supply chain costs, it offers creative product concepts. AM assists in reducing a large quantity of unused inventory and assists in meeting the market's and consumers' need for personalized products. [29, 30]. The effects of additive manufacturing technology on sustainable business models were investigated through the framework of Industry 4.0 and its technological concepts. AM, one of the core Industry 4.0 enablers, will be crucial in developing environmentally friendly, sustainably manufactured processes [31, 32]. AM is also part of a group of efficient and environmentally friendly ways to make things, which help save resources and protect the environment. The sustainability studies highlight two key advantages of AM: a significant decrease in material waste and fuel usage [33, 34].

3 Research Model and Hypotheses

A conceptual model, depicted in Fig. 1, was developed following a thorough description and content analysis of the theoretical background to demonstrate the relationship between AM & I4.0 integration and the resulting sustainability benefits as well as the barriers resulting, thereof. The next section proposes research hypotheses based on the conceptual framework, covering the main elements of the research agenda.

One of the foundational elements of Industry 4.0 is additive manufacturing. It has the power to disrupt the conventional manufacturing model and accelerate the widely acknowledged and essential transition to the conception, creation and adoption of sustainable & circular business models [35, 36]. The DEMATEL approach was used to attempt to determine correlation among the barriers in order to apply Industry 4.0 for sustainable production. Eight hurdles to implementing Industry 4.0 for sustainable production were taken into account in the study. Additionally, an effort was made to understand I4.0's theoretical necessity for sustainable production from an administrative perspective [37]. Few researchers have found that the energy savings, emission reductions, resource optimization, cost reductions, productivity and efficiency increases, higher economic performance, human resource development, social welfare and workplace safety are the sustainability outcomes that are most frequently observed [38, 39]. Industry 4.0 and sustainable development goals work together to improve environmental sustainability and establish an ecosystem that ensures high environmental performance with a greater positive impact than before [40]. In an I4.0 environment, AM has the ability to manufacture high-quality

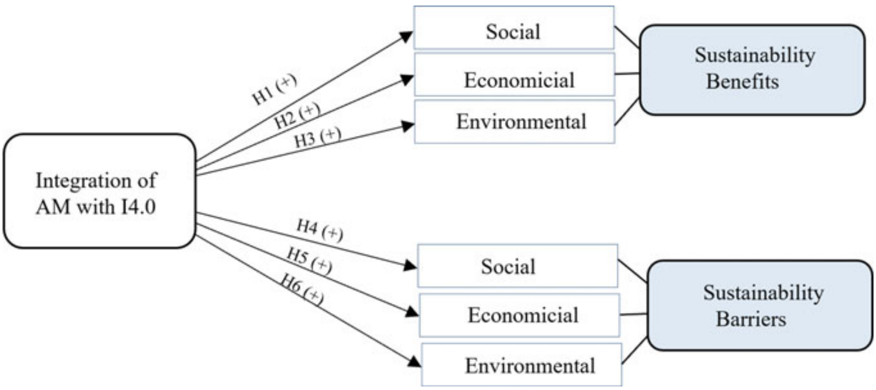

Fig. 1 Conceptual framework

goods. I4.0 enables AM during the design stage, allowing for modeling and simulation, as well as in situ monitoring and a digital twin during the process. High-quality product production is a component of sustainable manufacturing [7].

Based on the review and analysis of the extant literature, the following hypotheses are proposed, which could be validated in the future:

H1 Integration of AM with I4.0 have a positive impact on the social sustainability benefits.
H2 Integration of AM with I4.0 have a positive impact on the economical sustainability benefits.
H3 Integration of AM with I4.0 have a positive impact on the environmental sustainability benefits.
H4 Integration of AM with I4.0 have a positive impact on the social sustainability barriers.
H5 Integration of AM with I4.0 have a positive impact on the economical sustainability barriers.
H6 Integration of AM with I4.0 have a positive impact on the environmental sustainability barriers.

4 Conclusion

Numerous industrial sectors are currently adopting Industry 4.0 technologies. But only when the technology being employed are more ethically and societally responsible can industrial development be sustainable. Utilizing the cutting-edge technologies like, AM is expected to contribute to sustainability. From the perspectives of reduced material usage, reduced operational costs, less handling and so on, AM techniques are becoming more sustainable. In order to ensure the sustainable AM process's successful adoption, it is crucial to analyze its potential drivers. Design for sustainable manufacturing could benefit greatly from the use of the IoT, AI, big data and cloud computing components of AM.

In order to realize the sustainability benefits previously described and to identify the barriers, a conceptual framework has been proposed and hypothesized in the study. In the long run, this approach will allow managers to assess the positive effects of integration on sustainability as well as help them take appropriate actions to overcome the sustainability barriers identified.

In order to give the study's conclusions additional statistical strength and relevance, future research might concentrate on validating and testing the proposed hypotheses. The investigation and ranking of sustainability's benefits and challenges must be carried out in the future. Given the limited study in this field and the need for potential researchers to have access to relevant literature, future research may focus on how sustainability characteristics affect the manufacturing performance.

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A Socio-Economic Perspective of the Industry 4.0 Implementation in Indian MSMEs

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Abstract The current statusof the recent developments among India's MSMEs point to the fact that these establishments are more technologically savvy than their smaller competitors. It's understandable that SMEs would rather take it slow when it comes to investing in such technologies. Experts are paying more attention to how Industry 4.0 innovations will affect sustainability in terms of economic, environmental, and social factors. Numerous articles highlight the detrimental effects of not adopting Industry 4.0 on a country's economy. Many SMEs are cash-strapped and require proof of ROI before allowing upper management, customers, or employees to adopt new technologies. Non-empirically valid measurements are those used in investigations that rely on things like literature reviews or case studies. This means there is a substantial information gap when it comes to creating an all-encompassing performance monitoring system for sustainable manufacturing (SM) in the context of Industry 4.0. The impact of Industry 4.0 technologies on sustainability in society and the economy is of growing interest to academics. Using the triple bottom line approach to sustainable development, this study set out to investigate these consequences. To analyse the effect of Industry 4.0 technology on these metrics, a sustainability-oriented model is provided. This study aims to summarise current research efforts, identify key research themes, and identify research gaps and future development prospects to evaluate sustainable manufacturing research's contribution to the advancement of Industry 4.0. By examining the potential socio-economic impact in a developing

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country like India and identifying the benefits and challenges for its implementation process, this study goes beyond the technical approach that dominates academic literature on Industry 4.0.

Keywords Industry 4.0 · Smart manufacturing · Sustainable manufacturing · Socio-economic sustainability

1 Introduction

Sustainability challenges exist despite two to three decades of lean and green manufacturing. Industry 4.0 could foster sustainable growth. Defects must be found and fixed. TBL covers sustainable nonrenewable resource usage. Resource shortage and conventional production's social and environmental implications. Due to interdependencies, sustainable manufacturing entails integrating commodities, processes, and systems. Every SME fought the outbreak. To thrive, companies need new technologies and sustainable practises. The proposed research analyses Indian MSMEs' long-term viability. The conceptual framework of sustainable manufacturing literature will be identified through bibliometric and content analysis (SM). This initiative will use Industry 4.0 for sustainable manufacturing. This essay covers Industry 4.0 in Indian SMEs.

2 Literature Review

Sustainability challenges arise when businesses simultaneously fail to consider environmental, social, and financial factors in their strategic planning [1]. Businesses won't embrace a sustainable strategy if the benefits to the company's bottom line, society, and the environment are uneven [2]. Manufacturers are under increasing pressure to alter their existing model of industrial expansion due to rising consumer awareness of the social and environmental costs associated with operating industrial facilities. In order for businesses to implement sustainable projects, they need a plan, and a poorly executed SM strategy will not motivate them to do so [3].

2.1 Industry 4.0 and Sustainability

Industrial transformation combines information and automation to create new capabilities. Population growth, resource depletion, land scarcity, environmental degradation, food consumption, and waste management affect societies. Long-term economic viability requires new manufacturing and consumption systems. Sustainable practises, standards, assessment methods, and new technologies must be researched due to the obstacles. Technology complements Industry 4.0. Prioritize assessing organizations' social performance [4]. Industry 4.0 promotes business longevity. Future-oriented, multifaceted procedure [5] will constantly increase sustainability. Implementing cutting-edge manufacturing procedures and technology to transform, record, distribute, and analyse production equipment and autonomous system data. Companies get a competitive advantage by producing high-quality items at low costs and using nonrenewable resources. Modern industrial technology can interact and adapt in real time, enabling organizations to develop intelligent goods and services [6].

By incorporating BDA technologies, ROI can be increased by 15–20%. The majority of firms believe that integrating CRM data with analytics is a good way to boost customer loyalty [7]. The production of a "face-lift automobile" that improves customers' experiences can be achieved, for example, by mining previous orders and feedback from users [8]. And by analysing data from all of a company's machinery and procedures, output and competitiveness can be boosted [9]. For instance, the biopharmaceutical production chain requires the constant tracking of hundreds of variables to guarantee precision, quality, and output. It is possible to isolate critical parameters by analysing large data sets, which manufacturers do in order to improve their products.

The IoT is an interconnected world where things are implanted with electronic sensors, actuators, or other digital devices to collect and communicate data [10]. IoT enables object-to-object communication and data sharing by connecting physical things, systems, and services. IoT can automate lighting, heating, machining, robotic vacuums, and remote monitoring. Auto-ID technology can be utilized to develop smart objects in IoT. Due to the Internet and IoT, data is becoming more accessible and omnipresent in various industries, culminating in big data [11]. Sensors, devices, video/audio, networks, log files, transactional applications, the web, and social media feeds are common sources of big data. A "big data environment" has progressively formed in manufacturing. IoT (e.g., smart sensors) has expedited data collection, but it's unclear if this data can be correctly processed to offer the relevant information at the right time [12]. In a big data context, datasets may be too complicated for traditional data analytics [13]. For businesses and manufacturers with a lot of operational and shop-floor data, advanced analytics approaches are crucial for identifying hidden patterns, unforeseen connections, market trends, consumer preferences, and other relevant business information (Table 1).

Industry 4.0 is an industry transformation that integrates information technologies and automation to improve performance. Financial and social performance are examined. Industry 4.0 helps businesses achieve sustainability [24, 26]. The author researched a number of different facets of sustainability and dove deeper into the environmental issues related to manufacturing to gain a better understanding of the SM domain [27, 28]. As a result of the digital revolution, businesses are now able to increase their productivity by implementing cutting-edge technology in their production processes.

Table 1 Industry 4.0 tools and the respective support from the literature survey

Industry 4.0 Tools/Survey	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[23]	[24]	[25]
Additive manufacturing	*		*		*	*	*			*	*	*	*
Artificial intelligence	*		*	*	*	*	*			*	*	*	
Autonomous and collaborative robots	*		*		*		*	*	*	*	*	*	*
Big data analytics	*	*	*	*		*	*	*	*	*	*	*	*
Cloud computing and manufacturing	*		*		*		*	*	*	*	*	*	*
Cyber-physical systems			*	*	*	*	*	*	*	*	*	*	
Cybersecurity	*	*			*		*	*	*		*	*	*
Industrial internet	*	*	*		*	*	*		*		*	*	
Internet of things	*		*	*	*		*	*	*	*		*	
Mobile systems and devices	*	*	*			*	*	*	*		*		
Simulation	*	*	*	*		*	*	*		*	*	*	

2.2 Performance Measurement

A study from [29] shows that there are more than 40 indices and rating systems for sustainability assessment. Even though the topic of sustainability and Industry 4.0 plays an increasingly important role in the scientific discourse.

Several metrics were used to evaluate sustainable manufacturing by [30] to better understand the process's various stages and features. There are six areas in which they organized the 21 performance metrics: waste reduction, flow enhancement, pull-driven systems, multifunctional teams, and information systems. OEE has become an important success criterion for many companies because of the high initial and ongoing costs associated with using automated production systems [31]. Organizations reaped the benefits of maintenance-related performance assessments, such as condition-based and relireliability centredntenance [32]. The authors found that manufacturing businesses favour financial measures above non-financial metrics after classifying 73 indicators into twelve performance domains (Table 2).

Table 2 Manufacturing indicators and the respective support from the literature survey in the context of social and economic sustainability

Manufacturing performances/authors	[33]	[34]	[35]	[36]	[37]	[38]	[39]	[40]	[41]	[42]	[43]
Pollutant and effluent emission		*	*	*			*	*	*		*
Higher productivity	*		*	*	*	*		*		*	
Smart working	*	*	*		*			*	*	*	
Higher job satisfaction		*		*	*	*		*		*	*
Collaboration between companies	*		*	*	*	*	*	*			*
Collaboration between governments		*				*	*	*	*	*	
Rate of investments	*	*	*		*						
Cost of manufacturing	*	*		*	*				*		
Revenue	*	*	*		*	*	*	*	*	*	
Salary and benefits	*	*	*	*	*	*	*		*	*	*
Profitability		*	*								*
Return on investment	*	*	*	*			*	*	*	*	*
SALES Sales and Market Share	*	*		*	*			*		*	*
Operational cost	*	*	*	*	*	*	*		*	*	*
Acceptance rate of product	*		*	*			*	*	*	*	*
Machine/equipment performance	*		*	*	*	*	*	*	*	*	*

2.3 *Industry 4.0, TBL Sustainability*

Companies should embrace Industry 4.0 to maximize their resources for sustainable manufacturing. Successful sustainability adaption in Indian MSMEs would boost nation-building [44]. Sustainability and Industry 4.0 are important organizational elements for sustainable production [45]. Industry 4.0 technologies help overcome competition, changes, unpredictable market demands, and short product life cycles. They contribute to long-term growth. Several academic studies and concepts define sustainable manufacturing (SM). “It’s the process of making manufactured things in a way that reduces environmental impacts and conserves energy and natural resources,” says one definition. Productivity gains benefit labour, the environment, and the consumer. Globally, environmental management is more important. Many industrial enterprises lost money because they misunderstood sustainability. Industrialized nations’ manufacturing industries are eco-friendly. India has a lower sustainability adoption rate than the U.S. The latest business technology includes Big Data Analytics, Blockchain, and Machine Learning. If used in manufacturing, these technologies belong to Industry 4.0. This requires examining how to embrace sustainability. This study is focused on use of Industry 4.0 to help MSMEs in underdeveloped nations to adopt sustainable practices.

3 Research Methodology and Study Hypotheses

Top executives are responsible for developing and putting into action the business models, policies, and strategies that have a long-term focus. Whatever new strategy a firm decides to pursue, the senior executives of that organization need to be on board with it [26]. Senior management must be enthusiastic about Industry 4.0 if they want the initiative to be successful. According to the most recent findings from Sony, published in 2018, a company’s top management can impact the business’s financial and strategic orientation in Industry 4.0. Top management must have a working knowledge of the basics of Industry 4.0 in order for the managerial role to be reorganized to combine vertical, horizontal, and end-to-end integration. This is necessary in order to restructure the managerial position. According to the findings of the study, those who are seen as market leaders are more likely to spot revolutionary shifts in the industry. [46] (Fig. 1).

H1a: The Industry 4.0 tool BDA has a direct and significant influence on Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs.

H1b: The Industry 4.0 tool Cyber-physical systems (CPS) has a direct and significant influence on Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H1c: The Industry 4.0 tool Additive Manufacturing AM has a direct, positive, and significant influence on the social Sustainability Of Indian MSMEs.

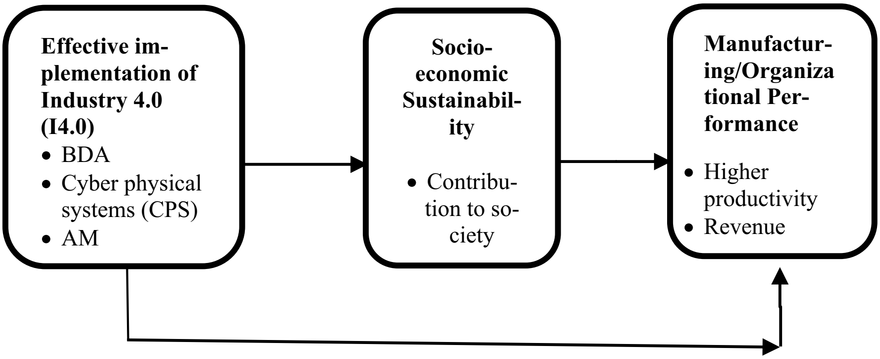

Fig. 1 Research framework

H2a: The Contribution to society mediates relation between the BDA and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H2b: The Contribution to society mediates the relation between the Cyber physical systems (CPS) and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H2c: The Contribution to society mediates the relation between the AM and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs.

H3a: The Employ satisfaction mediates relation between the BDA and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H3b: The Employ satisfaction mediates the relation between the Cyber physical systems (CPS) and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H3c: The employ satisfaction mediates the relation between the AM and manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs.

H4a: The Profitability mediates relation between the BDA and Manufacturing performance (i) Higher productivity (ii) Return on investments(iii) Revenue in Indian MSMEs. H4b: The Profitability mediates the relation between the Cyber physical systems (CPS) and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs. H4c: The Profitability mediates the relation between the AM and Manufacturing performance (i) Higher productivity (ii) Return on investments (iii) Revenue in Indian MSMEs.

4 Results and Discussions

The paper references 46 Scopus, Web of Science, and Google Scholar articles to highlight the critical Industry 4.0 technologies driving sustainable adoption and performance measurement. This survey ranked industry 4.0 technologies based on how often writers have used them. This study investigates the elements that influence Indian MSMEs' adoption of Industry 4.0 technology to fulfil socio-economic goals. The combined IoT, sensor, and CPS technologies have a favourable impact on economic and social pillars due to their ability to analyse and anticipate production performance in their deployed industries. The research showed that regional factors affect implementation. No evidence exists. Industry 4.0 may use interdisciplinary study to do further analyses. In the available research, there are few nuanced scenarios and in-depth examinations of these innovations' ramifications for workers. 4.0 disrupts manufacturing. Sustainable technologies promote recycling, says the report. Digital and intelligent technologies promote social sustainability by reducing dull and repetitive tasks, encouraging individuals, and enhancing job satisfaction. Industry 4.0 follows established trends, the study found. According to the research, industry 4.0 tends to preserve "conventional" route dependency over sustainable development. This contradicts fostering sustainable growth.

5 Conclusion

This study demonstrates how progress may be made toward nation-building through the socioeconomic paradigm of introducing Industry 4.0 to India's micro, small, and medium-sized enterprises. A research agenda and development forecast were also established from the analysis of relevant literature. This study examines how Indian SMEs adapt to the changes by Industry 4.0. This research helped shape a framework and scenario for the field's eventual transition to normative studies of the adoption of Industry 4.0. There are no threats to TBL's continued existence due to any major success drivers driving the I4.0 implementation. Setup times, labour costs, lead times, and business profit are all significantly impacted by I4.0 deployment. This research shows that businesses may accomplish all of the goals set out by Industry 4.0 by implementing the aforementioned beneficial principles and existing technologies. An exponential increase in the level of consciousness about the sustainability crisis among people of all socioeconomic backgrounds is required. All of the participants, who are spread out over the world and come from a wide variety of cultural and educational backgrounds, need to be exposed to and understand these ideas. Recent studies have shown a lack of quantitative and rigorous analysis of the social and economic ramifications of Industry 4.0 and its potential contribution to sustainable development. This information gap should be addressed in subsequent research. During the investigation, it turned out that geographical factors play a role in the execution. Evidence against this theory is lacking. Industry 4.0 may make use of interdisciplinary research, allowing for more in-depth studies to be performed. Little nuanced scenario-playing and in-depth evaluations of the effects of these innovations on either workers or employers can be found in the existing literature. With the advent of Industry 4.0, the manufacturing sector is significantly changing.

The research found that eco-friendly technology can facilitate and promote recycling efforts. Digital and intelligent technologies protect workers' well-being by decreasing the number of hazardous, repetitive tasks they must perform, while boosting morale and enhancing job satisfaction. While encouraging sustainable growth is desirable, this runs counter to that aim. Future studies should aim to bridge this knowledge gap.

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Application of the Theory of Inventive Problem Solving in Value Engineering Methodologies and Its Phases

Rajat Deshpande, Hari Vasudevan, and Rajendra Khavekar

Abstract This study was undertaken in a manufacturing organization to integrate various Theory of Inventive Problem-Solving (TRIZ) tools in implementing value engineering methodologies. The single-pointed focus of TRIZ used in the study was to find an inventive solution to a problem, which could be regarded a subset of the wide range acceptability that Value engineering/Value analysis offers. The primary focus was to enhance the function under observation, from whatever stand (technical, financial, and human factors etc.), which was most crucial to the job at hand. A case study was carried out, using TRIZ tools in solving the engine size issue of Boeing 737 aircraft, without compromising on the ground clearance. As part of the study, the volume of air was considered as an improvement parameter and length of engine case was considered as the worsening parameter. The problem at hand was solved using the contradiction matrix of TRIZ.

Keywords Value engineering · Value analysis · Function · Cost · TRIZ

1 Introduction

One of the biggest concerns of today's business is the undesirable cost associated with a product, process or a system. This undesirable cost, which existed yesterday is applicable today and could still be present tomorrow. Miles [1] defined Value Analysis (VA) as a systematic and innovative method, which has the potential to identify the undesirable cost. This cost helps neither in enhancing the quality, utility, age or appearance, nor the customer features of the products. Basically, the products,

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processes and systems are to be created to satisfy the needs of customers and it must serve a particular purpose. Primary responsibility of the one, who designs the product is to see that the purpose is constructed as per the needs of the customers, that too within the optimum cost. Therefore, the removal of undesirable cost is very important. In this context, the concept of Value Engineering (VE) is defined as a systematic usage of known techniques by various teams, which discover the functions of a product, process or service or system. Once done, it must then demonstrate a worth for the functions; create alternatives with imagination and provide the needed functions reliably with minimum overall cost. An extant literature survey carried out also showed that in order to enhance the efficiency and effectiveness of a system, tools like, "Theory of Inventive Problem Solving (TRIZ)" tools in VE may be implemented.

Further analysis of literature showed that various researchers have discussed on the benefits of VE and TRIZ tools in solving the technical problems in organizations. After a thorough survey of literature, this research work using a case study identified the use of VE concepts in a Boeing 737 plant to solve the issue of engine size, without compromising on the other parameters involved.

2 Literature Review

Akintola [2] classified various parameters pertaining to a building project and the costs involved there into two groups, i.e. (1) Factors pertaining to specific engineering systems and (2) General factors that were related to the whole building. They also stated that VE is productive, because of its procedures to give a chance to raise design issues, which is pertaining with the latter group of factors and also provide a peer-review of the designs. AbouRizk et al. [3] conducted a study on finding ways to enhance the VE processes, by assimilating various inventive problem solving techniques. They studied the W12 Inverted Siphon Project, which was proposed as part of the extension of drainage in Canada. The focus of the work was to carry deposited drainage waste from the north side of the North Saskatchewan river to the south side of the river and then to join to present drainage water treatment system, which has more capacity to serve waste discharge. They stated that the creative phase being the most decisive, required an inventive brainstorming approach. Thus, to enhance efficiency and usefulness of the workshop session of the project, it was suggested to have a modified workshop session, which involved the usage of various Theory of Inventive Problem Solving like, TRIZ tools.

Rane and Attarde [4] concluded that around 20% of the activities comprise around 80% of the cost and these activities should be considered part of VE. They also suggested that the right time for performing VE study is the planning stage of the project i.e., pre release to the contractor. It was also found that there is a requirement of usage of productive techniques, such as VE to resolve problems and enhance performance of projects [5]. VE is an established scientific method, that focusses on a quantitative function analysis to find innovative options. With the aim to obtain innovative ideas, TRIZ is generally deployed in analyzing technical parameters to get

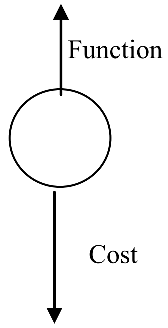


Fig. 1 Ideal condition, in which the function of the product increases with the decrease in cost. This is the most desirable condition for a product/ process/service/system

pertinent innovative rules for positive results [6]. Various researchers have discussed extensively on the benefits of VE and TRIZ tools in solving the technical problems. After a thorough literature survey, it was noted that the use of VE methodologies, such as TRIZ tools could be used to solve various relevant problems in industries.

3 Concept of Value

Value of any entity could be defined as the ratio of the functionality or the performance of that entity to the incurred cost. In today's economic environment, VE lays a lot of stress on the economic values. Values can be categorized in 4 main groups, such as Esteem value, Exchange value, Use value and Cost value [7].

Esteem Value: Esteem value can be associated with the product/process/ service/system, which could develop a strong urge in an individual to possess it. Companies in today's circumstances try to inculcate those values in their product, which could generate the desire in a person to buy them [8].

Exchange Value: It is the trade value in the product/process/service/system. The exchange value brings attraction that is more lucrative to the customer.

Use value: It is the use value of the product/process/service/system, for which the product has been produced. Use value of any product or service justifies its utility [9].

Cost Value: It is the value of any product/ process/service/system, which includes the total cost of producing it. It is basically the sum of all the costs involved in creating it, e.g. labors, material, land, and machines etc.

Value of any entity could be demonstrated as follows (Figs. 1, 2, 3, and 4).

4 Concept of TRIZ

TRIZ is the abbreviation used for "Theory of inventive problem solving", particularly as known in Russia. In 1946, it was developed by scientist Altshuller. Before coming

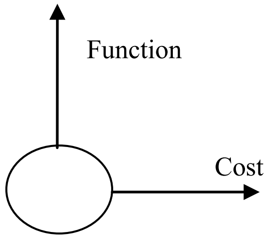


Fig. 2 This condition shows that the value of a product could be increased, if the function of the product increases with no change in cost

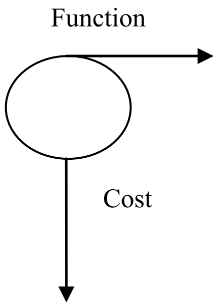


Fig. 3 The 3rd condition states that the value of the product could be increased by maintaining the functionality of the product and decreasing the cost

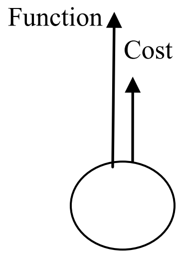


Fig. 4 The 4th condition displays that the value of the product could also be increased, if there is a substantial growth in the product function with the same growth in the cost

up with the concept, he had studied on two lakhs plus patents. During the study, he noticed that some basic principles appeared repeatedly in all the inventions carried out by many firms during different years. He conceptualized and arranged these basic principles behind the inventions into a systematic discipline, called TRIZ. It basically contains a bunch of tools and techniques, such as: (1) a contradiction Matrix and the creative Principles in 40 nos.; (2) Four principles for separation; (3) Su-field analysis and 76 standard solutions; as well as (4) Eight evaluation patterns. These tools and techniques were extensively employed in organizations to assess various problems from wider perspectives to get inventive solutions.

5 Application of TRIZ Tools in Value Engineering Phases

VE/VA mainly comprises of three stages, such as:

a. Pre-workshop Stage
b. Workshop Stage and
c. Post Workshop Stage.

Each of the three stages are further subdivided into various different phases.

The Key stage in the VE process is the workshop stage, which involves major integration of the TRIZ tools. It is mainly comprised of six different phases, as shown in the Fig. 5, i.e. Information Phase, Function Phase, Creativity phase, Evaluation phase, Development phase, and Presentation/Report phase etc.

Phase 1—Information phase: In this phase, the data pertaining to basic cost of the product is gathered from authentic sources. In case, if it effects the customers directly, a survey method is used. Data related to physical properties of products, such as dimensions, shape, material, color, and weight are then gathered and presented in proper formats.

Phase 2—Function phase: Function analysis permits the group members to discuss about various project functions, which need multi-disciplinary considerations. These functions are then conveyed in two-word reports, consisting of an “active” verb and “measurable” noun. This crisp description brings an attention to the function of the product, rather than focusing on itself and it allows the problems to be addressed objectively, without causing any ambiguity.

Phase 3—Creative phase: VE group members then create new ideas by adopting a suitable ‘creativity technique’, which leads to multiple thinking to find alternatives to perform the function, without compromising on the quality. No assessment of ideas is carried out in this phase.

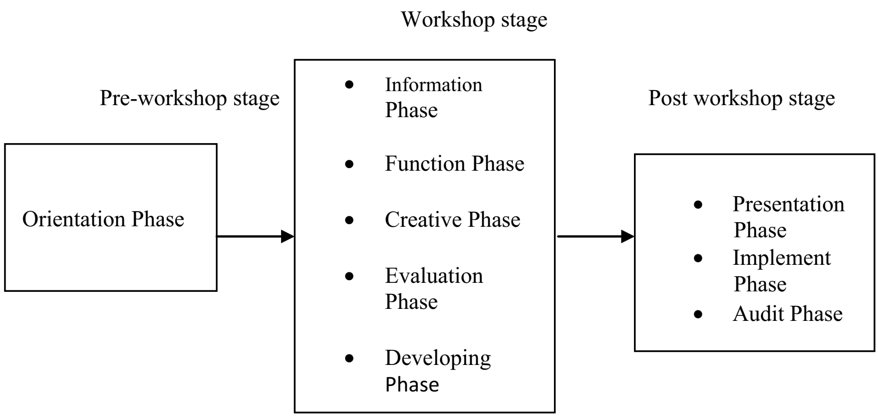


Fig. 5 Stages of value engineering

Phase 4—Evaluation phase: Selected ideas are then assessed for their feasibility, based on their advantages /disadvantages. Advanced filtering techniques like, criteria paired comparison, and decision matrix are also used in this phase.

Phase 5—Development phase: Ideas that pass the evaluation phase are then investigated upon to ascertain both their technical and economic feasibility. Idea is then refined further and prototypes made for trials and testing.

Phase 6—Presentation phase: VE Team prepares the report of changes before and after the VE application and indicates the implementation cost as well as saving in each change for obtaining the approval from the concerned authority.

Phase 7—Implementation phase: Once the changes are finalized for its implementation, individual responsibilities for implementation of each idea are assigned. Changes are then monitored and documented and saving after the implementation is then worked out. Results are also audited during the periodic review.

Phase 8—Audit phase: Technical audit and cost audit are then performed during this phase. During the technical audit, the VE group comprising of value engineers and experts examine the technical benefits. The cost audit is then carried out to examine the factual savings, which could be the zone time or the recurring one.

Creativity phase, being the most interactive phase, involves the brainstorming of various techniques to create innovative ideas for enhancing the project function as well as minimizing the costs. The details about the function of the product/service is gathered before executing the systematic brainstorming. Using the verb-noun combination, each function is then listed. To find the cost-function relationship, product cost is further allocated to each of the functions. Functional analysis system technique (FAST) is then used to spot the functions clearly. Function-Cost–Worth (FCW) analysis is also performed to identify the value gap of the product. The worth of the functions is generally used, based on the VE team's experience on generating different alternatives and also the amounts are only approximate.

The Guided innovation process (Fig. 6) could then be considered as an inventive algorithm. It has significant benefits in the creative phase and uses various TRIZ tools, which helps in generating, evaluating and developing innovative ideas. One such popular tool is the contradiction matrix.

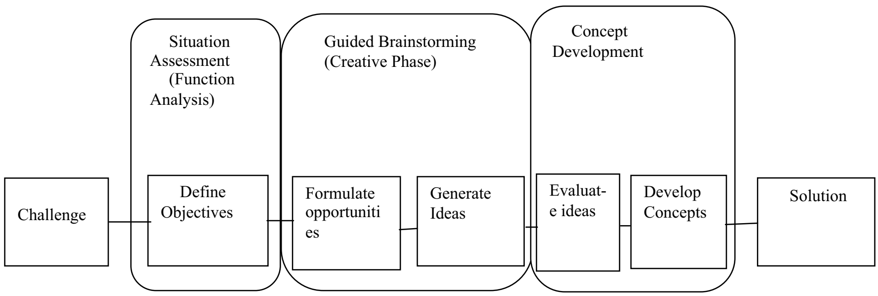


Fig. 6 Guided innovation process

6 Contradiction Matrix

The contradiction matrix is to be used as a potential tool, in order to make the brainstorming session more structured. It could be a vital tool used in the creative phase, wherein a number of different ideas to resolve a particular problem are suggested. Various technical specifications of the system may be in conflict with each other and it is named as a technical conflict. Answers to a technical conflict generally entail a settlement on some of the important parameters. If it is capable of elimination of this technical conflict, it is known as innovative solution. TRIZ has pin pointed 39 parameters that have frequently created technical conflicts in various systems across different areas and have found 40 inventive principles that have been commonly deployed to resolve the technical conflicts. As illustrated in Table 1, TRIZ has designed a 39 by 39 matrix, wherein the 39 parameters are listed on abscissa as fading attribute and ordinate as enhancement attribute. The coding number of the 40 creative principles are then put in the grid of the column as well as row. The principles in the grid then enhance the corresponding parameter on the ordinate, with no compromising on its counterpart on the abscissa. Therefore, once a technical conflict is described, creative principles are then employed to resolve the same using this matrix.

Steps to be followed for using the Contradiction Matrix:

a. Identify Contradiction: TRIZ method establishes the fact that "to gain something, one has to lose something". In TRIZ jargon, it is named as contradiction. For example, if a firm wants to manufacture a speed engine, it has to forgo the efficiency in fuel consumption. This is a general issue many firms face as contradiction. In contradiction matrix, it is taken as an input.
b. Determine Improvement and Degradation: The next step would be to be in a specific state. In this case, one could look at the speed as enhancement parameter, whereas fuel efficiency is the parameter, which is not to be compromised.
c. Design Parameters: TRIZ matrix utilizes the above details as input and cross verifies similar issues that have been faced in the past to get a general answer as output. This answer could be something like, using a lighter metal to manufacture the vehicle to reduce the weight and to increase the speed without compromising in the efficiency of fuel.
d. Examine Proposed Principle: TRIZ method typically acts like a guide, which suggests the solution. However, the final decision to accept the proposed solution for implementation lies with the decision makers.
e. Select Best Principle: TRIZ generally gives multiple inventive general solutions to the problems. The TRIZ matrix is famous, because it permits the firms to make a different answer, before it takes the action on them.
f. Apply Inventive Principle: Proposed general answer is then changed into a specific one to solve the present problem. Hence, at the end of TRIZ effort, the decision makers would have a number of solutions, which provide inputs to the decision- making process.

Table 1 Parameters of the contradiction table

1. Weight of moving object	14. Strength	27. Relaibility
2. Weight of Stationary objects	15. Durability of moving objects	28. Accuracy measurement
3. Length of moving objects	16. Durability of non- moving objects	29. Manufacturing Precision
4. Length of stationary objects	17. Temperature	30. External harm affects the object
5. Area of moving objects	18. Intensity of illumination	31. Object-affected harmful
6. Area of Stationary objects	19. Use of energy by moving objects	32. Ease of Manufacturing
7. Volume of moving objects	20. Use of energy by stationary objects	33. Ease of operation
8. Volume of stationary objects	21. Power	34. Ease of repair
9. Speed of objects	22. Energy loss	35. Adaptability of versatility
10. Force	23. Substance loss	36. Device complexity
11. Stress of Pressure	24. Information loss	37. Difficulty of detecting
12. Shape	25. Time loss	38. Extent of automation
13. Stability of obje cts	26. Substance quantity	39. Productivity

7 Case Study

As part of this study, the implementation of TRIZ was carried out on a Boeing 737 engine. It has a long history as the first 737 entered service in 1968. Through its many advancements, it is currently the biggest selling airliner of all time. The aerospace industry in general and Boeing in particular have a long and successful record of accomplishment of evolving their products, in order to offer the customers best performance economically and reliabiliy. Over the years, there have been several versions of the 737 and Boeing wanted to install a larger engine on a redesigned 737. This is expected and would increase the air intake in the engines.

7.1 Contradiction

To increase the engine air-intake capacity, the engine size of Boeing 737 was to be increased. But the problem, which the company encountered was that, upon increasing the engine size, the ground clearance would decrease. Therefore, the TRIZ tools were used to counter this problem and accordingly find an inventive solution to the technical contradiction.

Since the size of the engine was to be increased, the volume of the moving object was considered to be the improvement parameter.

On increasing the engine size, the ground clearance decreased, which was highly undesirable. Thus, the length of the moving object was considered as a worsening parameter. The engine inlet area and the cowl with the fuel lines made up the engine volume, thus an improving feature would be "Volume of the moving object" and the worsening feature "the length (engine diameter, i.e. clearance)". This intersection provided four key principles, which helped to resolve the contradiction and they were Asymmetry, Segmentation, Nested and Parameter Changes.

Segmentation: Due to large engine air inlet area, casing surrounding area of inlet was expected to be circular, because of the spinning blades inside the engine.

Asymmetry: The inlet area and the casing were not needed to be symmetric. Thus, a cylindrical intake area with an oval engine casing was considered.

Figures 7 and 8 show a simplified design of the engines, considered before and after. The lateral radius of the casing was increased to make sure that the intake area remained the same. Thus, making sure that the air intake area was increased and also the adequate ground clearance was maintained.

Table 1 shows the parameters of the contradiction table.

Fig. 7 Design (before)

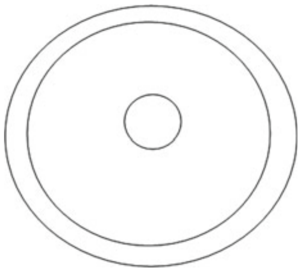
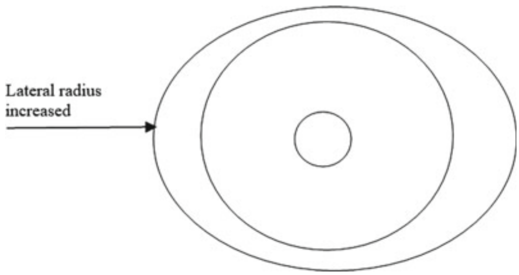


Fig. 8 Design (after)



7.2 Altshuller's 40 Principles of TRIZ

TRIZ used the following principles to solve the problem.

1. Segmentation
2. Extraction
3. Local quality
4. Asymmetry
5. Consolidation
6. Universality
7. Nesting
8. Counterweight
9. Prior counteraction
10. Prior action
11. Cushion in advance
12. Euipotentiality
13. Do it in reverse
14. Spheroidality
15. Dynamicity
16. Partial or excessive actions
17. Transition into new dimension
18. Mechanical vibration
19. Periodic action
20. Continuity of useful action
21. Rush through
22. Convert harm into benefit
23. Feedback
24. Mediator
25. Self-service
26. Copying
27. Dispose
28. Mechanical system replacement
29. Pneumatics and hydraulics
30. Flexible shells and thin films
31. Porous materials
32. Change color
33. Homogeneity
34. Discarding and recovering
35. Parameter changes
36. Phase transitions
37. Thermal expansion
38. Accelerated oxidation
39. Inert environment
40. Composite materials

Table 2 Contradiction matrix

Improving feature	Worsening feature				
	1. Weight of moving object	2. Weight of stationary object	3. Length of moving object	4. Length of stationary object	5. Area of moving object
1. Weight of moving object	*	–	15,8,29,34	–	29,17,38,34
2. Weight of stationary object	–	*	–	10,1,29,35	–
3. Length of moving object	8, 15, 29,34	–	*	–	15,17,4
4. Length of stationary object	–	35,28,40,29	–	*	–
5. Area of moving object	2,17, 29,4	–	14,15,18,4	–	*
6. Area of stationary object	–	30,2, 14,18	–	26,7,9,39	–
7. Volume of moving object	2,26,29,40	–	**1, 7, 4, 35**	–	1,7,4,17

Using the parameters of the contradiction table, following contradiction matrix was arrived at, for solving the issue in Boeing 737. Table 2. shows the contradiction matrix arrived at.

8 Conclusion

Value engineering is a crucial methodology, implemented by various organizations across the globe to aid the process of continuous improvement of their Products/Services. The concept of TRIZ comprises of various inventive principles, which are extremely useful for looking at a problem from a number of diverse view points, thus giving a broader perspective to the brainstorming session of the VE phase. As part of the case study, the problem pertaining to a Boeing 737 engine issue was successfully solved using the TRIZ tool. The study identified the improvement parameter as well as the worsening parameter of the engine. Using the contradiction matrix, it further identified four principles of TRIZ. They were segmentation, symmetry, nesting, and parameter changes. These principles further helped in modifying the parameters of the Boeing engine to increase the volume of air intake, without compromising on ground clearance. It also helped in enhancing the value of the engine as well as the customer satisfaction.

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Understanding the Drivers and Barriers in the Implementation of IoT in SMEs

Sanket D. Parab, Ashish Deshmukh, and Hari Vasudevan

Abstract Internet of Things (IoT) is important and contribute to the manufacturing competitiveness of Small and Medium-Sized Businesses (SMEs). However, not much is known as to how IoT is used in SMEs. Drivers steer the implementation of IoT in SMEs and barriers create hurdles in the implementation of the same. To realize the potential of the IoT, it will be necessary for SMEs to overcome the barriers by implementing the corresponding driver ensuring the implementation of IoT. The purpose of this paper was to study the existing literature and narrow down the most significant drivers and barriers, which will be the first step in creating a framework for IoT implementation in SMEs.

Keywords Drives · Barriers · IoT · SMEs

1 Introduction

Small and medium enterprises (SMEs) across the world are considered to be the backbone of global manufacturing sector [1]. SMEs are not just important providers of goods and services to multinational corporations; they are also a major source of new jobs and advancements in technology. SMEs benefit from emerging technologies such as IoT, because it opens up new avenues for them to pursue. These include better access to resources like, skilled workers, markets, funding, communication, collaboration, technology and product development [1]. For this reason, SMEs can compete with their larger counterparts on the level playing field, created by digital technologies. IoT has been hailed as the solution for various practices and processes in industries in developing nations, enabling the SMEs to leapfrog over earlier stages of

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business development [2]. These innovations can help SMEs in developing countries become more productive and competitive. SMEs often miss out on digital innovation opportunities or are slow to adopt new technologies, despite their potential benefits. To shed light on drivers and barriers in the implementation of IoT in SMEs, this paper examines them thoroughly and evaluates the feasibility of its adaptation. In the second section, the extant literature on the topic, and in the third, a comprehensive lists of the 31 barriers and 24 drivers with a detailed description identified by the study are provided.

2 Literature Review

IoT describes a future where physical objects are connected to the Internet and can recognize other devices. IoT is a network of IP-connected devices that communicate without human intervention. IoT includes smart objects, intelligent devices, smartphones, and tablets.

SMEs have the most trouble adopting IoT technologies. Barriers hinder readiness and adaptation, while drivers promote them. Adopting new technology and developing readiness can involve high initial barriers. Jan Stentoft et al. analyzed data from 308 SMEs to determine how SME managers' perceptions of IoT drivers and barriers affect their readiness for engaging with such technologies, how increased readiness affects the extent to which IoT technologies are adopted and how readiness mediates the effects of drivers and barriers on practicing IoT technologies [3]. Perceived barriers can lead to decisions not to invest in new technologies, such as when a firm decides not to respond to new order requirements due to a lack of knowledge and competence. Indirectly, perceptions of high barriers may be so strong that firms are hesitant to prepare their organizations for further developments in these emerging technological domains, stalling IoT readiness and further limiting IoT technology adoption [4].

IoT adds value to manufacturing outputs and systems by integrating emerging technologies in manufacturing and services [1]. High investments and unclear cost-benefits for IoT applications cause uncertainty. The workforce lacks the skills to deal with upcoming automation and unclear standards for IoT implementation have created ambiguity in many organizations [5]. As concluded by most researchers, IoT adoption affects SME performance and in this context, the study is an attempt to explore and evaluate the most prominent barriers and drivers.

3 Drivers and Barriers in Implementing IoT in SMEs

According to Jesper et al. [6], roughly 27% of Indian industrial firms rate their digitization level as high, which is actually quite low by global standards. This demonstrates that IoT adoption in India is still in its infancy stage [7]. On one hand, government initiatives to promote IoT are largely limited to organized MSMEs, whereas the unorganized sector employs a considerable number of MSMEs. Identifying the challenges to IoT deployment in Indian SMEs will be the first step toward its successful implementation. SMEs differ not only from Multinational enterprises (MNEs), but also from one another, when it comes to IoT adoption.

3.1 Detailed Description of Barriers

A number of real-world factors propell the widespread adoption of IoT in industries. IoT holds great potential for boosting development in the realm of digital business. Existing research is still reliant on limited literature, but scholarly articles are beginning to appear in peer-reviewed journals. However, there appears to be a dearth of studies in the existing academic literature that focus on the specific drivers and barriers for IoT and its actual application. To better understand the barriers, we conducted an intensive literature search was conducted aspect as part of this study. Research papers on IoT published in various journals, blog, news articles, and industry reports were reviewed and referred to get more information on IoT and its implementation hurdles. The following research inputs were analyzed and summarized as shown in the Table 1. These 31 barriers in IoT adoption were found to be the backbone which the future research could adopt and deploy. A brief description of each barrier as envisaged by various researches is also listed out.

Digitization is expected to make factories smarter and more knowledgeable. About 15–16% of India's GDP and 12% of the population are employed in manufacturing. Manufacturing is expected to add 25% to GDP and 100 million jobs by 2025 [21]. McKinsey defines digital transformation as reorganizing technology, business models and processes to create new customer and employee value. Digitization is also known to be driven by consumers in industries. With optimal and faster decision processes based on numeric data in each manufacturing step, the time between product design and manufacture is decreased, time to market is shortened, and a product range that quickly meets consumer wants is achievable. This increases productivity and reduces costs. Adaptable, real-time, knowledge-based business models respond to customer preferences. Manufacturing and manufacturing

Table 1 Barriers in IoT adoption

Sr. no	Barrier	Description
1	Lack of consultants and trainers in the field	IoT deployers must also compete to hire cloud computing and data science experts. Rapid growth in these sectors may cause skill shortages [8]
2	High implementation cost	Infrastructure investment required in SMEs for IoT implementation is difficult without adequate funding. IoT implementation can cause financial losses [9]
3	Order or business uncertainty	In SMEs any product or part being manufactured can become obsolete. Uncertainty can strain normal working methods in a serious crisis, thus daily tasks are prioritized over IoT
4	Lack of awareness about government policies	Lack of government policy awareness has slowed down IoT deployment across sectors. Without proper regulation, IoT could stagnate [10]
5	Lack of knowledge management systems	Knowledge management systems store and retrieve knowledge, promote collaboration, locate knowledge sources and mine repositories for hidden knowledge. Existing systems can't handle real-time IoT data [11]
6	Lack of clear comprehension of IoT benefits	IoT value creation and delivery must be understood by businesses. Variations in IoT business models should be analyzed. Doubtful IoT cost–benefit expectations hinder its implementation [5]
7	Lack of standards and reference architecture	Choosing an IoT architecture for different uses is difficult, especially for wireless sensor networks. Due to its novelty, IoT lacks standards or a reference architecture [5]
8	Lack of internet coverage and IT facilities	Insufficient IT to support IoT. Businesses and services can suffer from poor communication and signal coverage. Poor signal coverage reduces production signals [5]
9	Security and privacy issues	IoT data flows threaten privacy and cybersecurity. IoT makes CPS vulnerable to cyberattacks. Cyber-security threats include authorization, privacy, system, application, network and data access [5]

(continued)

Table 1 (continued)

Sr. no	Barrier	Description
10	Seamless integration and compatibility issues	Existing machinery and equipment may not be IoT-ready. Building a cyber-physical IoT infrastructure requires seamless integration and interoperability [12]
11	Regulatory compliance issues	Businesses must follow all relevant rules and regulations to achieve regulatory compliance. Machine work, working hours and IT security need stricter regulations [5]
12	Legal and contractual uncertainty	Digitalization increases competition. Digital strategy implementation must consider data protection, AI liability and standardization. Virtual organizations lack "legal personality," so they aren't separate legal entities [5]
13	Lack of R&D activities	Geissbauer et al. [6] say IoT implementers must double capital spending over five years. IoT goals require re-engineering and a large investment. Seuring says corporate and supply chain levels need to invest in people, processes, and technology. Most companies are hesitant to invest in IoT R&D [13]
14	Risk of security breaches	Complex value-chain links raise channel partner data security concerns. Breunig et al. [14] discuss IoT cyber-security and data loss. Lee and Lee [15] say hackers could hinder IoT adoption [16]
15	Low maturity level of preferred technology	Lee and Lee [15] discuss the risk of anarchy, when testing new technologies. Unproven devices and missing protocols can cause chaos. In a disconnected world, this has little impact, but in a networked one, it can have far-reaching effects [16]
16	Base levels of automation & Systems are not in place to start IoT implementation	IoT needs a base level of automation in place on which IoT implementation can be built. But most SMEs do not have a basic process and automation in place, thus it becomes difficult for starting IoT implementation in SMEs

(continued)

processes have become more practical, supply chains have improved, energy and infrastructure costs have decreased, fewer human resource is required and qualified manpower has increased [2]. Literature also shows that those, who embrace technology can thrive in the digital age. Innovation accelerators include IoT, robotics,

Table 1 (continued)

Sr. no	Barrier	Description
17	Lack of standards, regulations and forms of certification	SMEs fear IoT due to inconsistent standards and laws. Lack of standards prevents SMEs from joining value-creating activities and networks. Technology challenges lawmakers. Companies unprepared for fast-changing technology struggle to protect customer interests. Regulators must adapt to new technologies to know what to regulate [16]
18	High cost for recruitment of skilled workforce	Due to high training costs and lack of trainers, few people have the required IoT skills. Demand for skilled workers is high, because supply is low [8]
19	Challenges in ensuring data quality	Data quality is consistent, complete, accurate and redundant. In the age of big data, enterprises must be networked and accuracy cannot be measured. Data integrity and consistency suffer from frequent updates and sharing [16]
20	Lack of internal digital culture and training	IoT benefits require internal competencies and experimental culture. Because of scarce skilled labor companies move to worker-rich areas [17]
21	Resistance to change	Unwilling workers are a challenge for IoT implementation in firms. These employees dislike new technologies and their old habits of doing work create hindrance [18]
22	Lack of training for workers and managers	Many professionals have gained IoT skills over the past decade through experience or training. Most IoT project participants have computer science, engineering or software development backgrounds. Without extensive IoT training, many organizations lack an in-house expert [16]
23	Lack of a digital strategy alongside resource scarcity	IoT needs vertical and horizontal data flow. SMEs have fewer resources than larger competitors. Ahlers [16] discusses the Innovation Readiness Index (IRI) and claims SMEs reject cloud computing as top management fears IoT. Ahlers argues that IoT implementation is a strategic decision and management objections could hinder digital strategy development [16]

(continued)

Table 1 (continued)

Sr. no	Barrier	Description
24	Higher investment in employees' training	As IoT is a relatively new technology and many trainers are not available easily, the amount of investment is relatively high for getting a trainer
25	Unavailability of the data security system	Data security is very important, when we are dealing with a vast amount of sensitive data. As the budget is constrained in most SMEs, many of them do not have a data security system in place which is essential in today's era of hacking [8]
26	Lack of alternative solutions to the technological breakdown	After implementing IoT, computing power increases dramatically. Thus, system or component failures rise. SMEs can't afford alternative solutions [10]
27	Customers are hesitant to share data	In the cognitive era, consumers want their data to be secure and well-used. Personal data insights help individuals and organizations. Collecting, analyzing and securing personal data is difficult and thus customers don't share information
28	Future viability and profitability	Missing IoT advancements or using the wrong standards jeopardize the company's future. It is difficult to develop and commercialize value-added IoT business models in SMEs. Uncertainties in IoT implementation also effects profitability [19]
29	Lack of customer orientation in IoT technology	IoT improves customer relationships by enhancing their experience. We can easily detect maintenance needs, develop better products and more. But, customers must be trained to use IoT products and services for the same
30	Foggy value propositions	Value propositions should be simple and clear. Many SMEs do not know as to how much it will cost to provide a service after implementing IoT, which affects their business proposals
31	Non-uniformity of standards	IoT requires industry-wide uniformity in information exchange standards, because norms and standards vary. Smaller companies must usually conform to the larger company's standards. Norms and standards for IoT will strengthen its implementation [20]

3D printing, AI, augmented and virtual reality, new generation, security, simulation, horizontal/lateral software integration, and blockchain [3].

3.2 Detailed Description of Drivers

As mentioned previously, IoT is a nascent research area, where extant academic literature lacks study of adequate drivers as well as barriers for IoT. Based on literature review, the potential drivers for IoT are composed and illustrated in Table 2. These 24 drivers have been identified and complied, such that it could help in the future research work in the area.

4 Conclusion

Upon the analysis of the extant literature, it can be concluded that with government backing, it will be easier to recognize the importance of both technology and application pulls. There may be unrealized potential for IoT-based business model innovation reflected in the readiness and application of SMEs. While some SMEs may fail to recognize the potential benefits of IoT technologies, they are too preoccupied with day-to-day operations, whereas others may be hesitant to use them, because they cannot bring more benefits than the costs to clarify and implement them. It is also found from the literature that IoT deployment restructures a company's business using digital technology to increase productivity, save money and innovate. Budget deficits in SMEs, high investment and operational costs, data security, privacy concerns, inability to understand IoT technologies, connection problems, insufficient information regarding digital standards, not knowing the benefits of digitization and a lack of qualified employees are all barriers to IoT adoption.

In this paper, an attempt was made to identify both the drivers and barriers to IoT implementation in some of the selected Indian SMEs. The drivers and barriers described in Tables 1 and 2 could be classified into the same categories and co-related using multi-criteria decision-making models in the future. This will aid in mapping respective drivers that could either eliminate or reduce the effect of corresponding barriers, and it can act as the first step in forming a framework to adopt IoT in SMEs. It will also be based on the SME's unique set of drivers and barriers.

Table 2 Drivers in IoT adoption

Sr. no.	Driver	Description
1	Unlimited storage and processing capability	IoT devices have limited processing capabilities; however, CloudIoT resources have nearly unlimited processing capabilities by integrating with the cloud. CloudIoT resources have nearly infinite storage [22]
2	Scalability	CloudIoT services are highly scalable, allowing various smart items owned by different owners to connect to cloud resources with ease [8]
3	Service-oriented	It makes use of a service-driven business strategy i.e. services are provided on demand [23]
4	Maximizes asset utilization	CloudIoT enables organizations to outsource on-expertise work, so that they (infrastructure and people) can focus on their core functions
5	Reduced upfront investment in cloud analytics	With the advent of Cloud analytics tools, such as Google Cloud, Amazon service and Microsoft Azure data storage, analysis cleaning, etc., can be done as Pay-per-service, which is more affordable than hiring IT employees
6	Improved transparency	Transferring organizational activities under cloud infrastructure improves transparency within the organization [24]
7	Rapid deployment through Cloud IoT	Service providers help SMEs quickly implement CloudIoT resources. The main benefit for SMEs is the elimination of staff costs for implementation
8	Competition and pressure from business partners	It's due to industry competition that SMEs opt for CloudIoT, which allows SMEs to work remotely, expanding their operations by providing access to foreign markets and international networks [25]
9	Top management support	Top management support is critical for creating a supportive environment and making resources available for adopting new technologies [26]
10	Horizontal and vertical system integration	Even today, suppliers, customers and departments don't have fully integrated IT. IoT boosts department cohesion and functionality [24]

(continued)

Table 2 (continued)

Sr. no.	Driver	Description
11	Cybersecurity	Cybersecurity secures machine communication and access. It also provides much-needed vigilance [27]
12	Big data analytics	Digitization and modern technologies have made data sets too diverse for traditional databases and tools. IoT data quality and quantity can improve with more sensors and processors. Big data analytics interprets large data sets [21]
13	Simulation	Some industries use 3-D product simulations, which simulate plant operations. This simulates real-time system performance and helps check machine settings before physically switching, improving product quality and results [21]
14	Additive manufacturing	3D printing allows industries to create customized products in small batches, which has many benefits, such as lighter, easier-to-transport products. Additive manufacturing improves performance and reduces shipping and inventory costs [28]
15	Augmented reality	By delivering timely and relevant data to the appropriate parties, augmented reality will play a pivotal role in the Internet of Things. As a result, the system's adaptability and decision-making will be enhanced [21]
16	Autonomous cyber-physical systems	Remote working is possible, because of Autonomous Cyber-physical systems. Implementing IoT carefully can transform India's manufacturing sector [5]
17	Continued specialized skills training	IoT workers have to work with smart machines, connect smart factories and look at digital data. Digitization and safe use of IoT should be given top priority. Thus continued specialized skills training becomes one of the important factors in the implementation of IoT [21]
18	Enhanced corporate control	IoT boosts departmental productivity and profit. To solve problems and motivate employees, senior management must understand how digitization will affect each business component [21]

(continued)

Table 2 (continued)

Sr. no.	Driver	Description
19	Balanced and empowered team	Implementing IoT in Indian manufacturing requires a skilled, empowered team and the team should use IoT. Chen [29] mentions to identify and empower the right people to increase user participation [21]
20	Internet facility at a reduced price	India has one of the cheapest 4G networks and broadband services in the world, which help industries to digitalize manufacturing [21]
21	Confidence of customers in Internet transactions	IoT has transformed business and boosts online commerce. Customers must trust Internet transactions for IoT to be successful [21]
22	Total productive and preventive maintenance	IoT requires a large, regularly maintained IT infrastructure. Any disruption in the integrated process disrupts the system. Smart maintenance prevents breakdowns and also notifies periodic maintenance [21]
23	Strategic digitized vision	IoT requires a large, regularly maintained IT infrastructure. Any disruption in the integrated process disrupts the system. Smart maintenance prevents breakdowns. MSMEs need more money for maintenance support systems [21]
24	Employee acceptance by motivation and incentives	IoT implementation requires specialized skills and hence the employees must be qualified. The company must develop these skills and accept IoT. Thus motivating employees by giving incentives becomes crucial for the digital transformation of the firm [30]

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Study on Evolution of Hydrogen Gas Bubble on the Performance of the μ-ECDM Process

Mehul Prajapati and Devdas Lalwani

Abstract The evolution and breakdown of hydrogen gas bubbles at the tool electrode contribute to material removal in ECDM process. Gas film behavior in ECDM process is a very complex phenomenon. The film characteristics depend on several electrochemical and physical parameters, which are interconnected. Controlling the H_2 gas bubble evolution influences the response parameters like material removal rate (MRR), hole overcut (HOC), depth of penetration (DOP), heat-affected zone (HAZ), and surface roughness (SR). The present study gauges the evolution of hydrogen gas by controlling the inter-electrode gap (IEG), current density, with or without separator, system temperature, inclination angle, and surface wettability of electrodes.

Keywords Electrochemical discharge machining (ECDM) · Hydrogen bubble size · Ohmic resistance · Current density · Electrolysis

1 Introduction

Future energy sources will likely use hydrogen as a green fuel. In electrochemical discharge machining (ECDM), material removal is a result of hydrogen (H_2) gas evolution and spark generation. Melting, vaporization, and chemical etching all together remove the material. The miracle of material removal in ECDM differs from electron beam or laser beam [1]. In the ECDM process, electrolysis is paramount. The electrolysis process helps in splitting up water into its constituent elements of two parts hydrogen and one-part oxygen. Pure water is a poor conductor of electricity

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and hence is less efficient in process of electrolysis [2]. Even though green sparks emerge during the ECDM process, acidic electrolytes, such as sulfuric acid (H_2SO_4) and hydrochloric acid (HCL), are incapable of machining. The neutral electrolytes, namely, potassium chloride (KCL) and sodium chloride (NaCl), create a sluggish rate of material removal. Material is removed significantly faster by alkaline electrolytes (NaOH and KOH) as compared to neutral electrolytes [3–6]. The surface texture is affected by the concentration of the electrolyte, the type of electrolyte, and hence, its viscosity. The literature reveals that when a higher viscosity electrolyte is used, the texture of the channels on the surface changes from a feathery-like pattern to a smooth and spongy-like pattern [7, 8].

Stable H_2 gas can produce a quality of holes, and crack-free surfaces, achieving larger depths and reduced hole overcut. Attempts have been made by researchers in the direction of tool kinematics (changing tool shapes, rotating tools, and vibrating tools) to improve gas stability [9–12]. Several researchers altered the surface texture of the tool or insulated the tool to improve the gas stability [13–15].

The challenge is to generate stable H_2 gas after electrode activation, which will give stable performance in the ECDM process for prolonged operating periods. The objective of the paper is to unfold the measures for stable H_2 gas evolution, which is dependent on time-variation effects occurring on the tool electrode, the ohmic resistance of the system, current density at electrodes, and electrode wettability.

2 Effect of Ohmic Resistance on ECDM Process

Electrochemical discharge initiates only when the applied voltage reaches a critical value which depends on the type of electrolyte and its concentration [1, 16]. In any combination, the resistance to electronic current in the electrodes and ionic ohmic resistance contribute to critical voltage [17]. Ionic ohmic resistance is the ion migration resistance within the electrolyte.

Figure 1 depicts the current (I)—voltage (U) characteristics for 30% NaOH. When the voltage gradually rises from 0 to 2 V there is no current drawn in the thermodynamic and over a potential region (OA). Between 2 and 10 V current rises linearly with voltage in the ohmic region (AB). The current reaches a limiting value and becomes practically constant above point B. The highest point C is marked by a critical voltage Ucrit (usually 20–30 V) and a critical current Icrit, (typically around 1A). Beyond a point, C marks the instability area where the current gradually drops until it reaches point D. Micromachining takes place in the spark discharge region (DE) [18].

Beyond U^{crit} ohmic resistance has a strong influence on machining characteristics. The resistance of a cell can be broken down as:

$$R_{cell} = R_{circuit} + R_{electrolyte} + R_{bubbles} + R_{membrane} \quad (1)$$

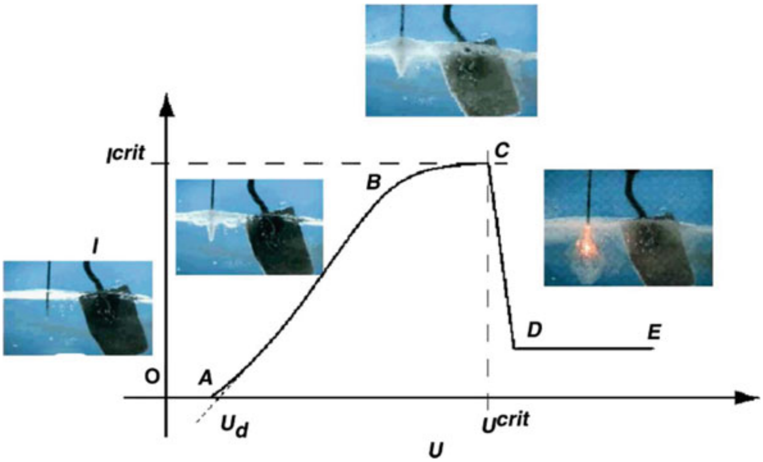

Fig. 1 Current—voltage plot for 30% NaOH [18]

The voltage drop between the electrodes (ohmic resistance) constitutes the drop due to the electrolyte ($R_{electrolyte}$) and due to the membrane ($R_{membrane}$) [2, 19]. Using ohms law, the expression for the voltage drop caused by the electrolytic solution:

$$|R_{electrolyte} = \frac{IL}{Ak} = \frac{iL}{k} \tag{2}$$

where I is the current in amperes (A), i is the current density in (A cm^{-2}), L is electrode spacing in cm, A is the cross-sectional area in cm^2, and k is the conductivity in Siemens per cm (S cm^{-1}). Referring to Eq. (3) either raise conductivity (k) or decrease the electrode spacing (L) to reduce voltage drop at the same current density. There is enough literature available where conductivity has been optimized for the two most used electrolytes, potassium hydroxide (KOH), and sodium hydroxide (NaOH) [8, 20–22]. Figure 2 depicts the influence of electrolyte conductivity on critical voltage. To reduce the resistance from the electrolyte optimizing the distance between the electrodes is a crucial area of research. The literature revealed a saving in ohmic resistance by 0.4 Ω cm^2 when an increase in electrolyte flow between the electrodes from 20 ml/min to 80 ml/min (Fig. 3a).

2.1 Optimum Inter Electrode Gap in ECDM Process

The use of the zero gap design seeks to reduce ohmic resistance by minimizing L, the distance between the electrodes, and minimizing the rise in R_{cell} caused by an increase in the void fraction [2, 19, 23]. Critical voltage decreased as the space became smaller with a current density between 0.1 and 0.5 A cm^{-2}. Beyond 0.6A cm^{-2}, the

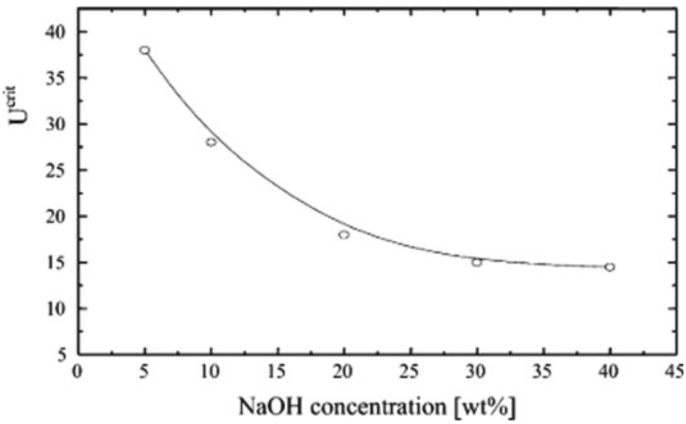

Fig. 2 Critical voltage with NaOH concentration at 25 °C [18]

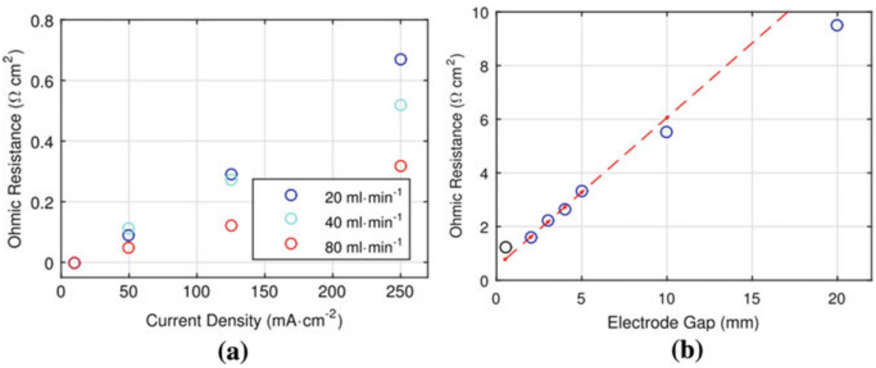

Fig. 3 Ohmic resistance with electrolyte flow **a**, Ohmic resistance with electrode gap **b** [19]

voltage increased a little with a small space between electrodes (1–2 mm) [24]. Hence, the efficiency of the ECDM process is based on an optimal inter-electrode gap, and the optimal gap relies on the current density [2, 19, 24]. Figure 3b shows the proportionality of the ohmic resistance and electrode gap.

The inter-electrode gap (IEG) affects the adherence of gas bubble volume on the tool electrode. At higher IEG, the electrostatic force generated is weak to affect the gas film shape. Electrostatic force increases by reducing IEG, leading to deviation of the gas film toward the auxiliary electrode. Figure 4 depicts the deviation of the gas film due to a change in IEG distance. HOC is reduced, due to a decrease in IEG distance, as the tool side facing opposite to counter electrode (Semicircle A) has reduced film thickness [25]. Semicircle-B region had a thin-deviated gas film developed resulting in increased machined hole deviation. The spark energy was diverted toward the machining of the elliptical hole, which reduces the hole's depth. Figure 5 depicts the images of the machined hole on changing IEG distance.

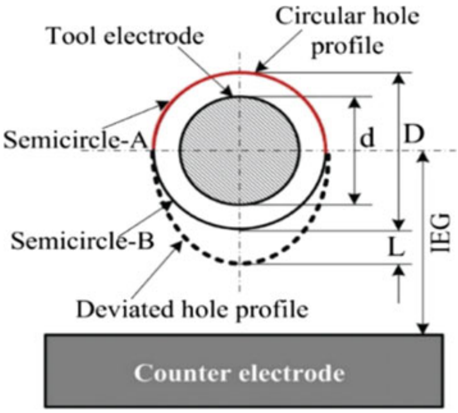

Fig. 4 Schematic of IEG [25]

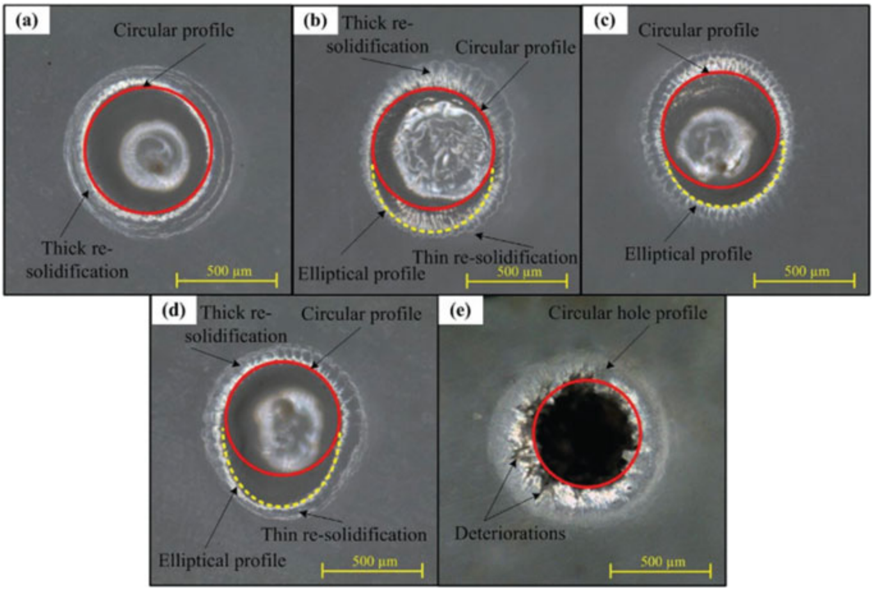

Fig. 5 Images of machined profiles at various IEG **a** 70 mm, **b** 55 mm, **c** 40 mm, **d** 25 mm and **e** 10 mm [25]

2.2 Effect of Current Density on ECDM Process

The introduction of a potential difference between the electrodes creates an electrochemical cell, initiates the electrolysis process, and causes the production of gas bubbles at both electrodes. Due to surface tension, the bubbles in the adhesion area cling to the tool surface. Researchers measured the buoyancy force F_b (upward force)

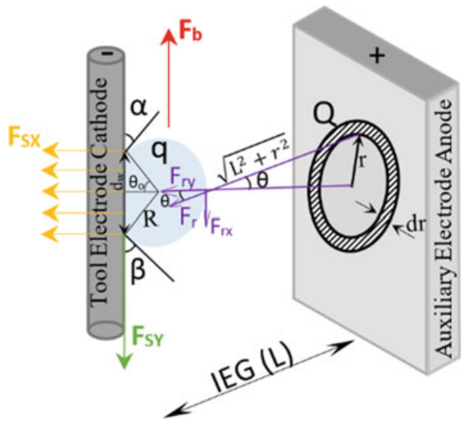

Fig. 6 Electro static forces acting on H_2 gas bubble by infinite charge plate

[26] and surface tension force F_{sy} (downward), and F_{sx} (toward the tool), acting on the gas bubble [25, 27, 28]. Figure 6 depicts the forces acting on the single gas bubble.

$$F_b = C_b \times g \times R^3 \times (\rho_L - \rho_g) \tag{3}$$

$$F_{sy} = C_{SX} \times \sigma \times R \tag{4}$$

$$F_{sx} = \frac{d_w \times \sigma \times \pi \times (\cos\beta - \cos\alpha)}{\alpha - \beta} \tag{5}$$

where R is the radius of bubble ρ_L, and ρ_g is electrolyte density and H_2 gas bubble, g is constant due to gravity, C_b is co-efficient of buoyancy force, and C_{SX} is the co-efficient for surface tension force (σ) in X-direction. The bubble on the tool's surface will remain stable until the forces operating in the X-direction are equal and the opposite. As the bubble size at tool electrode increases the buoyancy force overcomes the surface tension force (F_{sy}) and the bubble exits from the tool surface.

The bubble experiences an electrostatic force (F_{ES}) opposite to the surface tension force (F_{Sy}). It is possible to regulate the shape of the gas film by measuring and changing the strength of the electrostatic force.

When the two charged particles, Q (on the auxiliary electrode anode) and q (on the tool electrode cathode), are separated by the length L, Q creates an electrostatic field. The quantity of static electric field (E) produced by charge 'Q' is calculated using Coulomb's equation

$$E = \frac{K \times Q}{L^2} \tag{6}$$

Charge particle 'q' experiences an electrostatic force (F_E) if it comes close to the vicinity of the electrostatic field.

$$F_E = E \times q \tag{7}$$

From Eq. (6) and (7)

$$F_E = \frac{K \times Q \times q}{L^2} \tag{8}$$

Force (F_E) acts between two point charges in an electric field at a distance 'L'. In the ECDM process, the auxiliary electrode has a big area and the total electrostatic force (F_{ES}) acting on the gas bubble charge (q) is very large. Appalanaidu and Dvivedi, 2021, measured the total electrostatic force (F_{ES}).

$$F_{ES} = \iint_0^{F_{ry}} dr \tag{9}$$

where dr is the thickness of the circular ring on the auxiliary electrode, and F_{ry} is the perpendicular electrostatic force to the plate applied on the charge 'q'.

$$F_{ES} = (k \times 2 \times \pi \times C_d \times q) \iint_0^{\frac{rx(l+dl)}{\left(l^2+r^2\right)^{3/2}}} dr \tag{10}$$

The electrostatic force F_{ES} exhibits a connection with IEG (L), the charge density of a plate (C_d), and the charge on the bubble (q). Figure 7a–c depict critical voltage varying with current density and IEG.

Comparing Figure 7a–c, the critical voltage drops for the smaller height of electrodes when the current density is high. Hydrogen and oxygen bubbles are abundant in the upper area between the electrodes, and the average void percentage between electrodes of larger height is higher than between electrodes of lesser height [24]. In

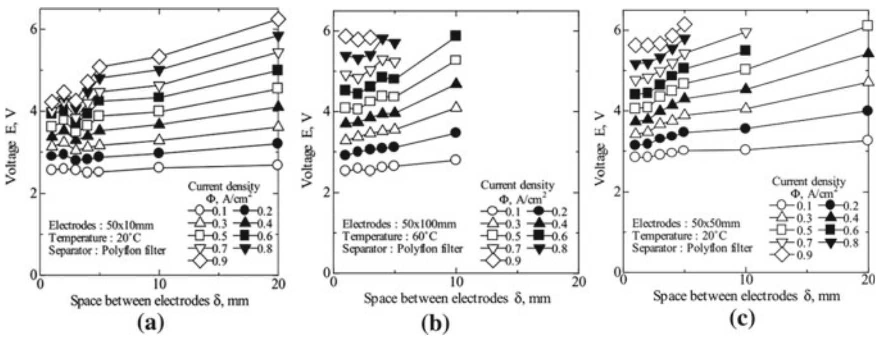

Fig. 7 Effects of height (10 mm **a**, 50 mm **b**, 100 mm **c**) of electrodes on critical voltage [24]

addition to the current density, the height of the electrodes also affects the existence of the optimal space.

3 Bubble Coverage on Tool Electrode

The evolution of gas bubbles at the tool electrode acts as a dielectric medium that generates sparks helping in the material removal process. Hydrogen gas coverage and its film thickness affect the geometrical characteristics such as hole overcut and tapered holes, and heat-affected zone (HAZ).

The fractional bubble coverage Θ is controlled by, the rate of gas evolution at the tool electrode surface (V_G/A), the average volume of gas bubble departure (V_r), and the average residence time of the bubble at the electrode (t_r). The gas evolution rate (V_G/A) at the electrode surface is controlled by the nominal current density (I/A), temperature, and pressure. The residence time (t_r) at the tool electrode is controlled by the bubble shape, the velocity of the bubble depending on the conditions of mass transfer to adhering gas bubbles, and the concentration of dissolved electrolyte around the adhering bubble. The gas volume is influenced by the shape, size, and direction of the operating electrode, the flow of the gas–liquid dispersion close to the electrode, and external forces like magnetic forces, gravity, and ultrasonic [29–31].

4 Wettability and Surface State of Tool Electrode

According to Sabahi et al. [7], the electrode and electrolyte's surface tension and electrode wettability have an impact on bubble contact angles. Surface tension and electrode wettability affect the thickness of the gas layer and the radius of the gas bubble. Adding surfactant to the electrolyte, the bonding forces between molecules become weaker, and consequently, the surface tension decreases. The change in wetting phenomena resulted in reduced stray erosion at the entrance of the microchannel, and improved sidewall quality fabricated with the stable and thinner gas film [7].

The electrode surface can have a synergistic effect on both the gas bubble evolution and the ion transport resistance ($R_{Electrolyte}$) or IEG. Modifying the surface's morphology to improve the surface area of the tool electrode, and to create active sites like cracks and crevices that encourage the release and capture of bubbles.

Arab et al. [15], studied the effect of surface characteristics of the tool electrode upon the overcut and the HAZ width of the through-holes. Roughness on the tool will attract large size bubbles with high contact angle on the tool electrodes. Thicker gas film, will result in larger overcut and HAZ widths. On the contrary, tool electrodes with lower surface roughness showed a thinner gas film which resulted in through-holes having lower overcut and HAZ widths. Figure 8a, b depict the roughness of the electrochemical finishing tool (ECF) and wire–EDM tool (W-EDM) on HOC and HAZ [15].

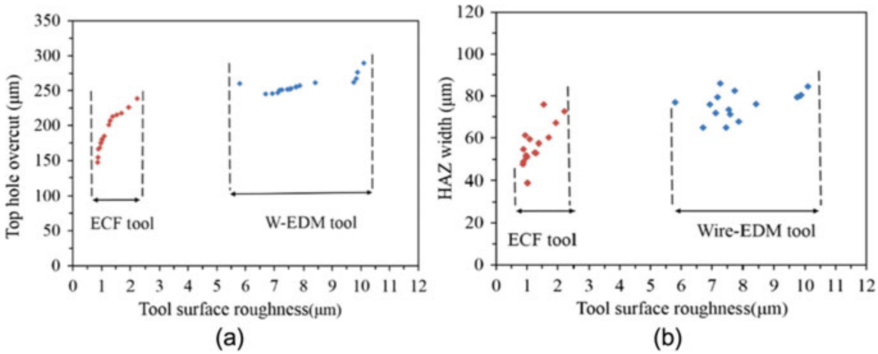

Fig. 8 Effect of surface roughness on HOC **a**, and HAZ **b** [15]

4.1 *Influence of Process Time on Bubble Stability*

The time-variation influence both the electrodes and their respective gas bubble evolution [17]. Figure 9 depicts bubble size variation near the electrode as bimodal distribution initially and transforms into a log-normal distribution over time at 60 mA [32]. Figure 10a illustrates the mean bubble size near the tool electrode gradually shrinks until it eventually reaches a steady state over time as electrolysis proceeds [32].

The frequency (f) of bubble generation at different locations of electrodes is inversely proportional to the cube of bubble diameter (D). The rate of gas evolution at different locations is constant for a given current, i.e., $f\ D^3 = \text{constant}$ (Fig. 10b) [32].

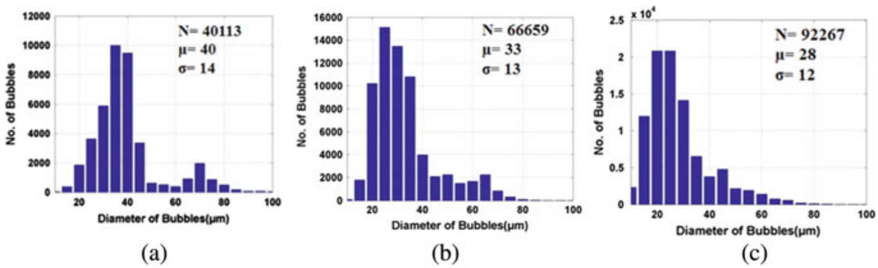

Fig. 9 Distribution of bubble size at different time period $t = 12$ min **a**, $t = 26$ min **b**, $t = 40$ min [32]

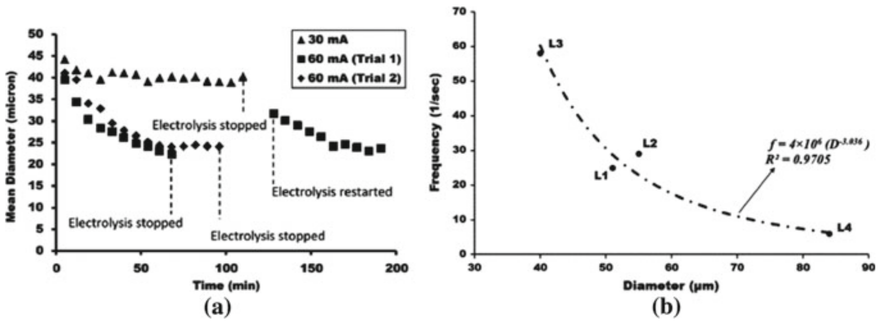

Fig. 10 Variation of mean bubble diameter with time **a**, Variation of frequency of bubble formation with bubble diameter **b** [32]

5 Conclusion

Reducing the hole overcut, increasing the depth of penetration, better surface quality, and decreasing the heat-affected zones are the prerequisite for the μ-ECDM process to become a successful micro-manufacturing technique. The μ-ECDM process depends critically on the gas film quality. Changes in gas bubble density at the cathode have an impact on the form of the gas film, and the same effect translates to machined geometry. By increasing the density of hydrogen bubbles, the temperature near the tool electrode reaches the boiling point of the electrolyte. The electrolyte's ohmic heating results in better MRR. Balancing the buoyancy and surface tension forces will give a reliable estimate of the detachment diameter. By reducing the ohmic resistance, the critical voltage and current come down, and thinner gas films generated will prevent overcutting during machining. The ohmic resistance of the system can be brought down by finding the optimum inter-electrode gap. The shape of the gas film is altered by regulating the electrostatic force changing the inter-electrode gap, charge density of the auxiliary electrode and applied energy. Surfactants added to electrolytes changes the wettability phenomena and lower surface tension results in thin gas film. In-depth research into the impact of various forces on the gas film can lead to precise control of the gas film. This presents an opportunity to investigate a novel area in the field of micromachining non-conducting material.

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Machine Learning to Estimate Gross Loss of Jewelry for Wax Patterns

Mihir Jain, Kashish Jain, and Sandip Mane

Abstract In mass manufacturing of jewelry, the gross loss is estimated before manufacturing to calculate the wax weight of the pattern that would be investment casted to make multiple identical pieces of jewelry. Machine learning is a technology that is a part of AI which helps to create a model with decision-making capabilities based on a large set of user-defined data. In this paper, the authors found a way to use machine learning in the jewelry industry to estimate this crucial gross loss. Choosing a small data set of manufactured rings and via regression analysis, it was found out that there is a potential of reducing the error in estimation from ±2–3 to ±0.5 using ML algorithms from historic data and attributes collected from the CAD file during the design phase itself. To evaluate the approach's viability, additional study must be undertaken with a larger data set.

Keywords CAD · Gross loss · Jewelry · Machine learning · Wax model

1 Introduction

Loss is an inevitable component of manufacturing. In the manufacturing of jewelry from precious metals, accounting and calculating the losses is very crucial. Gross loss of jewelry is the total metal loss during its manufacturing. Loss in metal happens during casting, filing, polishing, setting, and at almost every stage. Even though most of this lost metal is recovered and refined in the refinery to get a recovery of 92%, on average, these losses are extremely crucial not to be accounted for.

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The loss on each piece of jewelry varies, based on various factors. Estimating this gross loss beforehand was very crucial for the manufacturing of that jewelry. This estimated gross loss was used for while pulling wax patterns during the process of injection molding [1]. Jewelry made from the heavier wax piece will have surplus metal that must be filed down and recovered later, which is waste of time and materials because only some of the metal will be recovered. Therefore, estimating the total loss provides a general estimate of the wax weight and can be used as a guide for how each procedure should be carried out. In a production process, a step wise loss of each of step of manufacturing is collected. This is done by weighing the jewelry after each step. Hence after the jewelry has been manufactured, it can assess the final data of gross loss that the company bore. Total recovery that was done was also considered and added to the database.

This gross loss found out was further collected out of which a wide set of databases is manufactured by an in-house engineer. Calculations based on current trends are made where a few other variables are also taken into consideration. Variables like the weight of the finished product, the type of metal (White Gold, Yellow Gold, Pink Gold, Silver, Platinum, and Palladium), the cartage of metal (8 k, 9 k, 10 k, 12 k, 14 k, 18 k, 20 k, etc.), the customer for whom the jewelry is being made, the setting of the diamond (whether the piece is handset or wax set), and the type of jewelry it is (whether it is a ring, a pendant, an earring, a bracelet or a bangle).

Currently, the estimation comes with a variance of ±4–5%. Hence, there is a scope here by which, using the powerful tools of Machine Learning [2–5]. We can consider the variable constants to find out the gross loss in jewelry. These variable constants can most often than not be fetched directly from the CAD files which are made way before the actual manufacturing process even begins. The aim of the paper is to estimate the gross loss of jewelry at the CAD level with greater and repeatable accuracy using machine learning algorithms. This paper will systematically narrow down the variables responsible for gross loss of jewelry during its manufacturing, create a machine learning model that predicts the final gross loss based on the data collected from the CAD file generated before manufacturing and ensure greater accuracy of the model as compared to the traditional methods of estimating loss.

2 Methodology

As the project is a proof of concept, it only takes into account 26 rings as a sample size. This project will only use information from the last several months of production for all ring kinds for which CAD files were available (developed in Rhino 3D [6]) and for which the company knew the associated gross losses. It is important to highlight that only information that could be shown publicly has been included in this report. There were notably three stages to the project's execution.

Table 1 Parameters of the data set

#	Attribute	Datatype
1	Volume	mm^3
2	Surface area	mm^2
3	Metal	Karat-metal
4	Weight/piece (estimated)	gm
5	Total lot quantity	integer
6	Total weight of lot	gm
7	Inner diameter	mm
8	Outer diameter	mm
9	Minimum shank thickness	mm
10	Maximum shank thickness	mm
11	Minimum shank width	mm
12	Maximum shank width	mm
13	Total height	mm
14	Top height	mm
15	Number of components	Integer
16	Number of rings	Integer
17	Tone	1/2/3
18	True miracle	Binary
19	No. of true miracle	Integer
20	Diamond—handset and wax set	Integer
21	Filigree	Binary
22	J Back	Binary
23	Gallery	Binary
24	Fake beads	Integer
25	Plating	Binary

2.1 Creating the Data Set

The first phase comprised of selecting all possible attribute of the rings from the CAD file and listing them down with their corresponding values on an Excel sheet. This data was paired with its corresponding historic gross loss (Table 1).

2.2 Preparation of Data

The compiled data was obtained from the CAD files. This data had irrelevant parameters that are currently unknown but will be filtered out through processing. The reason why all possible data was collected was to avoid any human generated discrepancies in the very first stage of the project. Even though 26 is a small number for a machine learning algorithm, its corresponding volume would still suffice to give us the proof of concept required to carry on with the project. But in an ideal situation, the number of rows should be 4 × the number of columns. So, it can safely consider that the results obtained will only improve when the amount of data of rings increases. Before testing algorithms, the data was checked for any missing values and such values were designated a weighted average value. Feature scaling was done using standard scaling which standardize features by removing the mean and scaling to unit variance [7]. The standard score of a sample x is calculated as

$$z = (x - u)/s \tag{1}$$

where u is the mean of the training samples, and "s" is the standard deviation of the training samples.

2.3 Models

The above-mentioned data was split tested, and the mean value graph of each feature was derived. The data set was split as 80–20, where 80 was the train data set and 20 was the test data set. After the data set is split, feature scaling was done to make the comparison easier. This data was the processed through various algorithms.

1. Linear Regression Algorithm (Fig. 1)

   (a) Linear regression [8] is a supervised learning-based machine learning technique. One of its functions is to carry out a regression analysis. Through the use of independent variables, the regression model can predict a desired

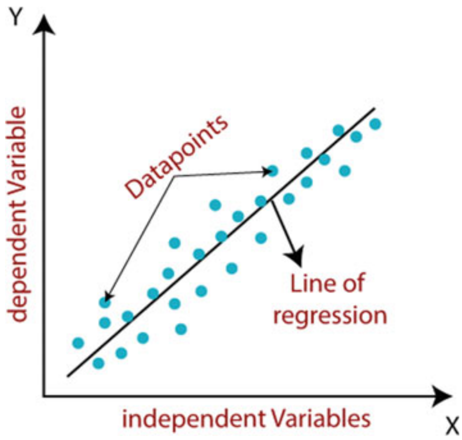

Fig. 1 Architecture of linear regression algorithm

outcome. Its primary function is to investigate causal links between factors and predicting.

(b) Predicting a value (y) of a dependent variable (x) from known values (y) of independent variables (x) is the job of linear regression (x). Accordingly, this method of regression establishes a linear connection between the input variable (x) and the output variable (y) (output). Linear regression perfectly describes this method [9]. Hypothesis function for linear regression is as follows:

$$y = \theta_1 + \theta_2 x \quad (2)$$

(c) When training the model—it fits the best line to predict the value of y for a given value of x. The model gets the best regression fit line by finding the best θ_1 and θ_2 values where θ_1 is the intercept and θ_2 is the coefficient of x.

(d) The best fit line is obtained by locating the optimal values of θ_1 and θ_2. When our model is used for prediction, it will give us y as a function of x.

2. Random Forest Regression (Fig. 2)

   (a) Random forest regression [10] algorithm is an example of a supervised learning algorithm that use the ensemble learning approach of regression. By combining the results of several different machine learning algorithms, an ensemble learning method can produce a more precise forecast than any one of them could on its own.

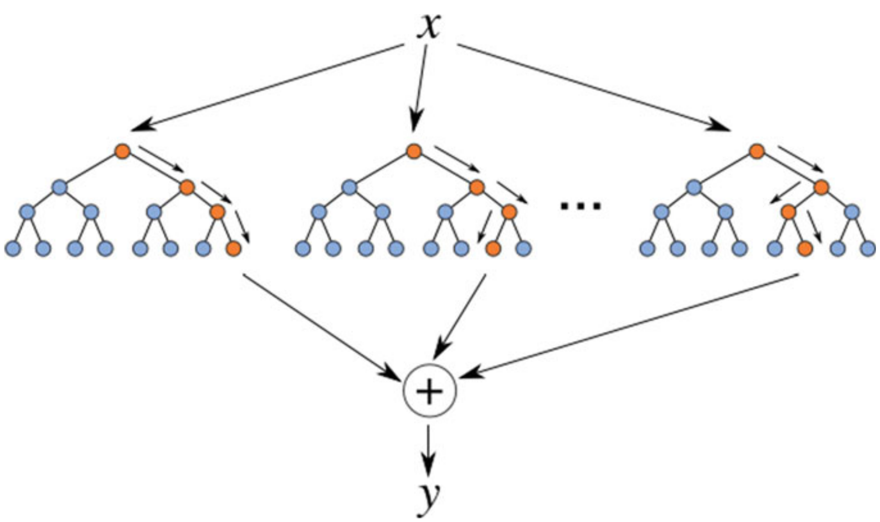

Fig. 2 Architecture of random forest algorithm

(b) Random forest relies on the “wisdom of the crowds” principle, which states that a large number of independent models working in concert can achieve better results than any of their parts working alone.
(c) This is owing to the fact that the trees buffer one another from their particular errors. Since a random forest is completely random, there is no communication between the trees that make up the forest. Random forest is an estimator technique that takes the outputs of multiple decision trees, compiles them, and then generates the ideal answer for the given situation [11].

3. Decision Tree Regression

(a) Decision tree [12] builds regression or classification models in the form of a tree structure. It breaks down a data set into smaller and smaller subsets while at the same time an associated decision tree is incrementally developed. The result is a tree with decision nodes and leaf nodes.
(b) There are three distinct sorts of nodes in this regression tree. The root node is the primary node, representing the whole sample and potentially being subdivided into further nodes. Features of a data set are represented by interior nodes, while decision rules are shown by branches. In the end, the result is shown by the leaf nodes. If you have an issue that requires a choice, this algorithm is excellent [13] (Fig. 3).
(c) A single data point is processed all the way down to the leaf node by asking and answering True/False queries. Ultimately, the dependent variable value in each leaf node is averaged to arrive at a final forecast. The tree is able to provide an accurate prediction after going through several rounds.
(d) The benefits of using decision trees include their simplicity, the fact that they require less data cleaning, the fact that nonlinearity has no effect on the

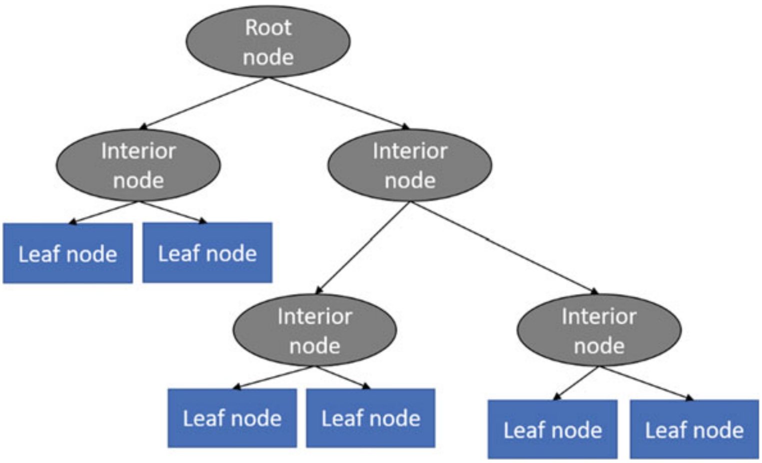

Fig. 3 Architecture of decision tree algorithm

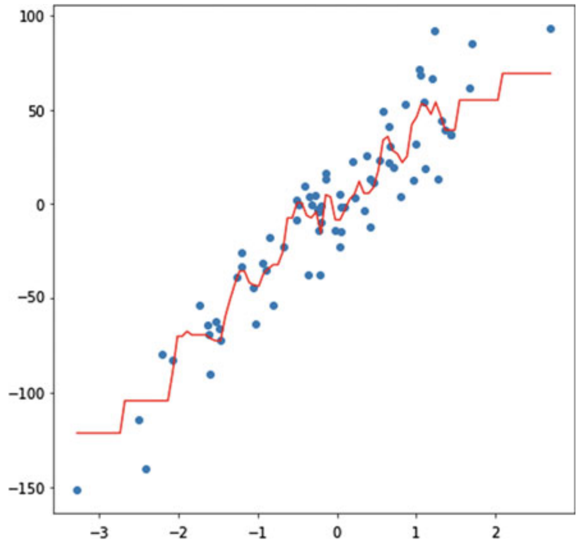

Fig. 4 Example of KNN algorithm

performance of the model, and the fact that the number of hyper-parameters to be set is practically zero.

4. K-Nearest Neighbors Regression (Fig. 4)

(a) K-Nearest Neighbors [14] is an easy-to-implement method that remembers past examples and makes a numerical prediction based on a similarity measure (e.g., distance functions). KNN is a nonparametric technique that has been utilized for statistical estimates and pattern recognition since the early 1970s.
(b) K-Nearest Neighbors [14] is an easy-to-implement method that remembers past examples and makes a numerical prediction based on a similarity measure (e.g., distance functions). KNN is a non-parametric technique that has been utilized for statistical estimates and pattern recognition since the early 1970s.
(c) We need to use cross-validation to choose K. Unlike classification we cannot accuracy use as metric, since our predictions will almost never exactly match the true response variable values. Therefore, in the context of KNN regression we will use root mean square prediction error (RMSPE) instead. The mathematical formula for calculating RMSPE i is

$$\text{RMSPE} = \sqrt{\frac{\sum_{1}^{n}\left(y_i - \hat{y}_i\right)^2}{n}} \tag{3}$$

where n is the number of observations, y_i is the observed value for the ith observation, and y^$_i$ is the predicted value for the ith observation.

Table 2 Mean absolute error of different methods

Method	Mean absolute error
Linear regression	0.56
Random forest regressor	1.72
Decision tree regressor	1.49
K-Nearest Neighbor regressor	2.02

(d) To put it another way, for each observation in our test (or validation) set, we calculate the squared difference between the anticipated and true response value, average over observations, and then square root. Since differences can be either positive or negative—that is, we can over or under estimate the genuine response value. We utilized the squared difference rather than merely the difference [15].

3 Results

As we've seen, we have put our data sets through their paces with a wide range of ML algorithms. The mean absolute error (MAE) represents the error that was introduced into our findings. The formula for the same is

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} \tag{4}$$

where y_i is the prediction, x_i is the true value, and n specifies the total number of data points (Table 2).

It was observed that all four algorithms performed well considering how small the data set was. All algorithms gave promising results with linear regression lending the lowest MAE. Though with increasing data set, it would be wise to consider all the remaining models as well. The scores will only improve as the data set increases.

4 Conclusion

The results show us that the gross loss can be predicted to an error margin of ±0.5. The proof of concept needed to be derived from the results was sufficient to take to the company to act on it. Each of the four algorithms has potential, linear regression being the most promising one so far. Further testing needs to be done by increasing the number of data set and even expanding to different category of jewelry. The implementation of this innovation in the field of jewelry manufacturing would be a big undertaking and would be a time consuming and labor-intensive processes but one which would bare fruitful results.

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Influence of Digitized Transforming Enablers on Manufacturing Performance in the Context of Economic Dimension of Sustainability

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Abstract Throughout the history, every industrial revolution has advanced in the direction of sustainability by balancing the needs of the profit generation, welfare of people, and the planet sustenance. The global manufacturing sector is currently riding on the waves of the Fourth Industrial Revolution, also known as "I4.0," which has been triggered by the emergence of new technologies. The umbrella keyword "Digitized Transforming Enablers (DTE)," discussed in this study encompasses the digital technologies of the I4.0. To date, research on the impact of DTE on manufacturing performance in the context of the economic dimension of sustainability has been relatively scarce and sparsely distributed, especially in the case of small and medium enterprises (SMEs). The extant literature available in the research reflects both positive as well as negative results. Due to the dearth of appropriate literature and varying findings, there has been a demand for further research on the subject. The objective of this study, therefore, was to synergize the DTE implementation and manufacturing performance through the lens of the economic dimension of sustainability, within the SMEs segment. The study presents a mediation research model developed with the help of theoretical background, based on descriptive and content analyses. This was done, while also describing the constructs selected and the hypotheses developed by collaborating on the DTE implementation, indicators of economic sustainability, and manufacturing performance.

Keywords I4.0 · DTE · Economic sustainability · Manufacturing performance

1 Introduction

The Fourth Industrial Revolution (I4.0), especially the digital era, is currently propelling the manufacturing ecosystem toward optimum performance across the spectrum in the value creation phase. This study introduces an umbrella keyword "Digitized Transforming Enablers (DTE)," defined as the digital technologies of I4.0

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for transforming reporting processes, acquiring and analyzing data in real time as well as applying insights to limit risk and enhance efficiency. The digital technologies of I4.0 could deliver manufacturing-economic sustainability as one of its most immediate sustainability outcomes [1]. This brings the other key aspect, sustainability into action. The intersection between these two key aspects, i.e., DTE and sustainability are growing leaps and bounds, supporting positive as well as negative remarks in the extant literature [2, 3]. Multiple studies report that the link between DTE and sustainability is in its early stage of research [4] and much more attention is required now [5]. SMEs managers frequently overlook the economic aspects of sustainability, in favor of emphasizing its social dimension and employee's well-being [6].

According to the opinion from the authors of [1] and [7], the study highlights that the concept of economic sustainability refers to the promotion of long-term economic growth, while simultaneously protecting natural and social resources. The study [2] further adds to the literature that the attainment of profit is the primary objective of economic sustainability. The economic-manufacturing sustainability pillar indicates that the manufacturers should be profitable in order to pursue other sustainability goals [8]. Since profit is in the middle of action, it brings forth economic dimension of sustainability (EDS) in the frame of this current study. The findings from a survey research [9] concluded that industries currently prioritize economic sustainability, more than social and environmental sustainability. The extant literature linking the impact of DTE on EDS is still young, underdeveloped and further research is therefore required, has also been corroborated by authors [10, 11]. The concerns and gaps raised above have motivated to articulate and compose this study. The research agenda conceptualized as part of this study was:

(1) To identify the indicators relating to EDS from the extant literature.
(2) To explore the influence of DTE implementation on manufacturing performance through the lens of EDS, and
(3) To develop the research model and research propositions collaborating DTE implementation, EDS and manufacturing performance.

The paper is structured as follows: Sect. 1 covers the introduction, and Sect. 2 offers the theoretical background along with a current review of the literature linking DTE implementation, EDS indicators, and manufacturing performance. Section 3 presents the research model, describing the constructs and the hypotheses developed.

2 Literature Review

The following section presents a theoretical background on the indicators of economic dimension of sustainability, collaborated with the digital technologies of I4.0 and its influence on the parameters of manufacturing performance.

2.1 Economic Dimension of Sustainability (EDS) and Its Indicators

Economic sustainability is the ability to consistently increase the domestic productivity over a prolonged period [12], and it must work in tandem with the other two dimensions [13]. Further, the authors opined that the economic sustainability strives to secure liquidity, profit [14], and efficiency [13]. The results of the study [15] revealed that the economic sustainability is the most important for Indian organizations, followed by the environmental and social. The research by [5] advocated that the software-defined networking is a cost-effective approach for economic sustainability. Considering the economic dimension, existing literature reports reduced set up times, reduced lead times, lower labor costs, optimized material handling and costs, higher production flexibility, increased productivity, enhanced customization, and organizational profit [2, 14, 16].

Further, the indicators related to the economic pillar of sustainability reported in the extant literature are operational cost, energy consumption, return on financial assets, business model opportunities, market share, growth in sales, manufacturing cost, product rejection and rework costs, inventory and warehouse management, profitability, production efficiency and effectiveness, and products/services to customers [2, 10, 15, 17]. As a result of the rising economic growth, there are more substantial demands across the labor market, higher wages, better workplace and working conditions, social stability, and economic equality [1]. The study [18] reported that, using more efficient production processes as well as improving productivity and economies of scale, it may result in increased economic sustainability.

Based on the above insights, the first research agenda was addressed, identifying the indicators for economic dimension of sustainability (EDS).

2.2 Influence of DTE on Manufacturing Performance Through the Lens of EDS

The extant literature has reported positive as well negative findings of the influence of DTE implementation on EDS and further its impact on manufacturing performance.

The analysis of the study [19] highlighted that mostly every I4.0 technologies entails an intersection with the economic dimension of sustainability. Digital technologies would allow countries, particularly less developed ones, to leapfrog their underperformed industrial growth and expedite the economic modernization process [20]. The extant literature brings out Internet of Things (IoT), Big data analysis (BDA), Artificial Intelligence (AI), Cyber physical systems (CPS), Additive manufacturing (AM), cloud computing (CC), and robotics as the digital technologies of I4.0 linked with economic pillar of sustainability [1, 17, 21, 22]. The widespread availability of digital connect has made it possible for businesses to develop fully automated self-optimized supply chains that can ship products directly to customers with little to no involvement from humans. Referencing the self-optimization of production networks according to a range of parameters, such as costs, availability, and use of resources is another step toward a more economically sustainable future [5]. Digital factories have a resounding influence on the monetary outlay necessary for the operation of a specific company, strengthening toward economic pillar of sustainability [23]. The study [1] discovered that business model innovation and manufacturing efficiency are the primary functions for industries to ensure economic sustainability in I4.0. Further, [24] found that I4.0 provides creative business models that can assist in achieving economic sustainability, while also increasing competitiveness. Researchers are confident that I4.0 would lead to lower production costs, enhanced economic performance of manufacturing processes, more reliable output, as well as more cost-effective global production networks [25].

The outcome of the study [17] concluded that IoT, CPS, robots, and sensors are expected to make positive economic impacts. The use of additive manufacturing techniques, such as cloud manufacturing could help reduce maintenance costs. Cloud manufacturing also enables real-time adaptive scheduling and condition-based monitoring [26]. Additive manufacturing could significantly cut the cost of materials and energy, which leads to economic sustainability [27, 28]. The findings from [29] reported that higher sustainability of I4.0 positively impacts the economic pillar of sustainability in Indian manufacturing industries. The study from [16] concluded that Industrial IoT is the topmost technology in the food and beverage business from the point of view of economic sustainability. It has been established that the IoT applications improve supply chain efficacy by reducing inventory inaccuracies [29]. Due to real-time data modeling and simulation, fault occurrences would become predictive in nature with industry 4.0 technologies, preventing significant faults from cropping up [26]. The findings from [30] indicated that I4.0 revolution would benefit economic sustainability by minimizing workforce, energy usage, lead time, and enhancing productivity in industrial operations. Literature indicate that the I4.0 is considered to enhance economic dimension, in terms of increased productivity across manufacturing systems [31]. Predictive analysis and predictive maintenance contribute in the reduction of faults and flaws in the manufacturing process. As a result, it has been stated that I4.0 implementation has an impact on the economic pillar of sustainability [29, 32].

Based on the above insights, the second research agenda was addressed, exploring the influence of DTE implementation on manufacturing performance through the lens of EDS.

3 Research Model and Hypotheses Development

The following section proposes a research model, constituting of DTE implementation, indicators of EDS, manufacturing performance, and the proposed hypotheses.

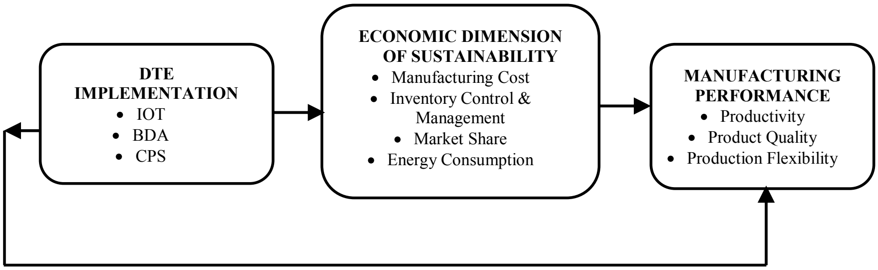

Fig. 1 Research model

3.1 Research Model Development

After a thorough descriptive and content analyses of the theoretical background, the study developed a mediation model as shown in Fig. 1, proposing the relationship between DTE implementation, EDS indicators, and manufacturing performance. Based on the developed conceptual framework, the study further proposes research hypotheses in the following section, covering the crux of the research agenda.

3.2 Linking DTE Implementation, EDS, and Manufacturing Performance

The following section identifies key EDS indicators, which mediate the relationship of DTE implementation and manufacturing performance from the extant literature and the conceptualization of the research propositions.

The study [33] suggested that I4.0 would present tremendous opportunity for research in many fields. Adding to that, the study highlighted productivity and sustainability as potential outcomes of I4.0 implementation. The study from [32] confirmed that the I4.0 applications encourages sustainability through economic improvements in productivity and product quality, ongoing environmental energy monitoring, lighter workloads, and job enrichment. The findings from the study [2] showed that the effective I4.0 implementation boosts a company's revenue earnings, i.e., financial performance, which is because of improved manufacturing performance. Hence, it could be concluded that the I4.0 implementation boosts manufacturing performance. IoT ecosystem provides improved visibility of the manufacturing execution systems, allowing real-time processing, leading to improved product and productivity [34, 35]. The investigation of the study [36] uncovered that the use of BDA improves project performance in the manufacturing industry. In terms of economic sustainability, manufacturing based on CPS is expected to create new economic opportunities [5]. It is also seen that the material selection, material reuse and recycling and energy management through real-time monitoring of energy usage could all benefit from the use of cyber-physical production systems [37].

This has led to hypothesize the following: ***H1a****: IoT implementation positively influences manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H1b****: BDA implementation positively influences manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H1c****: CPS implementation positively influences manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.*

The industrial sector could experience a number of significant benefits as a result of digitalization, including cost reductions in distribution and inventory handling, which would ultimately result in reduced lead times. Increasing economic sustainability is another benefit that comes from optimized distribution and material handling systems [26]. The usage of IoT, CPS, robotics, and sensor technologies has a greater beneficial influence on the economic pillar, than the other technologies [17]. This is because it has been shown that they improve the efficiency, cost cutting, and quality in the case of plastic manufacturing industry. In terms of the economic dimension, I4.0 implementation crafted better production, by making processes more efficient and flexible [32]. Adding to that, higher quality products and competitive advantage could be achieved. The research [28] concluded that I4.0 implementation boosts manufacturing economic productivity and profitability. The results of the study [38] highlighted that I4.0 is primarily concerned with the economic aspects of sustainability, while also including growth and productivity. IT infrastructure improvements and cost reductions lead to economic sustainability [2]. The results from [21] and [39] strengthened the fact that I4.0 technologies lower operational costs, improve market share of products, and generate new business models, all of which contribute to an increase in the economic sustainability of industries.

The study from [20] highlighted that I4.0 technologies, such as industrial automation and IoT make a significant contribution to manufacturing-economic sustainability by enhancing product quality and minimizing defect rates. Applications of IoT improve the efficacy and efficiency of supply chain management by reducing inventory inaccuracy and accelerating the time to market [40]. IoT technologies could also be incorporated across the supply chain members to track order delivery and raw material quality, which improves economic sustainability [27]. Adding to that, the findings from [29] revealed that the influence of I4.0 technologies has resulted in improved production efficiency and effectiveness, improved inventory and warehouse management, and overall economic benefit of the firm. The research from [32] indicated that the manufacturing firms that use sensors in their production lines for warehouse and inventory management strengthened their economic sustainability. BDA capabilities promote economic performance by increasing the market share, decreasing the severity of penalties for ecological mishaps, cutting energy usage, and bringing in more revenue [36]. CC and BDA ecosystem promotes to communicate vital information in real time across various stakeholders, including the customers.

This could also improve the economic sustainability by allowing them to more effectively capture consumer behavior patterns and gain an advantage through a deeper understanding of client expectations and tailored strategy [27].

The conceptual framework proposed for the Malaysia manufacturing sector in the study [41], further demands to investigate relationship between I4.0 implementation and productivity. It also revealed limited relationship between I4.0 and product quality together with sustainability. It is also noted that there is a dearth of information addressing the topic of establishing economic sustainability with I4.0 in the extant literature [10, 11, 25]. The study [42] highlighted that the influence of digital technologies on sustainability in terms of economic performance is still under-investigated. The study [43] advocated that some I4.0 technologies like horizontal and vertical integration, IoT, big data, and analytics are linked to economic sustainability, but their comprehensive review is still missing. This has led to hypothesize the following:

H2a: *Manufacturing cost mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H2b***: *Manufacturing cost mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H2c***: *Manufacturing cost mediates the relationship between CPS implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.*

H3a: *Inventory control and management mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H3b***: *Inventory control and management mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H3c***: *Inventory control and management mediates the relationship between CPS implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.*

H4a: *Market share mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H4b***: *Market share mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H4c***: *Market share mediates the relationship between CPS implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.*

H5a: *Energy consumption mediates the relationship between IoT implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H5b***: *Energy consumption mediates the relationship between BDA implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.* ***H5c***: *Energy consumption mediates the relationship between CPS implementation and manufacturing performance (i) productivity, (ii) product quality, and (iii) production flexibility in the SMEs.*

The third research agenda of this study was therefore proposed to be addressed, by developing a research model for DTE implementation, EDS with its indicators and manufacturing performance as shown in Fig. 1 and by constructing the research propositions posited above.

4 Conclusion

The umbrella keyword DTE, discussed in the study, encompasses the digital technologies of the I4.0. After descriptive and content analyses, based on theoretical background, this study was aimed at exploring three research agendas, mentioned in Sect. 1. For the first agenda, study identified the indicators of economic dimensions of sustainability that are frequently reported in the extant literature. The economic indicators are manufacturing cost, inventory control and management, market share, and energy consumption. For the second agenda, study explored the influence of DTE implementation on manufacturing performance through the lens of EDS indicators. The insights of the study revealed that the digital technologies of I4.0 like IoT, BDA & CPS are repeatedly interconnected with manufacturing performance parameters, such as productivity, product quality, and production flexibility. On synergizing the above with the indicators of economic dimension of sustainability for SMEs, the literature available is scant and fragmented.

Further, findings of the study report that the influence of DTE implementation on manufacturing performance of SMEs in the context of economic dimension of sustainability has positive as well as negative comments. In the third agenda, a mediation research model was developed with the help of a theoretical background, based on descriptive and content analyses, while also describing the constructs selected and the hypotheses developed by collaborating DTE implementation, indicators of economic sustainability and manufacturing performance. In all, the study presents fifteen propositions to the research world, guiding toward the influence of DTE implementation on manufacturing performance through the lens of economic dimension of sustainability.

Future research work could be aimed at testing of the proposed hypotheses, which would add statistical robustness to the findings as well as significance to the work presented in the study. Other economic sustainability indicators, such as return on financial assets, business model opportunities, product rejection and rework costs, revenue, and profitability could also be explored in the future. Moreover, in the future, the influence of digital technologies, like additive manufacturing, cyber-physical production system, cloud computing, advanced robotics, cyber-security, and mobile technologies on manufacturing performance of SMEs could be investigated. To further bolster the sustainability goals, future research work could be carried out to establish the influence of DTE implementation on manufacturing performance in the context of environment and social dimension of sustainability.

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Automation

Automation on Industrial Monitoring System for Salt Spray Test

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Abstract Automation is crucial to any given industry because it simplifies routine tasks and reduces stress for operators. The salt water test typically takes 1000 h, or 42 days, which is a long time to keep an eye on, but with the help of automation, the testing phase can be finished in that time. A low-cost, real-time automated monitoring system for salt spray testing equipment is presented in this paper. Electrochemical sensors, solenoid valves, float switches, and contactors make up the bulk of the system's hardware. The effectiveness of the automated system, as well as its ability to withstand a severe saline environment, its energy needs, and its air supply, were all assessed. The experiments showed that automation can be useful and implemented even in companies with limited funds for purchasing new automation equipment.

Keywords Automation · Salt spray · Monitoring systems

1 Introduction

The salt spray test is used to evaluate a coating's durability in simulated ocean spray condensation. Materials' ability to withstand the corrosive effects of elements like temperature, humidity, and salt water are evaluated by conducting corrosion tests. Normalized difference in corrosion resistance between the expected and actual values can be quickly determined through salt spray testing. Even just a modest relationship can be drawn between the coating's test duration and its actual expected life. Because corrosion is a complex process, many external factors can affect it. Because of this, salt spray testing is most useful when applied to samples in order to establish a passing or failing grade and then compare the results to those expectations. This

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is typically carried out in a quality control capacity or to evaluate the efficacy of a specific manufacturing technique. The use of a sealed testing chamber allows for accurate simulation of the actual salt spray environment. A spray nozzle is used to apply a salt water solution to a sample. As a corrosive experiment stand-in, we use this thick salt water fog. Oxides are analysed for their appearance after a time period that varies depending on the product's resistance to corrosion. Oxides take longer to appear on more durable products. Certain coatings may require testing periods of up to a thousand hours.

We can tell if a material or coating is robust and long-lasting enough for our purposes by looking at the results of a salt spray test for resistance to corrosion. It is a way to test how well a product holds up against corrosion in highly salty environments. Examining the effects of saltwater and chlorides on coated metals and alloys can be done quickly with this method. The samples are subjected to a severe corrosive environment by being exposed to a dense metal fog in a sealed chamber. Standards such as IS 1981:9844 or ASTM B117-11 are adhered to.

2 Literature Survey

Li et al. [1] in their paper have discussed new trend in the building automation field is to utilize more intelligent operations and distributed control based on the multi-agent system paradigm. Logic control problems, such as If-ELSE and sequence control, become complex distributed cooperative problems when implemented in a distributed architecture. However, most research focuses on distributed optimization problems rather than the fundamental logic control problem that is a prerequisite for system implementation. The aim is to achieve an automation system such that it follows all the conditions suitable for the plant to run effectively.

The plant runs mainly on three active conditions:

1. Saltwater tank level should be maintained.
2. Demineralized water tank level should be maintained.
3. Air supply should remain constant throughout the test.

All three conditions are set for IF control, even if one of the conditions fail to meet the requirement, the plant shuts off automatically.

Demetillo et al. [2] in their have discussed about low-cost, real-time water quality monitoring system which can be applied in remote rivers, lakes, coastal areas, and other water bodies is presented. Off-the-shelf components like electrochemical sensors, a microcontroller, a wireless communication system, and the specialized buoy make up the bulk of the system's hardware. In a set amount of time, it measures the pH, dissolved oxygen, and temperature of the water. The developed prototype provides the collected data to the intended audience in both visual and tabular forms via a branded web portal and mobile phones that have been pre-registered. The buoy's reliability in severe weather, energy usage, the efficacy of data transmission, and the clarity of data presentation on the web were all assessed to ensure the system's efficacy. The experimental results prove that the system has great prospect and can be practically used for environmental monitoring by providing stakeholders with relevant and timely information for sound decision making.

In their paper titled "Research on salt spray test of power facilities based on standardized laboratory construction", Qian et al. [3] have wrote about the continuous development of electric power systems, electric power companies have standardized the requirements for safety testing laboratories for salt spray test of electric power facilities in accordance with relevant national standards and specifications, and combined with the previous work experience of electric power companies, this paper analyses in detail the laboratory-based The characteristics and significance of standardized management of salt spray test of electric power facilities under standardized construction, and also elaborated the new requirements for laboratory construction. At the same time, it strengthened training, performed competence verification and comparison between laboratories, and strict. In the aspects of good method confirmation, enhanced management, and enhanced standard dynamic management, relevant suggestions for strengthening the standardized management of safety testing laboratories in power facilities for salt spray testing were put forward. It is hoped that the test results of power facilities salt spray testing laboratories can be effectively improved and accuracy to achieve sustainable development.

3 Methodology

3.1 Selection of Parameters

Temperature—35 ± 2 °C temperature must be maintained throughout the test.

pH—6 was maintained throughout the test.

Humidity(RH)—98–100 was maintained throughout the test [4, 5] (Fig. 1).

3.2 Design and Testing

Demineralized (DM) Water Tank—DM water is water that has been purified in such a way that (most of) its mineral and salt ions are removed. It is one of the purest forms of water that is widely used for industrial testing. The purpose of using DM water in the test is to provide hot humid air to the system by mixing compressed air and creating humid environment.

Fig. 1 Salt spray test apparatus—image courtesy Evergreen Engg. Co. Ltd., Vasai

Saltwater Tank—Saltwater free of iodides is used in testing (the actual salt rocks across the seashore). The purpose of using saltwater in the test is to create a corrosive environment in the system.

Air Supply—A standard 15–25 psi compressed air inlet is provided to the system. The air compressor must be oil-free or of any outside particles to avoid any problems in the system.

Atomizer—To increase the efficiency of atomization, we designed a new atomizer using acrylic material, it has a vacuum pick-up system which will atomize even after restoration of power.

As shown in Fig. 2, the acrylic block is of 25 × 25 mm which has holes for air pipe, saltwater, and an outlet hole.

The air pipe is of dia. 1/8″ British Standard Pipe (BSP), a through hole of 1 mm and inlet of saltwater of polyurethane pipe (4 mm diameter) perpendicular to the conical thread hole where vacuum pick up takes place.

The salt spray testing apparatus as illustrated in Fig. 1 is designed in such a manner that all above parameters should fulfil the requirements salt spray test.

Benefits of Designing Atomizer for Salt Test

- No abrasion/wear and tear of any holes in acrylic material due to saltwater.
- Long-lasting (can last up to 10 years easily).

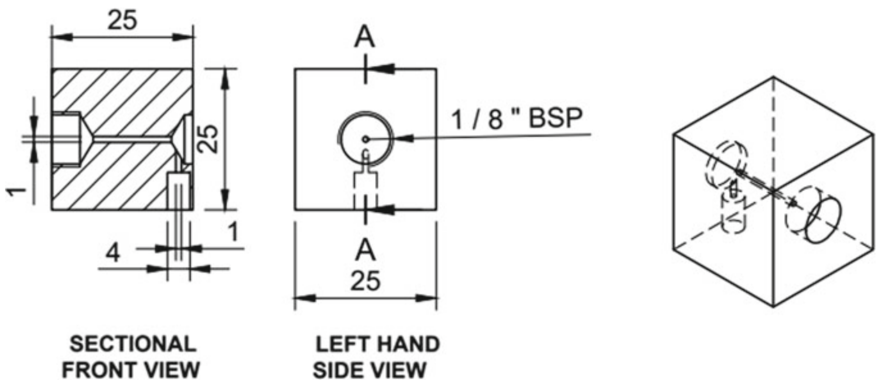

Fig. 2 Cross-section of designed atomizer

Materials Used

Heater Plates—The salt spray unit is a severely corrosive environment so the heater plates must be used of stainless steel (SS 316-food grade).

Flooring—Electrostatic discharge (ESD) flooring is to be used to protect the corrosive environment.

Light-anti-corrosive light must be used.

Block diagram in Fig. 3 represents the salt spray testing apparatus which includes all the necessary details. It is an essential to show all the, workflow and processes of the system. A block diagram makes it easier for the operator to understand the flow of processes.

This diagram gives a pictorial view of actual setup of the plant. It shows all the electrical connections, water lines, and air supply lines. Thereafter, each tank is shown along with solenoid valve connections.

Budget

Since this a low-cost automation (LCA) plant, we decided to design and install automation in-house itself.

Originally, the entire setup with automation costs around INR 2,50,000–3,00,000. Design and installation of automation in-house saved up a lot of money. The plant cost was around INR 1,00,000 and installation for automation costed us around INR 60,000–70,000.

The in-house setup also allows us to set the system according to our requirements in the industry. According to the Table 1, choosing a ready setup almost costs us double the price of in-house setup.

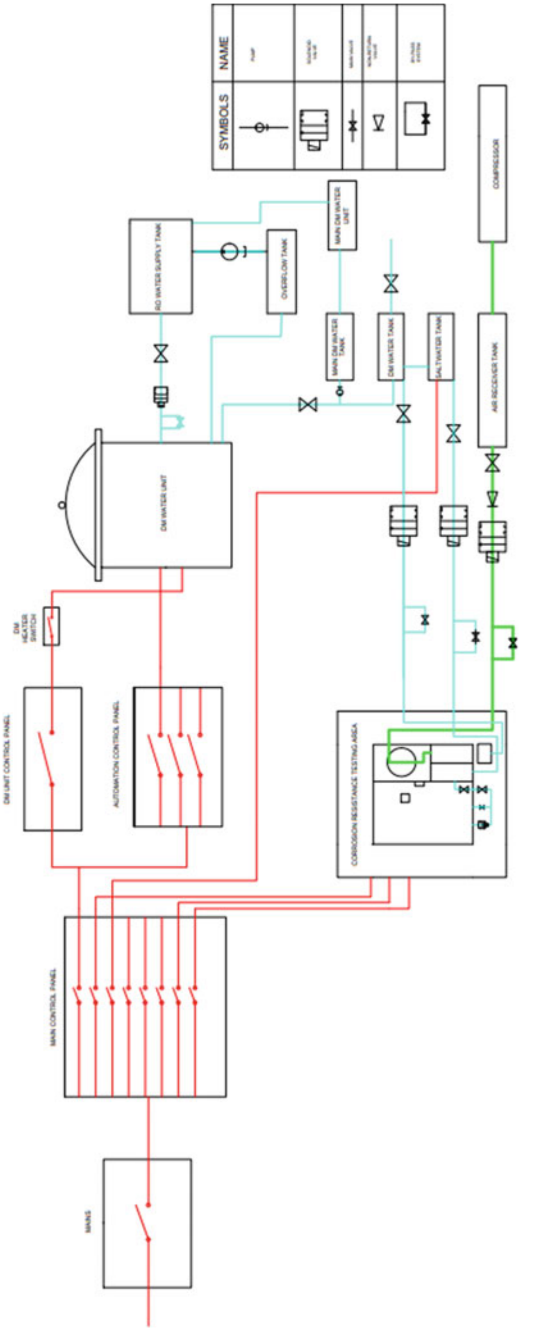

Fig. 3 Block diagram of control system of salt spray test apparatus

Table 1 Cost comparison of in-house setup v/s ready-made setup for salt spray test apparatus

	In-house setup cost	Ready-made setup cost
Installation	INR 60,000–70,000	INR 200,000*
Total cost	INR 170,000	INR 300,000*

* All figure values are approximate calculation done on basis of market rate

4 Conclusion

Thus, we can conclude that in order to run the salt spray test 24/7, it is necessary to be automated. Automation system ensures that no saltwater is wasted during power cuts. Automated plant eases the operator's job as it maintains water levels through float switches and solenoid valves. Continuous running of plant without any stoppages also ensures good efficiency of atomization. This test has designed as a low-cost automation test as it is saving around 50% of cost, but even high-cost automation could be used for more precision. Even if we purchase ready-made high-cost automation setup, but still needs to be customized according one's requirement and sometimes it may not have parameters that we need. Thus, it is better to design salt spray test in-house as it provides for easy customization along with cost saving.

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Enhancing Productivity of a Photometer Using Automation and Regression Analysis

Aayush Shah, Hari Vasudevan, and Rajendra Khavekar

Abstract A photometer is one of the main parts in a bio-medical equipment. This study was conducted to enhance the productivity of a photometer used in one such equipment, using regression analysis and automation. Installation of automated tools was carried out to reduce the wastage of time across the production line. As a result, the overall cycle time was decreased from 52 h per machine to 44.3 h per machine. A saving of $300 per machine was also achieved.

Keywords Mathematical model · Regression · Automation · Worker efficiency · Process improvement · Photometer

1 Introduction

Photometers are used to determine the intensity of light emanating from an unknown source. The basic approach in using photometers is to position the two sources, such that they illuminate two neighboring surfaces identically. Majority of the photometers use photo resistors, photodiodes or photomultipliers to detect the light. To examine the light, the photometer measures the wavelength and spectral distribution of light. Photometers in a bio-medical equipment machine use a low voltage halogen lamp, which has its own assembly. Each machine is supplied with five such lamps, which are required to be tested, before packaging [1].

Photometry is the major contributor in the field of diagnostics focused on clinical chemistry that studies light in terms of the colors experienced by the observer as a result of the physical stimulation of impinging photons into the eye and the resulting cerebral response. The trichromatic theory and basic notions like color, saturation and value are taken into consideration in photometry [2]. Accuracy of photometry is

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very important in clinical diagnostics, as it has influence on the records of the health condition of a person.

Photometer is a very important component of photometry. Enhancement of its productivity is required, so as to meet the delivery schedule as well as to reduce the overall cost of bio-medical machines used in the field of diagnostics. This study has made an attempt to enhance the productivity of a photometer, using automation and regression analysis.

2 Literature Review and Problem Definition

Christopher [3] expressed that the success in any competitive context depends on having either a cost advantage or a value advantage, or ideally, both. Today's business environments are reaching a point, where competition for survival and market share is an obligation. Finding the global economy will show that being good is not sufficient, therefore every organization really tries for transcendence, if it wants to remain in the competition [4].

In bio-chemistry, photometer uses proportionality of the color of the sample with the concentration of the parameters being tested. When a beam of light passes through the colored sample, the test material absorbs energy with a particular wavelength. By measuring the transmission or absorption, the photometer determines the sample's color. Interference filters of superior quality accurately restrict the wavelength and get high-precision measurement results. The lamp or the light source plays a very important role in the same. A minor difference can change the end result, which eventually gives incorrect readings to the consumers. Therefore, it is very important to test each lamp supplied with a photometer and enhance their productivity of the process [2].

Each process used for photometer assembly was thoroughly observed and studied. It was noticed that two processes, such as wire crimping and wire twisting needed to be focused on. It was also noted that the photometer lamp testing process was a critical process, in which the time could be reduced and overall productivity increased [5]. Wire crimping and wire cutting were two other processes, which were determined as critical processes and these were done manually. Manual crimping and cutting resulted in reduced accuracy and increased time. Hence, it was decided to find a solution for reduction in the overall cycle time of the equipment.

3 Regression Study

Simple linear regression is an effective technique for determining the connection between two continuous variables. One is referred to as the predictor (independent variable), while the other is referred to as the responder (dependent variable). It searches for statistical relationships, but not for deterministic ones [6].

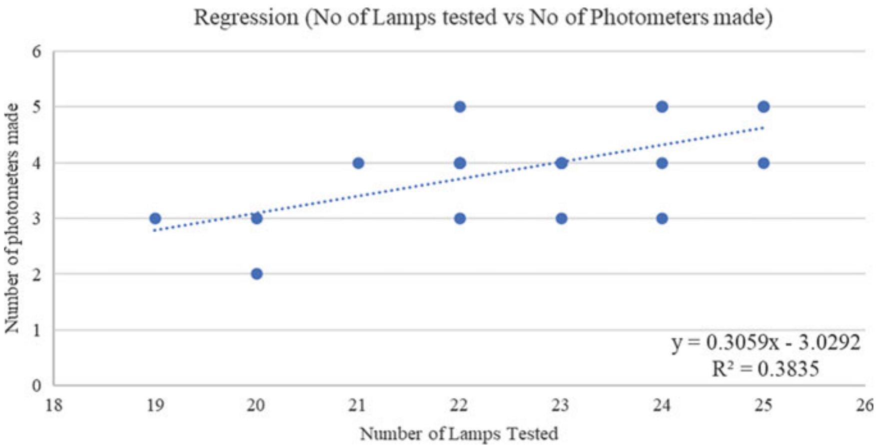

Fig. 1 Regression analysis

The fundamental concept is to find the line that best matches the data. The best fit line is the one with the smallest overall prediction error (across all data points). The term "error" refers to the distance between a point and the regression line.

It was necessary to search for key parameters, which would produce the best overall improvement and working in the electronic analyzer domain of the product. The data was collected and regression analysis was used for the estimation of relationships between the dependent variable and independent variable. In this case, number of lamps was the independent variable and the photometer output was the dependent variable. The coefficient of regression was 0.3835 (Fig. 1).

4 Development of Mathematical Model

For the lamp testing of photometer, it can be seen that the most important parameters were "gain" and the light emitted from the bulb. The photometer assembly has a light amplifier in its PCB, which amplifies the light signal and converts it into a readable output. The output in voltages and gain are further used to translate into the result of the analysis of the sample. If the amplifier gains are incorrect, that would indicate as a faulty set of reading, which is not desirable, since it risks the life of the patients. During the testing of the photometer lamps, they are required to be in the correct band of "gains", otherwise they would be rejected for faulty readings. Every machine was shipped with one lamp fitted and four spare lamps in the box. Also, as studied in the regression analysis conducted previously, it was found that the "number of lamps tested" correlated with the number of photometers produced, i.e., more the number of lamps tested, more the number of photometers built, since their testing could occur more quickly. Before this study was conducted, one lamp used to take roughly 5–7 min for the testing.

4.1 Theory

Before the study, the "gains" were obtained from the test rig after conducting a complete test on the machine. To use mathematical modeling, some electronics theory with experimentation was applied and is as follows.

Gain of an amplifier mathematically is represented as

Gain $= V_{out}/V_{in}$, where V_{out} = Output voltage of an operational amplifier (OPAMP) and V_{in} = Input voltage to the amplifier (voltage generated from the lamp).

The experiment was conducted to find the gain range of the bulbs, which would convert into a simple mathematical model and accordingly reduce the time required to test was implemented, i.e., from 5 to 7 min per bulb to 40 s.

5 Methodology

The experiment involved in the collection of data from multiple lamps by the conventional testing protocol, where it was attached to the machine. The voltages of the light emitted from the bulb by using a multi-meter and a Lux meter was then found out. Tabulated results of values for the lamps are given in Table 1.

Table 1 Analytical data

OP-Amps	OP1	OP2	OP3	OP4	OP5	OP6	OP7	OP8
BULB 1								
Voltage	2.5818	2.7125	2.5362	2.5238	2.7603	2.6639	2.8778	2.7756
Gain	525	496	457	552	499	486	492	453
Voltage in	0.0049	0.0055	0.0055	0.0046	0.0055	0.0055	0.0058	0.0061
BULB 2								
Voltage	2.3579	2.492	2.3303	2.3096	2.5182	2.4088	2.6045	2.5067
Gain	538	568	472	570	515	507	510	470
Voltage in	0.0044	0.0044	0.0049	0.0041	0.0049	0.0048	0.0051	0.0053
BULB 3								
Voltage	2.4961	2.609	2.471	2.504	2.7804	2.667	2.8732	2.681
Gain	559	528	491	593	533	524	526	488
Voltage in	0.0045	0.0049	0.005	0.0042	0.0052	0.0051	0.0055	0.0055

Table 2 Data for mathematical model to reduce the lamp testing time

Enter the lamp voltage	0.00544			
Operation amplifiers	Loss translation ratio	Input voltage	Output voltage	Gain
OP1	1.100833602	0.005988535	2.3579	393.736
OP2	1.027433936	0.005589241	2.492	445.857
OP3	0.976477655	0.005312038	2.3303	438.683
OP4	1.179473124	0.006416334	2.3096	359.956
OP5	0.968980032	0.005271251	2.5182	477.723
OP6	0.989345644	0.00538204	2.4088	447.563
OP7	0.923130388	0.005021829	2.6045	518.636
OP8	0.894213773	0.004864523	2.5067	515.302

The things that were evaluated from the entire exercise were:

1. *Input Voltage*: Necessary to determine the voltage of the light generated by the lamp using a photodiode, lux meter and LDRs. Using the same, it was easy to determine a benchmark voltage for the lamp [7].
2. *Loss Translation Ratio*: Since the current method involved direct inputs from the OPAMP, the calculation of losses and variations due to it were required for the mathematical model. A few lamps were tested and the values of individual OPAMP readings were found. It helped in finding the variation with the rated values and also in finding the loss ratio.
3. *Gains:* For a good lamp, the "gains" have to be in a range of 300–700 decibels.
4. *Loss Translation Ratio for each OPAMP*.
   The only factor, which needed to be entered was the lamp voltage and the model would then calculate the "gains" automatically. Table 2 shows the data for mathematical model to reduce the lamp testing time.

6 Implementation of Automation

Automation in manufacturing is the process of operating a factory using robotic equipment or automated machines. They are designed to reduce the time and efforts in the entire production process. Automation is strategized to replace certain repetitive processes in the production line [8].

It was planned to integrate the fully automatic crimping machine with the six facility stations available. It utilized new design concepts, so as to further increase in precision, durability as well as overall user friendliness, while also further reducing the setup time. Various configuration possibilities allowed for a variety of applications to be processed. Dynamic and powerful servo drivers combined with an intelligent control system provided high production rates to meet the most demanding production schedules. All parameters such as wire data, crimp data or seal data could be saved as well as retrieved for future use. Machine documentation including operating instructions, spare parts identification, drawings and schematics, etc., were all stored electronically in the machine software for its immediate access, as needed. The crimp tool was automated, which would do the entire crimping process automatically.

Wire twisting was another critical process that was performed on a frequent basis. This again has been a manual process and it was decided to automate this process. Before conducting the study, twisting a 1-m-long pair of wire used to take about 15–20 s and 60 m of wire to twist per machine. Hence, each machine required 20 min for twisting of the wire. Automated wire twister was then introduced and the time required for twisting of the wire significantly dropped down to 5–7 s/m. As a result, the overall time required reduced from 20 min per machine to about 5 min.

7 Conclusion

This study was conducted to improve the productivity and profitability of a photometer in a company in the bio-medical equipment arena, using a regression model and automation. Regression study helped in finding the correlation and causation between multiple factors in the given sample. The mathematical model helped in reduction of time required for testing of lamps. It was possible to reduce the cycle time per machine from 52 to 44.3 h, which saved $3000 per batch of ten machines. It also further enhanced the labors' job satisfaction in the firm and also machines were delivered as per the schedule.

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Development of IOT-Based Hybrid Helium Drone for Flight Time Enhancement

S. N. Waghmare, S. D. Shelare, N. P. Mungle, and K. R. Aglawe

Abstract Drones, also called as unmanned aerial vehicles (UAVs) which are more popular in a various industries. It is growing continually in all round the world. Today, unmanned aerial vehicle (UAV) technology is in high demand across a range of industries, from the military and the government to the private sector and the media (like tracking, monitor, surveying, watching, testing, observing, sampling, controlling, guarding, search, checking, rescue, monitoring, environmental surveillance, and entertainment). This study proposes the use of a newly developed design for a hybrid helium drone based on the Internet of Things in order to increase the drone's flying duration. The goal of this article is to use cutting-edge technology to demonstrate the viability and use of drones. In the first place, there is the present drone literature, from which we may learn about the capabilities and limitations of the technology as it is. The paper's most crucial section focuses on the drone's design, electrical system, and IoT technologies. The drone's Internet connection opens up a world of IoT possibilities. An updated design concept for a helium-assisted compound drone is proposed to extend the duration the drone can stay in the air and allow it to fly at high speeds in both the vertical and horizontal planes. The compound drone's principal design goal is to be inexpensive for the end user, and its many advantages among them ease of production and relative cheapness compared to other kinds of drones make this possible. To authenticate the effectiveness of the present design, practical experiments were conducted.

Keywords Helium drone · UAV · Drone analysis · IoT technology · Flight time enhancement

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1 Introduction

The term drone usually refers to a part of unpiloted aircraft [1, 2]. Any times mention to as "unmanned aerial vehicles" (UAVs), these crafts can move out an impressive area of tasks such as wildlife and environment monitoring [3, 4], cellular network [5], military and defense sector [6, 7], planetary exploration [8], entertainment [9, 10], and many more. Due to its capacity to hover over a specific place or area without the need of runways, drones equipped with vertical takeoff and landing capabilities have a broad range of applications [11, 12]. Because of this, certain types of drones (such quad copters) can only fly for a short period of time at a maximum speed, e.g., usually up to 20 min [13, 14], and can reach a certain amount of velocity (vertical or horizontal velocity) because of the fixed direction of propellers [15]. VTOL drones (such as quadcopter or hexacopters) use motors to generate lifting force, which uses high amount of electricity, and radio transmitter and receiver to operate the drone [16–20]. Because of the reason high performance parts required (such as bled motors, li-po battery, wireless radio module, and camera module) to make drone fly and communicate with the user, which directly affects the cost of the drone [21, 22]. Fixed-wing drones working in tandem with VTOL capabilities composite drones supported by extra lifting force and the utilization of solar-powered energy harvesting procedures are only a few of the methods used to increase the flight length, speed, and cost of VTOL drones [23–28]. As a result, the older techniques had a number of drawbacks, such as their bulk and difficulty in production owing to their special designs [29, 30]. We shall go through a few similar studies in more depth in the sections that follow, so you shall have a better idea of what research has already been done on this topic. After that, we shall describe the issue and the funding for this particular study.

Since it is having torus-shaped envelope, the "S-CLOUD" UAV built by Song et al. [31] presented little danger to anyone inside its flight radius. Envelopes made of thin polyethylene terephthalate (PET) are used for the S-CLOUD drone, which has coaxial rotor and two axis cross flaps [32, 33]. The flight controller is unique in that this UAV's flight duration is greater than that of ordinary VTOL drones, such as quad rotor, by roughly 63 min. This is a disadvantage of the design plan since the torus-shaped envelop is difficult to manufacture due to its hollow form and the aerial dynamics are very difficult for the UAV [34]. A low cost, self-flying indoor blimp was developed by Gonzalez and colleagues [35] using a 200 g plantar RC blimp. The blimp and its components were created with a smaller footprint and lighter on board gear due to its indoor usage [36, 37]. To help the blimp navigate across two distinct settings, the authors used PID and fuzzy logic controllers. Because the blimp depends on its neutral buoyancy to stay afloat, it has a smaller cargo capacity. Due to the smaller payload volume, a smaller selection of sensors could be employed in the development. In order to increase the UAV's flying time efficiency, Wan et al. [38] developed a 200.3 g solar operated blimp. Blimps are unmanned aerial vehicles (UAVs) that are low weight than air and rely on neutral buoyancy to stay afloat. Blimps have a number of advantages, including less power consumption, ease of takeoff and landing, and the capacity to fly for extended periods of time [39–41]. Using a blimp is a disadvantage since it is substantially bigger in size than a normal UAV, making blimps an unsuitable alternative for reaching caverns and other restricted areas. Blimps have limited cargo capacity and are difficult to manage because of their intrinsic sensitivity, such as to wind and temperature, to these issues. Old helium balloons for aerial photography have been used by Lonneville et al. [42]. As helium balloons have no electrical components, the device may continue to float till all the gas has been expelled. Due to the absence of control mechanisms in the helium balloon, this simple design would be uncomfortable since the balloon may readily be influenced by outer stimuli such as wind, making this design difficult. Propulsion may be produced in any direction in three-dimensional space by using numerous micro-blowers to generate a propelling force [43].

Quadcopter and hexacopter drones can hover for 20 min; however, this may not be enough time to complete many tasks that need a long term operation. In order for drones to communicate, they use radio waves on certain radio frequencies, known as bands. Hertz is the unit of measurement for radio waves, which are discrete waveforms on the electromagnetic spectrum (Hz). Devices employ frequencies ranging from 20 kHz to 300 GHz. Drones with VTOL (such as quadcopter or hexacopter) is easy to move vertically because of the propellers vertical position but bit difficult to move horizontally, while blimp can move in horizontal direction easily but it is difficult to move vertically. Conventional drones (such as quadcopter or hexacopter) needed high performance parts such as BLDC motor, li-po battery, radio transmitter, receiver and camera module, etc. Because of this reason, the overall price of the drone is increase which make them expensive for end users.

The most important objective in this research work is to working design model and build a compound drone that can fly longer while minimizing the key limitations of current drone systems. Here are the summaries of our scientific contributions.

An upper support structure supports a helium balloon in the suggested design. The tricopter will be attached to the top support structure through a connecting component. The suggested hybrid drone technology has the advantage of requiring just the bare essentials to fly. One of the advantages of the suggested design is that the components required to construct the hybrid drone may be obtained directly from marketplaces. System plan with the primary component linking the drone and balloon is what we are proposing in this study. And because the lifting force is generated by the helium balloons, helium drone can fly longer than conventional drones. To control the drone and take live video output from drone, Internet of Things (IOT) system is used. Any smart phone can be placed on the drone, which provides Internet to microcontroller and live video output to any device (such as smart phone, tablet, laptop, TV, etc.). With this connectivity drone can be control from anywhere over the Internet. While we can use sensors which are in the smart phone to do desirable work such as camera to capture HD video and images, GPS to get drones location, and many more. Most of conventional drones have fixed direction of propeller. In this project, we are using servo motors in which dc motors are directly connected to change the direction of dc motors by which drone can move vertically and horizontally with ease. This drone is getting lifting force by helium balloons, thus we need very little force to move drone from one direction to another, because of the reason the power requirement of the drone is less. For drone controls and video output, we used cell phone which can be remove after use, so the cost of the cell phone is not include in this project. After evaluating all the aspect of the project, we conclude it is more affordable than conventional drones, while provides greater flight time, connectivity, and affordability.

2 Proposed New Drone Configuration

The drone body is connected with the helium balloons by frame. All the lifting force required to lift the drone is generated by helium balloons, while propellers are used to move drone in any direction. To control the drone, android application is been developed which send data to firebase real-time database from where the microcontroller receives data and processes it. Microcontroller gives instructions to motor driver, servo motor, and termination system. As a result, the hybrid drone system's proposed design is a simple and cost effective one. As an advantage, any commercially available VTOL drones and helium balloons may be used to make the hybrid drone, rather than having to manufacture them all from scratch. This study focuses on the whole system's design, from the balloon through the drone's central component as shown in Fig. 1.

The balloon's form and size, as well as its lifting power, are documented in the study. Based on these findings, it seems that the balloon should have a certain form and shape, as well as a specific lifting force. The parts mentioned in Table 1 are required for this research work:

Each part has its function: Microcontroller is used to read data from firebase real-time database and processes it into instructions. DC motors are used to rotate the propeller by which small amount of force generated which can be used to move drone. Servo motors are used to rotate DC motor direction by which we can decide the movement of direction (vertical or horizontal). Propellers are used to generate small amount of thrust to move drone. Cell phone serves two purposed first, it provides

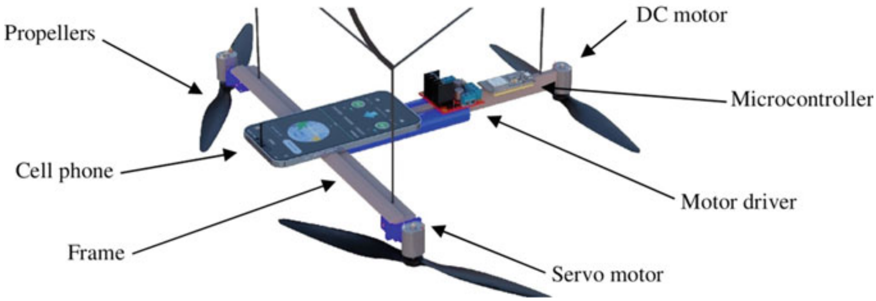

Fig. 1 Drone configuration CAD design

Table 1 Parts used in drone and their weight

Name of parts	Weight (g)	Quantity	Total weight (g)
Microcontroller (ESP-32)	9.3	1	9.3
DC motor (3v–6v DC motor)	40	3	120
Servo motor (SG90)	9	2	18
Propeller (10 in.)	10	3	30
Cell phone (any android phone)	180	1	180
Motor driver (L298N)	26	1	26
Frame (plastic)	50	1	50
Batteries (2600 mAh 18,650 cell)	45	3	135
Connecting wire, insulating tape, threads, etc. Total weight	NA	NA	50 600

live video output over the Internet, second it provides Internet to the microcontroller. Motor driver is used to operate 2 DC motors. All the parts are placed on the frame. Battery is used to provide power to microcontroller and all the motors.

2.1 Proposed Drone Connectivity

To enable seamless services and utilization, the Internet of Things (IoT) has emerged to allow physical diverse things to connect to the network infrastructure [26]. Internet of Things (IoT) is a potential answer for every part of our everyday lives since it is interoperable, distributed, and real time.

2.2 Shape and Size of Helium Balloons

There are two crucial things to consider while choosing between several helium balloon shapes as a candidate for the compound drone system: a size and shape limit and an up lifting force. Although the hybrid drone system's size restriction is dependent on the application, we employed a spherical-shaped balloon with a 36-in. diameter. It is a polyester balloon which has volume approximately 400 cm^3.

2.3 Power Requirements of Drone

Power requirement for lifting the drone in air is as shown in Table 2.

Drone is getting lifting force by helium gas and gets its motion by 3v–6v dc motor. Because of this, the power required to run the drone is less than conventional drone

Table 2 Power requirement of all the parts used in drone

Name of parts	Quantity	On load (mA)	Stall current (mA)	Total on load power required (mA)
Microcontroller (ESP-32)	1	200	600	200
DC motors (3v–6v DC motor)	3	120	730	360
Servo motors (SG90)	2	100–250	650	500
Motor driver (L298N)	1	36	NA	36
Total power required				Approx. 1100

(such as quadcopter or hexacopter). Two 18,650 cell are used with capacity of 2600 mAh to run microcontroller, two servo motors, 2 DC motors and motor driver. And one 18,650 cell with capacity of 2000 mAh is used to run third DC motor. The total capacity of all the batteries is 4600 mAh. And on load current drawn is 1100 mAh, so we can conclude the supplied power pack is good enough for 3–4 h of use.

2.4 Theoretical Analysis of Lifting Force

The most widely utilized lift gases are hydrogen and helium. Helium is heavier than hydrogen, both substantially light in weight than air. As a lightest gas in existence, hydrogen seems to be a most suitable for lifting. But it is extremely combustible, making it difficult to create in huge amounts. The second-lightest gas, after argon, is helium. Therefore, it is an appealing for lifting of gas as well. The key benefit is noncombustible gas. The following equation may be used to compute hydrogen and helium's lifting power in air: The density of helium is about twice that of hydrogen. However, buoyancy is determined by the difference in density between (gas) and (air). As may be observed from the buoyancy equation, the variance in buoyancies is thus around 8%.

All calculations are based on sea level and a temperature of 0 °C. The quantity of lift decreases with increasing altitude or temperature, but the ratio of hydrogen's lifting ability to helium's remains constant. The lifting gas envelope must have a mass of its own, which is not included in this calculation. Table 3 shows the theoretical lifting force of gas.

Table 3 Theoretical lifting force of gas

Lifting gas	Density at sea level and 0 °C (kg/m^3)	Lifting force of $1m^3$ of gas
Helium (He)	0.178	1.1115 kgf or 10.9 N
Hydrogen (H)	0.090	1.2033 kgf or 11.8 N
Air	1.292	NA

Given data:

Dia. of balloon (D) = 36 in. = 91.44 cm = 0.91 m; Radius of balloon (r) = 0.45 m. Volume of balloon (V) = 0.41 m^3; Total weight of drone (W) = 600 g.

Calculations:

Lift generated by one (36 in.) helium balloon = volume of balloon filled with helium lifting force of gas = 0.41 × 1.1115 = 0.45 kgf.

By taking purity factor of helium and the weight of the balloon into consideration, we need 2–3 helium balloons to lift the 600 g drone.

Note. Temperature of the lifting gas is considered 0 °C at sea level and density with 100% purity, in real-life values can be different.

2.5 Theoretical Flight Time Analysis

The hybrid drone is able to fly longer because of the helium balloon's lifting power. The following helium balloon flight time calculator analyzes the potential increase in flight time. Table 4 shows the variables of flight time analysis.

There are no system characteristics that are not tricopter dependent for helium balloon equipped tricopter, hence the system's t_{total} mass total remains constant. The helium balloon has no effect on any other variable. Helium balloons may minimize the flying duration, which is inversely related to t_{total}, according to previous research. So, for example, if t_{total} is cut in half, the hybrid drone's total flying duration will be increased by double. Each parameter's value for our tricopter in experiments is listed below.

m_{total} = 650 g; i average = 350 mA; P = 675 W, V = 7.4 V; C = 5000 mAh, and M = 0.8, occur in the total flight time $T_{tricopter}$ = 3600 min.

According to calculations, the helium balloon reduces the overall weight by 133 g, increasing the total flying duration by 347.9 min.

Thybrid = 5000 mAh × 0.8 × 7.4 V × 60 = 19 min.

Table 4 Variables of flight time analysis

Variable	Description
V	Battery pack voltage
C	Battery capacity in mAh
i average P	Current drawn by drone (average) Power to weight ratio
M	Battery discharge margin
m_{total}	Total mass of the hybrid drone system

By this calculation, the result come out which is about 2.62 times greater as compare to normal drone.

2.6 Experimental Results

The hybrid system weight 673 g was included the drone and the batteries as well as the support platform and the balloon the whole weight of the compound drone system may be replaced by the amount of helium in the balloon, which produces a lifting force. In order to increase the helium's lifting power, the balloon must be completely filled with helium. However, since the balloon is composed of thin polyester material, doing so might destroy it. As a result, determining the maximum amount of helium that can be pumped into a balloon while still providing a sufficient lift is an absolute need. We determined that the true balloon is filled to 94% of its total capacity, with 90% purity can result in the lifting force of 270 g. Thus, we used three to four balloons to lift the drone. By experiment this drone system in close room, we get over 2 h 10 min of flight time with stable motion. The velocity of drone is calculated based on practical experiment is approximate 20 m per seconds.

3 Conclusions

A longer flying duration for the drone was suggested in this article using an IOT-based hybrid helium system. It can be concluded from the above discussion that the helium powered drone can be used for various purposes. Because the lift force is generated from helium gas, we can use low performance parts (such as motor, battery, propeller, and frame) in drone. Drone is controlled by cell phone over the Internet. The suggested system, in contrast to current ones, is simple to construct and manage, and its size may be tailored to suit the needs of the user. The form of the balloon and the lifting force analysis were combined for the hybrid drone system. The flight time calculator is supplied, potentially ensuring that the compound drone system can fly additional than three to four times longer than the traditional system. For the future research on this topic, many thing can be improved such as by creating the custom board which can work as a microcontroller and motor driver. By this the power requirement and weight of the drone will reduce. Now day's phones with reverse charging are capable of powering the low power drone without any external power supply, with this approach the cost and the load of the drone will reduce significantly.

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Operational Logic for Electronic Continuously Variable Transmission Using PID Control

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Abstract In order to abstain from expensive and complicated conventional transmission devices and to reduce mechanical inefficiencies and energy losses, while still improving the performance further, an electronic continuously variable transmission is seen as an alternative solution. The actuation logic for such a transmission device is discussed in this study. Force analysis of the custom CVT model has been discussed in depth, and further equations were derived as part of the study. The logic made use of custom-derived CVT equations, coupled with a PID controller. A code has been developed for the same through testing, which could be used to realize the actuation in a physical setup. Based on the results, it was evident that the results obtained align with the expected results, thus tuning the CVT optimally throughout the lifecycle.

Keywords Electronic CVT · Force equations · PID control · Python code · Tuning · Force analysis · Transmission systems

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1 Introduction

The control systems have always been crucial to optimizing the conventional mechanical components in the view of today's changing and automation driven industrial world. Amongst all of these control systems, no other system proves to be as versatile and robust as the proportional integral differential (PID) control system. The benefits obtained with a PID controller is difficult to match. It can ensure satisfactory performances, that too with a simple algorithm. The PID controller is also known as three term controller—the proportional (P), integral (I) and derivative (D). The desired system performance can be achieved by adjusting these variables appropriately. This procedure is known as controller tuning. There are a lot of tools, methods and theories around tuning of the PID controller. However, finding optimal parameters for the PID controller is still an intriguing task. In practice, still the trial-and-error method is used for tuning process by the control engineers [1]. The controller can provide optimized control performance and minimal error performance with optimum tuning of the three parameters in the controller algorithm. The standard mathematical representation of a PID controller algorithm is shown in (1).

$$G_{\text{PID}}(s) = K_P\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{1}$$

where $G_{\text{PID}}(s)$ is the controller transfer function, K_{P}—Proportional gain, T_{i}—Integral time and T_{d}—Derivative time.

In this study, a PID controller logic was used to perform the tuning and continuously optimize the operations of the electronic continuously variable transmission (E-CVT). The PID was programmed to ensure that the engine RPM remained at its power peak and it achieved this by varying the reduction ratio of the E-CVT, based on the information it receives from various sensors in the subsystem. The constants of the PID logic were adjusted based on the characteristic performance desired from the E-CVT.

A continuously variable transmission (CVT) is a type of automatic transmission that provides a continuous range of gear ratios as opposed to other transmissions that provide a fixed number of gear ratios in distinct steps. These characteristics of a CVT with optimal tuning may allow the engine to operate at its power peak, while the vehicle moves at varying speeds. A CVT achieves this continuous gear ratio flexibility by using two opposing pulleys with a belt that runs between them. One pulley is connected to the crankshaft, while the other pulley transmits power to the driveshaft and wheels. The sheaves of the pulley move closer and further apart, which results in the belt moving up and down the two pulleys' sides. This radial movement changes the diameter of the belt, which changes the gear ratio depending on the power requirement. These changes happen continually as the car moves. The CVT can be tuned to ensure that it engages at the torque peak of the engine and it starts shifting out at the power peak of the engine. This will result in the engine staying at the power peak, resulting in maximum acceleration. The tuning of a mechanical CVT depends on various factors, such as the roller weights, ramp angle, primary spring stiffness in the primary pulley and the helix angle and secondary spring stiffness in the secondary pulley.

After looking at the various research papers available, it was found that the generic tuning equations available were very superficial. Detailed equations considering various approaches were lacking. Hence, this study was chosen, so as to derive detailed CVT tuning equations with the constraints, involving engine RPM instead of the general tuning equations involving the feedback from the ground. Doing so has resulted in simplification of the tuning process, making this approach more accessible and serviceable.

2 Literature Review

A lot of researchers have so far conducted various studies, concerning the CVT equations, but none of them cater to the need of E-CVT actuation. An extensive review of the papers was done to understand the fundamentals of CVT working and equations, so that it would be feasible to derive CVT equations for the aforementioned need. Crosby et al. discussed [2] the mathematical modelling for CVTs, which helped to understand the actual working of the CVT. This provided a strong understanding of the mathematics, which takes place during the operation of such a complex system. Aaen's deductions [3] helped to analyse the working with different perspectives, thus adding to the breadth of methodologies for mathematical modelling. [4] gave the detailed information regarding the CVT rolling friction actuation mechanism, which helped in determining the variables for the mathematical modelling.

Based on the above, equations proposed in the paper were derived. Various different methods were explored by authors [1, 5–7], ranging from modern methods, like genetic algorithm and particle swarm optimization to the conventional ones, like fuzzy logic and PID controllers. Upon further deliberation, PID was chosen for the control logic, which would contain the derived CVT equations due to its robustness. Studies, such as [5, 6] have thrown light on different conditional logics that could be applied and this helped in developing the controller logic used in the study.

3 Methodology

3.1 Force Analysis

There are two types of approaches for obtaining the equations for efficient performance. Both, energy balance or force balance equation methodology could be used as given in Fig. 1. The force balance methodology was used to design the equations for tuning in the study. The clamping force required to prevent slippage in V-belts

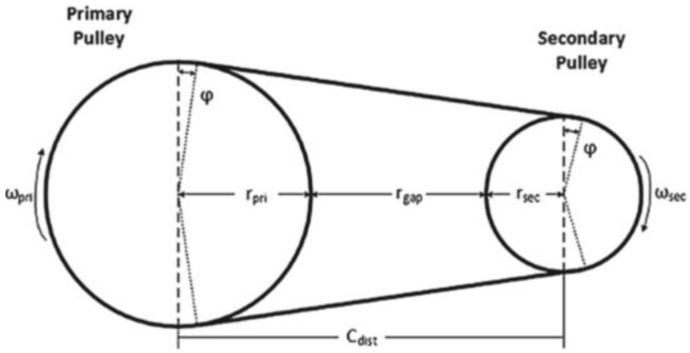

Fig. 1 Energy balance variables

was given by the Euler–Grashof's theory related to V belt. Taking this into consideration, the functional $Z(\text{th}, T_v)$ was applied alongside the contacts on the expression depicting the clamping force [2, 3]. To calculate both primary and secondary sheaves (Z_a and Z_b), the function $Z(\text{th}, T_v)$ could be used.

The axial force exerted by the cam on the secondary sheave was given. Here, for the secondary spring, the twist angle is denoted by delb and the torsional stiffness of the spring is denoted by k_b. C_a and C_b represent the torque in the primary and secondary sheaves, respectively. The tensions on the tight and slack sides of the belt are represented by T_1 and T_2. The stiffness of primary and secondary springs was given by k_1 and k_2, respectively. Force balance equations mentioned below are referenced from the work of Aulakh [5].

$$Z_a = \text{th}_a \tag{2}$$

$$Z_b(\text{th}_b, T_v) = \text{th}_b + \frac{k_1 - k_2}{p - k_2} * \frac{1}{2\left[\frac{\sinh(\Omega \text{th}_b)}{\Omega} - \text{th}_b\right]} \tag{3}$$

$$k_1 = k * \frac{\tan(\alpha + \Phi)}{\tan(\alpha)} \tag{4}$$

$$k_2 = k * \frac{\tan(\alpha + \Phi)}{\tan(\alpha)} \tag{5}$$

$$k = 0.8 * \left(\frac{\text{Rb}}{\text{Rb1:1}}\right)^2 \text{Rb1:1 is Rb at } T_v = 1 \tag{6}$$

$$p = \left((1.5 - f * \tan\alpha)^2 + 2 * k\left(1 + \frac{f}{\tan\alpha}\right) - (1.5 - \tan\alpha)\right) \tag{7}$$

$$\Omega = \frac{\sqrt{((k_1 - p) * (p - k_2) * \cos(\alpha + \Phi) * \cos(\alpha - \Phi))}}{p * \cos\Phi} \tag{8}$$

$$C_a = (T_1 - T_2) * \text{Ra} \tag{9}$$

$$C_b = (T_1 - T_2) * \text{Rb} \tag{10}$$

$$\omega = \sqrt{\frac{\left\{\frac{[(\text{kb}*\text{delb}*\tan\delta)*2*\tan\alpha*\text{za}/\text{zb}+\text{Ca}*\text{ka}]}{2*\tan\propto} + \text{ka}**\text{xa}\right\}}{m*r*\tan\theta}} \tag{11}$$

In addition to the above force analysis, the below equations were implemented in the logic and were derived from the above set of force equations

$$r_{\text{primary}} = r_{\text{min - primary}} + \left(\text{LBW} - a_{\text{p}}\right)/(t*\tan 14) \tag{12}$$

$$\begin{aligned} L = {} & \left(r_{\text{primary}} + r_{\text{secondary}}\right)*\pi + \left(r_{\text{secondary}} - r_{\text{primary}}\right) \\ & *(2*\sin-\left(\left(r_{\text{secondary}} - r_{\text{primary}}\right)/A\right) \\ & + 2*\left(A_2 - \left(r_{\text{secondary}} - r_{\text{primary}}\right)^2\right)^{1/2} \end{aligned} \tag{13}$$

$$r_{\text{secondary}} = r_{\text{min,secondary}} + (\text{LBW} - a_{\text{s}})/(2*\tan 14) \tag{14}$$

Here,

$r_{\text{min,primary}}$	Minimum radius of primary sheave.
$r_{\text{min,secondary}}$	Minimum radius of secondary sheave.
LBW	Lower belt width.
A	Centre to centre distance.
a_{p}	Primary axial distance.
a_{s}	Secondary axial distance.

4 PID Implementation

The PID control loop logic was developed by taking into consideration the above force analyses. The code aimed to provide the actuator motor with the target axial distance, up to which the actuator moved, in order for the CVT sheave to move and obtain the optimal gear ratio pertaining to the situation.

Initially, the PID variables were declared with random values, then the sensor data from the sensors mounted on the primary sheave and secondary sheave were inputted. Before applying the equation for PID, a target of 3600 was set for the primary and secondary sheaves, which set the RPM for the maximum power from the engine for the engine under consideration. This RPM value could be obtained from the power curve for the engine under observation, respectively.

PID equation was applied on the sensor data input from the primary and the equation is as given below

$$\begin{aligned}\text{PrimMotorVal} = \text{PrimMotorVal} + k_1 * \text{PrimError} \\ + k_2 * \text{PrimErrorSlope} + k_3 * \text{PrimErrorArea}\end{aligned} \tag{15}$$

where

K_1	Proportional gain.
K_2	Differential gain.
K_3	Integral gain.
PrimError	Error value.
PrimErrorSlope	Derivative of error.
PrimErrorArea	Integral of error.

PrimMotorVal was the optimized motor value obtained after going through the PID loop. The K_1, K_2 and K_3 were decided based on various iteration runs in various conditions. Furthermore, keeping these variables user defined, provides a flexible approach to problem under observation. Thus, in future, if an altogether different situation arose, then there is scope of optimization by changing the gain values. After the gains were defined, various other parameters pertaining to the PID equation were found and then calculated and plugged into the equation, in order to optimize the RPM values of the CVT sheaves. Based on the values of the primary sheave, the secondary pulley RPM requirement was calculated again to formulate using a relation between the primary RPM belt length and secondary RPM. Thus, the optimized values of the RPM at every instance of the operation were calculated.

The PrimMotorVal generated was further processed by inputting it to the Eqs. 12, 13, 14 where, using the PrimMotorVal, a_{p} was calculated to obtain r_{primary} as all other variables were either constants or could be fixed with respect to any given system.

Equation (13) was operated under a while loop condition until $r_{\text{secondary}}$ was less than or equal to 100 starting from 50, with increments of 0.001, so that maximum cases could be evaluated, while keeping the system as dexterous as possible for real-time tuning. The value of $r_{\text{secondary}}$ on which the RHS becomes one, the loop would break and then that value of $r_{\text{secondary}}$ would be considered as input for the third equation.

Finally, in Eq. (14), the secondary axial distance would be obtained after inputting the value of $r_{\text{secondary}}$ from the second equation.

The PID implemented could be strengthened by implementing SPO, GA, ACO technique, which would initially require a lot of data to produce very accurate results in the later stages.

4.1 Programme Code

Python code for the proposed methodology of the PID control logic for the operation of the E-CVT is as given below.

```
import time
import math


e = 50
l = 890
z = 500
rSec = 0
# Change these values only
primValue = [2600, 3400, 2900]
dt = 1000
PrimTarget = SecTarget = 3600
k1 = 0.5
k2 = 25.0
k3 = .00001


PrimError = PrimErrorArea = PrimMotorVal = 0
n = len(primValue)
for i in range(0, n):
time.sleep(1.0)
PrimActual = primValue[i]
PrimErrorOld = PrimError
PrimError = PrimTarget-PrimActual
PrimErrorChange = PrimError-PrimErrorOld
PrimErrorSlope = PrimErrorChange/dt
PrimErrorArea = PrimErrorArea+PrimError*dt


print(f'For iteration {i} :')


PrimMotorVal = PrimMotorVal+k1*PrimError+k2*PrimEr-
rorSlope+k3*PrimErrorArea
print("Prime Motor move this many degrees: " + str(PrimMotorVal))
ap = PrimMotorVal*5/360
rPrime = 19.05 + ((14.44-ap)/0.498)
e = 50.0
while e <= 100:
dummy    =    rPrime*(math.pi-(2*math.asin((e-rPrime)/z)))    +
e*(math.pi +


(2*math.asin((e-rPrime)/z)))     +     2*(math.sqrt((z**2)-((e-
rPrime)**2)))
e = e + 0.0010
if dummy == l:
rSec = e
print(rSec)
break
```

```
as1 = 44.0297 - 0.498*rSec
print(str(as1) + "In radians")
print(str(ap) + " in Radians")
SecMotorVal = 360 * as1 / 5
print("Prime Motor move this many degrees: " +
str(SecMotorVal))
print("Prime Target: " + str(PrimTarget))
print("Prime Actual: " + str(PrimActual))
```

5 Results and Discussion

Using the approach mentioned in this study, equations for tuning of the CVT have been derived keeping the engine RPM as the constraint. This has resulted in more detailed and simplified tuning equations (Fig. 2).

An acceptance criterion of 85% accuracy was set and based on the results obtained, it can be seen that the accuracy is approximately 90%. Therefore, within the given constraints, the tuning logic mentioned in this study was performing, as desired.

Therefore, the main aim, i.e., to obtain the axial displacement based on suitable RPM was achieved and in addition, the data collection of axial displacement and RPM was done. This could be used to analyse the CVT design and further improve it to enhance the performance as well as for visualization purposes. The data collected could help in optimizing the sheave design as well as parameters like shift out time and total axial travel of sheave throughout the power curve of the engine.

Furthermore, the constraints of this particular modelling could be eliminated on further research and testing. Reducing the constraints could also help in creating a generalized model of the E-CVT, which could then be tuned according to the need. On perfecting the PID controller, particle swarm optimization, ant colony optimization or genetic algorithm could be merged to optimize the controller, further.

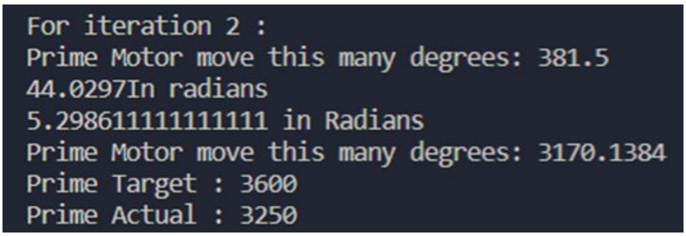

Fig. 2 Result obtained on running the code

6 Conclusion

The results of the study show that it helped in arriving at more detailed and simplified tuning equations. The acceptance criterion of close to 90% accuracy being achieved showed that, within the given constraints, the tuning logic mentioned in this study was performing, as per expectations.

The main aim of the study, i.e., to obtain the axial displacement, based on suitable RPM was achieved and additionally, the data collection of axial displacement and RPM was also done. The study also found that reducing the constraints could help in creating a generalized model of the E-CVT, which could then be tuned as per the requirements.

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Smart Social Distancing Robot for COVID Safety

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Abstract Social distancing plays an indispensable part during the ongoing pandemic. In this period, maintaining social distancing standards between people has turned into essential insurance to dial back the spreading of COVID-19. We present an original technique to recognize matches consequently of people in a jam-packed situation individuals do not maintain the social distance restriction, which calls for about 3 ft of space between them. This project assists in restricting the spread of the coronavirus by noticing the distance between disease-spreading people. Presently, it is absurd to expect to station an individual 24 × 7 at each line to screen social separating distance violations. For instance—banks, public offices, malls, schools, theatres, and so forth typically see long lines for hours consistently. To ensure social distancing in lines, this robot aids in monitoring the social distancing. Accordingly, this robot aids in maintaining the social distance between the crowd in a public environment to assist and forestall the spread of the virus. This robot serves to be an economical solution in public places where the gathering of people is significantly high. With appropriate obstacle detection, and crowd monitoring the official are also kept updated due to the Wi-Fi and IoT technology incorporated into a robot. This robot is expected to serve as a good solution in this pandemic time.

Keywords COVID · Social distancing · Sensor · Robot · IoT · Wi-Fi

1 Introduction

The virus caused by the coronavirus. Before the outbreak began in December 2019 in Wuhan, China, this virus and its symptoms were unknown. The consequence of the COVID virus leads to massive loss of human beings all over the world and creates a public health threat [1]. SARS is an important element in the discovery of

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COVID. The virus that causes COVID-19 and the one that resulted in the epidemic of the respiratory syndrome (SRAS) in 2003 are genetically close, but they infect and disseminate in the body in quite different ways. SARS was more hazardous than COVID-19, but it is less infectious [1, 2]. We can identify the infected person by symptoms observed in them. These symptoms are divided into several categories, such as follows: The usual symptoms include cough, fever, loss of taste, fatigue, and smell senses. Symptoms include a headache, sore throat, pains, diarrhoea, and red or irritated eyes. Breathing problems reduced intake of oxygen, vocal cord damage or mobility, and chest pain are all red flags [3, 4]. This virus transmits or spreads among the public like:

- Person-to-Person: By touching and other human activities.
- Droplets or Aerosols: when we will cough, and sneeze at a time few droplets are spread in the air and the droplets may be consumed by other people and may lead to infection.
- Airborne Transmission: The virus will allow in the air for a few hours so we can also breathe that air it may be a chance.
- Surface Transmission: Touching the surface in public places.

We can prevent coronavirus transmission by having a few safety measures in public places especially if they are infected such as cough, fever, etc., to COVID direct droplet contact. Avoid physical contact like handshakes, touching each other psychically. Avoid touching surfaces wearing masks, using sanitizes, and maintaining a safe distance [5]. After years of struggle with COVID-19 and extensive research, vaccines are developed by authorized pharmaceutical organizations with the help of doctors, scientists, and researchers to fight against the coronavirus. It is also aimed to improve immunity because even though we have perfect vaccination, we cannot estimate that everyone will be immune to the virus attack after having a double dosage vaccine. So to prevent unnecessary transmission of COVID-19, we must maintain social distance in public places. It is critical during the current epidemic because it aids in the management of disease spread by measuring the distance between disease-spreading persons in often visited places such as banks, public offices, malls, schools, theatres, and so on.

Every time it becomes difficult to remain or maintain the social distance and this demands the need of someone else to be present to control the crowd in public places such as security guard or police personnel. So, this kind of activity on a broader basis demands more manpower in public and it is also complicated since they also need to remain safe and get protected from virus transmission. It is no longer possible to station a person at each queue 24 h a day to monitor infractions of social distancing. On basing these issues and problems, this work provides a solution through a smart social distance monitoring robot which can maintain crowd in a perfectly aligned mannerism. Robots may also decrease manpower though we just have to compromise the initial expenses of setting it up it offers multiple beneficiaries in terms of efficiency, accuracy, maintenance, and reduced manpower and it is especially not prone to any sort of infections and disease transmissions [6, 7]. A robot is a combination of an embedded system and an AI-based application. Embedded systems are made up of computer-based software and hardware and other elector-mechanical components that are assembled to execute a particular process. It is a stable, real-time, software-driven, and microcontroller-based control system that operates via a network. Vijay et al. [8] present an IoT-based social distancing and monitoring robot which helps in monitoring the distance among the members in a queue to keep the public safe from several virus transmissions especially more helpful during the COVID-19 pandemic. It consists of four wheels, and it follows the principle of line following technique. The distance between two people is measured using an infrared sensor and an ultrasonic sensor. If there is a shorter distance between the members, a buzzer buzzes to alert the people and the camera captures the picture for the proof and sends it to the police and health sector authorities [8]. Karaman et al. [9] present a prototype of an AI network-based smart camera system, to use a bird's-eye perspective to track the distance between two people. To recognize persons in video sequences, researchers used the "MobileNet SSD-v3," "Faster-R-CNN Inception-v2," and "Faster-R-CNN ResNet-50" models. The final output, which is developed on the R-CNN model, is an embedded system which is integrated that uses the camera to measure social distance [9]. Surya and Yarlagadda [10] described an affordable AI-based smart device for detecting the COVID-19 pandemic and alerting on social distancing, which uses AI technology to keep two people at a six-foot distance. This smart device can be worn as a wristwatch in the hand. By estimating the distance between two persons on its measurement frames, a passive infrared sensor is crucial for seeing when two people are getting closer to one another. This watch consists of two major components: an IR sensor for the detection of moving persons and a PIR sensor to record the captured measurements [10]. Siddiqui et al. [11] presented (IoT)-enabled social distancing design which aids in social spacing activities and management of the COVID-19 epidemic IoT-based devices rely heavily on digital technologies. In the event of a pandemic, IoT architecture facilitates social distance. The architecture includes usual IoT-based cases for COVID. By taking the help of the proposed IoT system, the authors also developed a long- and short-term strategy for managing the physical boundaries of public space. The authors also discussed the numerous issues that each layer of architecture presents, as well as strategies for dealing with them [11]. Fedele and Merenda [12] presented a system that uses multi-sensor data to regulate crowds and unnecessary acts in public spaces for physical distancing and emergency management [12].

Fazio et al. [13] presented a COVID-19-fighting proximity-based indoor navigation system this IoT system mainly avoids the crowd in indoor environments and makes a social distance among the persons. This system's technical contribution is the latest proximity-based map-reading system that determines users' positions based on information provided by beacons [11].

2 Methodology

A robot is an embedded system that combines hardware and embedded software along with electromechanical components, to execute a particular task. An embedded system consists of a microcontroller-based hardware module which is an interactive control system that is an independent network interactive that operates on a variety of physical variables and settings. The proposed system consists of Raspberry Pi, rectifier, regulators (Voltage regulator 7805, LM25767), resistors, filters, DC motors, camera, ultrasonic sensor, IR sensor, wheels, robot body, connecting wires, motor drivers, NOOBS software, battery, display, Wi-Fi module, buzzer, and LEDs as shown in Fig. 1. The developed robot system consists of four wheels which help in the movement of a robotic vehicle. This robot uses the principle of line following technique to move along the queue to maintain social distance in public places. It uses an IR sensor to detect the line to travel along the queue for the easy identification of obstacles from a fixed distance. The detection of the obstacles is done by ultrasonic sensors and the distance between two individuals can be determined by the robot. If the distance between the two individuals is more than 3 feet, then the buzzer buzzes and a message will be displayed on the LCD to alert the public that they are not in the proper social distancing and the camera sends the picture to the officials to inform them of the breach so that disciplinary action can be taken right away. The entire system is connected to a small pocket-sized computer known as Raspberry Pi which has similar properties to a CPU of a computer. The Raspberry Pi board consists of many input and output ports. Raspberry runs on the new out-of-the-box software (NOOBS) which was specially designed for the Raspberry Pi to programme and operate.

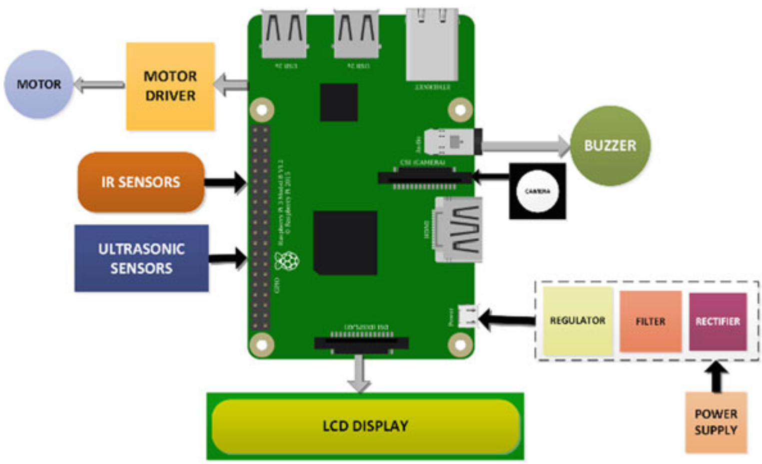

Fig. 1 Proposed system block diagram

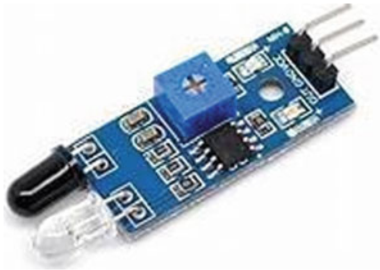

Fig. 2 Infrared sensor module

2.1 Path Detection

The robot consists of an IR sensor which helps in obstacle detecting as shown in Fig. 2. An infrared sensor module is composed of three parts: an infrared transmitter, an infrared receiver, and a circuit that controls the overall system. A LED in an IR sensor is usually used as an IR transmitter, and an IR detector is either a photo diode or a photo transistor. The comparator IC is present in the control circuit. The IR sensor in robot uses the line following principle along the queue. It moves on the line we provide it follows the line following technique. The IR sensor is externally connected to Raspberry Pi. This sensor passes the data to the Raspberry Pi using which it can control the robot wheel with the help of motor drivers.

2.2 Distance Sensing and Obstacle Detection

The ultrasonic sensor was in connection with Raspberry Pi as shown in Fig. 3. One or more ultrasonic transmitters, a receiver, and a control circuit make up this sensor. The transmitter sends out a high-frequency ultrasonic wave that bounces off any hard surfaces in the region. Some part of the noise is reflected and detected by the receiver on the sensor. The control circuit then manipulates the timing difference between the broadcast and received signals using the returned signal. The distance between the robot and the object is then estimated using this time difference, as well as some calculations.

2.3 Maintenance of Social Distancing

The IR and ultrasonic sensor both are assembled on the Raspberry Pi for the proper functionality of the robot. As we know that IR sensors predict the path for the robot to travel and ultrasonic sensors determine the presence of persons, the robot is programmed such that 3 ft of distance are maintained between every consecutive person, this distance is measured by the IR sensor for ultrasonic sensor. If the distance

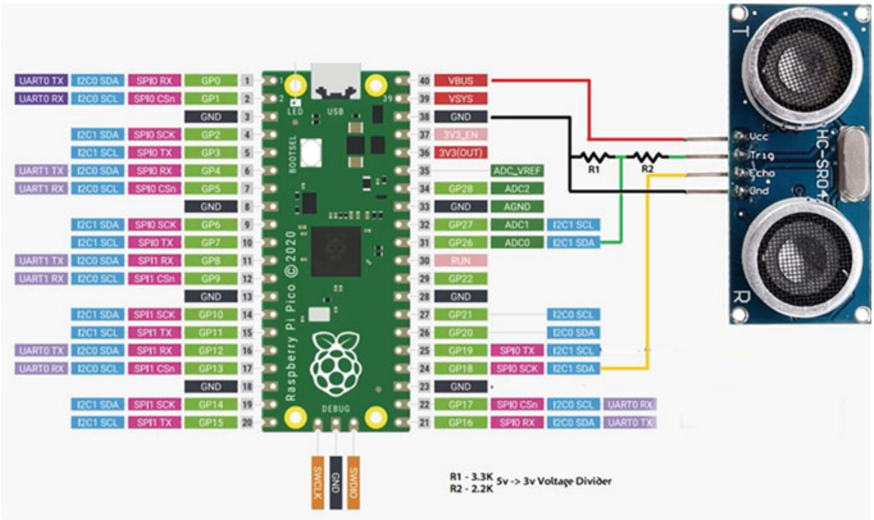

Fig. 3 Ultrasonic sensor connected to Raspberry Pi

between the two individuals is less than 3 ft, then the buzzer buzzes, the LCDs a message to the public to intimate and alert the public and at the same time, the camera captures the picture of the person and sends it to the higher authorities for the quick action on the public to be safe from the virus spread. The entire embedded system is developed on the Raspberry Pi board. It is a sophisticated tiny device that allows people to do experiments with computing. Users can programme using scratch and Python software.

2.4 Movement of the Robot

The motor drivers on the Raspberry Pi are essential parts of robot manipulation. The L293D is a double H-bridge motor driver integrated circuit. Motor drivers act as an amplifier of current because they transform a minimal current control-able signal into a higher-current-able signal. This large current signal is used to rotate the motor. L293D has a built-in H-bridge driver's circuit. DC motors will be driven in two ways onward and directions simultaneously in the common operation mode. The motors can be controlled by input logic at pins 2 and 7, as well as pins 10 and 15. If input logic 00 or 11 is utilized, the relevant motor will be halted. The robot is moved by a DC motor, which is controlled by a Raspberry Pi application.

2.5 Software for Robot

The Raspberry Pi 2 uses the NOOBS software to handle the process easily without delay, other software is also supported in it but it may lead to a delay in the process. NOOBS stands for "new out-of-the-box software," and it is a simple operating system installer for the Raspberry Pi. After installation of the software, the user can observe a lot of applications and the user must choose Python by clicking the menu option to programme the Raspberry Pi accordingly.

3 Results and Discussions

3.1 Hardware Model of the Robot

A four-wheel design mechanism is employed to operate the robotic vehicle in the robot. It uses a line-follow-up approach to keep up with the queue and keep an eye out for violations of social distancing. The infrared sensor traces the black line on the floor and signals the controller so that the motor rotates in a forward path and the robot moves over a straight-line track. This helps in ensuring that it can stay on a fixed path and monitor the over-crowding of people by maintaining social distancing. All the elements when combined resulted in the hardware model which are depicted in the following Figs. 4 and 5. The detailed parametric values of the design are not disclosed since the study is still being extended.

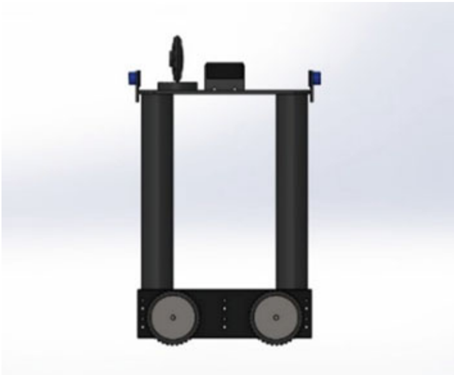

Fig. 4 Robot view from the side

Fig. 5 Developed hardware model of the robot

3.2 Obstacle Detection

The robot utilizes IR sensing to move along with the queue to identify violations. The system is now embedded with an object-detecting ultrasonic sensor to detect obstacles in the robot's travelling path. Any obstacles present are then detected so that the robot's path is not affected. The robot uses one more ultrasonic sensor to identify the distance between two individuals in a queue. It calculates the distance using the speed-time formula and triggers the microcontroller. If any two individuals are found within three feet of one another, the system immediately buzzes a buzzer and sends an alert to notify them of the violation. The police officials can then be notified to monitor and check the over-crowding which will be beneficial to avoid the virus from spreading.

3.3 Crowd Control Alerting

Also, the robot can send alerts of these violations along with an image snapped by a camera of the robot using Wi-Fi over the IoT platform to intimate the higher authorities/head office to intimate them about violations with proof so instant disciplinary action can be taken. The higher officials can arrive at the location with proof and aid in controlling the crowd with safety action (Fig. 6).

Fig. 6 Robot internal circuits

4 Conclusions

This robot used in this study assists with forestalling the spread of the virus. To guarantee social distancing in lines, this project aids in social distance checking since people will unfurl the infection before they handle it, they are wiped out. It becomes essential to remain at least six feet distant from others; however, they are not showing side effects of the virus. Social distance is particularly significant for individuals who are at an expanded chance of overcoming COVID-19. In this aspect following and social distance robot, using the help of an obstacle detection unit the distance between individuals and the breaking point of the advancement of viral diseases, particularly where social distance is a significant element. This project is suggested to be utilized in all lines of banks, government offices, shopping centres, theatres, and so on. Later, we can naturally apply for what's to come with the assistance of AI, PC vision, thermal imaging, and ultrasound innovation.

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Simulation of Hybrid Energy Systems Using Historical Meteorological Data of Location

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Abstract The renewable energy forms the alternate option to conventional power generation based on fossil fuels owing to limitations in availability and polluting nature. This study on hybrid energy generation strategy with solar and wind energy highlights on functional aspects of site/device selection, operational feature of MPPT to improve efficiency that reduces energy costs. The hybrid renewable system though less efficient than conventional system offers advantages of zero fuel cost and environmental benign nature. The hybrid model developed in MATLAB/Simulink takes input in form of climate and load parameters to develop strategies that maximize net energy gain. The solar irradiance, daylight hours, temperature, wind speed and geographical parameters constitute inputs to evolve operating strategies for hybrid system. The results obtained from the model deceits the effectiveness of the model. Weather prediction is done using genetic algorithm to predict cloud coverage of Hubballi location. The dataset is selected for 6 months and fitness of the model is found up to 85%.

Keywords Hybrid energy systems · MPPT · Simulation

1 Introduction

Energy is the vital factor that evolves congenial habitat on earth, upholding financial growth and personal satisfaction of citizens. The present energy drawn from existing fossil fuel sources has significant impact on current and future generations owing to

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loss of natural equilibrium and wellbeing both locally and globally. Today's energy scenario shows marked growth in demand for electric power and over-exploitation of fossil fuels. This has significant ecological effects leading to ozone-depletion and associated climate change phenomenon. The quest of clean energy sources worldwide has been the prime agenda of all member countries under United Nations as a measure to mitigate the onerous climate change. The eco-safe electric power based on solar, wind, hydro and biomass hold promise as future source owing to sustainable nature. The characteristics of renewable energy make it necessary to blend multiple resources that can improve reliability of power generation. The strategy is referred as hybrid power generation and can meet the requirements of growing power generation. The climate dependent renewable energy requires appropriate power conditioning to make it compatible to real-time load. During day period higher solar radiation, the solar contribution is high and compensated by wind during night hours when solar contribution is zero. Contrarily, during spells of high wind, climate turns shady with lower solar irradiation, thus the constituents of hybrid energy system ensure a steady supply of power. The solar power is prominent during summer and wind energy dominates during winter period since it is windy. Therefore, this ensures suitable power correction on seasonal as well as diurnal changes.

2 Literature Survey

The reported literature on hybrid energy system highlights various technological interventions that make reliable power. Martins et al. [1] have adopted MPPT based on reading system temperature to initiate panel cooling system. The study adopts simulation route to compare conventional system with MPPT enabled SPV system. The study revealed advantage of adopting solar energy as a part of hybrid power generation [1]. Aditi et al. [2] reported on stability of hybrid system and controllers to regulate output through fuzzy logic and facts. The classical fuzzy data was used to reduce output harmonic and improve power quality [2].

Zhang et al. [3] used 52,500 data points of wind for predictive deep Boltzmann machine with bottom-up approach yielding results 10% more accurate than traditional methods [3]. Kumar et al. [4] highlighted innovation in wind converters and factors that regulate the energy yield. The modifications in turbine, generators, pitch and yaw framework have improved capacity factor of generation [4].

Muralikrishna et al. [5] adopted wind data at location to simulate power potential and selection of suitable machine. The economics was investigated in terms of payback period and energy cost [5]. Godson et al. [6] investigated energy production of hybrid system incorporating CUK convertor, SPV system, wind turbine and related balance of system [6]. Ten et al. [7] investigated three hybrid plants using genetic algorithm in MATLAB to quantify voltage stabilization and harmonic distortion in time cycles of 10 s [7]. Woo et al. [8] adopted ANN model with single layer feed forward network with input, hidden and output zones with weights made through various algorithms [8]. Research on hybrid energy has strongly indicated its usage

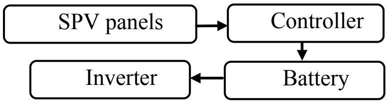

Fig. 1 Solar energy conversion system

to be an effective alternative to power generation as concluded through simulation route in operational study and performance predictions.

3 Methodology

3.1 Solar Energy System

The solar energy converter constitutes first segment of the hybrid system in Fig. 1 with SPV panels, controller, battery and inverter. The incident solar heat flux on SPV panel transforms into DC electric power that gets regulated by charge controller on power gain maximization strategy termed as "maximum power point tracking" (MPPT). The DC electric power gets stored into battery for later stage conversion into AC power using inverter and subsequent consumption by connected load. The average solar thermal flux on horizontal location ranges as 3.0–6.5 kWh/m^2/day that builds cumulative annual magnitude of 1000–2200 kWh/m^2. The overall efficiency of SPV systems limited to less than 20% leads to fixing break-even intensity of input solar power to make it an economically viable alternative. Albeit to all these concerns solar energy is emerging as a pioneering renewable alternative to fossil fuel-based generation.

3.2 Wind Energy System

Wind energy conversion system as highlighted by Fig. 2 includes wind turbine, gear box and generator. The wind turbine blades are special aerofoil structures that operate on the principles of aerodynamic fluid flow creating lift force that propels the wind rotor to deliver continuous mechanical work output. The wind power gets transformed into rotary shaft power to be taken up generator to produce electricity. The gearbox functions to tune the torque level compatible to generator of either permanent magnet synchronous (PMS) or induction type. The magnitude of conversion of wind power to mechanical energy by turbine is the coefficient of power (C_{p}) whose magnitude is limited by aerodynamic Betz limit with an ideal value of 0.593 for turbines with zero friction losses. The wind turbine has parameters—swept area, rated power, cut-in, rated and cut-out speeds. The selection of appropriate design of wind turbine to match location wind pattern is often a challenging task that decides the overall economics of power generation. The fraction of the time duration the installed turbine delivers

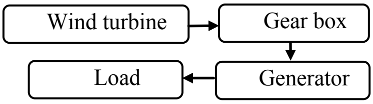

Fig. 2 Wind energy conversion system

the rated power is an important performance index—capacity factor (CF) that has a strong bearing on annual energy production.

3.3 *Weather Prediction for Design of Hybrid Energy System*

The hybrid system integrates solar energy and wind energy converters directly curtailing carbon emissions released to environment. The system output depends upon energy contributions through wind and solar sources that keep changing with time. The information of climatic inputs serves as an important input for design of hybrid energy system.

The reported study involves using simulation route for resource assessment (solar and wind) at specified location on basis of established co-relations of solar radiation geometry and Weibull statistics. The computational tool is adopted in predictions and optimizing the energy conversion devices. Python programming is utilized for execution of computational studies and major features are illustrated as follows,

NumPy: adds support for tremendous, multidimensional clusters and grids, just as countless undeniable level numerical capacities to chip away at them.

Matplotlib: plots 2D clusters with multi-stage information bundle dependent on NumPy clusters and proposed to work with the SciPy stack in general.

Tkinter: is the standard GUI library in standard Python interface. The quickest and least complex way to deal with build GUI applications is with Python and Tkinter.

Tensor flow: is a deep learning system used to shrink large tensor flow model to use in modular devices like mobile phones. It is complicated technique employed to get minimal reduction methodology.

Kerasis: is a high-level Python neural network module that uses Tensor Flow or Theano to execute. Other high-level Python neural network frameworks, such as TF-Slim, can be used on top of Tensor Flow, although they are less maintained.

Genetic algorithms use memory-based values to simulate processes in short period of time. The features of GA are utilized in providing optimal solution to any given problems. Figure 3 shows the flow chart of the genetic algorithm.

Population: is by-product of simulation in the current age characterized as a bunch of chromosomes. Features of GA populace include populace variety to be maintained in order to prevent untimely union; populace size to be sufficient large to capture decent pool of qualities.

Crossover: is comparable to propagation and natural hybrid with one or more offsprings created utilizing parent or guardian hereditary materials.

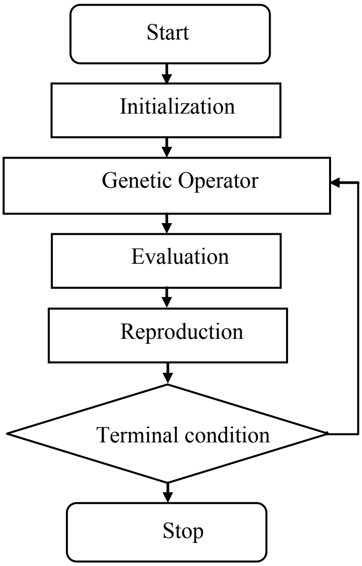

Fig. 3 Genetic algorithm flow chart [9]

Mutation: is disfiguration or change observed in the chromosomes as a source of developing new population for crossover. Change is piece of GA, which is identified with the "investigation" of the pursuit space.

4 Results and Discussion

4.1 Experimental Setup Sizing

Solar energy plays a vital part in hybrid energy model simulated for a simple 100 W load for 10-h duration, with matching rating for charge controller, battery, inverter and solar panels. Solar day length of 8 h was adopted as illustrated in simulation.

Solar Panels:

Total load is 100 W for 10-h operation: $100 \times 10 = 1000$ Wh.

Duration of sunlight available: 8 h.

Solar panel wattage = 1000/8 = 125 W.

Solar panel is put in series/parallel combinations.

Charging Controllers

Power, $P = VI$; for voltage of 12 V, charging current is calculated as, $I = P/V$.

$I = 100/12 = 8.33$ A; Charge controllers of 10 A available in market is adopted.

Battery Capacity:

Wh of battery = 100 × 8 = 800 Wh; Battery capacity = 800 × 4 = 3200 Wh.

Ideal range of Ah battery would be 500 Ah 12 V.

Number of batteries = 3200/500 = 6.4 approximated to 7 batteries.

For safer side, 10 batteries of 500 Ah can be used for storing the energy.

Inverter: Pure sine wave inverter was used whose size is ideally more compared to load. Hence, an inverter of the 150 W is ideal for the simulation purpose.

Simulink studies:

The PV—wind turbine system frameworks in MATLAB/Simulink was used to simulate operation of hybrid system. The solar irradiance and temperature are dependent variables that influence PV yield in terms of system current and voltage (Fig. 4).

The converter circuit receives panel power output and transforms it into DC power that gets routed to the inverter circuit to produce sinusoidal AC yield. The wind turbine converts kinetic energy of wind into rotary mechanical power that later gets converted into electric power. The output of the hybrid system is networked to electrical loads. A consistent voltage interface is maintained in order to have access over the network side converters for both the systems. The functional objective of converters is to manage a consistent DC connect voltage.

Simulations through the hybrid model yields interesting parameters useful for design of system on basis of intended load to be connected. Figure 5 shows P_{mean}, V_{mean} obtained for the defined irradiance, temperature and duty cycle. The trend noticed is identical for both voltage and power of the hybrid energy system over the specified simulation cycle. Similarly, Fig. 6 shows the power characteristics of solar power output obtained from solar energy system.

Temperature and irradiance is same throughout simulation, i.e., 45° and 1000 W/m^2. P_{mean} fluctuates between 0 and 20 kW, while V_{mean} has peak up to 0.5 V.

Figure 7 shows the power consumed by the load supplied by hybrid model with a peak magnitude of 100 W.

4.2 Genetic Algorithm for Weather Prediction Studies

The installation of hybrid energy system takes irradiance and wind velocity at the location to predict resource potential and thereby sizing equipment. The genetic algorithm takes certain set of input and predicts the weather for that particular region. The meteorological data (temperature, sunshine, wind speed, rainfall and sky clearance) for location 15.37 N and 75.10 E was adopted for computations. The cloud value is 0, indicates clear sky for entire dataset was fed to python software for simulation purpose.

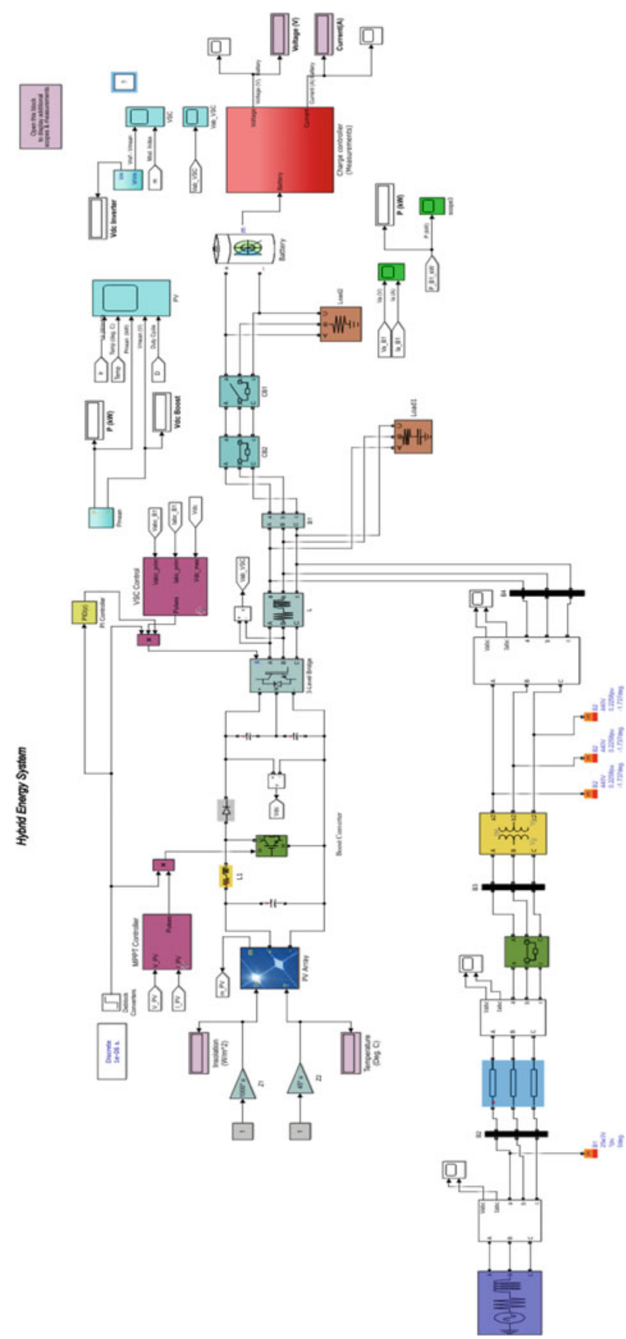

Fig. 4 Hybrid energy system simulation

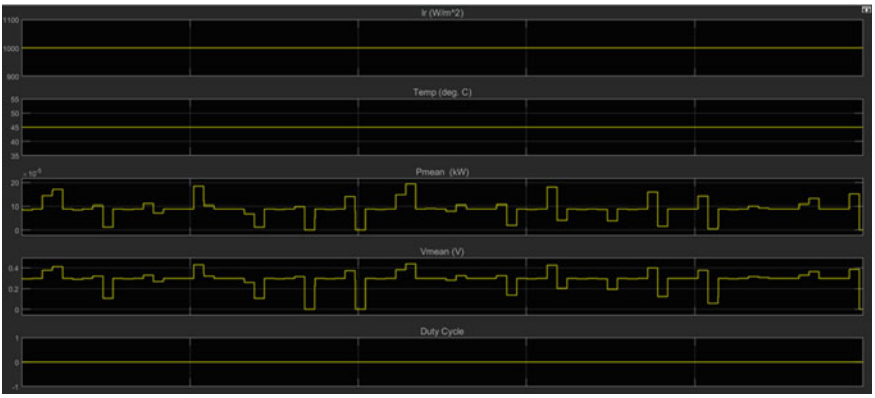

Fig. 5 Simulink output results

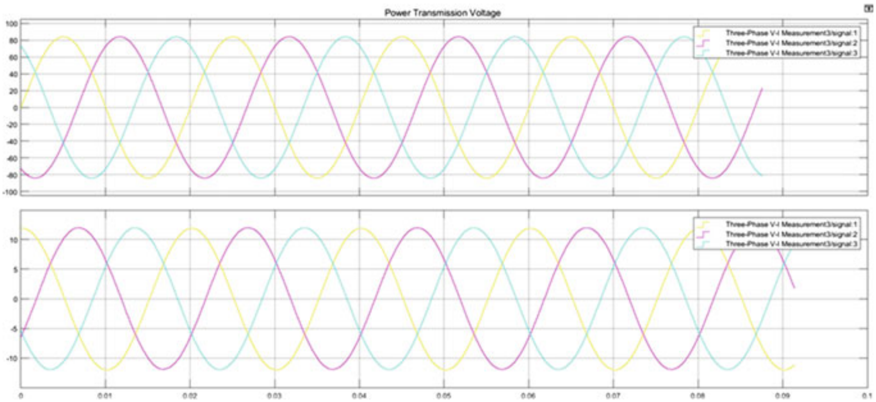

Fig. 6 Power and voltage from solar system

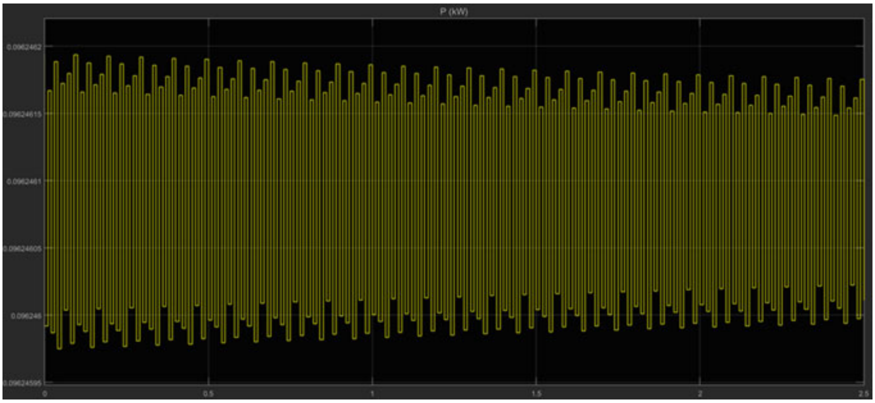

Fig. 7 Power obtained from wind energy

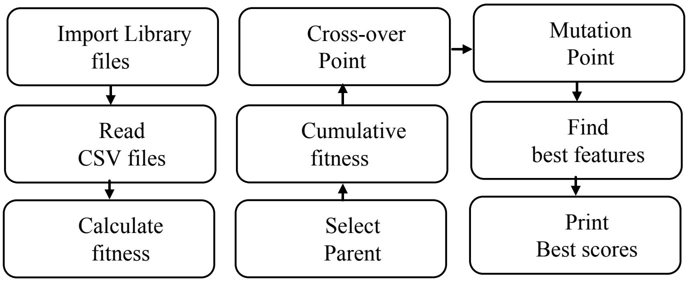

Fig. 8 Genetic algorithm execution

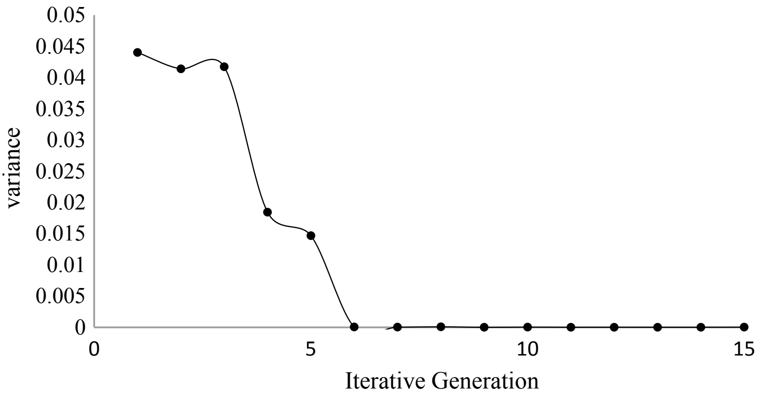

Fig. 9 Variance convergence with iteration number

4.3 Code Output

The Python code tests effectiveness of dataset with inbuilt python libraries like Keras, Matplotlib and NumPy used for simulation purpose. Sklearn kit was used for machine learning as indicated through Fig. 8 showing stages of implementation.

The iterations for the data set indicated fitness of 85.5846%.

Figure 9 shows the fitness of the model that reached maximum efficiency after fifth generation and went on to remain almost constant.

5 Conclusions

The conclusions drawn from the study can be concluded as,

- Simulation with sample 574 data points indicated average fitness of 85.5846% indicating wind-solar hybrid system as viable option for decentralized power.

- The hybrid system is more reliable and efficient when compared to single energy source and yields more energy output. The results of the same can be seen with the help of 100 W of load.
- The simulated model is an alternate option for fossil-based power plants and helps in achieving the goals that are set by Paris agreement, sustainable development goals and many other such national and international policies.
- Genetic algorithm is one the best option for weather prediction as it is an efficient model and can predict the output up to 99%. In this case, the predicted output sums up to 85.6% thereby increasing the credibility of the model and the dataset.

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Design and Prototyping of a Trekking Smart Backpack

Vrushabh Vora, Kartik Ajugia, Meet Patel, Meet Solanki, and Ronak Gohil

Abstract This project aims at designing and prototyping of a trekking smart backpack for the trekkers to provide solutions to all the basic needs and requirements of an individual during trekking in a cost-effective way. Smart backpacks are like any ordinary backpacks, but integral with some smart features. Smart backpacks combine everything under the fabric sack. It is made to adapt to the lifestyle of the modern user. During designing, various factors such as weight distribution, force applied, etc., were taken into consideration. The calculations and analysis were done manually using various engineering techniques and software. Designing was done in accordance with the values obtained by various calculations and considering all practical scenarios that can affect the backpack performance. Prototype modelling was done for the parts which were designed for optimizing the performance and accordingly the required OEM parts were selected. After the completion of the modelling, we proceed to test our design so as to check the sustainability and the degree of optimization that we have achieved.

Keywords Smart backpack · Cost-effective · Prototype modelling

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1 Introduction

In the most basic, frameless form, a backpack is simply a fabric bag worn on the back and fastened with two straps that cross the shoulders. Due to the restricted ability of the hands to hold big weights for extended periods of time, backpacks are frequently chosen to purses when carrying heavy loads or carrying any kind of equipment. Carrying goods on one's back while hiking for more than a day is known as backpacking. It frequently entails a lengthy trek and may include outdoor camping. Backpacks are highly practical since they make it simple to access your belongings, you can quickly glance inside, and everything is within easy reach.

Portable electronic devices (PEDs) are any piece of lightweight, electrically powered equipment. PEDs have developed rapidly in recent years as we become increasingly dependent on portable electricity because these devices are easily portable and designed for use away from an office environment, small and light, able to be operated without an external power supply, designed as a complete unit which makes the users' daily lives and work easier. Over the past decade, humans have become more and more dependent on electronic devices. Civilians are using them to enhance the quality of life [1]. We aim to integrate both the above said elements and tried to develop a prototype model of a smart backpack which is mainly used by the trekkers. Smart backpacks combine everything under the fabric sack that one needs while trekking. These backpacks can charge one's devices, can help in water purification, and can be converted into a chair and more. Portable devices are generally powered by a rechargeable battery, and the limited storage capacities of these batteries can hinder extensive use of these electronic devices. Exploration into the field of energy harvesting has shown that useable amounts of energy can be gained from human movement during daily activities [2].

To overcome this problem, we have developed an energy-harvesting device embedded into a backpack to efficiently scavenge human biomechanical energy to sustainably charge portable electronic devices in remote area or on a trip, where battery is very inconvenient to be recharged. Energy-harvesting technologies for powering wearable electronic devices have received great attention attributed to their distinct advantages that effectively address the problems of traditional chemical batteries such as limited capacity and service time, environmental pollution, and huge weight [3]. Along with energy-harvesting device some other features like water purification, mosquito repellent, backpack able to be converted into a chair, LED lights are added to the backpack in order to meet the difficulties faced by the trekkers. Providing all these features will help the hikers whiling trekking as one gets all the necessary equipment under one backpack and one can have a stress-free hike.

2 Literature Review

In 3300 BC, the first backpack was unearthed next to Tzi the Iceman's frozen remains. This prehistoric man was slain and preserved in the glaciers while traversing the Val Senales Valley in Italy. In 1991, a pair of hikers from Germany discovered his body as well as his belongings [4].

A leather, Hazelwood, and Latchwood bag was one of the things uncovered. Tzi carried his necessities in this bag. The adventure, the desire to discover a world outside of our daily life, and the resulting self-discovery are what make backpacking so special.

Today, it is challenging to attribute the invention of the backpack to a single person because a number of people have contributed. In the 1920s and 1930s, two individuals who worked in the hiking industry named Lloyd Nelson and Gerry Cunningham produced bags with straps, zippers, and lightweight materials. Then Dick and Nina Kelty advanced the concept by creating contemporary bags with padded straps that resemble the backpacks we use today [4].

There were yearly developments. During the American Civil War in 1870, bindles were made from sticks and canvas cloths. While these were a strain to carry, there was really nothing better available for soldiers on the battlefield at the time. For the American military, Henry Miriam created one of the first usable knapsacks in 1877 [4]. With the Duluth Pack, Camille Poirier enhanced the military backpack in 1882. The head strap on this bag was fastened by straps and buckles. Today, it is frequently used for journeys in canoes and kayaks. The advent of World War I in 1914 created a demand for upgraded military backpacks known as Haversacks. The American military carried ammunition, canteens, and other supplies in these bags that were tied to the upper and lower back [4].

The first zipped backpack was developed in Boulder, Colorado, by Gerry Cunningham in 1938. Military backpacks improved in 1943, becoming able to support more weight. This was important because soldiers had to carry a lot of heavy equipment, weapons, and ammunition during World War II. Children began bringing backpacks to school later in the 1940s. Following the Second World War, additional materials were available to create these bags that were practical, light, and fashionable [4].

Plastisol ink revolutionized the back-to-school backpack printing industry in 1959. During the Vietnam War in 1960, a new, sleek backpack known as the Alice made its appearance. This bag had many compartments that could be accessed by releasing metal straps, and it was sturdy enough to hold big objects. Transparent backpacks first appeared on the market as plastic Lucite clutches in the 1960s [4].

A Harvard law student suggested to L. L. Bean in 1980 that they start selling bags for carrying bulky books. They gladly obliged with the book pack, which soon made its way to the bookstores at Harvard. High school student Steve Mann created the first wearable computer in 1981 by combining technology with bags. The EyeTap computer was hooked into the bag and connected to a head-mounted display. The modular lightweight load-carrying equipment, or Mollie backpack, was first made available by the military in the middle of the 2000s [4].

During the Iraq War, it was a basic item for the military and had strong nylon straps for maximum comfort. Late 2000s: Carrying your daily essentials in style with a fashion backpack. There are currently bags made of leather, canvas, and many other materials. The functionality of backpacks began to increase. For instance, some bags have many pockets for optimal storage and are made for photographers. The side opens to reveal a small carrying box that is ideal for holding cameras, while the straps on the rear may support the weight of the stand. All of the pupils at Jefferson County Public School received digital backpacks in 2018. These bags were created with the intention of making it simpler for teachers and parents to monitor development [4].

So, as we go ahead and ahead the demand for backpacks goes increasing and the development has been rising year by year. It is expected to see a modern generation of backpacks integrated with smart features in the near future. Some of the features like GPS navigation, portable Wi-Fi, and other modern functions make the bags smart and such developments are rising nowadays.

3 Features of the Backpack

Based on the features, we integrated within a bag, firstly we created a design of the prototype in AutoDesk Inventor. Since it is a prototype model; we decided to mount all the components on a wooden ply as it is easily available in the required size. We calculated the various dimensions required by the various components and accordingly selected an appropriate size for the wooden ply. Later we mounted all the components on the ply and calculated and recorded all the output results. Figure 1 shows the CAD model of the prototype.

3.1 Water Purification System

The UV chamber and membrane filter combinedly form the water purification system. In water purification system, we have used UV and membrane unit to purify water. UV filters are compounds, mixtures, or materials that block or absorb ultraviolet (UV) light. Membrane filters allow the flow of fluids or gases while preventing the passage of particles and microorganisms. They are made of porous plastic films and the substances that are too large to fit through the filter's pores are retained on the membrane's surface and excluded from the purified stream. The water purification system consists of pump, UV, membrane, and various pipes connections. Firstly, the water is sucked from the sink source and passed through UV and membrane unit where large contaminants are removed and water is purified by UV rays. The distilled water is then stored for use.

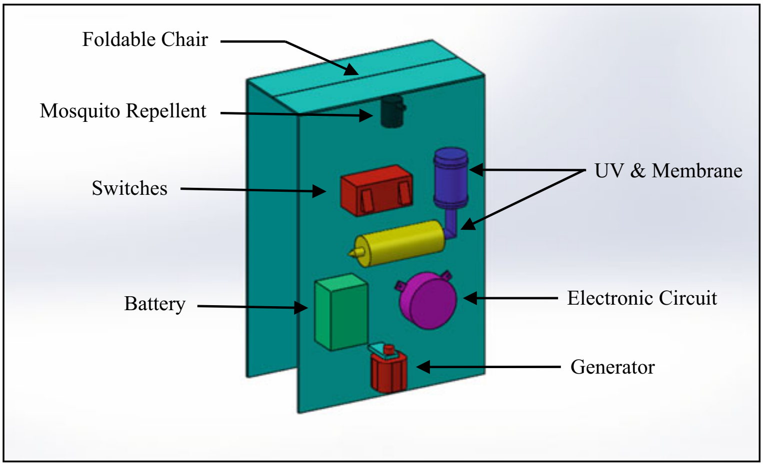

Fig. 1 CAD model of the prototype

3.2 Electricity Generation System

The generator, battery, and electronic circuit combinedly form the electricity generation system. This feature serves the requirements of daily need, i.e. electricity. The feature consists of generator, pulley, a means to rotate pulley, i.e. a wire rope which provides rotary motion to pulley with the help of oscillatory motion of hand, an electronic circuit which allows the current to flow in one direction and can transfer both clockwise and anticlockwise motion to generate constant voltage and a battery. When the hand is oscillated during walking the motion is transferred to rotary motion of pulley. The pulley shaft indeed rotates the generator which causes electricity generation. The electricity produced is stored in a battery for further use passing it through an electronic circuit. The electricity stored is enough to run the other applications. This feature provides the basic need and serves as a resource to other applications without any major effort required by a trekker.

3.3 Portable Chair

This feature is provided to provide comfort to an individual during trekking. The chair is designed such a way that it gets fold when not in use which provides compact design and during requirement one needs to just open it with the help of hinges provided and lock it. This feature is integrated such that it does not affect an individual with back comfort and also with regards to weight. This function helps an individual to take rest at any time and at any location. It is made flexible in design which enables to fit it in any angle which provides better comfort.

3.4 Mosquito Repellent

This feature is specially placed for trekker because during trekking at various locations due to insects many individuals face issues with skin. Insect repellents are agents that are used to protect the body from the bites of insects that can cause local or systemic effects. While some bites cause only local skin irritation, some can cause serious illnesses and possibly death as the insects act as carriers or vectors of diseases. This repellent is active against a wide variety of biting insects. It is non-irritating to the skin and mucous membranes. It has cosmetically appealing odourless or have a pleasant odour and greaseless. In this feature, we have provided a DC heater so that the repellent gets vaporized which will in turn keep away the mosquito and other inspects as well.

3.5 LED Lighting

This feature is integrated especially because many times in night during trekking individual carries a light source in their hand or wear cap in their head. This takes more effort, so we have integrated a light source on bag which provides source of light at any instant without any load on individual. LED strips are inculcated in the bag near bag strips. A LED strip light is a flexible circuit board that is populated with LEDs that one can stick almost anywhere as per the requirement that adds powerful lighting in a variety of colours and brightness.

4 Design Calculations

The calculations for different components are discussed as below.

4.1 Calculations for Human Walking Ergonomics

The diameter of pulley is 12 mm with the circumference of 37.64 mm. Horizontal hand movement in one direction is 500 mm. (measured by human walking ergonomics) Normal walking speed is 50 m/min (3 km/h)—assuming. Walking distance (1 step) is 0.5 m. (measured by human walking ergonomics)

$$\begin{aligned}&\text{Rotation of pulley in one direction (revolutions per movement)}\\&=\frac{\text{Horizontal hand movement in one direction}}{\text{Circumference of the pulley}}=\frac{500}{37.64}=13.26.\end{aligned}\tag{1}$$

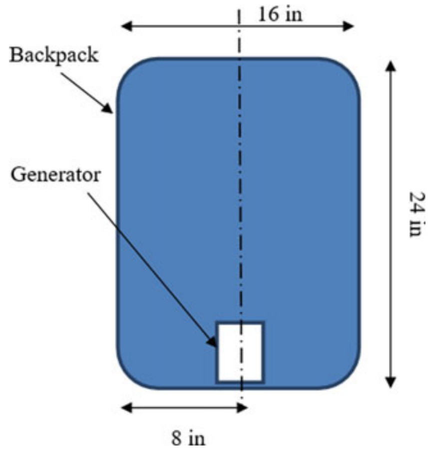

Fig. 2 Layout of generator w.r.t the base of the backpack

$$\text{Motion of legs/min} = \frac{\text{Walking Speed}}{\text{Walking distance}} = \frac{50}{0.5} = 100\,\text{steps/ min}\,. \quad (2)$$

Taking fatigue factor as 0.7, thus actual number of steps is 70 steps per min and taking ratio of hand to leg movement as 1:1. Thus, hand movement = 70 movements per min. Figure 2 shows the layout of the generator w.r.t the base of the backpack.

$$\begin{aligned}\text{Revolution of pulley} &= \text{Rotation of pulley in one direction} \\ &\quad \times \text{Actual number of steps} \\ &= 13.26 \times 70 = 928\,\text{RPM} \approx 900\,\text{RPM}. \quad (3)\end{aligned}$$

Generator is 12 V—2 A at 1000 rpm = 12 × 2 = 24 W output.
Considering 70% efficiency of generator (frictional and conversion losses)

$$P_{\text{act}} = \frac{\textbf{Wact} \times \textbf{Nact}}{\textbf{Nth}} = \frac{24 \times 900}{1000} = 21.6\,\text{W}. \quad (4)$$

$$P_{\text{act}} \times \text{Efficiency} = 21.6 \times 0.7 = 15\,\text{W}. \quad (5)$$

Power output = 15 W at 12 V; thus, current = 1250 mA.

4.2 Calculations for Battery

Battery specifications are 12 V, 8 Ah. and power output from battery is 12 × 8 = 96 Wh.

$$\text{Thus, charging time by generator} = \frac{8000}{1250} = 6.4\,\text{h.} \tag{6}$$

Considering 20% loss; so, the charging time comes to 7.68 h. and adapter specifications are 12 V, 2 A and 24 W output.

$$\text{Thus, charging time by adapter} = \frac{8000}{2000} = 4\,\text{h.} \tag{7}$$

Considering 20% loss; so, the charging time comes to 4.8 h.

4.3 Force on Human Hand

The torque required at the generator is 10 kg-cm.

$$\begin{aligned} \text{Let, } R &= \text{Perpendicular distance from centre of pulley to hand} \\ &= 8\,\text{in.} = 0.203\,\text{m.} \end{aligned} \tag{8}$$

$$\begin{aligned} \text{We know, } \mathbf{Torque} &= \mathbf{F} \times \mathbf{R} \\ \mathbf{10} &= \mathbf{F} \times \mathbf{20.32} \\ \mathbf{F} &= \mathbf{0.49}\,\text{kg} \end{aligned} \tag{9}$$

$$\begin{aligned} \text{Total force} &= 0.49\,\text{kg} + \text{Friction Taking friction as 50\% of load} \\ F &= 0.49 + 0.5 \times 0.49 = 0.735\,\text{kg.} \end{aligned} \tag{10}$$

4.4 Calculations for Water Purifier

UV and pump specifications are 12 V, 0.5 A. and the power required by UV and pump is given by

$$P_{\text{uv}} = P_{\text{pump}} = 12\,\text{V} \times 0.5\,\text{A} = 6\,\text{W each.} \tag{11}$$

Discharge (Q) of the pump is 15 lpm and diameters of PU tubes are 5 and 8 mm. The head is 6 ft, i.e. 1.828 m and the pump is designed to carry water for a height of 1 m. The frictional losses and resistance by fittings and membrane is 0.828 m of water. Thus, H_{act} is 1 m and Q_{act} is 10 lpm. Taking the actual running time as 2 min for filtering 20 L per day. Considering 3 min as setting time and waste in time because of human error. Taking t = 5 min = 0.0834 h. Thus, total power used is,

$$P_{total} = (6\,\mathrm{W} + 6\,\mathrm{W}) \times 0.0834 = 1\,\mathrm{Wh}. \tag{12}$$

4.5 Calculations for Heater of Mosquito Repellent

Heater specifications are 12 V, 2 A. Power required by the heater for repellent is

$$P = 12\,\mathrm{V} \times 2\,\mathrm{A} = 24\,\mathrm{W}. \tag{13}$$

Considering working for 2 h.

$$P_{total} = 24\,\mathrm{W} \times 2\,\mathrm{A} = 48\,\mathrm{Wh}. \tag{14}$$

4.6 Calculations for USB Port

USB port specifications are 5 V, 2 A. Power required by USB port for charging any device is

$$P = 5\,\mathrm{V} \times 2\,\mathrm{A} = 10\,\mathrm{W}. \tag{15}$$

To charge 3000 mAh, the Wh required will be

$$\mathrm{Wh} = \mathrm{Ah} \times \mathrm{V} = 3 \times 5 = 15\,\mathrm{Wh}. \tag{16}$$

4.7 Calculations for LEDs

Power output for LEDs = 10 W. Let us consider LEDs are working at 10 W for 3 h. Power required is

$$P = 10 \times 3 = 30\,\mathrm{Wh}. \tag{17}$$

Table 1 Comparison between total input power and total output power

Input	Output
Battery capacity—96 Wh	Water purification unit—1 Wh for 20 L of water
	Heater for mosquito repellent—48 Wh for 2 h use
	USB port—15 Wh for 3000 mAh of charging a device
	LEDs—30 Wh for 3 h use
Total—96 Wh	Total—94 Wh

4.8 Total Input and Output Power Comparison

Table 1 compares the battery capacity and power consumption of different features.

5 Conclusion

As the name, smart trekking backpack indicates it is smart with its unique feature, i.e. instant electricity generation by walking. Smart trekking backpack prototype model provides better comfort to a trekker, and it helps in overcoming the various issues a trekker faces normally during their trekking. Smart backpack combines many functions under the fabric sack that one needs while trekking; one of the important functions is that it helps an individual to generate electricity by walking without much effort. The water purifier feature helps an individual to purify the water from any river, lake, or any other sources and within few seconds distilled water is available.

This backpack overcomes with the problem of getting a comfort place to seat and take rest. Within the backpack, a foldable attachment serves the function of seating arrangement and a trekker can easily seat or take rest at any location. Many a times the trekkers face issue with insects harming their body, this problem has also been overcome by our smart backpack by providing repellent.

Thus, the smart backpack provides solution of all the needs of an individual during trekking in a cost-effective way and without much more effort required by an individual to run all the applications.

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Numerical Validation of Thrust Produced by Remotely Operated Vehicle

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Abstract This paper inspects the use of computational fluid dynamics (CFD) analyses in order to obtain various hydrodynamic characteristics of an observation class remotely operated vehicles (ROVs). This is accomplished by comparing the thrust generated from CFD analyses with the thrust measured from experimental results. Hence, analyses are conducted using ANSYS FLUENT solver, for steady state linear motion of the ROV at different speeds, while considering the rotational motion of propeller. Subsequently, few of the most commonly used turbulence models and methods for simulating propeller motion are compared. As a result, the k-w (omega) shear stress transport (SST) model for turbulence, with moving reference frame (MRF) approach for propeller motion is used in this study. The paper also goes over a simple and low-cost test Jig that was used to measure the thrust produced. This paper also briefly describes the process of 3D printing the propellers used in this study.

Keywords Computational fluid dynamics (CFD) · Remotely operated vehicle (ROV) · Moving reference frame (MRF)

1 Introduction

Underwater structures such as bridges, oil rigs, underwater pipes, offshore wind turbines, etc., are a crucial part of modern infrastructures. These structures tend to get damaged over time, hence regular inspection and maintenance are vital. Subsequently, skilled underwater divers are required to conduct these dangerous tasks of inspection. Hence, using remotely operated vehicles (ROVs) instead of divers for this process is the practical solution to the problem. ROVs are underwater robots with an

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on-board camera, sensors and other necessary equipment's, thus, it also reduces the human error involved in the process.

However, it is difficult to anticipate the hydrodynamic behavior of an ROV operating underwater, hence any unforeseen reaction to its environment could result in loss of time and resources that were devoted to developing the ROV. Apart from this, the energy consumed by the thrusters is directly proportional to the resistance or drag force experienced by the ROV. Hence, it is important to measure these hydrodynamic characteristics [1].

Conducting experiments to accurately measure hydrodynamic characteristics may require costly infrastructure and equipment, which are not easily available. Thus, it is quite advantageous to solve this problem computationally using CFD analysis. Computational fluid dynamics (CFD) is the process of solving a physical problem containing some fluid flow conditions, numerically using an iterative method. It converts the problem into a mathematical model, which is then solved using some computational power. Nowadays, many applications can be found where CFD is used for simulating real world fluid flow problems [2–4]. Also, many literatures exist, where CFD is used for simulating hydrodynamic behavior of ROV [5–7].

However, these methods are still being developed and its accuracy fundamentally depends on the setup used and boundary conditions given. Hence, these analyses need to be validated with some form of experimental data that are easily measurable. Therefore, in this paper, CFD analyses were performed to calculate the thrust produced by an observation class ROV, which are then compared with experimental data to validate the model. Subsequently, the setup for a simple test jig used for measuring this data is also discussed. In order to capture the thrust generated by propeller, the blades rotational motion need to be simulated in the CFD analysis, thus, many such studies have been conducted to simulate propeller motion [8–10]. Thereby, in this paper, moving reference frame (MRF) is used for calculating the effect of propeller motion.

2 Propeller Testing

This test was performed using a test jig in order to understand the current requirement of the motor and the thrust produced by the propeller in the water.

2.1 3D Printing

The blades of the selected propeller followed a left-handed helical path on the hub surface. But, the right-handed equivalent of the same propeller was not available in the market and as it was an essential component for the ROV, it was decided to 3D print the propeller. However, there are many inaccuracies involved in the process of measuring the dimensions from original propeller and 3D printing. Hence,

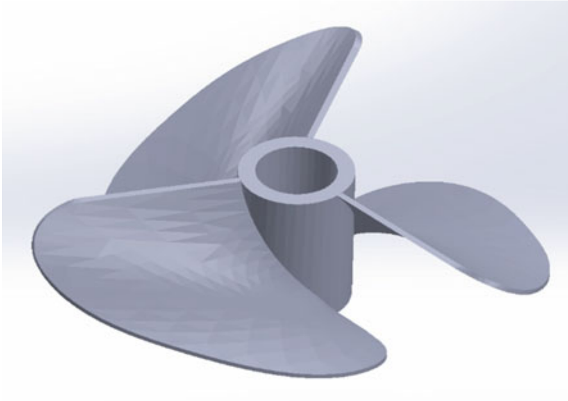

Fig. 1 CAD model of left-handed propeller

Table 1 Propeller dimensions

Parameter	Value (mm)
Thickness	1
Hub length	16
Hub diameter	10
Number of revolutions of helix on hub surface	0.33

the 3D printed propeller cannot be exactly identical to the original one. Since the difference in propeller geometry imparted by this process is not negligible, both left- and right-handed propeller were 3D printed.

This process began with the CAD modeling of the available propeller on SOLIDWORKS. Thus, the required curve was sketched by taking vertical and horizontal propeller projections on paper. Once the CAD model of one of the propellers was designed, it was mirrored to produce its counterpart. Thereafter, STL files from both CAD files were prepared. The final CAD of left-handed propeller used is shown in Fig. 1.

Once the STL file was made, fused deposition modeling (FDM) was employed using ABS as the material for producing the required propellers. This process is cheaper and faster and it took only 3 h to print a set of propellers. The final dimension of the propeller obtained in this process is mentioned in Table 1

2.2 *Test Jig and Results*

A test jig was built as shown in Fig. 2 consisting of a long stick, a handheld weighing machine and the motor as seen in the image. The motor along with the propeller was attached to one end of a long stick and the stick was attached to a weighing scale on the other end. The weighing scale was hooked on another stick so that it could

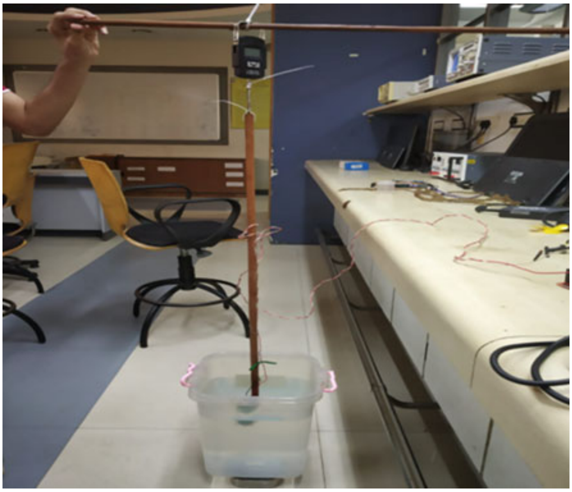

Fig. 2 Motor testing using the test jig

Table 2 Current supplied and thrust produced

Value	Current (A)	Thrust (gf)
Minimum	1.1	20–25
Maximum	5.26	75–80

be stable and give accurate readings. As the motor turned on, it exerted a force on the weighing scale (measured in grams) through the stick. The results obtained from this test are listed in Table 2.

3 CFD Analyses

3.1 Method of Analyses

ANSYS FLUENT software was utilized to carry out these CFD analyses. The turbulence model called k-w (omega) SST was used to simulate the flow around ROV. It is a widely used turbulence model to capture the pressure gradients near the wall as well as away from the wall regions. It combines the merits of k-w (omega) and k-epsilon models, respectively [11]. In order to calculate the forces acting on the ROV, it is necessary to capture these pressure gradients. Hence, this model has been used in many similar studies [12, 13].

Moving reference frame (MRF) which is steady state or pseudo-transient approach and sliding mesh which is dynamic or transient approach are two of the most widely used methods for computing the effects of propeller motion. Paz et al. [14] have conducted a study to compare these two methods for propeller motion of a quadcopter. Similarly, the study has been conducted on a marine propeller in order to compare the results from MRF and arbitrary mesh interface or sliding mesh technique (AMI) approaches with experimental data [15]. MRF model calculates the flow around propeller separately in rotating domain and then connects it with rest of the stationary fluid domain using an appropriate mesh interface at the contact surfaces. Propeller simulation has been studied using MRF technique and suggested it to be more efficient than transient simulation [16], considering the relatively huge computational time required. Hence, MRF approach was used in this paper.

3.2 Model Preparation

A simplified CAD model was created using SOLIDWORKS software, replacing the complex features with simple geometries and avoiding the tangential contacts, as shown in Fig. 3. As the ROV is symmetric about its vertical planes, only half of the geometry was computed by using a symmetry boundary condition for the dividing wall. This helps in reducing the overall computational time of the analysis. An appropriately large domain and body of influence (BOI) dimensions were selected to capture all the flow features properly as shown in Fig. 4.

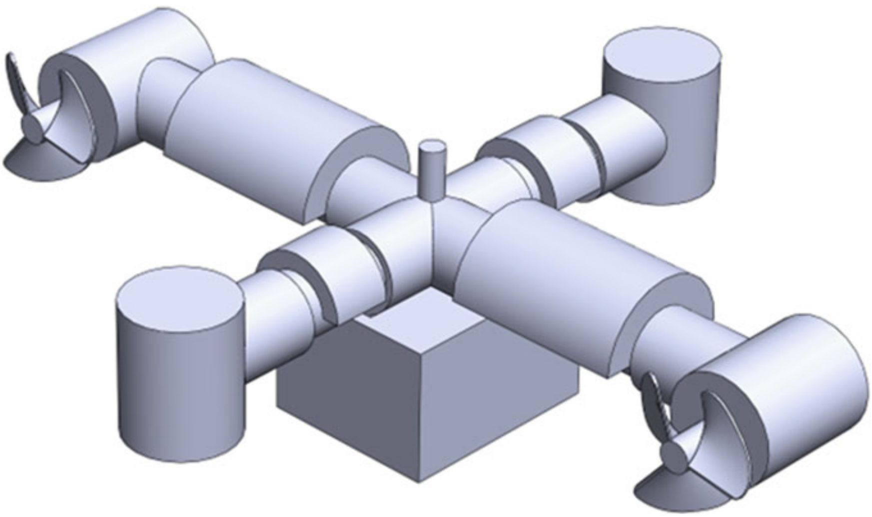

Fig. 3 CAD model used for CFD analysis

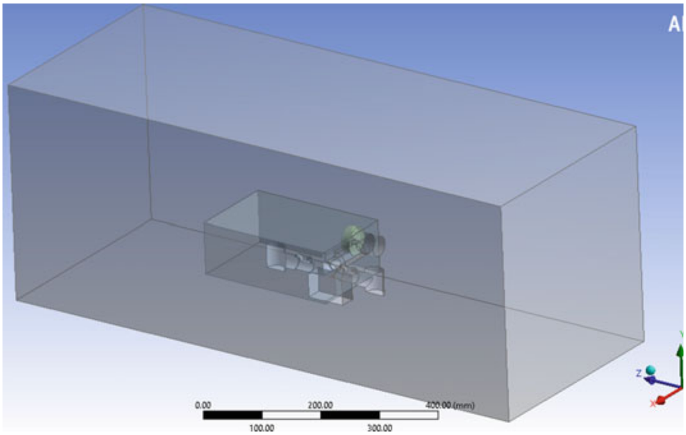

Fig. 4 Domain creation for CFD analysis

3.3 Mesh Generation

ANSYS has its own meshing module, hence it was used to create tetrahedral mesh for the model. Gutierrez and Garcia [17] proposed, better refinements are essential at the propeller blade and the rotating domain around it in order to accurately compute the pressure gradients and flow around it, for thrust calculation. Hence, refinements were given to propeller blades, rotating domain faces and wake region to better capture these results. The details of these refinements have been listed in Table 3. Also, five prism layers were created on ROV surfaces to better capture the boundary layer which is crucial in determining the drag force, as shown in Fig. 5. Hence, the final mesh created for the model had 3.85 million mesh elements, as shown in Fig. 6.

Table 3 Mesh attributes

Mesh tool	Size (mm)	Mesh size (mm)
Domain (global mesh)	1025 × 400 × 400	30 (max 70)
Face sizing	ROV surface	1.5
Volumetric control (BOI)	250 × 160 × 95	3
Face sizing	Propeller faces	0.5
Face sizing	Rotating zone faces	1

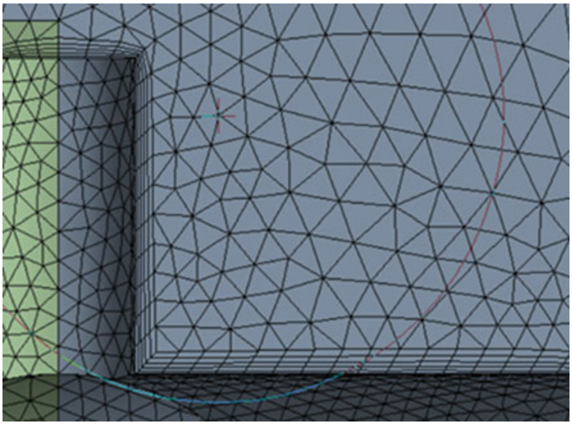

Fig. 5 Prism layers

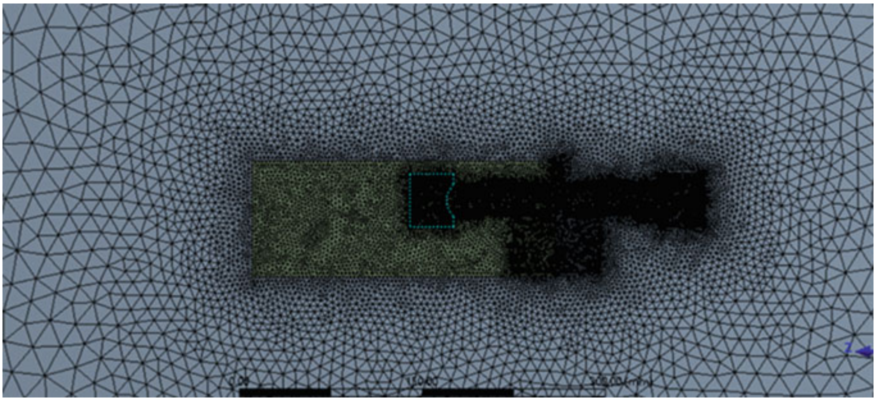

Fig. 6 Mesh used in CFD analysis

3.4 Setup for Analysis

In order to calculate the rotational velocity of the propeller, a slow-motion footage was captured of the propeller rotating underwater using the camera of a smartphone which was then slowed down eight times the actual speed to calculate the RPM of the propeller, which came out to be 1035 (maximum) and 470 (minimum).

Considering the conditions of test sight, the initial gage pressure of 8943 Pa was given. This was to simulate the environment of swimming pool where the manufactured ROV was tested. However, this test is out of the scope of this paper. Hence, analyses were carried out for steady state linear motion for a range of expected velocities from 0.1 to 0.4 m/s. Out of which the most stable solution was reached for 0.3 m/s at maximum RPM and 0.1 m/s at minimum RPM. Velocity-inlet and pressure-outlet conditions were used at inlet and outlet. No slip wall, boundary condition was given to all the surfaces of ROV's geometry.

3.5 Results and Observations

Apart from the residuals plot, the plots for the thrust force generated by propeller blades and the net pressure force acting on the ROV were also monitored. These plots became stable after about 450 iterations, as shown in Figs. 7 and 8.

As observed in Fig. 9, the pressure rises at the leading-edge region of the ROV forming a stagnation region, represented by red patches. The velocity decreases at

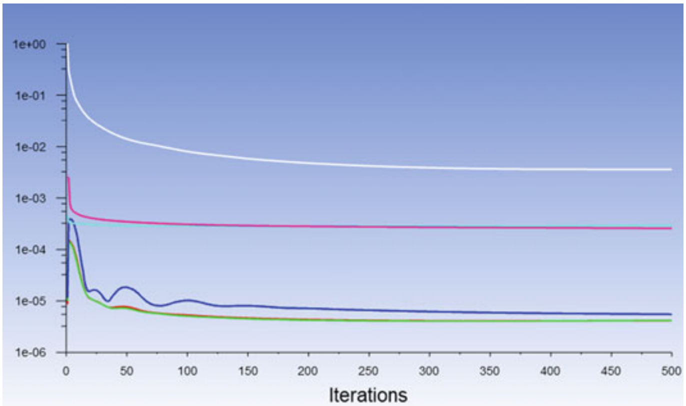

Fig. 7 Graph of residuals versus iterations

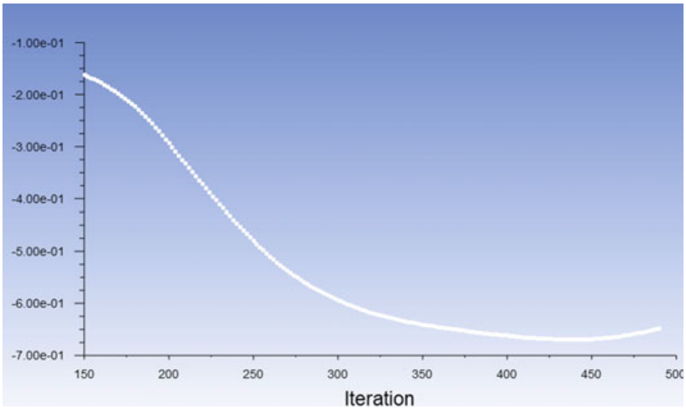

Fig. 8 Graph of propeller thrust versus iterations

high pressure regions and wake regions, also it is minimum at the surface of the wall (ROV), i.e., zero due to no slip condition as shown in Fig. 10. The blue patches at the trailing edges represent the wake region. Also, it could be seen the flow accelerates around the edges of the curved surfaces forming some turbulence. The velocity profile created due to flow around rotating propeller is shown in Fig. 11.

As shown in Table 4, the obtained thrust values were in fair agreement with the experimental data. Even though the results were deemed satisfactory, the percentage error observed was relatively higher.

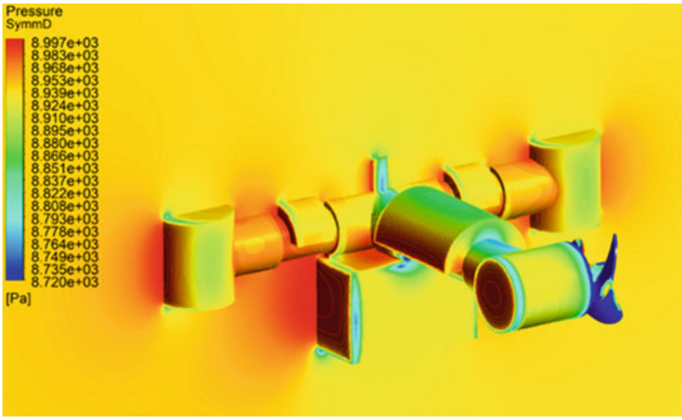

Fig. 9 Pressure contours

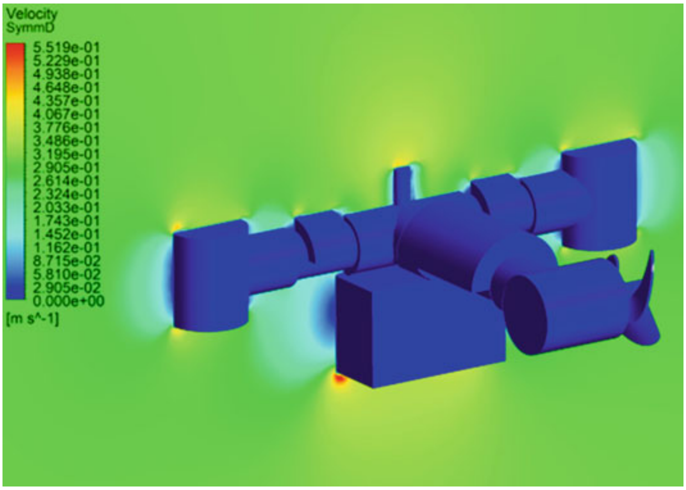

Fig. 10 Velocity contours

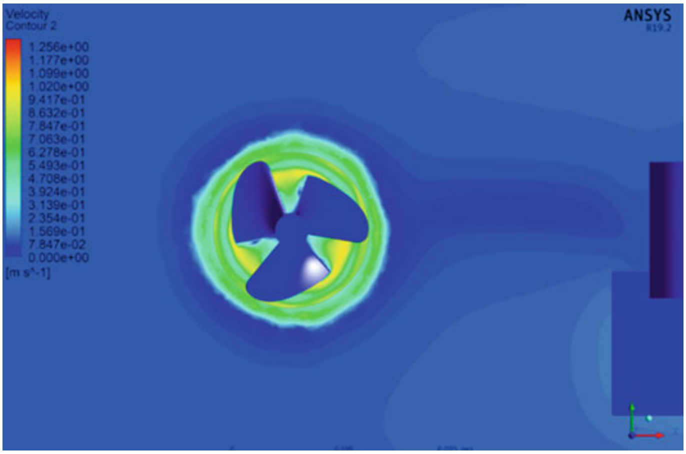

Fig. 11 Velocity contour around propeller

Table 4 Results achieved from CFD analysis

Velocity (m/s)	RPM	Drag (N)	Thrust (N)	Thrust (N) from testing	Percentage error (%)
0.1	470	0.3525	0.3871	0.49	21
0.3	1035	1.527	1.297	1.56	14.94

3.6 Error Speculations

A number of variables might have contributed to these research findings. Owing to the limitations of computer performance and calculation time, in this paper, few approximations were used such as simplification of geometry, using the symmetry plane, mesh quality, etc. For the input velocity, some expected velocities in the designing phase were used, but actual speed of ROV may deviate from these values. Hence, all these factors might have contributed in the error due to CFD. Although the MRF technique is industrially accepted for simulating propellers, this may have contributed to a small part of the error, as the propeller itself does not rotate in the domain, but it offers an approximate solution.

The container used for the testing of propeller as shown in Fig. 2, had considerably smaller dimensions. Due to smaller area along the propeller, additional swirling velocities may have been added in the flow. This may have increased the thrust readings, similar to the flow around a ducted propeller as opposed to an open propeller. Also due to smaller height of container, the thrust readings might have increased, owing to ground effect. A single thruster fixed along the vertical axis was used for experimentation using the test jig as discussed before. This does not consider the effect of ROV geometry adjacent to the propeller, in the fluid flow. Furthermore, in the geometry used for CFD analyses, the propeller was aligned along the horizontal axis, as opposed to the vertical alignment used for testing. All these factors may have further contributed in the deviation between these thrust values.

4 Conclusions

In this paper, the thrust obtained from CFD analyses of a ROV was compared with the experimental data. Firstly, the thrust produced by the propeller was measured using a simple and cost-effective test jig. The pair of propellers had to be 3D printed, since the right-handed counterpart of the selected left-handed propeller was not available in market. Then, in order to study the hydrodynamic flow around ROV, CFD analyses were performed for steady state linear motion of ROV at maximum and minimum RPM of propeller. Further, few of the most commonly available turbulence models and methods for simulating propeller motion were explored in brief. Out of these *k-w* (omega) SST was selected as the turbulence model and MRF approach was used for propeller motion. Hence, the values for drag and thrust forces produced by the ROV were obtained.

The obtained results suggest that this method may not be suitable for obtaining the accurate values of these hydrodynamic parameters such as thrust. But as the resulting values are in fair agreement with the experimental data, they might be useful for initial designing of the model, where such parameters need to be compared. However, in order to calculate the resulting values more accurately using CFD analyses, further research and improvements are required.

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Design of Gripper Arm for a Robot Trolley

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Abstract The current COVID-19 pandemic situation necessitates the need for a prompt, safe and a contactless method for the dispatch of basic items and other essentials in various domains such as hospitals, manufacturing industries and warehouses. Contemporary robot technology can help build robots that can handle objects safely and replace and/or assist humans in such domains. Robots with soft grippers can be used in hospitals where lightweight items like bottles, medicines and tablets can be handed over to patients. They can be used in warehouses to lift objects of varying topology. This paper discusses the design of the gripper arm for a robotic trolley that can be used to pick and place objects. The gripper arm was modelled on Autodesk Fusion360, and the analysis was done on Ansys. The arm and the gripper were manufactured using ABS plastic and a composite material consisting of elastosil silicone rubber, respectively.

Keywords Gripper · Robotic arm · Compressed air

1 Introduction

The COVID-19 pandemic situation requires people to maintain social distancing between two or more individuals and limit contact with other people. However, in supermarkets, shopping malls, drug stores, hospitals, etc., maintaining proper social distance is not possible and crowding is inevitable. In such places, a non-human

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alternative like a robot trolley that can pick and place objects using a robotic arm can significantly reduce the spread of the coronavirus.

This paper describes the design of the gripper arm for a robot trolley that can mimic a human hand. The pneumatically actuated three-finger soft robotics gripper is capable of handling most lightweight objects without undergoing any permanent deformation. It is made of flexible silicon elastomer that consists of multiple air chambers which fill up and bend in specific directions as designed. It is a capable of lifting objects of varying topology and can sufficiently lift items commonly available in shopping markets and drugstores, hospitals, etc.

A robot trolley with a soft robot gripper can find potential application in hospitals where lightweight items like bottles, medicines and tablets can be handed over to patients. They can also be used in warehouses that require handling of customized objects of various shapes and sizes.

2 Literature Review

Illievski et al. [1] demonstrated the behaviour of soft silicone grippers using different types of geometries and different materials. The wall thickness of the air chambers decided the direction in which the gripper deflated/expanded. The use of composite layers (one-layer silicone and other inextensible or more rigid material like PDMS rubber) hindered the expansion of the layer made up of inextensible material causing the actuator geometry to bend. Rus et al. [2] explained the application of different types of soft robots and described the actuation, sensing, design, fabrication, control, modelling and kinematics of soft robots. The challenges and limitations of the CAD/simulation software were also discussed in this review paper. Polygerinos et al. [3] discussed the use of robots with soft pneumatic actuators to provide rehabilitation for patients with disabilities including neurological problems and those suffering from injuries. The paper specified the material and the geometrical parameters required for designing the actuator. FEM analysis and contact forces developed were also discussed in the paper. Mueller et al. [4] explained the design approach for heavy duty soft robotics grippers for lifting objects weighing more than 10 kg. The authors used Fin-Ray gripper design for the purpose of the study. The authors proposed the use of Polyurethane grippers for their application. The maximum pull-off force was determined using grip simulation. Gupta et al. [5] designed pneumatic actuators of polymer sheet comprising of paper layers. Three high stiffness mode grippers were designed which could lift a 4.5 kg toolbox. Kim et al. [6] described the nonlinear properties of Polydimethylsiloxane (PDMS) silicone rubber. According to the authors, second-order Ogden model was the best suitable for the modelling of PDMS in FEM simulation. Shintake et al. [7] proposed the use of gelatin-glycerol composition for the fabrication of a unique type of soft robot called edible robot. Two different compositions of gelatin-glycerol (1:1 and 1:2) were studied. Design and fabrication of the robot was also discussed. Results and discussion showed that the edible soft robot was able to show comparable performance to the silicone elastomer alternatives like PDMS and Ecoflex. Duka et al. [8] suggested the use of feed-forward neural network approach to solve inverse kinematics problems in a robotic arm. Joint variables were used to determine the end-location effector in Cartesian space, as well as its position and orientation, in the forward kinematics problem. Random joint angle values that uniformly cover the ranges defined in forward kinematics equations were used to generate the training data for the neural network. The corresponding end-effector localization was computed for each set of joint angle values using forward kinematics equations. Choi et al. [9] studied and tested a pneumatically actuated flexible gripper with pneumatic inflation and compatible materials (i.e. rubber). They investigated the effects of process and design variables such as pressure, friction, rubber content and initial jaw displacement. Based on the FEA findings, a simple single rubber pocketed flexible gripper was developed and created. To demonstrate and gain a better understanding of the gripper's capabilities and weaknesses, feasibility tests were carried out. It was discovered that objects of various shapes (egg, steel hemispheres and wax cylinders) and types (cylindrical, prismatic, weighing 50 g–20 kg) could be picked and positioned without losing control of the object. Sun et al. [10] investigated two types of actuators: bending actuators and rotary actuators. They also developed two measurement setups to classify actuators of various geometries. A simple model was developed to gain physical insight into the behaviour of the soft actuators. Moseley et al. [11] presented a complete design and development method for soft pneumatic actuators (SPAs), using an open-source design tool and finite element analysis (FEA). A sample soft material (Ecoflex 00_30) was used to demonstrate and characterize hyperelastic and viscoelastic behaviour. Duriez et al. [12] introduced SOFA, a new architecture that allowed soft robots to be controlled in real time using the finite element method. The nonlinear deformations of the robots were computed at interactive rates using a FEM-based simulation. The main feature of this method was that the same model could be used for both interactive simulation and control of the fabricated robots.

3 Design and Analysis of the Robotic Arm

The robotic arm that was designed had 3 degrees of freedom. The CAD model of the robot trolley is shown in Fig. 1, while that of the robotic arm is shown in Fig. 2. The material chosen for the robotic arm was acrylonitrile butadiene styrene (ABS) which is a thermoplastic polymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. ABS can be used between $-20°$ and 80 °C. It has a yield strength of 52 MPa.

The robotic arm components viz. the arm base, base plate, link 1 and link 2 were analysed under a static load of 2 kg. A high factor of safety of 5 was considered for the various parts of the robotic arm. FEA results (Ansys) indicate that the components can withstand the induced stresses (Figs. 3, 4, 5 and 6).

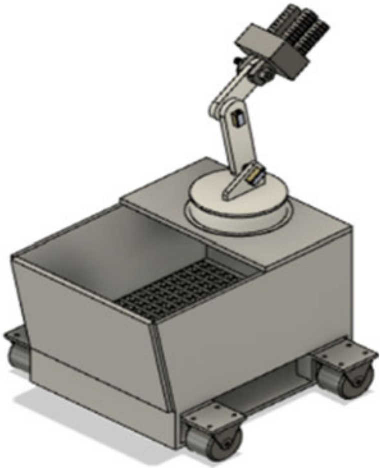


Fig. 1 Robot trolley assembly

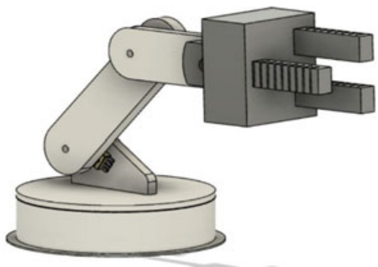


Fig. 2 Robot arm assembly

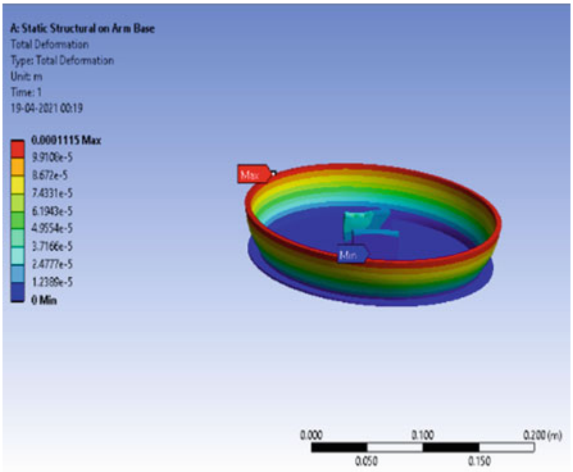


Fig. 3 Deformation of the arm base

Fig. 4 Deformation of the base plate

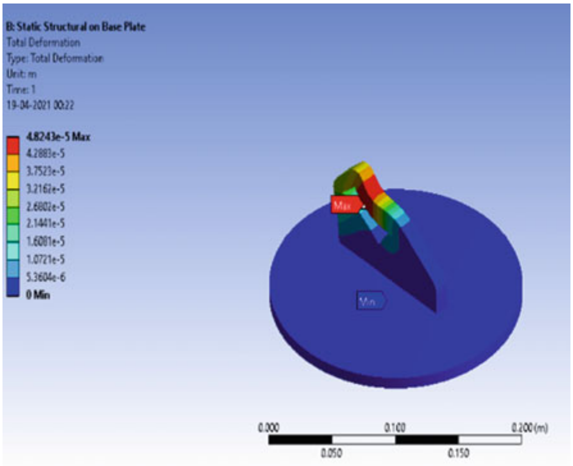


Fig. 5 Deformation of link 1

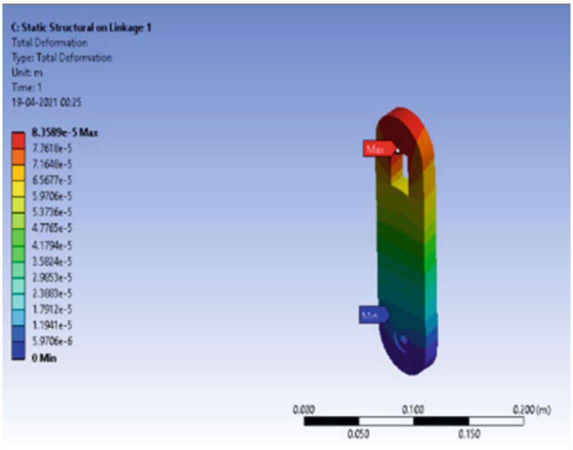
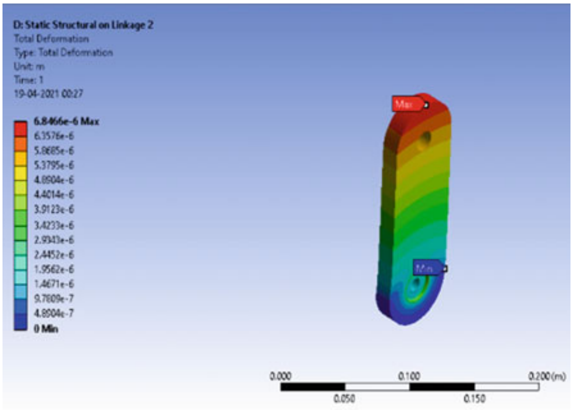


Fig. 6 Deformation of link 2



4 Design and Analysis of the Gripper

The soft pneumatic actuator, i.e. gripper, was modelled in Fusion360. Its sectional view is shown in Fig. 7. According to Polygerinos et al. [3], parameters like the number of pneunets (air chambers which fill up with air), wall thickness and pneunets height, define the behaviour of the soft robotics gripper. Air is preferred over other fluids in pneunets since it has low viscosity, is compressible, is convenient to store and has low weight. The modelled gripper had 11 pneunets, each with a height of 13 mm and a width of 30 mm. The wall thickness was 2.5 mm, while the distance between pneunets was 2 mm.

FEA analysis of the gripper was performed to identify the induced deformation and the stresses. The material selected initially for the gripper was Elastosil M46401 A/B silicon elastomer with a density of 1130 kg/m^3. The data available in Ansys Engineering Data was used for curve fitting and to determine the best hyperelastic model from Moody-Rivlin, Neo-Hookean, Yeoh and Ogden models. Linear regression was used and Yeoh model which had the least normalized error was selected.

When compressed air is filled in the air chambers, the air pressure on the inner walls may cause the outer walls of the chambers to come in contact. To model this, surfaces were generated in design modeller workspace in Ansys workbench. A total of 86 inner faces and 20 outer faces were generated. The contact surfaces were assumed to be frictionless. The physical preference was set to nonlinear mechanical; element order was quadratic, and the element size was set to 0.003 m. One end of the gripper was fixed and standard gravity was applied. Pressure was applied normal to the walls of the air chambers. The results (Fig. 8) indicate that the material fails at a pressure of 55 kPa.

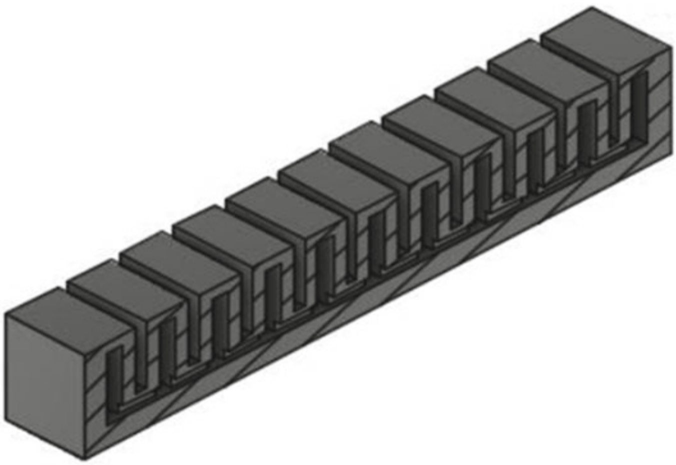


Fig. 7 Sectional view of gripper

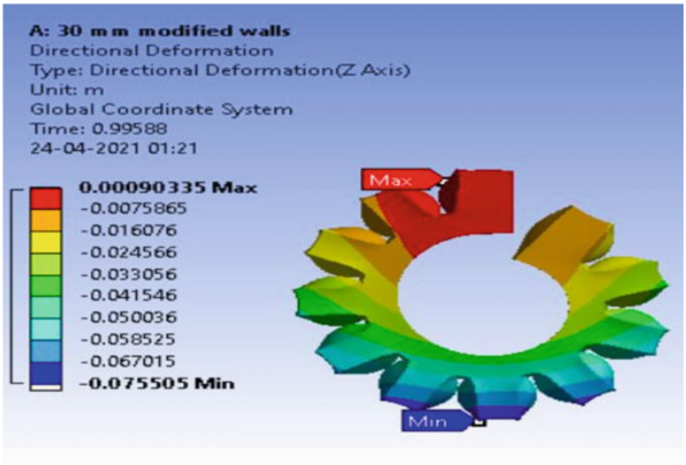


Fig. 8 Bending of gripper under 55 kPa

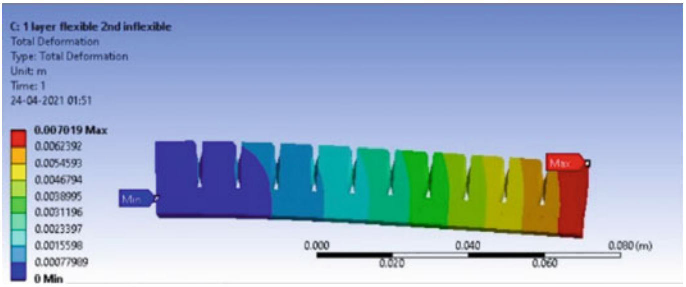


Fig. 9 Total deformation for the composite gripper with 4 mm thick paper layer

To withstand the pressure of 55 kPa, a composite gripper consisting of a silicone layer and a 4 mm thick paper layer was analysed in Ansys. Figure 9 shows that the gripper does not bend/deform significantly. However, a gripper should bend/deform at the desired pressure to correctly grasp the object that is to be picked up. The 4 mm thick paper layer was replaced by a 2 mm thick layer and re-analysed. Figure 10 indicates that the gripper deforms adequately at a pressure of 55 kPa.

5 Conclusion

The gripper arm for a robot trolley was successfully designed and analysed. Results indicate that the arm can successfully pick objects weighing up to 2 kg. The stresses induced and the corresponding deformation of the various links are within permissible

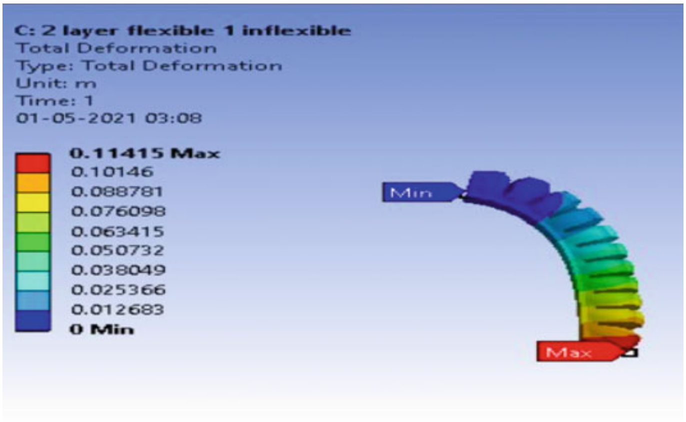


Fig. 10 Total deformation for the composite gripper with 2 mm thick paper layer

limits. Analysis of the soft pneumatics gripper made of elastosil silicone rubber reveals that the material fails at a pressure of 55 kPa while that with a composite material of elastosil silicone rubber and 4 mm thick inextensible layer of paper does not deform adequately. Composite material of elastosil silicone rubber and 2 mm thick inextensible layer of paper was finalized for the gripper as it can withstand the induced pressure and at the same time deform and grasp the object to be picked up.

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Materials

Experimental Investigation of Sound Absorbing Materials

Vishakha V. Mankar, Sandeep Thorat, Sachin Pawar, and Khushal Mulik

Abstract Noise has become one of the four major pollution types in the world. Constant exposure to noises can cause all kinds of health problems such as hearing loss, cardiovascular disease and sleep disorder. Following paper investigates the ability of porous and solid materials to absorb the generated sound for different geometries. Many natural and synthetic material have been developed and tested for acoustic applications. Impedance tube is used to find absorption coefficient of specimen is tested experimentally and the research shows the peak of absorption coefficient changes with porosity and peak value affected with various geometrical shapes in specimens. Finally, we get the peak absorption coefficient in porous material than the solid geometry of same material. In this research, we study the different sound absorbing materials with different geometry and comparative study between the materials. A thorough analysis of the research on the future scope of work, issue statements and goals connected to converting two-wheelers with IC engines into electric two-wheelers. In accordance with our practical analysis, our bike come in second position in overall championship, it is found that motor of electric vehicle generates high frequency sound. The intensity of research and the development in manufacturing processes, we anticipate that the range of new sound absorbing materials will expand to manufacture the casing of motor over the next few years.

Keywords Sound absorption · Carbon fibre · Electric vehicle · Pollution · Natural and synthetic material · Porous material

1 Introduction

Sound is becoming the most serious problem for livelihood many researches has been done and now researcher is more focused on the material which absorbs sound efficiently and that material does not have any adverse effect on lifestyle, it should be natural and concentrated on cost effectiveness. Control over the sound is becoming

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the need, sound not only interrupt the sleep but it causes a loss of hearing during continuous exposure with noise. Sound is a wave of vibration that propagates in various medium. A porous specimen has becoming the barrier which converts sound energy to heat energy. The factors which mainly affects the sound absorption are material thickness, airflow resistivity, porosity, density, etc. Wood-based material, hemp and coir are the natural fibres which is the better option for improving sound absorption.

In terms of porous materials and different geometrical specimen, Jiang et al. [1] investigated the comprehensive analysis of hole diameter, porosity, thickness and consist 3D printed material with 1mm diameter holes. The result shows the peak value of absorption at range from 0.24 to 0.99 from frequency range 4800–6400 Hz. Guzman examined the sound absorption in bricks by redesigning with different geometrical shapes which improves its structural strength. The mixture of brick is made up of plastics and raw dust of sawmill. From data, it is observed that the triangular shape design gives better sound absorption than hexagonal and octagonal shape. Atiénzar-Navarro et al. focused on the study of regular textile material without giving any structure which gives good absorption. By just folding the cotton textile and it gives the aesthetic look too and it is found that folding textile boosts sound absorption at medium and high frequencies but folding effect reaches saturation with a specific number of folds in the operating frequency range. Monkova et al. examined sound absorption qualities of open porous structures. The four different 3D structures (Cartesian, octagonal, rhomboid and starlit), it has been found that starlit sample absorbs the better sound than other three sample. David Griese et al. explored the study of honeycomb structure in sandwiched panel and results in large drop of sound transmission loss (STL). Dr. Muna S. Kassim focused on natural materials and to produce reinforced composites, used waste material like chicken feather, palm leaf, egg shell and wood dust. It is found that the jute woven and the saw dust has great ability to absorb sound than the chicken feather, palm leaf composites for frequency range 50–2000 Hz.The surface layer of egg shell particles and chicken feather has great insulation properties than jute and saw dust. Xie investigated the sound absorption ability of lotus type porous copper. It is found that the absorption coefficient increases with increase in frequency. The absorption coefficient of the 10 mm thick specimen which has uniform porosity 58% increases with decrease in pore diameter. It is found little challenging to customize the frequency for the noise control of specific application.

2 Statement of Problem

- Sound pollution causes a severe health issues.
- Sound in automobiles explores noise to surrounding.

3 Objectives

- To find the composition of material which is effective for sound absorption.
- Selection of specimen geometry for absorption of both low and high range of frequency.
- Manufacturing and experimentation of specimen
- Comparative analysis between different materials.

4 Research Methodology

4.1 Geometry Selection
4.2 Software Analysis
4.3 Experimentation.

4.1 Geometry Selection

Specimen

In this study, all specimens are made of 3D printing material of carbon fibre. The structure of test specimen as shown in Fig. 1, the geometries of these specimens are of 29 and 99 mm in diameter and 10 mm thickness with pore holes of 1 mm diameter. Specimen as shown in Fig. 2, the geometries of these specimens are of 29 and 99 mm in diameter and 10 mm thickness with pores of hexagonal shapes shows in fig. The unit cell is shown in Fig. 3 for two honeycomb panel cell angle (θ), , vertical member height (*h*), angled member length (*l*) and cell wall thickness (*t*). The unit cells in Fig. 2 shown are of hexagonal model, the relationship between the unit cell size and geometric parameter is given.

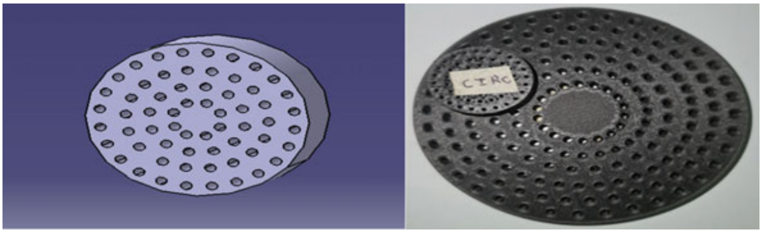

Fig. 1 Cad model of specimen with circular holes and its 3D printed specimen

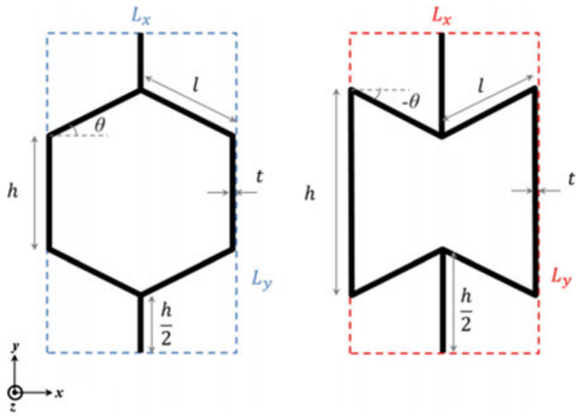

Fig. 2 Unit cell of honey-comb

$\mathrm{Lx} = 2l \cos\theta$
$\mathrm{Ly} = 2(h + l \sin\theta).$
$l = 1$ mm
$h = 1$
$\theta = 30°$

4.2 Software Analysis

The harmonic acoustic analysis gives an idea about how much sound is absorbed at given frequency. A test setup is modelled in Ansys software and the specimen is imported to modelled setup where the acoustic boundary condition is specifying by giving velocity of sound and density of material. At the one end of impedance tube force is defines and on the other end surface velocity resistance and reactance is defined. Two different microphones are placed at two different position which is used to find the reflection and transmission of sound. For mesh sizing, select mesh

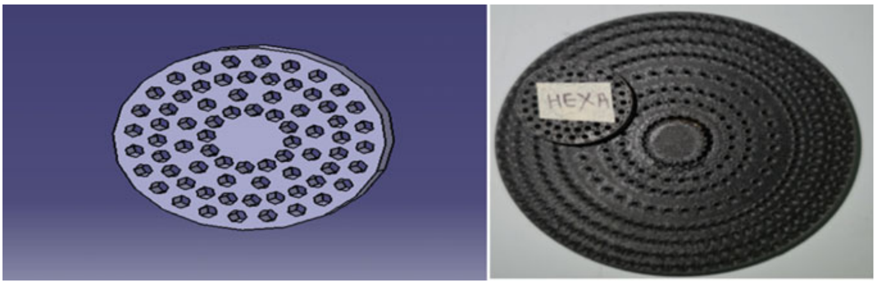

Fig. 3 Cad model of specimen with hexagonal holes and its 3D printed specimen

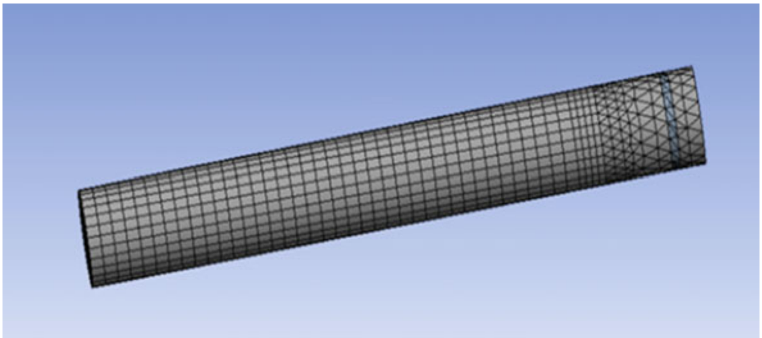

Fig. 4 Meshing

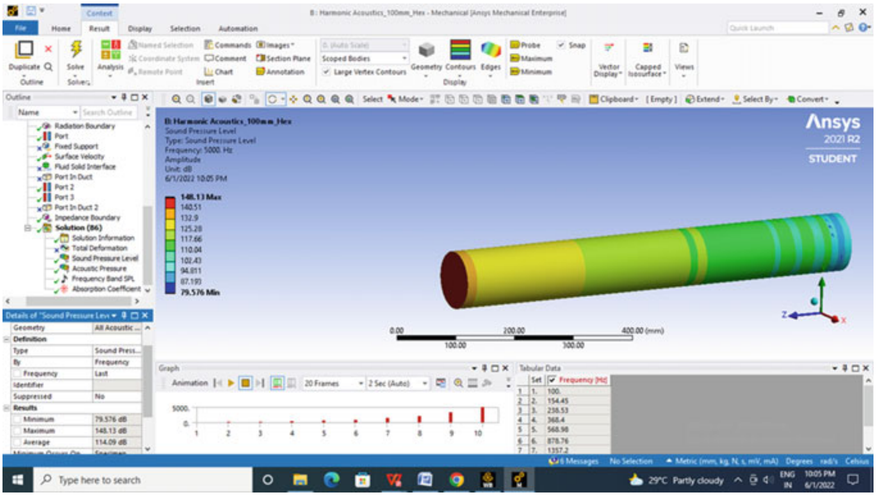

Fig. 5 Sound pressure level distribution

as default and 3 edges are defined so that fine mesh is obtained as shown in Fig. 4 and a sound pressure level in Figs. 5 and 6.

4.3 Experimental Analysis

The sound absorption coefficient of the 3D printed specimen of both porous (circular and hexagonal) was calculated by BSWA SW series impedance tube which is having minimum sound absorbing material with diameter of 30 and 100 mm. The specimen was placed at extreme end of tube and on other end loudspeaker was placed which acts as a source of sound. To find the acoustic properties of specimens, two microphones were placed at distance as shown in Figs. 7 and 8.

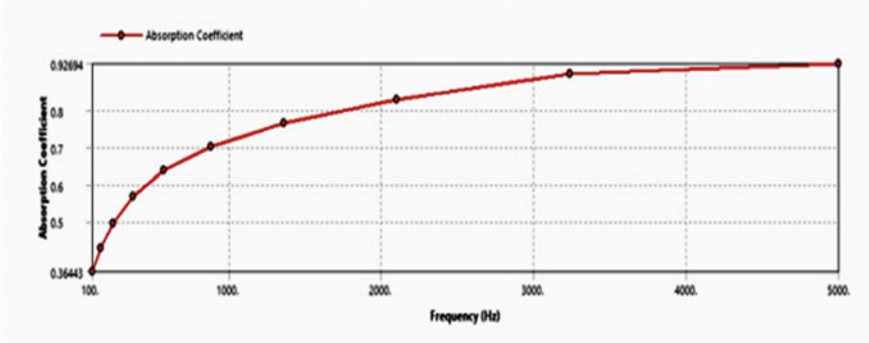

Fig. 6 Sound absorption coefficient

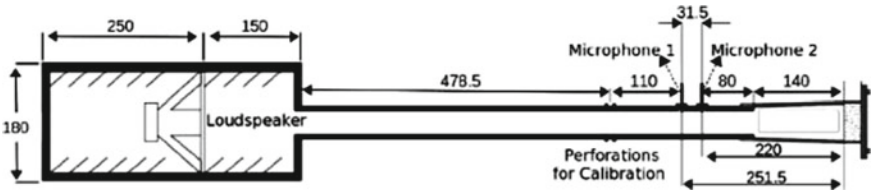

Fig. 7 Experimental setup

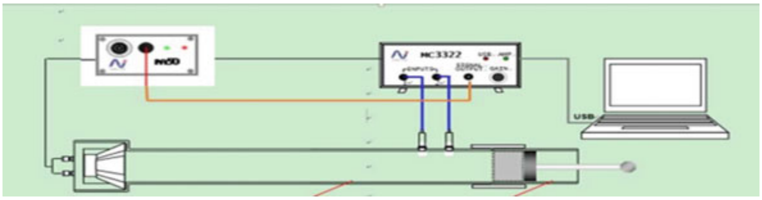

Fig. 8 Connections of testing

5 Results and Discussion

The result of experimentation of carbon fibre specimen for the harmonic acoustic and absorption coefficient. This study analyses the 3D fabric honeycomb and circular holes structure under certain boundary conditions, and in previous research, it has been found that honeycomb and circular structure improves the sound absorption performance in a better way than in solid structures. Sound waves are efficiently get reflected in cavity like structure. The sandwich structures are effective isolation provider for low frequencies. It is found that the porous material specimen showing great results for higher frequencies and the solid specimen of same material shows a good absorption coefficient for higher frequency. Specimen of carbon fibre having circular holes has absorption coefficient 0.7–0.88 for higher frequencies 5000–6000

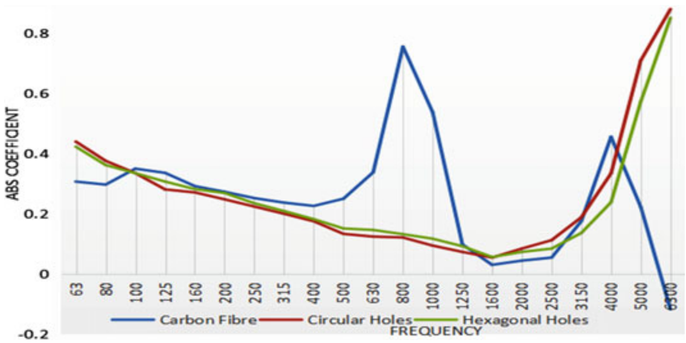

Fig. 9 Graph of sound absorption coefficient of carbon fibre with circular and hexagonal voids

Table 1 Absorption coefficient of different specimen

S. No.	Material	Frequency range (Hz)	Absorption coefficient
1	Carbon fibre	800 1000	0.756 0.538
2	Carbon fibre (circular)	5000 6000	0.881 0.71
3	Carbon fibre (hexagonal)	5000 6000	0.573 0.852

Hz which shown in Fig. 9. Specimen of carbon fibre having hexagonal holes has absorption coefficient 0.57–0.85 for higher frequencies 5000–6000 Hz. Comparison of absorption coefficient for different frequency ranges between carbon fibre, carbon fibre with circular and hexagonal voids as shown in Table 1. Experimental results as shown in Fig. 9.

6 Conclusion

In this paper, we investigated the fabricated 3D printed specimen testing in an impedance tube and its sound absorption coefficient has been calculated. The result shows the maximum sound absorption coefficient for higher frequencies. The sound absorption coefficient of different materials has been studied and carbon fibre with different geometry are tested in stand wave tube. The results of the analysis show the values of harmonic response and sound pressure level at different frequencies. Material properties and initial boundary conditions are applied under harmonic acoustic. It has been seen that the honeycomb and circular void structure are effective for higher frequency. By increasing thickness of material sound absorption increases for medium and high frequency. The highest sound absorption coefficient ranging from 0.85 to 0.88 was achieved by specimen and having good performance for higher frequencies ranging 5000–6000 Hz. It has been concluded from experiment that the frequency characteristics of specimen with voids are better to achieve sound absorption for maximum frequency range. Practically, we can use natural materials like coir, jute and carbon fibre solid specimen for low frequency range like muffler works in range of 63–500 Hz. Composition of carbon fibre and onyx material with different geometry can work for industrial noise range from 1 to 600 MH and carbon fibre with voids helps to manufacture casing of motor as its produce high frequency of sound.

7 Future Scope

- It also can used in a noise controlling duct in heating, ventilation and air conditioning (HAVC) system. Muffler is the best example of pipes, duct that can reduce the sound. Fundamentals used to develop the muffler are reflection of sound and dissipation of sound. Porous material is used to increase dissipation and thermal effect as they are converting sound into heat.
- We have practical experience for electric vehicle bike where we see that there is high frequency sound in motor. So we can make carbon fibre casing for motor which can absorb high frequency sound.

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Improvement of Quality in Adhesive Mass Coating Process Using Statistical Process Control

Aanchal Gandhi, Hari Vasudevan, and Rajendra Khavekar

Abstract This study was conducted in production firm to enhance the process capability of adhesive mass coating process to reduce rejections of adhesive coats due to their out specifications. Statistical tools were integrated for analysis. The causes for deviation were identified and using controls, the process was made capable. The process performance level was brought to the desired range of Ppk > 1.33. As a result of the study, the number of rejections was decreased and a saving of approximately $10,000/annum was achieved in the firm.

Keywords Statistical quality control · Process capability · FMEA · Process improvement · Critical to quality parameter

1 Introduction

The main objective of this study was to improve the quality standards of a production firm and to establish ways of maintaining it in the future. The production firm's quality policy states that "We shall understand the needs of our customers… continuously develop, produce, sell and distribute products, that meet or exceed their expectation", as well as "Continuously challenge and improve our work processes". In the policy, the need for an approach to maintain and continuously improve the quality is demonstrated.

Currently, many quality check systems are abandoned in the firm, because they are not related to the operating plan and are seen as extra effort. Non-value added activities (NVAA) and duplication of work result in deviations/losses. The standards have not been revised. The goal was to ensure that quality systems are implemented, defects discovered are resolved within the agreed-upon time frame. Statistical process

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control (SPC) helps in creating a sustainable system for maintaining product quality standards. When SPC gives early warning of unraveling concerns, it is essential that the key workers on production line are informed and can take suitable action to remedy the problem, before it becomes a line-stopping issue. SPC can assist catch issues as they surface out, rather than after they have occurred, by shifting the responsibility for quality inspection closer to the real time. This paper deals with enhancement of Ppk values of OH-coater machine using SPC.

2 Literature Review

SPC is a method of determining how consistently a product operates in accordance with its design parameters throughout the manufacturing or production process. At its most basic level, SPC is a continuous statistical survey of parametric measurements to ensure that they operate in a normal distribution [1]. While no two products of the same model and design will ever perform identically, the performance of the products is expected to follow a similar fundamental distribution. Measurements gathered from multiple iterations of same product that do not follow a usual distribution may indicate a fault with the materials, staff, design, production or testing technology [2, 3].

SPC is practiced in two phases: The first phase is the initial establishment of the process, and the second phase is the regular production use of the process. In the second phase, a decision of the period to be examined must be made, depending upon the change in 5M&E conditions (Man, Machine, Material, Method, Movement and Environment) and wear rate of parts used in the manufacturing process (machine parts, jigs and fixtures) [4, 5]. Inspection, which emphasizes early detection and prevention of problems, rather than correcting them after they have occurred is an advantage of SPC over other methods of quality control. In addition to reducing the waste, SPC can also lead to a reduction in the time required to produce the product. SPC makes the finished product, which less likely needs to be reworked or scrapped [6].

3 Methodology

For creating a culture and system in the plant that relies on collecting and tracking data patterns, in order to identify and manage the system faults, it was necessary at first to establish the initial structure and then expand it across the entire production line. The process was selected using a decision matrix. The OH-coater machine for coating was selected, since it was found to be the most important step of production based on business considerations (customer complaints and costs associated with dealing of low-quality products).

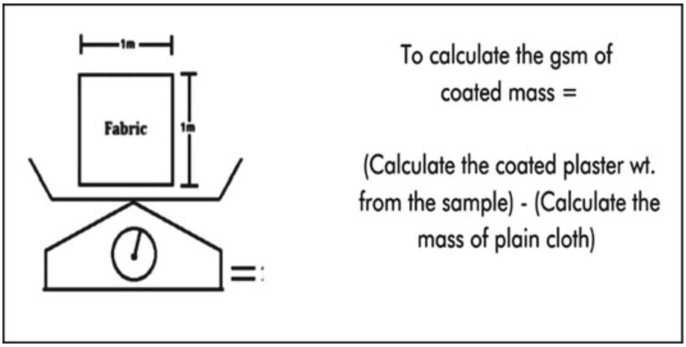

Fig. 1 GSM calculation method of cloth sample

3.1 Tracking Critical to Quality Parameters

The crucial to quality/special factors that must be tracked using statistical analysis in Minitab were decided before beginning the statistical process control. Any risk-related property of material, method, part or assembly that has an impact on product fit, form, function or any other expected deliverable as defined in a requirement was referred to as a special characteristic. When expected process variation affects process function, product function or customer/stakeholder satisfaction, a characteristic with a set aim must be centered on a target.

In the coating operation, the mass blended in the previous step of production was coated on the fabric bale. As a result, the critical to quality (CTQ) tracking parameter was established as grams per square meter of coated mass on the cloth. Collecting a 1 × 1 m cloth sample from each bale of coated cloth to check its mass was established as part of the tracking method. For analysis, 125 GSM readings were gathered and divided into 25 subgroups. The sample GSM calculation method has been shown in Fig. 1.

3.2 Performing Process Failure Modes and Effect Analysis (FMEA)

FMEA is a step-by-step approach for identifying all possible failures in a design, manufacturing or assembly process or a product or service. Through this, the potential failure modes were identified and controls were brought in to avoid any deviation from the results. For performing the process FMEA, it was essential to map the entire process and making a list of steps, establishing descriptors for FMEA. Table 1 shows the process steps and FMEA performed.

Table 1 Process FMEA

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
Loading the roll in the shaft	This step involves loading a jumbo truck	The roll may fall down	Safety risk for the personnel involved in the operation	10	While loading if operation is not done properly	1	Pneumatic lifting crane for loading of the bale, authorized personnel from govt. conducts regular safety inspection	3	30	NA
		Air not inserted in air expander shaft	The roll will slip and tension will not be maintained	3	Leakage	1	Manual check to see if the roll is not slipping	5	15	
		Roll may shift from it's position	Cloth will move from the center, Improper coating	7	Locking not done correctly	1	Manual check to see if the roll is not slipping	5	15	

(continued)

Table 1 (continued)

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
Stitching	This step involves stitching the new roll of cloth with the old cloth roll end	Improper stitch on the cloth	Cloth tearing during operation which will lead to loss of time due to machine stoppage	9	If stitching is not done properly	4	Ensure two joints are made on stitch, checked manually for the strength of the joint	2	72	N.A
			Rejection	9	Stitching not done correctly by the vendor	5	QI raised	8	360	Alignment with the vendor for product property requirements
			Restitching will be required leading to wastage	3	If not done in the proper direction	2	Manually on the spot before stitching	2	12	N.A
Unwinding	This step involves unwinding of cloth roll from jumbo truck	The dotted tape on pulling roller worn out which provides the grip for cloth drive	Speed will not be maintained speed reduces on cloth causing slippage	8	Wear of the dotted tape grip after use	3	N.A	10	240	Visual checks before starting the operation

(continued)

Table 1 (continued)

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
			Wear and tear of the cloth roll	9		3	N.A	10	270	Visual checks before starting the operation
		Crease formation in the cloth	Improper coating and problems at winding end	8	Load cell not calibrated which could lead to incorrect tension	3	Tension gets maintained by automatic tension control system	2	48	Proper training for how to set the tension give to operators
		Cloth touches the base of coater	Issues faced during coating and mass transfer to the bottom surface of coater	9	Tension not maintained or weaving incorrect	3	Visual checks before starting the machine	2	54	OPL for how to do proper weaving
Braking	To adjust and monitor tension on the cloth	Brakes not applied	Crease formation, improper coating and problems at winding end	7	Improper braking	1	Auto synchronization	1	7	NA

(continued)

Table 1 (continued)

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
	To adjust and monitor tension on the cloth	Drive transfer	If the gear shifts from location break failure will happen	5	Brakes not get applied properly at unwinding end	1	Manually checked/visual check for gear positioning	3	15	NA
Edge alignment post winding	Maintaining the alignment of the cloth roll in the center of the passage to ensure proper and centered coating	Cloth will shift to one end	Improper coating which will lead to rejection of cloth as mass is concentrated on one end	9	Nozzles blocked, oil level low could lead to malfunction, any other internal failure	5	Before start, inspection done	2	90	CIL cleaning inspection lubrication
		Improper movement of shaft roll		8	Oil leakage or issue in the internal mechanism of the hydraulic cylinder	3	CIL	2	48	NA
Blade setting	This step involves setting the blade height to maintain the GSM of coating	GSM in variation	Off quality product produced which may lead to rejections	10	Man error while setting the blade setting	4	NA	10	400	Having proper way of checking and recording setting data

(continued)

Table 1 (continued)

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
				10	Block loosened which causes rollers to shift from original position	2	NA	10	200	Frequency to be set for checking the gap between blade and coating roller
Coating	Coating of mass on the cloth	GSM in variation	Off quality product produced which may lead to rejections	10	Cloth GSM variation through out single roll	4	Cloth GSM checked on each roll	7	280	Aligning with vendor/SQM should be maintained
		Cleaning not done properly it may lead to contamination	Rejection	8	Cloth fluff or mass residual gets stuck	1	Cleaning	3	24	Documentation to be maintained for this
		Machine stoppage and rejection due tearing	If blade not raised on a joint in cloth, tearing of the cloth will happen	10	Cloth fluff or mass residual gets stuck	5	Visual checks before starting the machine	2	100	Labels needed on joints

(continued)

Table 1 (continued)

Process step	Process function	Potential failure mode	Potential effect of the failure mode	Severity	Potential causes of the failure mode	Occurrence	Current controls	Detection	RPN	Proposed action
		Uneven coating on the cloth leading to variation	Off quality product produced which may lead to rejections	9	Viscosity less of the mass	3	Viscosity checks	3	81	NA
Solvent suction	This step involves suction of solvent from the mass coated on the cloth	Solvent remaining in coated cloth	Safety issues as well as recovery improper	10	Suction mechanism not functioning	2	Concentration sensor trips	1	20	NA
		Leakage will lead to skip out of hexane	Safety issues as well as recovery improper	6	Suction mechanism not functioning when operations are stopped	7	NA	10	420	Extraction blower should remain in operation during any power failures, checks needed for the same, check for leaks

3.3 Data Analysis Minitab Phase 1

Process established for analyzing the data collected for the parameters include:

- Characteristics classified as critical to quality parameters, shall have a performance level of Ppk > 1.33.
- The performance level, Ppk > 1.33 shall be confirmed in a process qualification/validation study including at least 125 individual measurements.
- Data should be collected in at least 25 subgroups distributed over the time frame in representative and rational way.
- To indicate future performance, the qualification/validation study must be conducted on a stable process. Process stability should be monitored and controlled preferably by using X-Bar and R-charts.
- These requirements apply to a qualification/validation study, whose end point is the validated state. Thus, there is no requirement (including Ppk) that applies to long term data. However, the validated state shall be maintained using the living control system (Minitab tracking), implemented in the production system and must be possible to repeat.
- Once these data points were collected and process was validated, same experiment was repeated for a set of 25 observations to check the results.
- After the process was validated, the data collection becomes part of the daily production process, where these data points were entered into Minitab for checking, if the value meets the control parameters. If not, the process owners could find the root cause for deviation and correct it.

3.4 Data Collection and Analysis

- The process of data collection was initiated by setting up a method for sample collection.
- In the initial runs, an out of specification point was observed with mass GSM 88. Figure 2 shows the X-chart for the data, in which OOS point was observed.

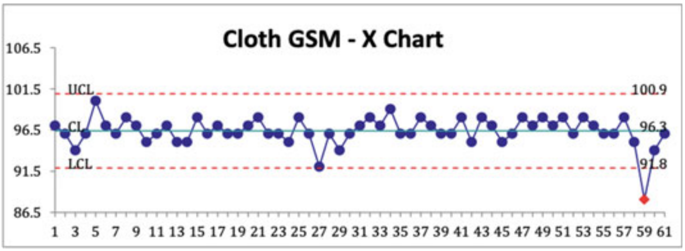

Fig. 2 X-chart for the data of out of specification point

- To analyze this OOS point, root cause analysis was performed. Table 2 shows the root cause analysis, in which WHY-WHY tool was used.
- For the first problem, training session was conducted, explaining the operators about different specification limits and the reaction plan, which should be followed in case, an out of specification cloth bale is found. A display chart was simultaneously put up near the coater showcasing the specifications for various products.
- For blade setting procedure development, a test study was conducted, where keeping the cloth GSM constant, the effect of change in blade setting on coated mass GSM was observed. This process was carried out for cloth with GSM 110,

Table 2 WHY-WHY analysis

WHY-WHY analysis					
Problem	WHY 1	WHY 2	WHY 3	Counter Measures	Implemented yes/no
A cloth roll without of specs GSM was used for coating operation in tapes department for Leukoplast product, batch number xyzzy	Operators were not aware of the correct control mechanism (for rejecting cloth) to deal without specs GSM cloth	Operators were not trained about the correct controls and product specifications	Training program for operators was not performed	Training needs to be performed. Content and duration of the training should be decided and then executed	Yes
	Operators were not aware about the correct cloth GSM specifications as per the SOP	Operators were not trained about the correct controls and product specifications			
		Visual representation of specs was missing	NA	Display chart should be put-up containing all specs in the coating section	Yes
Blade setting not changed after loading a new roll with different cloth GSM compared to previous roll	No procedure defined as to how blade setting must be changed as per the cloth GSM in order to get required coating GSM	NA	NA	A procedure should be established by testing which explains how blade setting is supposed to be adjusted for change in cloth GSM	Yes

111, 112, 113, 114, 115, 116, 117, 118, 119 and 120. Through this study, a procedure document was made showcasing how the blade setting should be changed to get the required mass coating value.

- A study was started on the vendor specifications and the variation of fabric GSM in one bale of cloth roll, based on the data points observed. Multiple tests revealed that the cloth rolls had a GSM variation of grams per square meter. This resulted in a complaint being filed with the stores department.

After implementation of the control measures, data point collection was performed for 25 subgroups, containing five sample values.

3.5 Test Runs

Test Run 1:

The process was stable as the X-Bar R control charts plotted adhered to all the SPC rules. The performance level, Ppk was ≥ 1.33. The results are shown in Fig. 3.

Test Run 2:

The process was stable as the X-Bar R control charts plotted adhered to all the SPC rules. The performance level, Ppk was ≥ 1.33. The results are shown in Fig. 4.

Phase I was completed after executing the process and it confirmed that it was stable and capable of two test runs with 125 sample values.

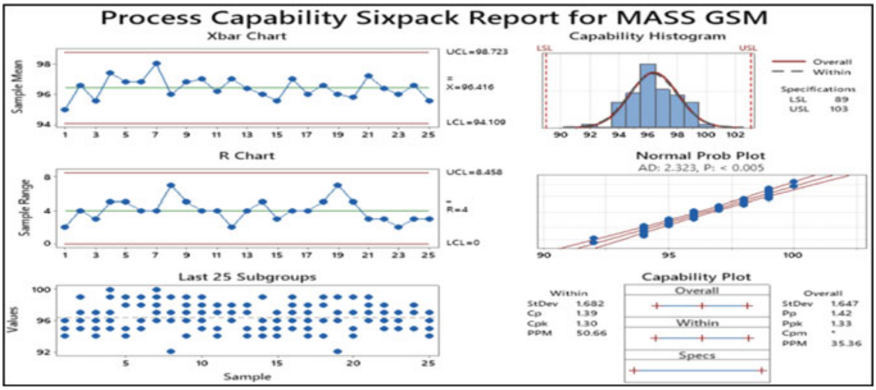

Fig. 3 Test run 1 results

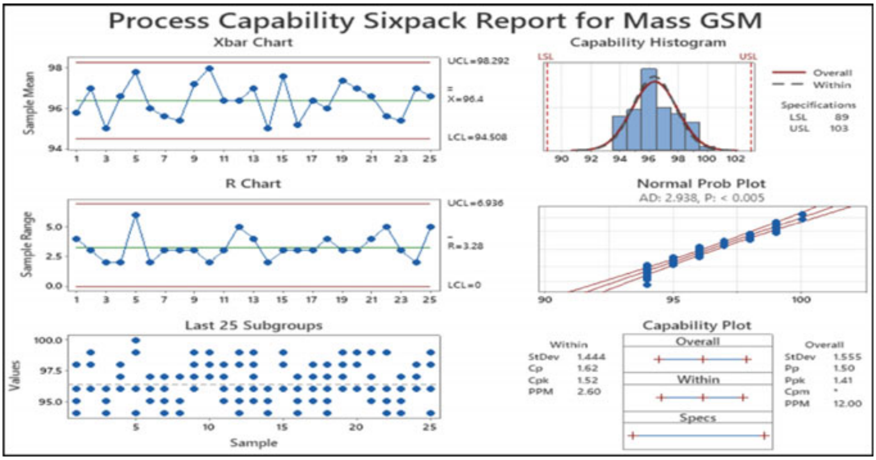

Fig. 4 Test run 2 results

3.6 Data Analysis Minitab Phase II

The sampling frequency for phase II was set at three readings per coated cloth bale in a batch.

For phase II implementation, training was conducted for the production officers on how to use Minitab and interpret the charts. Minitab was used by the officers to analyze the daily production data and look for deviations.

Simultaneously, a manual was prepared for implementing SPC in other areas of the plant using Minitab, so that the work implemented in the coater region could be replicated to the entire line. In order to improve the process stability, the entire production line needed to be integrated with Minitab. This document also contained the information regarding how to interpret charts and what actions need to be taken to make the process stable.

The results of Minitab were also made a part of the daily operations meeting in the production department. Through this any deviations observed could be discussed and analyzed.

4 Conclusion

The study involving the implementation of SPC showed that the tape production line was made capable and also the following enhancements were made. Process capability, with a recurring performance level of Ppk > 1.33 was achieved. As a result of the study, the production plant approximately saved $10,000 per annum. Moreover, Officers were trained on how to utilize Minitab, a data analysis tool; and a manual was prepared for future reference. Using the FMEA, process variability was reduced by implementing improved controls for important failure modes. The mass GSM of coating was recognized as critical to quality metric and the FMEA was used as a method to understand the many elements that influenced it. The primary concern areas were addressed and better controls were implemented to lower the RPN of those failure modes. This also resulted in data driven culture at the production line of the firm.

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Study of Properties of Aluminium Composites Reinforced with Triple Reinforcements

Greegory Mathew, K. N. Vijaya Kumar, and Suhasini Vijaykumar

Abstract Aluminium metal matrix composites have widely replaced aluminium alloys as the preferred material for the fabrication of components and products. Researchers have fabricated these composites by reinforcing aluminium alloys with ceramic reinforcements of various sizes and types. Some researchers have also experimented by reinforcing aluminium alloys simultaneously with three different reinforcements. This paper specifically reviews the work done by such researchers and the overall effect of triple reinforcements on the mechanical and physical properties is summarized.

Keywords Aluminium composite · Ceramic reinforcements · Triple reinforcement · Mechanical properties

1 Introduction

Aluminium metal matrix composites (ALMMCs) are a class of materials that have an aluminium alloy (AA) as the base matrix and any other material with different physical and chemical properties as the reinforcement. Generally, ceramics such as silicon carbide, aluminium oxide, boron nitride, etc., are used as reinforcements for composites developed for engineering applications.

Even though composites have better strength and hardness as compared to the base aluminium alloy, the improvement is usually at the expense of a loss in other properties such as ductility. To achieve a balance between these properties, some researchers reinforced aluminium alloys simultaneously with two different reinforcements. Some of them have also experimented by reinforcing aluminium alloys simultaneously with

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three different reinforcements. They have varied the size, type and the concentration (weight/volume fraction) of the reinforcements in these composites and have studied its mechanical properties such as tensile strength, yield strength, compressive strength, impact strength, flexural strength, hardness, ductility, modulus of elasticity and physical properties such as density.

2 Materials and Methods

Researchers have used various combinations of graphite (Gr), multi-walled carbon nanotubes (MWCNT), carbon black (CB), ceramics such as aluminium oxide (Al_2O_3), silicon nitride (Si_3N_4), boron carbide (B_4C), titanium dioxide (TiO_2), silicon carbide (SiC), molybdenum disulphide (MoS_2), zirconium diboride (ZrB_2), tantalum carbide (Ta_2C), magnesium oxide (MgO), zirconium dioxide (ZrO_2), aluminium nitride (AlN), boron nitride (BN), titanium diboride (TiB_2), alumino-boron carbide (Al_3BC) and iron oxide (Fe_3O_4), metals such as nickel (Ni) and titanium (Ti) and rare-earth oxides such as lanthanum oxide (La_2O_3) and cerium dioxide (CeO_2) as reinforcements. The reinforcement particulates used were of different sizes. Some researchers used particulates of size as low as 17.3 nm, while some used particulate of up to 220 μm.

These composites were fabricated through various processes such as powder metallurgy—hot pressing (PM), squeeze casting (SQC), stir casting (SC), stirring and liquid metal infiltration (SLMI), selective laser melting (SLM), in-situ synthesis (IS) and friction stir process (FSP). Some researchers preheated the reinforcements before adding them to the molten alloy, to increase the wettability. The combination of the reinforcements and the fabrication process employed is given in Table 1.

3 Fabrication and Effect on Properties

Ovall et al. [1] reinforced AA 2024 with Al_2O_3 (<8 μm), MgO (10–30 nm) and Gr (<10 μm) particulates through powder metallurgy (hot pressing). Two different composites with Al_2O_3/MgO/Gr weight fractions as 10/3/1.5 and 10/3/3 percentages were fabricated. The composite with 10/3/1.5% reinforcements had the highest hardness of around 111.2 HB. Natarayan and Kumar [2] reinforced AA 2024 with Al_2O_3, SiC and Gr particulates of size 10 μm through squeeze casting. The weight fraction of each reinforcement was 3%. The composite had a hardness (Vickers) of around 167 HV and tensile strength of around 469 MPa. Singh [3] reinforced AA 2024 with Al_2O_3, ZrO_2 and Gr particulates of size 10 μm through stir casting (followed by heat treatment). Four different composites with Al_2O_3/ZrO_2/Gr weight fractions as 1/1/1, 1.3/1.3/1.3, 2/2/2 and 3.3/3.3/3.3 percentages were fabricated. The composite with 3.3/3.3/3.3% reinforcements had the highest hardness (Vickers) of around 156.6 HV

Table 1 Aluminium alloys and their reinforcements

Authors	Alloy	Reinforcement			Process	References
		R1	R2	R3		
Ovall et al.	AA2024	Al_2O_3	MgO	Gr	PM	[1]
Natrayan and Kumar	AA2024	Al_2O_3	SiC	Gr	SQC	[2]
Singh	AA2024	Al_2O_3	ZrO_2	Gr	SC	[3]
Kumar et al.	AA2618	Si_3N_4	AlN	ZrB_2	SC	[4]
Raja et al.	AA5083	Al_2O_3	SiC	B_4C	SC	[5]
Gopinath et al.	AA6061	Al_2O_3	BN	Gr	SC	[6]
Sharma et al.	AA6061	CeO_2	Al_2O_3	SiC	SC	[7]
Sharma et al.	AA6061	B_4C	CeO_2	Gr	SC	[8]
Vaishnav et al.	AA6061	Gr	TiB_2	MoS_2	SC	[9]
Shuvho et al.	AA6063	TiO_2	Al_2O_3	SiC	SC	[10, 11]
Khare et al.	AA7075	Al_2O_3	B_4C	CB	SC	[12]
Ozturk et al.	AA7075	SiC	B_4C	Al_2O_3	SLMI	[13]
Abirami and Arravind	AA7075	Al_2O_3	B_4C	TiO_2	SC	[14]
Raja et al.	AA7075	B_4C	MoS_2	MWCNT	SC	[15]
Ranjan and Shanmugasundaram	AA7075	MoS_2	ZrO_2	Ni	SC	[16]
Kumar et al.	AA356	Al_2O_3	SiC	Gr	SQC	[17]
Anoop et al.	AA356	B_4C	Gr	Fe_3O_4	SLM	[18]
Paulraj et al.	AA356	TiO_2	SiC	B_4C	SC	[19]
Bian et al.	Al	ZrB_2	Al_3BC	Al_2O_3	IS	[20]
Kalra et al.	Al	SiC	Al_2O_3	C	SQZ	[21]
Bhatia and Singh	Al-Si(12%Si)	Al_2O_3	B_4C	Gr	SC	[22]
Moustafa et al.	AA2024	Ta_2C	Al_2O_3	MWCNT	FSP	[23]
Singh et al.	AA6082	Al_2O_3	Gr	B_4C	SC	[24]
Smart et al.	AA7075	TaC	Si_3N_4	Ti	SC	[25]
Sharma et al.	AA6063	SiC	CeO_2	La_2O_3	SC	[26]

and tensile strength of around 157.36 MPa. The composite with 1.3/1.3/1.3% reinforcements had the lowest density of around 2.512 g/cc. Kumar et al. [4] reinforced AA 2618 with Si_3N_4, AlN and ZrB_2 particulates through stir casting. Four different composites with 2, 4, 6 and 8% reinforcements were fabricated. The composite with 8% reinforcements had the highest hardness (Vickers) of around 178 VH, ultimate tensile strength of around 493 MPa and ultimate compressive strength of around 413 MPa. Raja et al. [5] reinforced AA 5083 with Al_2O_3, SiC and B_4C particulates through stir casting. Three different composites with Al_2O_3/SiC/B_4C weight fractions as 5/5/2.5, 5/5/5 and 5/5/10 percentages were fabricated. The composite with 5/5/10% reinforcements had the highest ultimate tensile strength of around

262 MPa and percentage elongation of around 46.2%. The composite with 5/5/2.5% reinforcements had the highest hardness (Brinell) of around 42.

Gopinath et al. [6] reinforced AA 6061 with Al_2O_3 (50 μm), BN (75 μm) and Gr (60 μm) particulates through stir casting. Two different composites with Al_2O_3/BN/Gr weight fractions as 20/20/5 and 10/30/5 percentages were fabricated. The composite with 10/30/5% reinforcements had the highest tensile strength of around 158 MPa, percentage elongation of around 29%, compressive strength of around 187 MPa, impact strength (Charpy) of around 12 J and microhardness (Vickers) of around 63 HV. Sharma et al. [7] reinforced AA 6061 with CeO_2, Al_2O_3 and SiC particulates through stir casting. Three different composites with CeO_2/Al_2O_3/SiC weight fractions as 0.5/2.5/2.5, 1.5/5/5 and 2.5/7.5/7.5 percentages were fabricated. The composite with 1.5/5/5% reinforcements had the highest impact strength (Charpy) of around 56 J. The composite with 2.5/7.5/7.5% reinforcements had the highest ultimate tensile strength of around 123 MPa, percentage elongation of around 11.5%, flexural strength of around 615.6 MPa, microhardness (Vickers) of around 92.8 HV and hardness (Rockwell) of around 82.5 HRB. The composite with 0.5/3/2.5% reinforcements had the lowest density of around 2.75 g/cc. Sharma et al. [8] reinforced AA 6061 with B_4C, CeO_2 and Gr particulates. The weight fraction of each reinforcement was 5%. The composite had a microhardness (Vickers) of around 68 VHN, macrohardness (Brinell) of around 44 BHN and ultimate tensile strength of around 175 MPa.

Vaishnav et al. [9] reinforced AA 6061 with Gr, TiB_2 and MoS_2 (80 nm) particulates through stir casting. Three different composites with Gr/TiB_2/MoS_2 weight fractions as 10/10/10, 10/10/15 and 10/10/20 percentages were fabricated. The composite with 10/10/20% reinforcements had the highest tensile strength of around 162.9 MPa. The composite with 10/10/10% reinforcements had the highest hardness (Rockwell) of around 53.6 HRB. Shuvho et al. [10] reinforced AA 6063 with TiO_2, Al_2O_3 and SiC particulates of size 47 μm through stir casting. Four different composites with TiO_2/Al_2O_3/SiC weight fractions as 1/1/2.5, 1/1/5, 1/1/7.5 and 1/1/10 percentages were fabricated. They also reinforced AA 6063 with TiO_2, Al_2O_3 and SiC particulates of size 65 μm through stir casting [11]. Four different composites with TiO_2/Al_2O_3/SiC weight fractions as 1/1/4.5, 1/1/7, 1/1/9.5 and 1/1/12 percentages were fabricated. The composite with 1/1/12% reinforcements had the highest hardness of around 98.56 HB, ultimate tensile strength of around 148.62 MPa and yield strength of around 109.8 MPa. The composite with 1/1/4.5% reinforcements had the highest percentage elongation of around 6.65%. Khare et al. [12] reinforced AA 7075 with Al_2O_3, B_4C and CB particulates through stir casting. The weight fraction of the reinforcements (Al_2O_3/B_4C/CB) was 12/4/5%. The composite had a hardness of around 149 BHN, ultimate tensile strength of around 282 MPa and flexural strength of around 343 MPa. Ozturk et al. [13] reinforced AA 7075 with SiC (91 μm), B_4C (15 μm) and Al_2O_3 (91 μm) particulates through stirring followed by liquid metal infiltration. Four different composites with SiC/B_4C/Al_2O_3 weight fractions as 20/8/2, 20/6/4, 20/4/6 and 20/2/8 percentages were fabricated. The composite with 20/2/8% reinforcements had the highest hardness (Brinell) of around 153.7 HB.

Abirami et al. [14] reinforced AA 7075 with Al_2O_3 (44 μm), B_4C (210 μm) and TiO_2 (180 μm) particulates through stir casting. Three different composites with $Al_2O_3/B_4C/TiO_2$ weight fractions as 3/5/5, 6/5/5 and 9/5/5 percentages were fabricated. The composite with 9/5/5% reinforcements had the highest hardness (Brinell) of around 105.3 HV. The composite with 6/5/5% reinforcements had the highest impact strength (Charpy) of around 4 J. The composite with 3/5/5% reinforcements had the highest ultimate tensile strength of around 175 MPa, yield strength of around 140 MPa and percentage elongation of around 16%. Raja et al. [15] reinforced AA 7075 with B_4C, MoS_2 and MWCNT particulates through stir casting. Three different composites with B_4C/MoS_2/MWCNT weight fractions as 1.41/4.24/0.19, 2.82/2.82/0.19 and 4.24/1.41/0.19 percentages were fabricated. The composite with 4.24/1.41/0.19% reinforcements had the highest tensile strength of around 146.39 MPa, percentage elongation of around 8.9% and impact strength (Charpy) of around 16 kJ/mm^2. The composite with 2.82/2.82/0.19% reinforcements had the highest hardness (Vickers) of around 108.73 HV. Ranjan and Shanmugasundaram [16] reinforced AA 7075 with MoS_2, ZrO_2 and Ni particulates through stir casting. Three different composites with MoS_2/ZrO_2/Ni weight fractions as 2/4/4, 3/8/9 and 4/12/14 percentages were fabricated. The composite with 4/12/14% reinforcements had the highest microhardness of around 206 HV. The composite with 2/4/4% reinforcements had the lowest density of around 2.792 g/cc. Kumar et al. [17] reinforced AA A356 with Al_2O_3, SiC and Gr particulates of size 10 μm through squeeze casting. Five different composites with Al_2O_3/SiC/Gr weight fractions as 1/1/1, 2/2/2, 3/3/3, 4/4/4 and 5/5/5 percentages were fabricated. The composite with 3/3/3% reinforcements had the highest hardness (Brinell) of around 119 HV and tensile strength of around 315 MPa. The composite with 1/1/1% reinforcements had the highest percentage elongation of around 4.7% and the lowest density of around 2.66 g/cc.

Anoop et al. [18] reinforced AA A356 with B_4C, Gr and Fe_3O_4 particulates through selective laser melting. Three different composites with B_4C/Gr/Fe_3O_4 weight fractions as 2/2/2, 4/4/4 and 6/6/6 percentages were fabricated. The composite with 6/6/6% reinforcements had the highest microhardness of around 188 VHN and ultimate tensile strength of around 325.4 MPa. Paulraj et al. [19] reinforced AA A356 with TiO_2 (100 nm), SiC (10 μm) and B_4C (10 μm) particulates through stir casting. The weight fraction of the reinforcements (TiO_2/SiC/B_4C) was 1/10/10%. The composite had a percentage elongation of around 0.63%, tensile strength of around 332.4 MPa, hardness of around 176 BHN, impact strength of around 5.25 J, wear rate (at a load of 10 N, sliding velocity of 1.25 m/s and sliding distance of 1000 m) of around 1.1×10^{-12}mm^3/Nm and coefficient of friction of around 0.34. Bian et al. [20] reinforced Al alloy with ZrB_2, Al_3BC and Al_2O_3 particulates through stir casting and in-situ synthesis. The weight fraction of the reinforcements ($ZrB_2/Al_3BC/Al_2O_3$) was 9.2/5.6/5.5%. The composite had a hardness of around 96 HBW, modulus of elasticity of around 89 GPa, ultimate tensile strength of around 371 MPa and percentage elongation of around 8.1%. Kalra et al. [21] reinforced Al alloy with SiC, Al_2O_3 and C particulates through liquid stir with squeeze casting. Three different composites with SiC/Al_2O_3/C weight fractions as 10/5/3, 15/7.5/5 and 20/10/7.5 percentages were fabricated. Bhatia and Singh [22] reinforced Al-Si (12%Si) alloy with Al_2O_3 (30 μm), B_4C (50 μm) and Gr (80 μm) particulates through stir casting. Five different composites with Al_2O_3/B_4C/Gr weight fractions as 5/1/1, 10/2/3, 15/3/5, 20/4/8 and 25/5/11 percentages were fabricated. The composite with 15/3/5% reinforcements had the highest microhardness (Vickers) of around 70.08 HV. The composite with 10/2/3% reinforcements had the highest tensile strength of around 186.1 MPa.

Moustafa et al. [23] reinforced AA 2024 with Ta_2C (280 nm), Al_2O_3 (17.3 nm) and MWCNT (40 nm inner diameter and 80 nm outer diameter) particulates through friction stir process. The composite had a microhardness (Vickers) of around 145 HV, wear rate of around 0.00533 mg/s and coefficient of friction of around 0.505. Singh et al. [24] reinforced AA 6082 with Al_2O_3, Gr and B_4C particulates of size 50 μm through stir casting. Four different composites with Al_2O_3/Gr/B_4C weight fractions as 2.5/1/0.5, 5/2/0.75, 10/3/1 and 15/5/1.5 percentages were fabricated. The composite with 10/3/1% reinforcements had the highest microhardness (Vickers) of around 98.76 HV. Smart et al. [25] reinforced AA 7075 with TaC (200–250 nm), Si_3N_4 (20 μm) and Ti (70 μm) particulates through stir casting. Four different composites with TaC/Si_3N_4/Ti weight fractions as 0.25/2/0.5, 0.5/4/1, 0.75/6/1.5 and 1/8/2 percentages were fabricated. The composite with 1/8/2% reinforcements had the highest compressive strength of around 634 MPa. The composite with 0.25/2/0.5% reinforcements had the lowest density of around 2.85 g/cc. Sharma et al. [26] reinforced AA 6063 with SiC (220 μm), CeO_2 and La_2O_3 (5 μm) particulates through stir casting. Three different composites with SiC/CeO_2+La_2O_3 weight fractions as 3/1, 6/2 and 9/3 percentages were fabricated. The composite with 6/2% reinforcements had the highest microhardness (Vickers) of around 114.24 HV, ultimate tensile strength of around 91 MPa and impact strength of around 56 J. The composite with 3/1% reinforcements had the lowest density of around 2.771 g/cc.

The percentage increase/decrease in microhardness (MH), tensile strength (TS), compressive strength (CS), percentage elongation (%E), impact strength (IS), flexural strength (FS), density (d), yield strength (YS) and modulus of elasticity (E) have been given in Table 2. These values were computed only for composites whose base alloy properties were determined experimentally by the corresponding researcher.

4 Conclusion

Researchers have successfully reinforced aluminium alloys with triple reinforcements through various processes. The total weight fraction of reinforcements in the composite have been up to 45% in some studies. Some researchers used particulates of size as low as 17.3 nm while some used particulate of up to 220 μm. This has led to an overall improvement in the mechanical properties of such composites. Of the composites selected for the study, a high compressive strength of around 634 MPa was observed in the composite AA7075/1%TaC/8%Si_3N_4/2%Ti, flexural strength of around 615.6 MPa was observed in the composite

Table 2 Percentage increase/decrease in composite properties

Composite	MH	TS	CS	%E	IS	FS	d	YS	E
AA2618/Si_3N_4/AlN/ZrB_2	48	12	11	–	–	–	–	–	–
AA6061/Al_2O_3/BN/Gr	90	61	71	52	135	–	–	–	–
AA6061/CeO_2/Al_2O_3/SiC	17	–	–	–	–	81	3	–	–
AA6061/B_4C/CeO_2/Gr	51	9.4	–	–	–	–	–	–	–
AA6063/TiO_2/Al_2O_3/SiC	–	35	–	− 14	–	–	–	39	–
AA7075/MoS_2/ZrO_2/Ni	136	–	–	–	–	–	3.8	–	–
AA356/Al_2O_3/SiC/Gr	–	40	–	− 13	–	–	0.3	–	–
AA356/TiO_2/SiC/B_4C	–	62	–	− 73	− 63	–	–	–	–
Al/ZrB_2/Al_3BC/Al_2O_3	–	–	–	–	–	–	–	–	26
Al-12%Si/Al_2O_3/B_4C/Gr	46	54	–	–	–	–	–	–	–
AA2024/Ta_2C/Al_2O_3/MWCNT	53	–	–	–	–	–	–	–	–
AA6082/Al_2O_3/Gr/B_4C	79	–	–	–	–	–	–	–	–
AA7075/TaC/Si_3N_4/Ti	–	–	95	–	–	–	1.8	–	–
AA6063/SiC/CeO_2 + La_2O_3	–	–	–	–	–	–	− 0.1	–	–

AA6061/2.5%CeO_2/7.5%Al_2O_3/7.5%SiC, impact strength of around 56 J was observed in the composite AA6061/1.5%CeO_2/5%Al_2O_3/5%SiC, microhardness of around 206 HV was observed in the composite AA7075/4%MoS_2/12%ZrO_2/14%Ni, modulus of elasticity of around 89 GPa was observed in the composite Al/9.2%ZrB_2/5.6%Al_3BC/5.5%Al_2O_3, percentage elongation of around 46.2 was observed in the composite AA5083/5%Al_2O_3/5%SiC/10%B_4C, tensile strength of around 493 MPa was observed in the composite AA2618 with 8% of Si_3N_4/AlN/ZrB_2, yield strength of around 140 MPa was observed in the composite AA7075/3%Al_2O_3/5%B_4C/5%TiO_2 and a low density of around 2.512 g/cc was observed in the composite AA2024/1.3%Al_2O_3/1.3%ZrO_2/1.3%Gr. Aluminium composites with triple reinforcements thus possess superior mechanical properties and can be utilized for the fabrication of engineering components.

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Optimization of Machining Parameters for Surface Roughness in the End Milling of Hybrid Composite Using Response Surface Methodology

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Abstract A certain degree of machining must be done on hybrid composites (glass and carbon fibres), created by basic manufacturing procedures, so as to achieve close fits and tolerances. End milling is a common method for finishing machined flat plate hybrid composite products, having aerospace, automobile, wind turbine blade and prosthetic applications. This study was performed using, PVD TiAlN coated carbide tools, under dry conditions. Three input parameters, namely nose radius, having two levels, cutting speed and feed rate, having three levels each were considered. Surface roughness parameter Ra was considered as the output performance measure. Taguchi L18 orthogonal array (OA) was applied for the design of experiments. Response surface methodology was adopted to optimize the input performance parameters. A response surface was generated to investigate the effect of input variables and their interactions on the response. From the analysis of the mean effect plot, it was observed that the most significant input parameter on surface roughness was the feed rate. Optimization results revealed that the best surface roughness was observed at a combination of A1B2C1, i.e. nose radius of 1 mm, cutting speed of 94.69 m/min and feed rate of 300 mm/min.

Keywords Carbon fibre · Hybrid composite · CFRP · Response surface methodology · Surface roughness

1 Introduction

Composite materials incorporate properties of two or more materials that neither fibre nor matrix can attain, when operating alone. For many decades, hybridization of the glass and carbon fibres has been employed effectively in structural components

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of aircraft and naval ships. Carbon fibres have been used as a reinforcing material for the past few decades along with glass fibres, while manufacturing hybrid composites. Furthermore, carbon fibre-based composites are currently seeing significant use in a variety of fields. They are robust and lightweight and find use in sailboats and motorbikes today, where the high strength-to-weight ratios are required. They are also used in laptops, tripods, fishing rods, racquet frames, stringed instrument bodies as well as golf clubs [1–4].

Energy is used up during the manufacture of carbon fibres, which use between 198–595 MJ/kg. Thus, carbon fibres have greater embodied energies than other manmade fibres, like glass fibres (around 10 times higher). Thus, the potential environmental impact of utilized carbon fibres can be considerably reduced by recovery [5]. This transition from metals to composites is extremely difficult, due to the high cost of carbon fibre composites in the modern society. The cost of carbon fibre is regarded as the main factor in the entire cost. The price of carbon fibres is around $10.0 per lb, based on a production facility with a capacity of 1500 tonnes per year [6]. Depending on the final product or performance specifications for the intended application, carbon fibre is rather specialized from a volume standpoint. To explicitly address the material requirements for a given project, custom designs are frequently employed. The "standard products" offered by manufacturers probably began as a special design to replace a metal or other material to improve the performance.

Due to their adaptable qualities, such as the lightweight nature, high strength-to-weight ratio, low cost and ease of structure creation, hybrid composite materials are employed in a wide range of technical applications [7]. Hybrid composites are produced wherever they can contribute to the improvement of functional requirements by merely replacing the current materials, taking into consideration the ease of production methods under the larger range of fabrication techniques [1, 7]. Composite milling process is a fairly complex task due to their non-uniformity and the number of problems that arise during the machining process, such as surface delamination and deterioration of surfaces as well as tool wear. In the production of fibre-reinforced plastic products, milling is the machining process, most often utilized, as composite parts are commonly manufactured by Netscape and require the removal of small amount of additional material to control tolerances. Parts are defined to produce a high-quality surface [8]. Meher et al. [9] presented an overview of the advanced cutting conditions, based on CNC milling, considering various types of materials to assist researchers to explore further in machining process, particularly milling operations.

Kesarwani and Verma [10] experimentally investigated the effect of cutting parameters on surface roughness and cutting force during milling operation on polymer composite. They revealed that the feed rate and percentage weight of nano-filler content were highly influencing factors for milling performances. Rajeswari and Amirthagadeswaran [11] conducted experiments to investigate machinability characteristics of hybrid composites during end milling operation and optimized cutting parameters based on response surface methodology along with grey relational analysis. They pointed out that weight % of silicon carbide and spindle speed are the most important parameters that influence as to how easily aluminium composites can be machined. Sankar and Umamaheswarrao [12] conducted experiments to obtain optimum setting of cutting parameters during the end milling on hybrid composite, using an integrated approach of grey relational analysis and principle component analysis. They reported that weight fraction was affected on multi-objective optimization index grey relation grade.

Numerous research work has been done on carbon and glass fibre reinforced composites, but very few research work is found on machinability of 60% bidirectional E-glass fibre and 40% plain-woven carbon fibre with epoxy matrix and hence there is a wide scope to explore. This study is an attempt in that direction.

2 Fabrication of a Hybrid Composite Based on Glass and Carbon Fibres

In this cutting-edge technological era, where the demand for durable, lightweight and affordable materials has significantly increased, attempts have been made to develop a new hybrid reinforced composite across a number of industries, including automotive, building and aviation and in these applications, industries have benefited from the use of composite materials. Hybrid composite made of glass and carbon fibres reinforced material was synthesized in this study.

It combines 60% bidirectional E-glass fibre and 40% plain-woven carbon fibre with epoxy matrix, by using the cost-effective method of the hand layup process and samples of these laminates have been fabricated. Industry overall has benefited from the characteristics of carbon fibres such as their mechanical properties, as well as those of glass fibres such as their incombustibility and low thermal conductivity.

For the fabrication of the composite, as mentioned earlier, the "hand layup process" was used and same is depicted in Fig. 1. It is the simplest method of forming a composite with minimal infrastructural requirements and simple processing steps. The first step was applying polyester to the flat plate. Then, the epoxy matrix was applied all over it. The building of laminate began by placing one layer of carbon fibre, applying an epoxy matrix on the top surface and then a layer of glass fibre as well as the epoxy matrix on its top surface and another layer of glass fibre. The formation of a laminate comprising 60% of glass fibre and 40% of carbon fibre was achieved accordingly.

3 Experimental Work

The objectives of this study were to determine as to how machining parameters affected the surface roughness, while end milling a hybrid composite as well as to optimize the input parameters using the response surface methods. The significant input process parameters considered in the study were nose radius at two levels,

Fig. 1 Fabrication of hybrid composite using hand layup process

cutting speed and feed rate, each at three levels. Taguchi L_{18} orthogonal array (OA) was applied for design of experiments [13].

The surface roughness of samples in the dry machining environment was established. The workpiece used in this study was a hybrid composite with a dimension of 150 × 50 × 5 mm^3 with a trail of 30 mm. The cutting tools used were PVD TiAlN coated carbide tools with nose radius of 1, 1.5 mm and diameter of 12 mm. Figure 2 depicts the milling setup used to analyse the hybrid composite. Individual clamps were used to mount the workpiece on top of the parallel bar and secure it. The hybrid composite panel would not bend, since each clamp is sufficiently apart from the others.

Table 1 displays the variety of cutting parameters employed in this investigation. Taguchi's L_{18} O.A. was utilized for conducting the design of experiments with two process parameters with three levels and one process parameter with two levels. The process settings shown in Table 2 were used in the experiments, using a vertical milling machine. On a Taly surf-4 configuration with data gathering via diamond

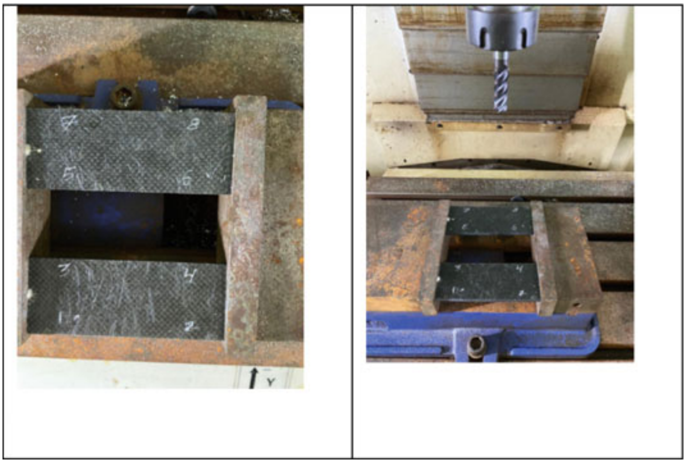

Fig. 2 Experimental setup

Table 1 Factors and their levels

Factors	Levels		
	1	2	3
Nose radius	1	1.5	–
Cutting speed	85	95	105
Feed rate	300	350	400

tip stylus profiler, utilizing Se-surf software, the centre line average roughness was measured. The results are shown in Fig. 3.

4 Results and Discussion

4.1 Effect of Process Parameters and Their Interaction on Surface Roughness

A response surface was generated to investigate the effect of input variables and their interactions on the response. While, 3D surface diagrams could help get the best state for a particular reaction, contour diagrams could help set reaction values and operating conditions, as needed. The contour line represents the relationship between the two input variables and the response variables of the 2D graph by graphically projecting the maximum and lowest points of the 3D graph onto the 2D graph. Coloured contour bands depicted the range of response values. The RSM

Table 2 Experimental plan and the measured mean values of responses

Expt. No	Nose radius	Cutting speed	Feed rate	Ra (μm)
1	1	1	1	0.328
2	1	1	2	0.249
3	1	1	3	0.295
4	1	2	1	0.206
5	1	2	2	0.301
6	1	2	3	0.291
7	1	3	1	0.290
8	1	3	2	0.418
9	1	3	3	0.282
10	2	1	1	0.233
11	2	1	2	0.340
12	2	1	3	0.338
13	2	2	1	0.282
14	2	2	2	0.278
15	2	2	3	0.312
16	2	3	1	0.289
17	2	3	2	2.691
18	2	3	3	0.299

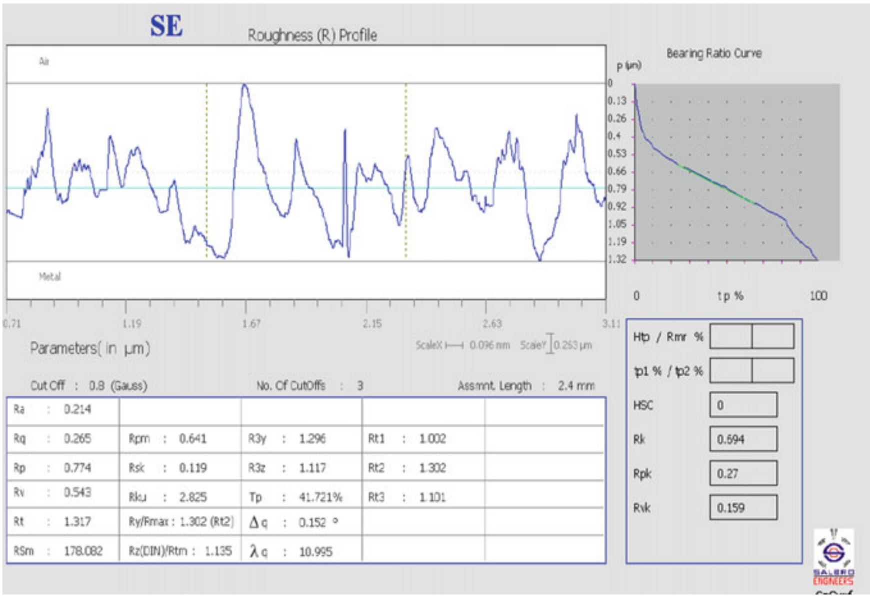

Fig. 3 Profile of surface roughness

showed probable correlations between the response variable and two input variables on the Z-axis and the X- and Y-axes, respectively.

The statistical influence of the input factors on the surface roughness as a measurable response was generated by analysing the experimental data. The 3D surface plot represented the functional relationship between surface roughness and experimental factors: cutting speed, nose radius and feed rate. The following Figs. (4, 5, 6) indicate the interaction effect between the process parameters on the surface roughness. In Fig. (4), the graphical representation indicated that for a value of 1.00 mm nose radius, the surface roughness was the least and as the nose radius increased gradually, the surface roughness also increased. Furthermore, it was also observed that for a cutting speed of 84–85 m/min, the surface roughness (Ra) was higher as compared to cutting speed of 90–95 m/min, where the surface roughness was observed to be minimum. Further, as the cutting speed increased, the surface roughness increased and was maximum at a cutting speed of 105 m/min.

Additionally, in Fig. 4, it can be seen that at higher cutting speeds (105 m/min) and at a 1.5 mm nose radius, the dark green area of the 2D plot indicated the greatest value of surface roughness. High-quality surface roughness can be obtained in the light green area for cutting speed, ranging between 90–100 m/min and nose radius, ranging between 1.0–1.2 mm.

From Fig. 5, it is evident that the surface roughness first increased with increase in feed rate, reaching a maximum value at 350 mm/min and then decreased with further increase in feed rate. The feed rate vs surface roughness curve was steeper at lower cutting speeds and wider as we move towards higher cutting speeds. A slight drop was observed in surface roughness as cutting speed increased, reaching a minimum at 90 mm/min, following which there was a gradual increase.

As can be seen in Fig. 5, the greatest value of average roughness was represented by the darkest green area of the contour at a medium feed rate of 350 mm/min and a cutting speed of up to 102.5 m/min. At feed rates between 305 and 395 mm/min and cutting speeds between 85 and 95 m/min, superior surface roughness of 0.1–0.2 m could be achieved. It was also observed that the average roughness increased, when the feed rate rose from its low to medium level (300 to 350 mm/min) and that a

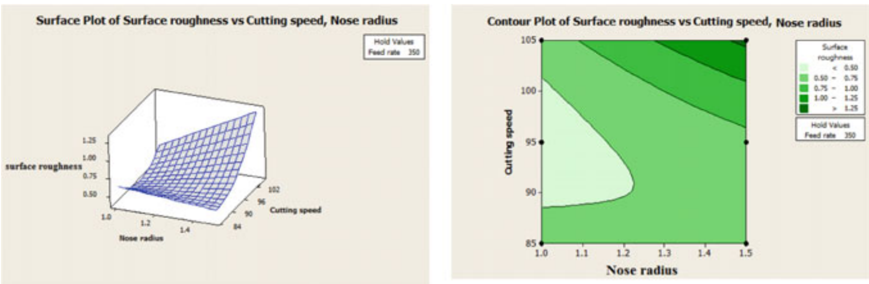

Fig. 4 3D and 2D plot of surface roughness (Ra) versus cutting speed, nose radius

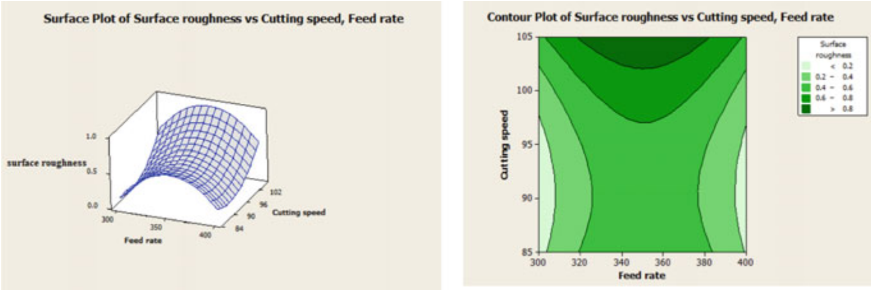

Fig. 5 3D and 2D plot of surface roughness versus cutting speed, feed rate

further increase in feed rate (350 to 400 mm/min) resulted in a decrease in surface roughness.

As can be seen in Fig. 6, the surface roughness rose and then progressively decreased as the feed rate increased from 300 to 400 mm/min. High-quality surface roughness was observed at feed rates of 300 and 400 mm/min, whereas the worst surface roughness was observed at roughly 350 mm/min. Additionally, the surface roughness steadily rose as the nose radius grew from 1.0 to 1.4 mm, but the effect was less noticeable than in the case of feed rate.

Also, from Fig. 6, it can be seen that superior surface roughness (0.1–0.3 μm) could be obtained at a feed rate of 300 to 320 mm/min and any rose radius in the range of 1.0 to 1.5 mm. As the feed rate increased from 320 mm/min, the surface roughness started deteriorating. Worst surface roughness (0.6 μm >) was spotted at feed rates between 340 and 370 mm/min, with a corresponding nose radius of 1.35 to 1.5 mm, as indicated by the dark green portion of the graph. As the feed rate further increased, i.e. from 380 to 400 mm/min, the surface roughness started improving (0.2–0.1 μm).

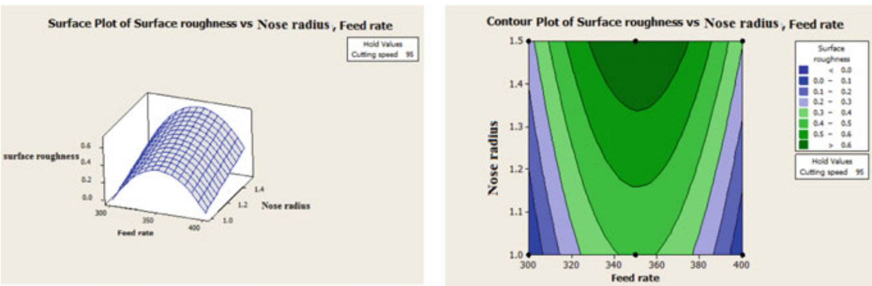

Fig. 6 3D and 2D plot of surface roughness versus nose radius, feed rate

4.2 *Mean Effect and Optimization of Machining Parameters Using RSM*

Based on the results obtained from Fig. 7 mean effect plot, the optimal parameters achieved were nose radius at level 1, cutting speed at level 2 and feed rate at level 1 for achieving minimum surface roughness. The optimal solution A1B2C1 found in this study was only the near optimal solution.

According to the values given in response Table 3, the difference between the maximum and the minimum value of the surface roughness of the milling parameters is as follows 0.2782-nose radius, 0.4162-cutting speed and 0.4245-feed rate. By comparing these results, the most important factor influencing the surface roughness was identified. The highest of these numbers was the important controllable factor. Here, 0.4245 was the highest value among 0.2782, 0.4162 and other values. The result showed that, among the milling factors, the feed rate had the greatest impact on surface roughness. The response table's A1B2C1 row displayed the surface roughness value with the lowest corresponding value for parameters A, B and C. As a result, A1B2C1 was the prerequisite for the milling process' ideal parameter combination.

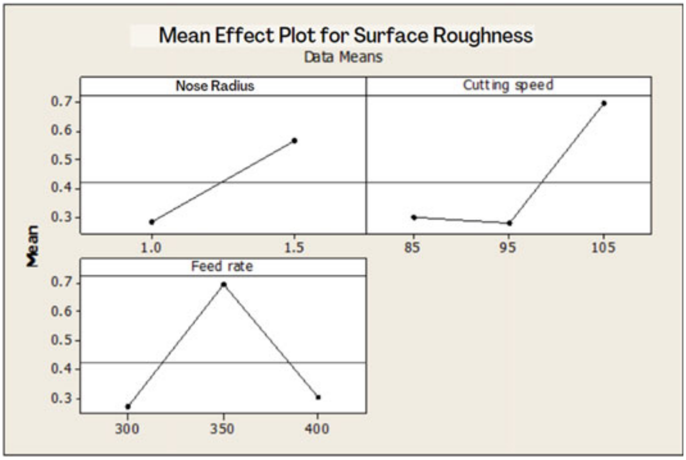

Fig. 7 Mean effect of parameters on surface roughness

Table 3 Response table for the mean effect plot

Factors	Levels			Max–min (Δ)	Rank
	1	2	3		
A	0.2842	0.5624	–	0.2782	3
B	0.2972	0.2783	0.6945	0.4162	2
C	0.2713	0.6958	0.3028	0.4245	1

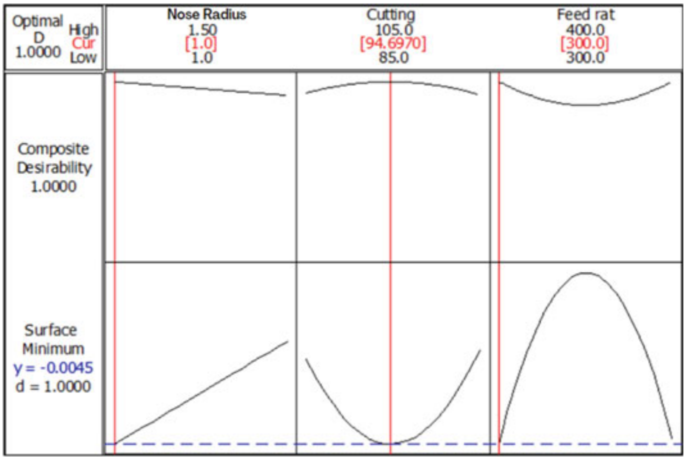

Fig. 8 Optimization graph of machining parameters

Figure 8 shows the optimum conditions for the edge milling of the composite to yield minimum surface roughness (optimum settings are displayed in red colour). At a nose radius of 1 mm, cutting speed of 94.6970 m/min and feed rate of 300 mm/min, the highest quality surface roughness was expected. It was also noted that at a feed rate of 400 mm/min, surface roughness was low, but not comparable to the optimum setting.

5 Conclusion

In this research study, the influence of process parameters on surface roughness during the end milling of a hybrid composite, made up of 60% glass fibre was examined experimentally. The effort was to optimize the cutting parameters, using response surface methodology.

The response surface generated was utilized to study the effects of input variables on surface roughness. The feed rate was shown to have the greatest impact on surface roughness as indicated by the mean effect plot. Nose radius of 1 mm at level 1, cutting speed of 95 m/min at level 2 and feed rate of 300 mm/min at level 1 were the condition for optimal parameter (A1B2C1) combination for edge milling. From response surface methodology, the optimum conditions for the edge milling of the composite to yield minimum surface roughness at a nose radius of 1 mm, cutting speed of 94.6970 m/min and feed rate of 300 mm/min were selected.

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Effect of Agro Waste Reinforcements on the Mechanical Properties of Aluminium Composites

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Abstract Research on the development of cost-effective aluminium composites have led researchers to explore agricultural waste materials as potential reinforcements. Aluminium composites with such agro waste reinforcements have been reported to possess properties that are comparable to those with purely ceramic reinforcements. This paper specifically reviews the work done by these researchers and summarizes their fabrication details and the effect of agro waste reinforcements on the mechanical properties of aluminium composites. The corresponding improvement/reduction in their properties as compared to the base aluminium alloy has been tabulated.

Keywords Aluminium composite · Agro wastes · Reinforcements · Mechanical properties

1 Introduction

Ceramic-reinforced aluminium metal matrix composites have widely replaced traditional aluminium alloys in most domains. They are now the preferred material for engineering components due to their superior mechanical properties. However, their high costs have led researchers to explore alternate materials that can replace or partly substitute ceramics as reinforcements.

Agricultural wastes such as bamboo leaf ash (BLA), bean pod ash (BPA), coconut shell ash (CSA), corn cob ash (CCA), cow dung ash (CDA), eggshell powder (ESP), groundnut shell ash (GSA), lemon grass ash (LGA), locust bean waste ash (LBA), maize stalk particulates (MSP), melon shell ash (MSA), neem leaf ash (NLA), palm kernel shell powder (PKS), rice husk ash (RHA) and sugarcane bagasse ash (SBA),

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potentially offer a cost-effective replacement to the expensive synthetic ceramic reinforcements. Of late, researchers have increasingly focussed on the fabrication and characterization of properties of aluminium metal matrix composites reinforced with such agro wastes. The details of their fabrication and their overall impact on the mechanical properties are summarized in the subsequent sections.

2 Materials and Methods

Agro wastes which are used as reinforcements consist of naturally occurring ceramics and are therefore inexpensive when compared to the traditionally used synthetic ceramics. Researchers have therefore used various combinations and sizes of agro wastes along with ceramic particulates, for reinforcing aluminium composites. Table 1 summarizes the major constituents of agro waste reinforcements that were selected for this study.

These composites can be fabricated through various processes such as stir casting (SC), double stir casting and double layer feeding (DD), electromagnetic stir casting (ESC), squeeze casting (SQC), compo-casting (CC), sintering (SI) and friction stir processing (FSP). Reinforcements were preheated in some cases to increase the wettability.

Table 1 Agro wastes and their major constituents

Agro wastes	Al_2O_3	C	CaO	Fe_2O_3	K_2O	MgO	P_2O_5	SiO_2	TiO_2	References
BLA	4.13	4.2	6.68	–	5.62	–	–	76.2	–	[1]
CSA	21.84	–	0.67	18.45	–	12.37	–	41.26	–	[2]
CCA	5.64	–	2.45	2.97	–	1.71	–	77.05	–	[3]
CDA	–	–	6.92	–	7.29	5.79	8.57	67.39	–	[4]
GSA	–	–	29.72	17.07	9.81	6.76	–	18.79	–	[5]
LGA	0.17	–	6.45	–	29.73	3.55	–	57.93	–	[6]
LBA	14.98	–	1.08	0.28	–	0.09	–	55.38	–	[7]
MSA	3.54	–	2.11	1.3	4.7	–	–	84.3	–	[8]
PKS	9.43	–	11.21	–	9.71	4.85	–	55.69	–	[9]
RHA	–	–	0.379	0.287	1.759	0.394	–	96.319	–	[10]
SBA	97.4	–	0.8	0.6	–	–	–	–	1.2	[11]

3 Fabrication and Effect on Properties

Research studies on aluminium composites with agro wastes reinforcements and the fabrication processes employed are discussed in this section.

3.1 BLA Reinforcements

Bodunrin et al. [12] reinforced AA 6063 with silica sand (<75 μm) and BLA (<50 μm) particulates through stir casting. Five different composites with silica sand/BLA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness of around 64.6 VHN. The composite with 0/10% reinforcements had the lowest density of around 2.383 g/cc. Kumar et al. [1] reinforced Al-4.5%Cu alloy with BLA particulates through stir casting. Three different composites with BLA weight fractions of 2, 4 and 6 percentages were fabricated. The composite with 2% reinforcements had the highest percentage elongation of around 3.06%. The composite with 4% reinforcements had the highest hardness (Brinell) of around 99.3 BH, microhardness of around 104.4 MH, tensile strength of around 177.304 MPa and yield strength of around 133.19 MPa. The composite with 6% reinforcements had the lowest density of around 2.619 g/cc. Fatile et al. [3] reinforced Al–Mg-Si (0.396% Mg and 0.4% Si) alloy with SiC (30 μm) and BLA (<50 μm) particulates through stir casting. Four different composites with SiC/BLA weight fractions as 10/0, 8/2, 6/4 and 4/6 percentages were fabricated. The composite with 10/0% reinforcements had the highest microhardness of around 82 HV, ultimate tensile strength of around 164 MPa, yield strength of around 123 MPa and percentage elongation of around 26.1%. The composite with 4/6% reinforcements had the highest fracture toughness of around 10.2 MPam$^{1/2}$ and the lowest density of around 2.615 g/cc.

3.2 CSA Reinforcements

Panda et al. [13] reinforced AA 1200 with m-CSA particulates (i.e. modified CSA with CSA:graphite:Mg in the ratio 1:1:2.5) through compo-casting. Three different composites with m-CSA weight fractions of 2, 4 and 8 percentages were fabricated. The composite with 4% reinforcements had the highest hardness (Brinell) of around 77.7 BHN. The composite with 8% reinforcements had the lowest density of around 2.56 g/cc. Lakshmikanthan and Prabu [14] reinforced AA 6061 with CSA (<150 μm) particulates through stir casting. Five different composites with CSA weight fractions of 3, 6, 9, 12 and 15 percentages were fabricated. The composite with 6% reinforcements had the highest hardness (Brinell) of around 55.2 BHN and tensile strength of around 160.27 MPa. Bodunrin et al. [12] reinforced AA 6063 with CSA particulates through stir casting. Four different composites with CSA weight fractions of 3, 6, 9 and 12 percentages were fabricated. The composite with 3% reinforcements had the highest modulus of elasticity of around 1.018 MPa. The composite with 12% reinforcements had the highest hardness of around 40.2 HRB and ultimate tensile strength of around 73.62 MPa, while it had the lowest density of around 2.59 g/cc. Kumar et al. [2] reinforced AA 6082 with ZrO_2 (<50 μm) and CSA (<75 μm) particulates through stir casting. Six different composites with ZrO_2/CSA weight fractions as 0/10, 2/8, 4/6, 6/4, 8/2 and 10/0 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness (Brinell) of around 64 BHN. The composite with 8/2% reinforcements had the highest tensile strength of around 202 MPa and yield strength of around 142 MPa. The composite with 2/8% reinforcements had the highest flexural strength of around 92 MPa. The composite with 0/10% reinforcements had the highest percentage elongation of around 13.8% and impact strength of around 15 J. It had the lowest density of around 2.63 g/cc. Mohanavel et al. [15] reinforced AA 7050 with CSA (60–70 μm) particulates through stir casting. Two different composites with CSA weight fractions of 4 and 8 percentages were fabricated. The composite with 8% reinforcements had the highest microhardness of around 78 HV and tensile strength of around 203 MPa. Subramaniam et al. [16] reinforced AA 7075 with B_4C (75 μm) and CSA (62 μm) particulates through stir casting. Five different composites with B_4C/CSA weight fractions as 0/3, 3/3, 6/3, 9/3 and 12/3 percentages were fabricated. The composite with 12/3% reinforcements had the highest hardness of around 169 BHN. The composite with 9/3% reinforcements had the highest tensile strength of around 189 MPa and impact strength of around 2.3 J. The composite with 0/3% reinforcements had the highest percentage elongation of around 13.5%. Table 2 summarizes details of aluminium alloys with BLA/CSA reinforcements.

Table 2 Aluminium alloys with agro wastes (BLA/CSA) as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Bodunrin et al.	AA6063	Silica sand	BLA	SC	[12]
Kumar et al.	Al-4.5%Cu	BLA	–	SC	[1]
Alaneme et al.	Al-0.396% Mg-0.4%Si	SiC	BLA	SC	[17]
Panda et al.	AA1200	m-CSA	–	CC	[13]
Lakshmikanthan and Prabu	AA6061	CSA	–	SC	[14]
Bodunrin et al.	AA6063	CSA	–	SC	[12]
Kumar et al.	AA6082	ZrO_2	CSA	SC	[2]
Mohanavel et al.	AA7050	CSA	–	SC	[15]
Subramaniam et al.	AA7075	B_4C	CSA	SC	[16]

3.3 GSA Reinforcements

Palanivendhan and Chandradass [18] reinforced AA 6063 with GSA particulates through stir casting. Three different composites with GSA weight fractions of 2.5, 5 and 7.5 percentages were fabricated. The composite with 2.5% reinforcements had the highest hardness of around 42.2 HV and tensile strength of around 111.2 MPa. Venkatesh et al. [5] reinforced AA ADC12 with B_4C (7.78–10.40 μm) and GSA (<50 μm) particulates through squeeze casting. Three different composites with B_4C/GSA weight fractions as 2.5/7.5, 5/5 and 7.5/2.5 percentages were fabricated. The composite with 7.5/2.5% reinforcements had the highest hardness of around 115.6 BHN, yield strength of around 286.5 MPa, tensile strength of around 348.45 MPa and impact strength of around 3.41 J. The composite with 2.5/7.5% reinforcements had the lowest density of around 2.525 g/cc. Refaai et al. [19] reinforced AA 8079 with GSA particulates through stir casting. Six different composites with GSA weight fractions of 3, 6, 9, 12, 15 and 18 percentages were fabricated. The composite with 3% reinforcements had the highest impact strength of around 0.9 J/mm^2. The composite with 18% reinforcements had the highest hardness (Brinell) of around 60.1 BHN and the lowest density of around 3.34 g/cc. Alaneme et al. [20] reinforced Al–Mg–Si (0.5% Mg and 0.45% Si) alloy with SiC (28 μm) and GSA (<50 μm) particulates through stir casting. Five different composites with SiC/GSA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness of around 63.5 HRV, yield strength of around 129 MPa and tensile strength of around 158 MPa. The composite with 5/5% reinforcements had the highest percentage elongation of around 12.8%. The composite with 0/10% reinforcements had the highest fracture toughness of around 7.7 MPam$^{1/2}$.

3.4 RHA Reinforcements

Dinaharan et al. [21] reinforced AA 6061 with RHA (8 μm) particulates through friction stir processing. The volume fraction of the reinforcements was 18%. The composite had an ultimate tensile strength of around 285 MPa. Alaneme and Sanusi [22] reinforced AA 6063 with Al_2O_3 (30 μm) and RHA (<50 mm) particulates through stir casting. Five different composites with Al_2O_3/RHA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 7.5/2.5% reinforcements had the highest percentage elongation of around 12.7%. The composite with 10/0% reinforcements had the highest hardness of around 68.7 VHN, ultimate tensile strength of around 133 MPa, yield strength of around 100 MPa and toughness of around 8.8 J/m^3. Arora and Sharma [10] reinforced AA 6351 with SiC and RHA particulates through stir casting. Three different composites with SiC/RHA weight fractions as 2, 4 and 6 percentages were fabricated. The composite with 6% reinforcements had the highest microhardness of around 72.5 VHN and ultimate

Table 3 Aluminium alloys with agro wastes (GSA/RHA) as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Palanivendhan and Chandradass	AA6063	GSA	–	SC	[18]
Venkatesh et al	ADC12	B_4C	GSA	SQC	[5]
Refaai et al	AA8079	GSA	–	SC	[19]
Alaneme et al	Al–0.5%Mg–0.45%Si	SiC	GSA	SC	[20]
Dinaharan et al	AA6061	RHA	–	FSP	[21]
Alaneme and Sanusi	AA6063	Al_2O_3	RHA	SC	[22]
Arora and Sharma	AA6351	SiC	RHA	SC	[10]
Verma and Vettivel	AA7075	B_4C	RHA	SC	[23]
Saravanana and Kumar	AlSi10Mg	RHA	–	SC	[24]

tensile strength of around 186 MPa. The composite with 2/6% reinforcements had the lowest density of around 2.63 g/cc. Verma and Vettivel [23] reinforced AA 7075 with B_4C (50 μm) and RHA particulates through stir casting. Three different composites with B_4C/RHA weight fractions as 5/0, 5/3 and 5/5 percentages were fabricated. The composite with 5/5% reinforcements had the highest hardness (Vicker's) of around 121.42 HV and compression strength of around 563.3 MPa. The composite with 5/0% reinforcements had the highest tensile strength of around 260.5 MPa. Saravanana and Kumar [24] reinforced AlSi10Mg alloy with RHA particulates through stir casting. Four different composites with RHA weight fractions of 3, 6, 9 and 12 percentages were fabricated. The composite with 9% reinforcements had the highest ultimate tensile strength of around 173 MPa. The composite with 12% reinforcements had the highest compression strength of around 524 MPa and hardness of around 80.9 BHN. The composite with 3% reinforcements had the highest percentage elongation of around 9.3%. Table 3 summarizes details of aluminium alloys with GSA/RHA reinforcements.

3.5 SBA Reinforcements

Harish et al. [25] reinforced AA 5056 with SiC (40 μm) and SBA particulates through stir casting. Three different composites with SiC/SBA weight fractions as 0/4, 3/2 and 3/4 percentages were fabricated. The composite with 3/4% reinforcements had the highest microhardness (Vicker's) of around 73.2 HV. Chandla et al. [11] reinforced

AA 6061 with Al_2O_3 (53 μm) and SBA (38 μm) particulates through vacuum-assisted stir casting. Four different composites with Al_2O_3/SBA weight fractions as 5/0, 5/4, 5/6 and 5/8 percentages were fabricated. The composite with 5/6% reinforcements had the highest tensile strength of around 151.1 MPa and microhardness of around 35.2 HV. The composite with 5/4% reinforcements had the highest percentage elongation of around 8.6%. The composite with 5/0% reinforcements had the highest impact strength of around 6.9 J. The composite with 5/8% reinforcements had the highest compression strength of around 411 MPa. The composite with 5/8% reinforcements had the lowest density of around 2.665 g/cc. Palanivendhan et al. [26] reinforced AA 6262 with SBA (40 μm) particulates through stir casting. Two different composites with SBA weight fractions of 2 and 5 percentages were fabricated. The composite with 5% reinforcements had the highest ultimate tensile strength of around 161.97 MPa. The composite with 2% reinforcements had the highest microhardness (Vicker's) of around 70.4 HV. Imran et al. [27] reinforced AA 7075 with graphite (20–60 μm) and SBA (0.1–100 μm) particulates through stir casting. Three different composites with graphite/SBA weight fractions as 1/2, 1/4 and 1/6 percentages were fabricated. The composite with 1/6% reinforcements had the highest ultimate tensile strength of around 294.2 MPa, hardness (Brinell) of around 88.3 BHN and yield strength of around 184.93 MPa. The composite with 1/2% reinforcements had the highest percentage elongation of around 6.7%. Subramanian et al. [28] reinforced Al-Si10-Mg alloy with SiC (<25 μm) and SBA (<75 μm) particulates through stir casting. Four different composites with SiC/SBA weight fractions as 0/9, 3/9, 6/9 and 9/9 percentages were fabricated. The composite with 0/9% reinforcements had the highest percentage elongation of around 2.615%. The composite with 9/9% reinforcements had the highest tensile strength of around 161.73 MPa, hardness of around 129.7 BHN and impact strength (Charpy) of around 0.039 Jmm^2.

3.6 CCA, MSA, PKP, CDA and LBA Reinforcement

Odoni et al. [29] reinforced AA 6063 with CCA particulates through stir casting. Six different composites with CCA weight fractions of 2.5, 5, 7.5, 10, 12.5 and 15 percentages were fabricated. The composite with 2.5% reinforcements had the highest impact energy of around 0.87 J/mm^2 and tensile strength of around 196 MPa. The composite with 15% reinforcements had the highest hardness (Brinell) of around 58 BHN and the lowest density of around 2.44 g/cc. Fatile et al. [3] reinforced Al–Mg-Si (0.396% Mg and 0.4% Si) alloy with SiC (50 μm) and CCA (<60 μm) particulates through stir casting. Five different composites with SiC/CCA weight fractions as 10/0, 9/1, 8/2, 7/3 and 6/4 percentages were fabricated. The composite with 10/0% reinforcements had the highest microhardness of around 93 HVN, ultimate tensile strength of around 185 MPa, yield strength of around 144.2 MPa and percentage elongation of around 24%. The composite with 6/4% reinforcements had the highest fracture toughness of around 12 $MPam^{1/2}$ and the lowest density of around 2.6 g/cc. Suleiman I et al. [8] reinforced Al-12%Si alloy with MSA (50 μm) particulates through stir casting. Four different composites with MSA weight fractions of 5, 10, 15 and 20 percentages were fabricated. The composite with 15% reinforcements had the highest hardness of around 103.5 HRC and tensile strength of around 207.1 MPa. The composite with 5% reinforcements had the highest impact strength of around 17 J and percentage elongation of around 27.6%. Edoziuno et al. [30] reinforced AA 6063 with PKP particulates through stir compo-casting. Six different composites with PKP weight fractions of 2.5, 5, 7.5, 10, 12.5 and 15 percentages were fabricated. The composite with 7.5% reinforcements had the highest yield strength of around 192 MPa, ultimate tensile strength of around 187 MPa and modulus of elasticity of around 14,014 MPa. The composite with 12.5% reinforcements had the highest percentage elongation of around 39.6%. The composite with 2.5% reinforcements had the highest hardness of around 612 BHN. The composite with 10% reinforcements had the highest impact energy of around 31.96 Manikandan et al. [4] reinforced AA 7075 with B_4C (50–70 μm) and CDA (40–60 μm) particulates through stir casting. Five different composites with B_4C/CDA weight fractions as 0/10, 2.5/7.5, 5/5, 7.5/2.5 and 10/0 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness (Brinell) of around 152 BHN. The composite with 0/10% reinforcements had the highest impact strength (Charpy) of around 3 J. The composite with 2.5/7.5% reinforcements had the highest flexural strength of around 358 MPa. The composite with 7.5/2.5% reinforcements had the highest tensile strength of around 288.38 MPa. Usman et al. [7] reinforced AA A356 with LBA (<75 μm) particulates through stir casting. Five different composites with LBA weight fractions of 2, 4, 6, 8 and 10 percentages were fabricated. The composite with 2% reinforcements had the highest impact energy of around 33.5 J. The composite with 10% reinforcements had the highest tensile strength of around 0.84 GPa and hardness of around 15.1 HRB. Jose et al. [6] reinforced AA 6061 with LGA (50–250 μm) particulates through compo-casting. Three different composites with LGA weight fractions of 3, 5 and 7.5 percentages were fabricated. The composite with 7.5% reinforcements had the highest microhardness of around 155 HV and tensile strength of around 195 MPa. The composite with 3% reinforcements had the highest percentage elongation of around 11.7%. Table 4 summarizes details of aluminium alloys with SBA/CCA/MSA/PKP/CDA/LBA reinforcements.

The percentage increase/decrease in tensile strength (TS), hardness—Brinell (H), percentage elongation (PE), microhardness (MH), yield strength (YS), flexural strength (FS), impact strength (IS) and density (D) have been given in Table 5. These values were computed only for composites whose base alloy properties were determined experimentally by the corresponding researcher.

4 Conclusion

There exists an increasing trend among researchers to fabricate aluminium composites with agro wastes and their combinations. They have successfully reinforced aluminium alloys with agro wastes such as BLA, CSA, RHA, GSA

Table 4 Aluminium alloys with other agro wastes as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Harish et al	AA5056	SiC	SBA	SC	[25]
Chandla et al	AA6061	Al_2O_3	SBA	SC	[11]
Palanivendhan et al	AA6262	SBA	–	SC	[26]
Imran et al	AA7075	Graphite	SBA	SC	[27]
Subramanian et al	Al-Si10-Mg	SiC	SBA	SC	[28]
Odoni et al	AA6063	CCA	–	SC	[29]
Fatile et al	Al-0.396%Mg -0.4%Si	SiC	CCA	SC	[3]
Suleiman et al	Al-12%Si	MSA	–	SC	[8]
Edoziuno et al	AA6063	PKP	–	CC	[30]
Manikandan et al	AA7075	B_4C	CDA	SC	[4]
Usman et al	A356	LBA	–	SC	[7]
Jose et al	AA6061	LGA	–	CC	[6]

Table 5 Percentage increase/decrease in composite properties

Composite	TS	H	PE	MH	YS	FS	IS	D
Al-4.5%Cu/BLA	17.8	37.2	– 11.6	24.4	11.7	–	–	– 4.9
AA1200/m-CSA	–	19.9	–	–	–	–	–	5.3
AA6061/CSA	129	35.1	–	–	–	–	–	–
AA6063/CSA	– 7.2	–	–	–	–	–	–	–
AA6082/ZrO_2/CSA	23.2	45.5	– 6.8	–	26.8	9.5	– 3.8	– 1.5
AA7050/CSA	33.6	–	–	38.1	–	–	–	–
AA7075/B_4C/CSA	65.8	33.1	– 2.2	–	–	–	283	–
AA6063/GSA	– 2.7	–	–	–	–	–	–	–
ADC12/B_4C/GSA	13.1	17.4	–	–	17.4	–	– 3.1	– 7.5
AA8079/GSA	–	140	–	–	–	–	–	– 3.7
Al–0.5 Mg–0.45Si/SiC/GSA	53.4	–	– 52.1	–	63.3	–	–	–
AA6061/RHA	29.5	–	–	–	–	–	–	–
AA6063/Al_2O_3/RHA	– 4.3	–	16.5	–	– 2.9	–	–	–
AA6351/SiC/RHA	7.5	–	–	12.6	–	–	–	– 3.1
AA7075/B_4C/RHA	30.2	–	–	73.3	–	–	–	–
AA6262/SBA	62.1	–	–	3.1	–	–	–	–
AA6063/CCA	– 18	123	–	–	–	–	–	–
Al-12%Si/MSA	69.1	–	– 21.8	–	–	–	– 2.9	–
AA6063/PKP	78.1	79.5	428	–	86.4	–	147	–
AA7075/B_4C/CDA	56	38.2	–	–	–	11.9	– 6.3	–
A356/LBA	52.7	–	–	–	–	–	– 7.8	–

and SBA through various processes. Of the composites selected for the study, a high tensile strength of around 348.45 MPa was observed in the composite ADC12/7.5%B_4C/2.5%GSA, hardness (Brinell) of around 169 BHN was observed in the composite AA7075/12%B_4C/3%CSA, percentage elongation of around 39.6% was observed in the composite AA6063/12.5%PKP, microhardness of around 121.42 HV was observed in the composite AA7075/5%B_4C/5%RHA, yield strength of around 286.5 MPa was observed in the composite ADC12/7.5%B_4C/2.5%GSA, fracture toughness of around 12 MPam$^{1/2}$ was observed in the composite Al-0.396 Mg-0.4Si/6%SiC/4%CCA, flexural strength of around 358 MPa was observed in the composite AA7075/2.5%B_4C/7.5%CDA, impact strength of around 33.5 J was observed in the composite A356/2%LBA, compression strength of around 563.309 MPa was observed in the composite AA7075/5%B_4C/5%RHA and a low density of around 2.383 g/cc was observed in the composite AA6063/10%BLA. Aluminium composites reinforced with a combination of agricultural wastes and ceramics thus offer a cost-effective alternative to those reinforced with synthetic ceramic reinforcements.

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Fabrication of Fibre-Reinforced Composites Using Vacuum Infusion Process and Testing

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Abstract Nowadays, industrial requirements for lighter components with high mechanical resistance have motivated research studies on alternative materials along with their appropriate forming processes. To meet the demands of the industry, fibre-reinforced composites have shown to be an appropriate solution as can be seen, especially in the increment in aircraft components manufacturing. Though, research on composites is reasonably at an advance stage now, it still faces many limitations to be covered, like temperature resistance, fabrication, and also sometimes the strength. In the context of this, two types of fibre-reinforced composites were fabricated using the vacuum infusion process with polymer, such as epoxy and polyester and reinforcement as fibre, such as woven fabric and chopped fibre along with different types of filler materials. Fabricated fibre-reinforced composite was tested for mechanical properties, such as tensile strength and flexural strength. A combination of three woven mats impregnated with epoxy resin with mica filler gave the highest tensile strength of 183.67 N/mm^2. Whereas, composites with epoxy and silica filler gave the highest flexural strength of 127.811 N/mm^2.

Keywords Fibre-reinforced composites · Polyester · Epoxy · Vacuum infusion process · Flexural strength

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1 Introduction

As a result of technological advancements, there has been a demand for light weight and stronger materials in the case of high-speed and long-distance applications. Metals are strong and can withstand high temperatures, but they have a very high density. Due to this inherent limitation of metals, a new alternative was always needed to meet the demands of modern industrial applications. This was achieved by forming composites, as composite materials are as strong as metals or even stronger and are almost half or one fourth the weight. Composites, also called as the "material of the future", are now slowly replacing metals everywhere. As the high-speed requirements cannot be met by the metals due to its high density, composites are widely used in aerospace and racing applications, where weight is a major consideration [1–4].

Yuexin et al. [5] investigated the compression responses in vacuum infusion process of different fabrics under dry or wet environments. It was based on external factors, such as the vacuum pressure, the layup design, the kinds of fabrics, and the resin viscosity as well as some internal factors, namely nesting and elastic recovery of fibres, lubrication of resin and friction between fibres. Sunilpete and Cadambi [6] modified vacuum infusion process by adding a double bag to avoid low Fibre Volume Fraction (FVF) and voids content in the manufacturing of composite laminates. They revealed that modified vacuum infusion process increased the FVF to 58.3% and reduced the void content to 1.29%, along with increased tensile and flexural strength. Vasudevan et al. [7] presented an overview of different types of two-dimensional and three-dimensional fabric weaving processes, while also considering their applications. They also reported that non-crimp fabrics produced using noobing have better moulding and mechanical properties.

Mackin and Saha [8] analysed the experimental design and the mechanical and environmental (water exposure, cold environment, and corrosion) testing results of pultruded poly-methyl methacrylate (PMMA) thermoplastic GFRP rebars. They pointed out and revealed no statistical difference in the means of the flexural strengths between the thermoset and thermoplastic-based GFRPs. Karthik et al. [9] manufactured a hybrid composite epoxy-based with natural and synthetic fibre (carbon and kenaf), using vacuum bag moulding method and found 170 MPa tensile strength. Zhang et al. [10] developed a new composite material to enhance the thermal conductivity and the thermal storage capacity from KH-550-decorated mica (Md) and polyethylene glycol (PEG) by vacuum impregnation method. They demonstrated that the new composite has fabricating potential in building the energy conservation.

VijayKiran et al. [11] investigated the effect of polymer nanocomposite, while E-glass fibre-reinforced graphene oxide nanoplatelets, using hand layup technique on mechanical properties. They revealed that the properties of material, namely tensile strength, compressive strength, and flexural strength increased during the process. Bhatta et al. [12] investigated experimentally to explore the effects of inclusion of nano-silica, along with silica fume and plasticizer, on cement mortar and concrete, in order to find out their appropriateness and advantages for concrete building. They concluded that the appropriate usage of nano-silica improves the enactment of cemented materials. Navaneethan et al. [13] investigated mechanical behaviour, such as tensile, flexural, and impact analysis of polymer nanocomposites with aluminium oxide (Al_2O_3) and zinc oxide (ZnO) as an epoxy along with different percentages. They revealed that the composite with 5% of Al_2O_3 and ZnO showed good mechanical responses in all the tests.

Velavan et al. [14] synthesized the metal matrix composites with the inclusion of different percentages of mica. They point out that the inclusion of 3wt% of mica in hybrid composite gives best mechanical properties. Further increases in percentages of mica in composite pull down the mechanical prospects. They also concluded that fabricated composites are highly suitable for automotive-related sheet forming operations. So far, in the present fabrication of FRP composites based on mica and silica with different percentage have not been fully explored. Hence, this study aims to discuss the details about fibre-reinforced composites, fabricated using the vacuum infusion process with different types of polymer, fibre, and filler materials.

2 Fabrication of FRP Composite Using Vacuum Infusion Process

A composite is a combination of two different phases, fibre reinforcement and matrix in terms of polymer, metal, and ceramic. For the current research study, polymer-based composites were fabricated using the vacuum infusion process. Gel point is the time at which liquid to solid transition takes place in the polymer during the polymerization process. Before preparing the samples, it was very important that the gel point of the resins is calculated. It was calculated for polyester as well as epoxy, as per the ATSM D2471 standard. To prepare the composite samples, glass fibre, polymer, and filler material were used and the same is mentioned in Tables 1 and 2.

Also, equipments, such as vacuum pump, weighing balance, beaker, petri dish, PVC pipes—6 mm diameter, peel ply, flow media, glass plates, double-sided tape, modelling clay, mould release agent—wax, duct tape, and vacuum bag—PE sheet were used. The quantity of raw material required was selected based on available literature and expert opinion. As provided by the manufacturer for 1 kg of epoxy resin, 100 g of amine hardener was required for it to have a curing time of 24 h.

2.1 The Following Steps Were Followed, While Making the Composite Samples

1 Preparation of Mould: Like any lamination process, a good quality mould was required for vacuum infusion. The mould should be rigid and have a high-gloss finish. Ideally, this mould would have flange of at least 6 inches to be used for the placement of sealant tape and tubing. After the mould was properly cleaned, the

Table 1 FRP composite samples data

Sr No	Composite mat 3 layer		Resin/Wt. of resin (g)	Wt. of catalyst/hardener (g)	Filler/Wt. of filler (g)
	Woven roving	Chopped strand			
1	–	3	Polyester /150	1.8/1	Silica/7.5
2	3	–	Polyester/150	1.8/1	Silica/10.5
3	3	–	Polyester/140	1.68/0.93	Mica/9.8
4	–	3	Polyester/140	1.68/0.93	Mica/7
5	1	2	Polyester/140	1.68/0.93	Silica/9.8
6	–	3	Polyester/140	1.68/0.93	Silica/9.8
7	–	3	Polyester/140	1.68/0.93	Mica/7
8	–	3	Polyester/140	1.68/0.93	Mica/9.8
9	–	3	Epoxy/120	– /12	Silica/6
10	–	3	Epoxy/120	– /12	Silica/8.4
11	3	–	Polyester/140	1.68/0.93	Silica/7
12	–	3	Epoxy/120	– /12	Fumed silica/0.48
13	–	3	Epoxy/120	– /12	Fumed silica/0.72
14	–	3	Polyester/140	1.68/0.93	Fumed silica/0.56
15	–	3	Epoxy/100	– /10	Silica/10
16	–	3	Polyester/120	1.44/0.79	Fumed silica/0.24
17	3	–	Epoxy/100	– /10	Silica/5
18	–	3	Polyester/120	1.44/0.79	Fumed silica/0.72
19	3	–	Epoxy/130	– /13	Silica/9.1
20	3	–	Polyester/140	1.68/0.93	Silica/14
21	–	3	Epoxy/125	– /12.5	Fumed silica/0.25
22	–	3	Polyester/120	1.44/0.79	Silica/6

Table 2 Material used to prepare the composite samples

Raw materials	Quantity
Epoxy resin	2 kg
Epoxy hardener—Aradur 951	200 g
Polyester resin	4 kg
Catalyst—Cobalt naphthanate	100 ml
Polyester hardener—MEKP	100 ml
Woven fibre mat (650 gsm)	1 kg
Chopped strand mat (425 gsm)	1 kg
Soap stone (silica) filler	500 g
Mica filler	500 g
Fumed silica filler	50 g

ordinary, preferred mould release agent was applied. Mould used for preparation of FRP composite and application of mould release agent are depicted in Figs. 1 and 2. From the mould selected below, samples of the size 25 mm x 15 mm and thickness ranging from 1.5 to 3 mm were prepared.

2 Selection and Cutting of Reinforcement Material, Flow Media and Peel Ply: Glass fibres were selected as reinforcement material for fabrication and two types of glass fibre mats were chosen, namely woven mat of 650 gsm thickness and chopped strand mat of 400 gsm thickness. A concept unique to vacuum infusion is the idea of flow media and aiding the flow of resin is the job of flow media. Peel ply is a material, which is employed to ensure easy removal of the flow media and composite sheet from the mould, once curing of the composite was completed. The glass fibre and flow media are cut according to the dimensions 25 mm × 15 mm. In order to obtain thickness in the range 2–3 mm, three layers of glass fibres were used. For quick removal of the sheet, the peel ply was cut larger, by roughly 1 inch in length and width. Figure 3 shows glass fibre, peel ply, and flow media used in the sample preparation.

Fig. 1 Mould used for sample preparation

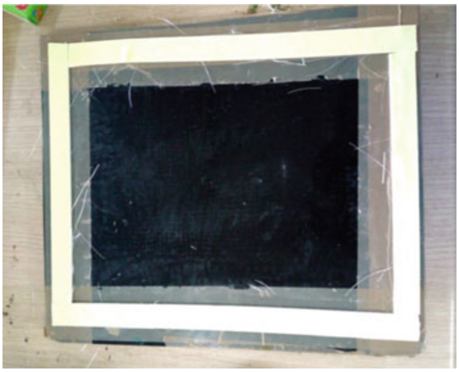

Fig. 2 Application of mould release agent

Fig. 3 Glass fibre, attachment of peel ply, and flow media

3 Resin and Vacuum Lines: Though spiral tubing is best suited for resin and vacuum lines, it was not easily available commercially, and hence, standard transparent polypropylene pipes were used for the same.
4 Attaching Resin and Vaccum Lines: Before fixing the lines on the mould, a boundary on the mould was marked using double sided tape with respect to the sample size. This was used to fix the pipe on the mould. A total of three layers of double-sided tape were required for installation and same is depicted in Figs. 4, 5 and 6.

 Layer one—surrounding the glass fibre mats, on which the peel play was fixed.

 Layer two—used to securely fit the peel ply and attach the resin and vacuum lines.

 Layer three—used to provide support to the pipes and attach the vacuum bag above it.
5 Vacuum Bag: When vacuum bag is set up properly, the vacuum tubing would flow out of the laminate and connect directly to the resin trap. A separate tube would then leave the resin trap and connect to the vacuum pump. The final mould and pump arrangement are depicted in Figs. 7 and 8.

Fig. 4 First layer of tape

Fig. 5 Second layer of tape

Fig. 6 Third layer of tape

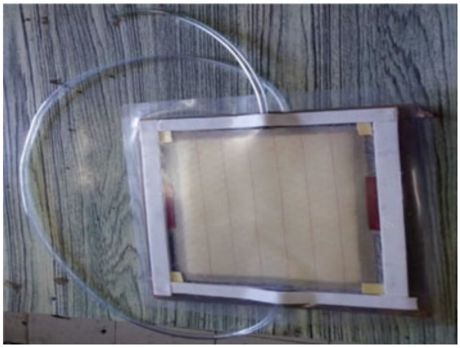

Fig. 7 Seal packed final mould

6 Connection to Vacuum Pump: Once all the components were in place, it was time to attach the vacuum pump itself. Because resin is infused through vacuum pressure.
7 Prepare for Infusion: Resin choice is another key aspect of VIP. Resins selected

Fig. 8 Vacuum pump arrangement

Fig. 9 Completion of infusion process

for this research study were polyester and general purpose epoxy. Polyester and epoxy are economical and commercially available in small quantities.

8 Resin Infusion: Once everything was in place and ready to go, the resin was mixed up. The inlet pipe was inserted in the prepared resin and the pump switched on. Once full, the resin would begin to expand outward into the reinforcement. Completion of infusion process of FRP composite is shown in Fig. 9. In order to maintain constant vacuum pressure until the resin has sufficiently gelled, the pump was kept on, else air could be introduced prematurely.

3 Results and Discussion

The tensile and flexural test was conducted at a Chemical Process Equipment Laboratory in Govandi, Mumbai. The Blue Star Make Universal Testing Machine was used for the test purpose.

The following standards were followed, while testing of the samples was prepared. Test method with ASTM D638—2a standard was used for the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens. Test method with ASTM D790—03 standard was used for the determination of the flexural properties of unreinforced and reinforced rigid plastics, including high-modulus composites. Both tests were carried on the universal testing machine. The load at which the specimen fails was noted and the flexural strength was calculated using the formula given below:

$$\sigma_{\text{flexural}} = 3 * P * L \big/ 2B * D2(\text{in MPa})$$

where P = Breaking Load (N), LL = Length (mm) = 16 ∗ thickness (approximately), B = Width (mm), D = Thickness (mm).

The following Table 3 includes flexural and tensile results, combined together for the comparison and analysis.

Table 3 Test results obtained for tensile and flexural strength

Sample no	Max. load (N)	Displacement at max. load (mm)	Max. displacement (mm)	Ultimate stress (N/mm^2)	Flexural strength
1	1380	2.60	2.70	42.488	33.103
2	2110	2.70	4.00	101.932	60.215
3	3300	4.60	4.90	147.321	91.139
4	860	2.80	3.00	31.273	25.862
5	1400	3.20	3.40	45.455	20.000
6	1500	3.60	3.90	44.978	37.333
7	660	1.70	2.00	44.000	25.157
8	750	2.20	2.50	45.455	79.947
9	1860	3.50	3.60	65.608	104.09
10	1960	4.60	4.70	56.795	80.000
11	3360	5.00	5.20	177.966	76.700
12	2160	4.80	5.60	76.460	71.006
13	2540	4.90	5.10	75.595	46.921
14	1280	3.60	3.80	41.933	15.484
15	2220	3.20	3.30	68.350	127.81
16	1920	4.20	4.40	92.754	61.538
17	3080	4.40	4.70	142.593	94.581
18	1420	3.90	4.20	44.514	34.483
19	3240	3.80	4.80	183.674	84.210
20	2530	3.80	3.90	128.950	47.619
21	2430	3.10	3.30	91.698	68.750
22	1810	3.40	3.70	58.766	20.000

The results obtained were satisfactory, and the thickness of 3 mm was achieved by using three layers of double-sided tape. However, further thickness would demand the use of a thicker double-sided tape and also a bigger mould as well as a powerful pump for the suction of resin and its uniform impregnation. The highest tensile strength of 183.67 N/mm^2 was given by sample no 19, which is a combination of three woven mats, impregnated with epoxy resin with mica filler. The second highest tensile strength of 177.96 N/mm^2 was given by sample 11, which was again a combination of three woven mats impregnated with polyester resin and silica filler. The highest flexural strength of 127.81 N/mm2 was given by sample no 15, which was a combination of three chopped strand mats impregnated with epoxy resin and silica filler. Thus, the composites could replace the articles used for domestic applications, like furniture panels and musical instruments.

4 Conclusion

This study was an attempt to explore various types of FRP composite materials and further to find out the influence of different types of resins, fibres, and fillers on its mechanical properties. Based on various test results and graphs, the following conclusions are arrived at. A combination of three woven mats impregnated with epoxy resin with mica filler gave the highest tensile strength of 183.67 N/mm^2. Whereas, composite with epoxy and silica filler gave the highest flexural strength of 127.811 N/mm^2. Epoxy resin is found to be much more superior to polyester resin, in terms of strength, bond, shrinkage, and temperature resistance. Composites made of woven roving mat are seen much stronger than composites made of chopped strand mat. Mica fillers could also enhance the mechanical properties of composite materials. Vacuum infusion process was found to the best method, by far to manufacture composite materials, as it provides very strong and light weight components, as it also has a resin to fibre ratio of 30 to 70. Any shape and size components can be manufactured using this process. Thus, composites are materials of the future, especially with more and more research and development of advanced composite materials being conducted. They are expected to gradually replace metals in all the domains in the future.

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Optimization of Process Parameters in CNC Turning of Hastelloy C276 Through Taguchi Method

Mahir Mistry and Greegory Mathew

Abstract The current work focusses on an experimental investigation to determine how tool geometry and machining process parameters affect the surface irregularities and rate of material removal during CNC turning of Hastelloy C276. Feed rate, cutting speed, depth of cut and nose radius were the selected parameters. The experiments were designed and conducted using Taguchi method. Statistical tool—Minitab was used to compute the S/N ratios and the mean values to determine the optimum values of the process parameters. The results indicate that nose radius and cutting speed significantly affect the quality of the machined surface and the rate of material removal.

Keywords Optimization · Taguchi method · Surface roughness · Hastelloy

Abbreviations

S/N	Signal to noise
Ra	Surface roughness
MRR	Material removal rate
Vc	Cutting speed
d	Depth of cut
f	Feed rate
Rn	Tool nose radius

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1 Introduction

Achieving good machinability in difficult to cut materials is a challenge that most manufacturers face. Good machinability is described by a set of features that include low cutting force, improved surface smoothness, reduced power usage, increased rate of material removal, precise and steady geometrical characteristics of the work piece and good chip breakdown. A manufacturer needs to ensure dimensional accuracy and should be able to control tool wear and surface finish while machining, to guarantee improved performance and durability of engineering components [1]. Higher MRR, increased surface finish and steadiness of the cutting tool (insert) can improve productivity and quality. However, it leads to an increase in heat generation at the tool-chip interface and decreases the dimensional accuracy, tool durability and the surface integrity of the machined element [2]. Surface irregularities have a noteworthy effect on the properties such as wear and fatigue resistance. Optimising the machining parameters can help machining industries in improving the cutting efficiency, cut costs and in achieving superior finish and better dimensional accuracy of the workpiece.

2 Materials and Method

The purpose of this experimental investigation was to understand how the process parameters (Vc, d, f and Rn) affect MRR and the surface finish of machined Hastelloy C276 components. Hastelloy C276 is a Ni-Mo-Cr alloy (as shown in Table 1) with high shear strength. It resists the formation of grain boundary precipitates which degrades corrosion resistance [3]. It is used widely in aerospace, chemical and nuclear industry due to its excellent corrosion, temperature and wear resistant properties [4]. However, they are resistant to material removal. The huge amount of heat generated during its machining may cause it to weld to the cutting tool surface, thus making it difficult to machine and cut.

Traditional experimental design and plans are time-consuming and incur huge costs. To overcome these limitations, experiments were designed using Taguchi method. It is an excellent tool based on orthogonal arrays for designing experiments and has been widely used by researchers [5–8]. It helps to identify the significant parameters and their optimum values by using only a limited number of experiments. The specifics of the process parameters and the levels that were selected for each are listed in Table 2.

Table 1 Chemical composition of Hastelloy C276 (measured using material analyser)

Elements	Ni	Mo	Cr	Fe	W	Co	Mn	Nb
Percentage (%)	58.19	15.90	15.52	5.61	3.55	0.52	0.27	0.10

Table 2 Process parameters and their levels

Designation	Process parameters	Units	Levels		
			Level 1	Level 2	Level 3
A	Cutting speed	m/min	60	70	80
B	Feed rate	mm/rev	0.06	0.08	0.10
C	Depth of cut	mm	0.8	1.00	1.2
D	Nose radius	mm	0.4	0.8	1.2

These values were selected in consultation with machine operators and other experts. Since carbide tools are best for cutting Ni alloys [9], three tool inserts (Make: KYOCERA) of the same grade but with different Rn, i.e. TNMG160404MS PR1535, TNMG160408MS PR1535 and TNMG160412MS PR1535 were used for the experiments.

3 Experimentation and Results

In order to perform the experiments, a Hastelloy C276 bar of diameter 25 mm and length 550 mm was cut into 9 smaller bars of size Ø25 mm × 50 mm. Each workpiece was then machined by CNC turning to a size Ø21 mm × 30 mm as shown in Fig. 1.

Turning of each workpiece was carried out on TSUGAMI-MO8J-II CNC machining centre in accordance with L9 experimental plan as shown in Table 3. The weight of each workspace was measured both before machining and after machining in order to calculate the MRR. The Ra values of each workpiece were measured by using a surface roughness tester (Make: MITUTOYO). Each workpiece was

Fig. 1 Machined Hastelloy C276 bars

Table 3 Experimental observations

Run no	Cutting Parameters				Output Response	
	Vc (m/min)	f (mm/rev)	d (mm)	Rn (mm)	MRR (mm^3/min.)	Ra (μm)
1	60	0.06	0.8	0.4	1.991814276	0.70
2	60	0.08	1.0	0.8	0.973069543	1.022667
3	60	0.10	1.2	1.2	0.600662622	0.176
4	70	0.06	1.0	1.2	4.738103389	0.144333
5	70	0.08	1.2	0.4	2.606459907	1.039333
6	70	0.10	0.8	0.8	1.715059055	1.065333
7	80	0.06	1.2	0.8	2.699662542	0.302667
8	80	0.08	0.8	1.2	4.386051743	0.287
9	80	0.10	1.0	0.4	2.57043451	0.901

supported by a magnetic V-block and slip gauges for accurate measurement. Three separate readings were taken for each workpiece, and their average value is listed in Table 3.

The S/N ratios and the mean values were calculated using MINITAB. The S/N ratios for MRR and Ra were calculated using 'larger the better' and 'smaller the better' characteristics, respectively. Table 4 displays the response values for MRR. It is clear from the tabulated results that Vc has a significant impact on MRR followed by f, d and Rn. Figure 2 shows the main effects plot (*MRR*). The optimum levels of machining parameters (Vc, f, d and Rn) for higher material removal rate are A3-B1-C1-D1, i.e. 80 m/min, 0.06 mm/r, 0.8 mm and 0.4 mm, respectively.

Table 5 displays the response values for Ra. It is clear from the tabulated results that Rn has a significant impact followed by f, d and Vc. Figure 3 shows the main effects plot (Ra). The optimum levels of machining parameters (Vc, f, d and Rn) for better surface finish are A3-B1-C3-D3, i.e. 80 m/min, 0.06 mm/r, 1.2 mm and 1.2 mm, respectively.

Table 4 Outcome response table for MRR (S/N ratios)

Level	Vc	f	d	Rn
1	0.4402	9.3744	7.8373	7.5020
2	8.8396	6.9751	7.1584	4.3582
3	9.8893	2.8194	4.1733	7.3087
Delta	9.4491	6.5550	3.6641	3.1438
Rank	1	2	3	4

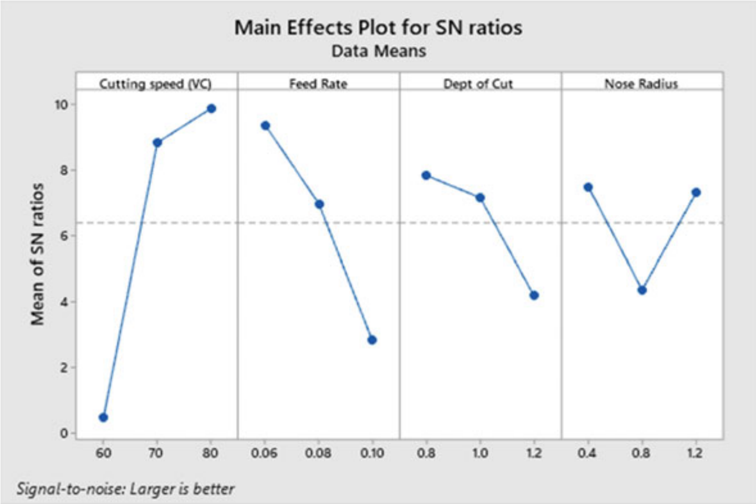

Fig. 2 Main effects plot for MRR (S/N ratios)

Table 5 Outcome response table for Ra (S/N ratios)

Level	Vc	f	d	Rn
1	5.998	10.097	4.464	1.223
2	5.309	3.438	5.841	3.212
3	7.376	5.149	8.378	14.248
Delta	2.067	6.660	3.915	13.025
Rank	4	2	3	1

4 Conclusion

The experimental investigation to determine the significance of process parameters on surface roughness and material removal rate of Hastelloy C276 was successfully carried out using Taguchi's L9 array. The results indicate that cutting speed significantly affects material removal rate while nose radius significantly affects the surface finish. The optimum values of cutting speed, feed rate, depth of cut and nose radius to achieve higher material removal rate are 80 m/min, 0.06 mm/r, 0.8 mm and 0.4 mm, respectively, while that to attain better surface finish are 80 m/min, 0.06 mm/r, 1.2 mm and 1.2 mm, respectively. This combination of parameters will improve the surface quality of the machined surface at minimum cost and will thereby improve productivity.

Fig. 3 Main effects plot of S/N ratios for Ra

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Experimental Investigation, Modeling, and Optimization of Cutting Forces in Dry Hard Turning

Sandip Mane and Hari Vasudevan

Abstract The capacity of hard turning to replace traditional grinding operations is attracting the interest of automobile and allied industries today. In this context, the thermal modeling and tool life estimation depend on a precise understanding of cutting forces, under different cutting conditions. Cutting force is a critical technological parameter that must be controlled continuously by selecting the appropriate cutting parameters during the machining process. Given the background, this study used response surface methodology to model and optimize radial cutting force (Fr) during dry hard turning of AISI 52100 alloy steel. The influence of cutting parameters on the individual components of the cutting force was investigated using 'analysis of variance' (ANOVA). The depth of cut (d) was shown to be the most important cutting parameter, whereas the feed rate (f) and cutting speed (v) had minimal effect on cutting force components. The cutting parameters were shown to have an effect on the most noticeable radial cutting force component. Response surface methodology (RSM) was applied to build a cutting force (Fr) model. To establish the validity of the investigation, diagnostic and confirmatory tests were carried out. The model's cutting force predictions matched the experimental values well.

Keywords Hard turning · Radial cutting force (Fr) · Response surface methodology (RSM) · Central composite rotatable design (CCRD)

1 Introduction

Hard turning is a viable substitute to traditional grinding since it reduces lead time due to the fewer setups required without sacrificing the surface quality. Huang et al. [1] observed that production costs can be decreased by 30%, when complex parts are machined using the hard turning process. AISI 52100 alloy steel is commonly used in the manufacturing of automobile components like gears, excel, shafts, bearings, tooling, and dies. Cutting force is an important performance indicator in determining

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the power needs as well as the design of machine tool parts, tool holders, and fixtures to ensure a vibration-free operation. According to Chen [2], the radial force was the largest force component in comparison with the axial and tangential force components, when turning hardened alloy steel in the 45–55 HRC range, using a CBN tool. Arsecularatne et al. [3] studied the influence of cutting parameters on cutting forces, when using PCBN tools to turn AISI D2 steel at an elevated hardness of 62 HRC. According to their findings, cutting force was found to be the most strongly influenced by feed rate, followed by the depth of cut and cutting speed. According to Lalwani et al. [4], the axial force was affected by the depth of cut in the finish turning of MDN 250 hardened steel, whereas the radial and tangential forces were affected by the feed rate and the depth of cut. According to Gaitonde et al. [5], the depth of cut had the greatest effect on cutting force and power in the turning of AISI D2 hardened tool steel with wiper ceramic inserts. Cutting force and cutting power were discovered to rise linearly with the depth of the cut. Aouici et al. [6] examined the effect of cutting parameters on cutting force, cutting temperature, tool life, and surface roughness, when turning AISI H11 steel to a hardness of 50 HRC using a CBN tool. According to the results, cutting force was strongly influenced by the depth of cut, surface roughness by the feed rate, and temperature by the cutting speed.

Bouacha et al. [7] used response surface methodology (RSM) and analysis of variance (ANOVA) to analyze the cutting forces in turning heat-treated AISI 52100 grade steel with a CBN insert. The feed rate and cutting speed had the greatest effect on surface roughness, whereas the depth of cut had significant effect on cutting forces. Azizi et al. [8] investigated the effect of cutting parameters, such as speed, feed rate, and depth of cut on the finish hard machining of AISI 52100 steel, using an Al2O3+TiC-coated mixed ceramic insert and established a mathematical model for cutting force. Among all other force components, the thrust force was observed to be the greatest. Bartarya and Choudhury [9] investigated the effect of cutting conditions on different forces during the hard turning of EN 31 steel, using an uncoated CBN tool. Feed rate and depth of cut were the most important parameters influencing the tangential and radial forces, respectively.

Bouziane et al. [10] investigated the effect of cutting parameters on cutting forces, when hard turning AISI 52100 bearing steel with mixed ceramic inserts (CC650). It was discovered that the depth of the cut had a significant effect on the axial (Fa), tangential (Ft), and radial (Fr) forces whereas cutting speed had a negligible effect on axial force (Fa) and no effect on (Ft) (Fr). Patel et al. [11] investigated the effect of cutting parameters and the nose radius of the cutting tool on the finish hard turning of AISI D2 steel, using a CBN tool. The results indicated that the cutting forces increased with feed rate, depth of cut, and tool nose radius and decreased with cutting speed in the axial, tangential, and radial directions. Ahmed et al. [12] used RSM to predict the hard turning response of AISI H13 hot work steel, and the prediction error for the validation experiments was found to be less than 5%. Rajguru and Vasudevan [13] applied RSM to develop a second-order mathematical model to establish the relationship between surface roughness parameter and process parameters in dry end milling of Inconel 625.

However, very few studies have explored the effect of cutting parameters on cutting forces that are generated during hard turning at an elevated hardness of 58 HRC. Consequently, the objective of this study was to examine the effect of cutting parameters on the cutting forces generated when hard turning AISI 52100 steel with a multilayer-coated carbide insert.

2 Problem Statement

After going through an extensive literature review and analysis, this study has conceptualized and formulated the focus of the study, as follows. Experimental investigation on effects of cutting parameters on major machinability characteristics with respect to cutting force components in the dry turning of hardened AISI 52100 (58 HRC) alloy steel with low cost (TiN/TiCN/Al2O3) multilayer-coated carbide tool inserts.

3 Material, Cutting Conditions, and Experimental Design

3.1 Material

The work material was selected to be AISI 52100 steel due to its broad applicability in automotive and allied industries for a variety of applications, including bearings, spinning tools, CV joints, ball screws, gauges, punches, and dies. The BRUKER optical emission spectrometer (Model—Q4 TASMAN) was used to test the chemical composition. The hardness of work material was obtained to be 58 $\pm$ 1 HRC after heat treatment.

3.2 Cutting Tool and Cutting Conditions

The experimentation used the MTCVD multilayer-coated carbide (TiN/TiCN/Al2O3)—[HK150, K-type] cutting tool insert with specification CNMG120408 [14]. Experiments were conducted on an HMT NH-18 lathe machine. The process parameters were chosen in accordance with the tool manufacturer's recommendations. Table 1 shows the process parameters with their levels based on RSM's CCRD design.

Table 1 Process parameters and their levels[14]

Process parameters	Units	Limits				
		− 1.682	− 1	0	1	1.682
Cutting speed	m/min	90	100	115	130	140
Feed rate	mm/rev	0.05	0.075	0.10	0.125	0.150
Depth of cut	mm	0.1	0.2	0.3	0.4	0.5

3.3 *Experimental Design*

RSM generates models through the use of statistical experimental design and least square fitting. Experiments were designed and performed using the CCRD of response surface methodology (RSM). The major radial cutting force component (Fr) was predicted in terms of process parameters. The cutting forces were measured using an IEICOS tool lathe dynamometer (Model 620 C-500 kg). The experimental design and result for cutting forces were as shown in Table 2.

Table 2 Experimental design and result for cutting force components

Sr No	v (m/min)	f (mm/rev)	d (mm)	Cutting Force (N)		
				Fa	Fc	Fr
1	115	0.10	0.3	68.62	148.34	204.303
2	130	0.08	0.4	81.76	168.67	234.414
3	115	0.10	0.3	71.83	149.84	199.256
4	90	0.10	0.3	56.35	109.97	154.693
5	140	0.10	0.3	76.36	141.62	190.427
6	115	0.10	0.1	38.51	74.21	90.490
7	115	0.05	0.3	58.91	119.15	164.642
8	115	0.10	0.3	73.47	151.34	210.285
9	115	0.10	0.3	80.85	159.32	203.695
10	100	0.08	0.2	42.42	83.76	114.085
11	130	0.12	0.4	101.08	225.27	282.075
12	115	0.10	0.5	95.24	217.65	273.596
13	130	0.12	0.2	53.83	110.28	146.259
14	115	0.10	0.3	83.32	155.48	202.733
15	130	0.08	0.2	57.64	114.71	155.195
16	100	0.08	0.4	61.52	119.51	153.028
17	100	0.12	0.4	77.96	178.58	252.407
18	100	0.12	0.2	47.45	112.03	149.300
19	115	0.10	0.3	81.87	157.99	200.609
20	115	0.15	0.3	82.65	183.58	253.538

4 Results and Discussion

The statistical analysis of results was carried out for all the force components at 95% confidence level by conducting ANOVA test. It was evident from the ANOVA analysis that the depth of cut (d) and feed rate (f) had the greatest influence, while the cutting speed (v), quadratic cutting speed (v*v), and feed rate and depth of cut (fd) interaction had a less noticeable effect on cutting force components. However, the quadratic feed rate (f*f), quadratic depth of cut (d*d), cutting speed and feed rate (vf) interaction and cutting speed and depth of cut (vd) interaction all had no influential effect on cutting force components, except the minor influence of the quadratic value of depth of cut (d*d) on axial cutting force (Fa). Radial cutting force (Fr) is the largest and most dominant force component in hard turning process considered for further analysis.

Table 3. below shows that the depth of cut had the most statistical significance on the cutting force components with contributions of 62.33, 64.97, and 65.17%, followed by feed rate with contributions of 12.94, 14.71, and 15.21% and cutting speed with contributions of 8.21, 7.78, and 6.40% for axial cutting force (Fa), tangential cutting force (Ft), and radial cutting force (Fr), respectively.

However, less or no significant interaction and quadratic effect of cutting parameters were observed on the cutting force components. The discrepancy between the

Table 3 ANOVA for cutting force components

		Fa			Fc			Fr		
Source	df	Adj.R^2 = 0.9931 Pred R^2 = 0.8143			Adj.R^2 = 0.9697 Pred R^2 = 0.8931			Adj.R^2 = 0.9855 Pred R^2 = 0.9507 Adeq Prec. = 43.08		
		Seq SS	Contr	P-Value	Seq SS	Contr	P-Value	Seq SS	Contr	P-Value
Model	9	5219.0	94.70	0.000	29,489	98.41	0.000	49,793	99.24	0.0001
v	1	452.66	8.210	0.003	2332.1	7.78	0.000	3212.5	6.40	0.0001
f	1	712.98	12.94	0.001	4407.4	14.71	0.000	7632.5	15.21	0.0001
d	1	3435.1	62.33	0.000	19,469	64.97	0.000	32,697	65.17	0.0001
v*v	1	182.05	3.300	0.012	1399.9	4.67	0.000	1662.1	3.31	0.0001
f*f	1	24.390	0.440	0.164	0.8000	0.00	0.636	178.6	0.36	0.3197
d*d	1	199.13	3.610	0.026	116.00	0.39	0.150	772.9	1.54	0.0012
v*f	1	4.4400	0.080	0.705	154.60	0.52	0.102	1148.9	2.2	0.0003
v*d	1	59.190	1.070	0.185	555.30	1.85	0.007	665.9	1.33	0.0019
f*d	1	149.13	2.710	0.047	1054.1	3.52	0.001	1822.9	3.63	0.0001
Error	10	292.14	5.300	–	477.10	1.59	–	382.5	0.7	–
Lack-of-Fit	5	104.94	1.900	0.730	374.80	1.25	0.090	308.9	0.62	0.0709
Pure	5	187.20	3.400	–	102.40	0.34	–	73.7	0.15	–
Total	19	5511.24	100	–	29,966	100	–	50,176	100	–

predicted R^2 of 0.9507 and the adjusted R^2 of 0.9855 was less than 0.2. Adeq precision evaluated the signal-to-noise ratio. A ratio of 4 or more was preferable, and a ratio of 43.08 was observed. Regression analysis was employed to develop parametric relationship between the independent factors, cutting speed (v), feed rate (f), depth of cut (d), and cutting force (Fr) was developed as per the proposed second-order polynomial model using regression method. The response function representing cutting force (Fr) was expressed as Y = f(v, f, d). The resulting relationship is expressed as equations in terms of the coded and actual variables as below.

$$\begin{aligned}\text{Cutting Force (Fr)} = &+ 203.16 + 15.39 * v + 19.30 * f + 45.21 * d \\ &- 11.98 * v * f + 9.12 * v * d + 15.10 * f * d \\ &- 1.56 * v * v + 0.8415 * f * f - 5.54 * d * d\end{aligned}$$

The influence of cutting speed and feed rate on cutting force (Fr) was as depicted in Fig. 1a. The lowest cutting force (Fr) of 134 N was obtained, when the cutting speed was between 100 and 110 m/min and the feed rate was between 0.06 and 0.10 mm/rev. At a feed rate of 0.13–0.15 mm/rev and a cutting speed of 100–110 m/min, a cutting force (Fr) of 234 N was reported. Figure 1b illustrates the influence of cutting speed and depth of cut interaction on cutting force (Fr). Between a depth of cut of 0.10–0.17 mm and a cutting speed of 100–120 m/min, a minimum cutting force of 114 N (Fr) was obtained. At a depth of cut 0.35–0.50 mm, a cutting force (Fr) of 234–282 N was observed. The cutting force (Fr) versus the depth of cut and feed rate was as shown in Fig. 1c. Between a depth of cut of 0.10–0.17 mm and a feed rate of 0.08–0.10 mm/rev, a lower cutting force (Fr) of 100–110 N was achieved.

The 3D surface plots illustrate the aforementioned results with more clarity. Figure 2a–illustrates the relationship between the cutting force and independent process variables using a surface plot.

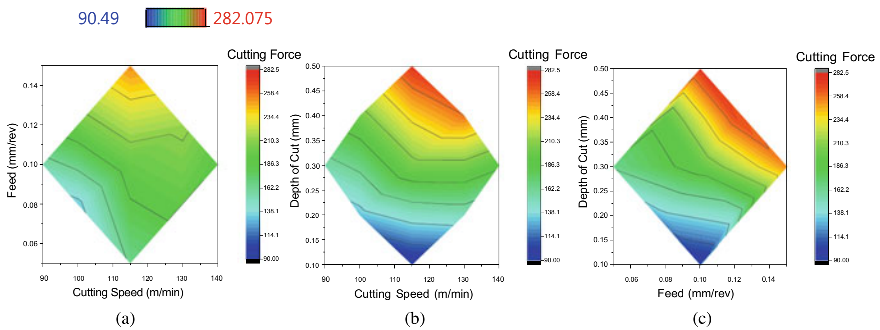

Fig. 1 Contour plots for radial cutting force (Fr) **a** Cutting speed versus Feed rate **b** Cutting speed versus Depth of cut **c** Feed rate versus Depth of cut

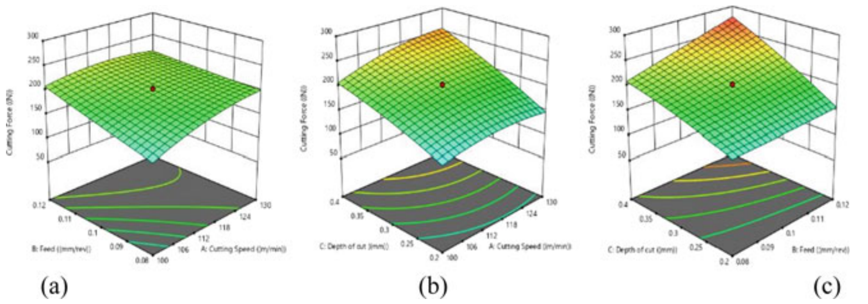

Fig. 2 Surface plots for radial cutting force (Fr) **a** Cutting speed versus Feed rate **b** Cutting speed versus Depth of cut **c** Depth of cut versus Feed rate

Table 4 Optimization results

Sr No	v (m/min)	F (mm/rev)	d (mm)	Fr (N)	Desirability	
1	**100.284**	**0.055**	**0.192**	**102.533**	**1.000**	Selected
2	103.074	0.053	0.116	97.189	1.000	
3	136.935	0.051	0.101	136.424	1.000	
4	102.514	0.063	0.108	91.947	1.000	
5	138.232	0.051	0.111	141.252	1.000	

4.1 Optimization of Cutting Parameters

The cutting parameters settings to minimize cutting force (Fr) were determined by numerical optimization using the desirability function. Table 4 reveals that the optimal cutting speed was 100.284 m/min, the optimal feed rate 0.055 mm/rev, the optimal depth of cut 0.192 mm, and the optimal cutting force response 102.533 N with higher desirability value of 1.

4.2 Model Validation

Experiments and confirmatory tests were used to validate and verify the expected response values. The proportion of error between the experimental and predicted values was less than 5%, indicating that the model was accurate. Table 5 depicts the model validation through the confirmatory test.

Table 5 Confirmatory test for the model's validation

Response	Prediction	95% CI low	95% CI high	95% PI low	95% PI high	Experimental
Fr (N)	203	197.64	208.68	173.28	233.03	210.532

5 Conclusion

The cutting force (Fr) was estimated in terms of the cutting parameters within the constraints, in the turning of AISI 52,100 (58 HRC) alloy steel using the RSM-based CCD design. The study's findings revealed that the depth of cut exhibited the greatest impact on cutting force, while the feed rate, cutting speed, quadratic term of cutting velocity (v), and the interaction of feed rate and depth of cut (fd) had a minor impact. The quadratic terms of feed (f), depth of cut (d), cutting velocity and feed rate interactions (vf), and cutting velocity and depth of cut interactions (vd) were shown to have no effect on cutting force. Cutting parameters, such as cutting speed, feed rate, and depth of cut, contributed 65.17, 15.21, and 6.40% to the cutting force (Fr), respectively. It was found that, during the turning of AISI 52,100 steel with a hardness of 58 HRC, the built predictive model would successfully estimates the cutting force (Fr) within the constraints defined.

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Process Optimization Using Design of Experiments on Rubber–Metal Bonded Products Using Full Factorial Method

Latesh Shah and Trupti Markose

Abstract The term "design of experiments" (DOE) refers to a subfield of applied statistics that focuses on the planning, conducting, analyzing, and interpreting of controlled experiments to determine the variables that affect the value of a parameter or set of parameters. It is a methodical approach to figure out the connection between the inputs and outputs of a process. The main objective of this research was process optimization of rubber–metal bonded products using DOE by full factorial method. This helps in obtaining the best input parameters for the process resulting in an optimized product and thereby saving time and cost. It's a method for determining the relationship between factors affecting a process and the process's output. It allows for the manipulation of multiple input factors in order to determine their impact on a desired output (response).

Keywords Design of experiments (DOE) · Orthogonal array · Full factorial · Transfer molding

1 Introduction

Design of experiments (DOE) is the process of organizing, carrying out, analyzing, and interpreting controlled tests to identify the factors influencing the value of a parameter or set of parameters. It's a systematic method for determining the relationship between factors affecting a process and the process's output. A full factorial DOE design is one of several methods for planning and conducting an experiment to determine the impact of different levels of inputs on outputs. The goal of the DOE is to figure out at what levels of the inputs you'll get the best results [1].

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2 Full Factorial in Transfer Molding

In each full trial or replication of the experiments, full factorial design creates experimental points by combining all feasible combinations of the levels of the components. In a full factorial design, the experimental design points are located at the vertices of a hypercube in the n-dimensional design space defined by the minimum and maximum values of each component. These experimental points are also called factorial points. In this case, the input factors during transfer molding are input weight of rubber compound, upper platen temperature, lower platen temperature, curing time, and pressure. Among these input factors, some are controllable input factors and some are uncontrollable input factors wherein one can't change any value. In this study, the input weight of rubber compound is uncontrollable input factor, while the rest are controllable input factors. A full factorial design is used to analyze how each element and its interactions will affect the outcome (FFD) [2]. An example of a common experimental design is one in which each input factor is set to two levels [3]. These are known as high levels, or + 1, and low levels, or − 1, correspondingly [4]. All potential high/low groupings of each input element are included in a full factorial design with two levels [4, 5]. As stated before, if there are k factors, each with two levels, a full factorial design will have 2^k runs [6].

2.1 Product Specifications and Customer Requirements

Current input factors*:*

- Time—12 min
- Temperature—165 °C
- Pressure—2100 psi
- Input weight of rubber—25 ± 5 gms/cavity.

Response factors are as follows:

- Hardness—60 ± 5 (shore 'A')
- Static Stiffness—71.7 kg/mm
- Bonding Strength—100 kg load (minimum).

2.2 L_9Orthogonal Array Calculation and Observations

Orthogonal arrays can be considered of as multifactor experiment plans, with the columns representing the factors, the entries representing the test levels of the factors, and the rows representing the test runs as given in Tables 1, 2, and 3 [7, 8].

$$L_a\left(b^c\right) \tag{1}$$

Table 1 Experimental plan using L_9 orthogonal array (OA)

Experiment number	Parameters level	
	A	B
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Table 2 For the given product input parameters

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
A	Time	Minutes	8	10	12
B	Temperature	°Celsius	155	165	175

where
L = Latin square
a = Number of experiments
b = Number of levels
c = Number of factors

- Orthogonal L_9 array for 2 factors and 3 levels

$$L_9 - \left(3^2\right) \tag{2}$$

3 Response Optimization

Here, response optimizer from Minitab is used to identify the combination of input variable settings that optimizes the set of responses as given in Tables 4.1, 4.2, 4.3, 4.4 and 5.1, 5.2, 5.3, 5.4. One can use the fit values to determine the point estimate of each response variable for the settings in the optimization plot. The optimization plot (as shown in Figs. 1 and 2) shows the fitted values for the predictor settings [9].

Table 3 L_9 orthogonal designs for 2 factors and 3 levels

Exp. no	Factors		Responses		
	Time (min)	Temperature (°C)	Hardness (shore 'A')	Bonding strength (kg)	Static stiffness (kg/mm)
1	8	155	58	283	55.3
2	8	165	61	296	71.4
3	8	175	60	285	74.1
4	10	155	59	420	53
5	10	165	57	422	56.4
6	10	175	59	380	73.6
7	12	155	58	328	51.1
8	12	165	59	446	55.3
9	12	175	57	329	53.3

3.1 Considering Static Stiffness, Bonding Strength, and Hardness

(See Tables 4.1, 4.2, 4.3, 4.4 and Fig. 1)

Table 4.1 Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Static stiffness	Target	51.1	71.7	74.1	1	1
Bonding	Maximum	283.0	446.0		1	1
Hardness	Target	57.0	60.0	61.0	1	1

Table 4.2 Solution

Solution	Time	Temp	Static stiffness fit	Bonding fit	Hardness fit	Composite desirability
1	12	165	55.3	446	59	0.514158

Table 4.3 Prediction

Variable	Setting
Time	12
Temp	165

Table 4.4 Multiple response

Response	Fit	SE fit	95% CI	95% PI
Static stiffness	55.30	*	(*, *)	(*, *)
Bonding	446.0	*	(*, *)	(*, *)
Hardness	59.00	*	(*, *)	(*, *)

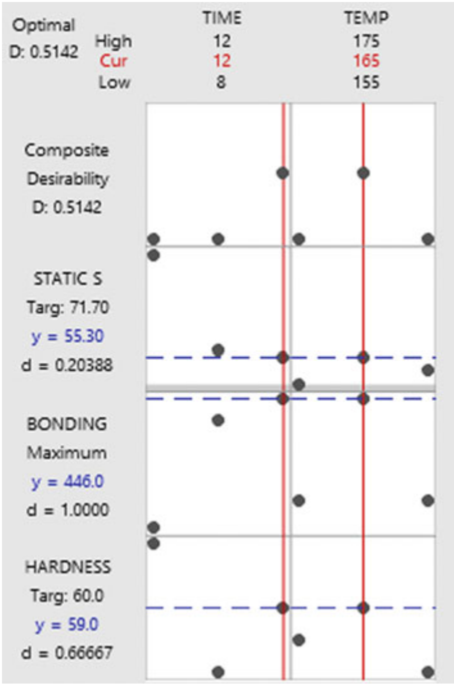

Fig. 1 Relation of all responses wrt to input factors

3.2 Considering Only Hardness and Static Stiffness

(See Table 5.1, 5.2, 5.3, 5.4, and Fig. 2)

Table 5.1 Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Static stiffness	Target	51.1	71.7	74.1	1	1
Hardness	Target	57.0	60.0	61.0	1	1

Table 5.2 Solution

Solution	Time	Temp	Static stiffness fit	Hardness fit	Composite desirability
1	10	175	73.6	59	0.372678

Table 5.3 Prediction

Variable	Setting
Time	10
Temp	175

Table 5.4 Multiple response

Response	Fit	SE fit	95% CI	95% PI
Statics stiffness	73.60	*	(*, *)	(*, *)
Hardness	59.00	*	(*, *)	(*, *)

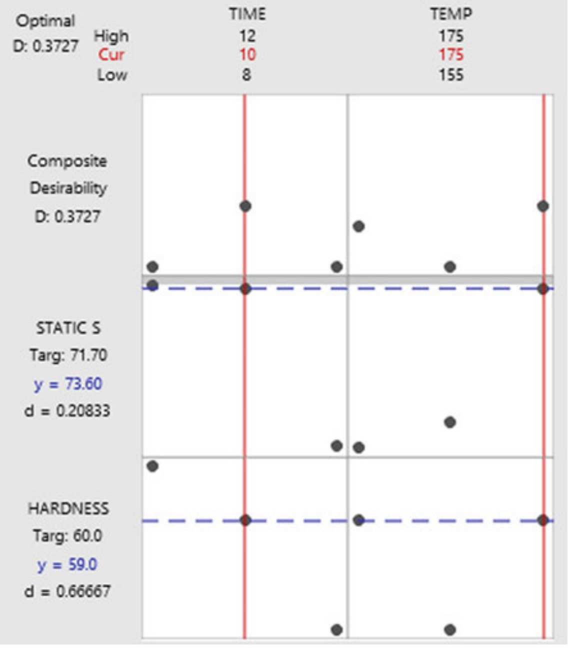

Fig. 2 Relation of hardness and static stiffness with respect to input factors

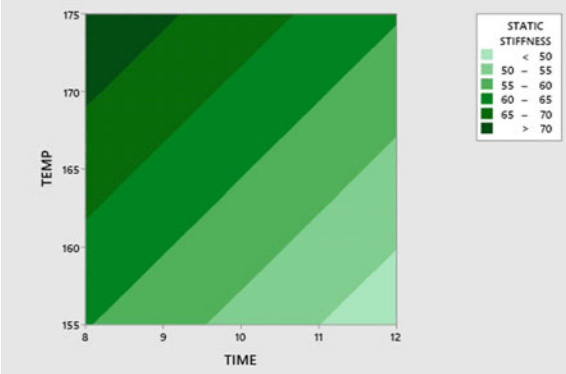

Fig. 3 Contour plot analysis of static stiffness

4 Relationship of the Output Parameters Against the Input Factors (Time and Temperature) Using Contour Plot Analysis

Contour plot is used with a saved model to depict the connection between a fitted response and two continuous variables. In a contour plot, points with the same response value are joined to form contour lines in a two-dimensional perspective [9, 10].

The following rules are to be considered while performing the analysis and interpreting the data to guarantee that results are accurate.

- Firstly, carry out an analysis that fits and stores a model.
- At least two continuous variables are required in the model.
- Check that the model adheres to the assumptions of the analysis.

4.1 Contour Plot of Static Stiffness Verus Time and Temperature

Here (in Fig. 3), we can see that the static stiffness requirement is 71.7 kg/mm which is > 70; hence, to achieve optimum static stiffness, high temperature and less time are to be taken.

4.2 Contour Plot of Hardness Versus Time and Temperature

Here (in Fig. 4), we can see that the hardness requirement is 60 which is > 59.6; hence, to achieve optimum hardness, high temperature and less time are to be taken.

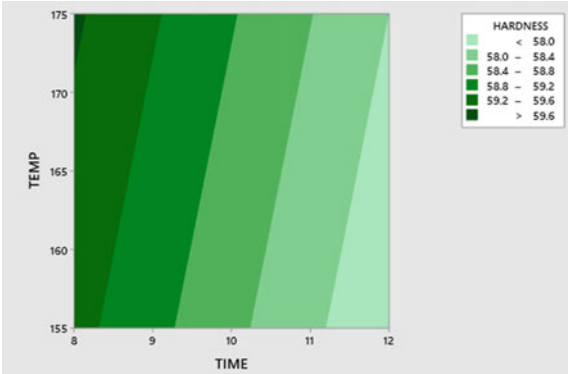

Fig. 4 Contour plot analysis of hardness

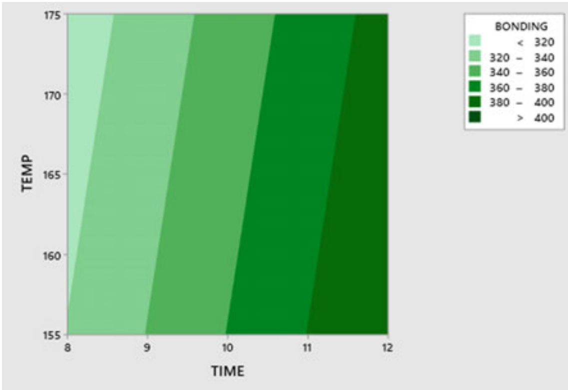

Fig. 5 Contour plot analysis of bonding strength

4.3 Contour Plot of Bonding Versus Time and Temperature

To achieve maximum bonding strength, more time and moderately less temperature are taken into consideration as shown in Fig. 5.

5 Conclusion

From the above response optimizations done on Minitab, one can see that if the customer demands to optimize all the response parameters, the best input parameters achieved are Time—12 min and Temperature—165° (as given in Table 4.3).

However, the bonding strength is satisfied by a wide margin in all experiments. Hence, ignoring bonding strength as the response parameter and considering only hardness and static stiffness, the best input parameters achieved are as follows: Time—10 min and Temperature—175° (as given in Table 5.3). Therefore, saving

2 min in overall production time for each cycle and saving almost 3 h per day, assuming average daily production of the component is 100 pieces a day. The contour plot analysis shows that by increasing the temperature and decreasing the time required to produce the product, we can optimize the individual response parameters as well.

In the future research, implementing design of experiments (DOE) on every product in departments with a high rejection rate can save a lot of time and money. Furthermore, the organization can save time and effort by avoiding repeating the entire design of experiment by constructing a regression equation between the input components and response parameters [11].

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Predictive Modelling of Cutting Force in the Machining of Duplex Stainless Steels Using Artificial Neural Network

Naresh Deshpande and Hari Vasudevan

Abstract Artificial Neural Network (ANN) method is used in this research study to develop a predictive model for main cutting force, during the turning of Duplex Stainless Steel (DSS). The primary network architecture consisted of three layers, namely input, hidden and output. Input layer consisted of four neurons and output layer consisted of single neuron. Different architectures of ANN were tested by varying the neurons in the hidden layer from three to ten. Three training algorithms, viz. Levenberg–Marquardt (LM), Bayesian regularization (BR) and scaled conjugate gradient (SCG) were applied to train each of the network. Three evaluation metrics, namely R square, Root mean square error (RMSE) and mean absolute percentage error (MAPE), were used to select the best performing models. Finally, the prediction accuracy was calculated for each of the three best performing models by comparing the predicted values with the actual experimental observations. The network having 9 neurons in the hidden layer and trained using Bayesian regularization (BR) displayed the highest prediction accuracy of 99.96%.

Keywords Duplex stainless steel (DSS) · Artificial neural network (ANN) · Bayesian regularization (BR) · Levenberg · Marquardt (LM)

1 Introduction

Duplex Stainless Steel (DSS) possesses almost double the strength, as compared to austenitic stainless steels and better toughness and ductility, as compared to ferritic stainless steels. They also have improved resistance to pitting corrosion and stress corrosion cracking. Due to these desirable properties, they are used in several applications across different industrial sectors such as mining and hydrometallurgy, chemical

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processing plants, oil and gas, bulk materials handling equipment, desalination, shipbuilding and marine and pollution control equipment, to name just a few. Many products in these fields of application are processed using conventional machining. DSS is categorized as difficult to cut material, because it has low thermal conductivity, higher tendency for work hardening and built-up edge formation. It also displays higher tensile strength and toughness [1]. During the machining of these steels, high cutting forces are generated, and there is a need to minimize them to achieve better tool life and lower power consumption. Proper selection of cutting parameters is important in this sense. Every time, when there is a need to change the selected independent variables, experimental determination of optimum values turns out to be costly and time consuming. Therefore, so many researchers have developed models for estimation of machining performance measures, like cutting force and surface roughness, based on the input variables. Different types of modelling approaches, like analytical, soft computing-based, empirical and hybrid have been used to develop such predictive models for many difficult to cut materials, but there are very few papers on such studies, pertaining to DSS.

Kumar et al. [2] investigated the effect of minimum quantity lubrication on cutting force during the turning of DSS. They used central composite response surface design for conducting the experiments and three types of cutting fluids, viz. deionized water, emulsified fluid and neat oil. Cutting speed, feed and depth of cut were varied at three levels each, and Analysis of Variance was done to find the most influential factor. It was found that the use of emulsified fluid resulted in minimum values of cutting force, while the feed rate was the most influential factor affecting the variation. Reddy et al. [3] studied the effect of cutting variables on components of cutting force, during the hard finish turning of AISI H13 tool steel. They used Taguchi's L-25 design to conduct the experiments. Feed rate and depth of cut were the most significant factors affecting the variation in cutting force. Artificial Neural Network (ANN) models with good prediction abilities were also developed in addition to this analysis. Lokesha et al. [4] developed ANN models to predict the friction force between the tool and workpiece. They used various ferrous as well as non-ferrous materials with different combinations of cutting variables and calculated the friction force using Merchant's circle diagram for around 648 trials.

Thiyagu et al. [5] used Box Behnken response surface design to study the effect of independent turning variables on surface roughness and cutting force, while turning DSS. They developed second-order models for both the responses. Speed and feed rate were significant for variation in surface roughness, while feed rate and nose radius were significant for cutting force. Koyee et al. [6] investigated the effect of cutting variables on various performance characteristics such as radial cutting force, cutting power, tool flank wear and chip volume ratio, while multi-pass face turning of standard and super duplex stainless steels. Response surface modelling, fuzzy rule-based modelling and Artificial Neural Network modelling approaches along with the combination of meta heuristics optimization algorithms, like Cuckoo search were used in their study. Ezugwu et al. [7] developed ANN models to predict the input–output relationship, while turning of Inconel 718 alloy. Vasudevan et al. [8] developed an ANN model to predict delamination factor and cutting force during

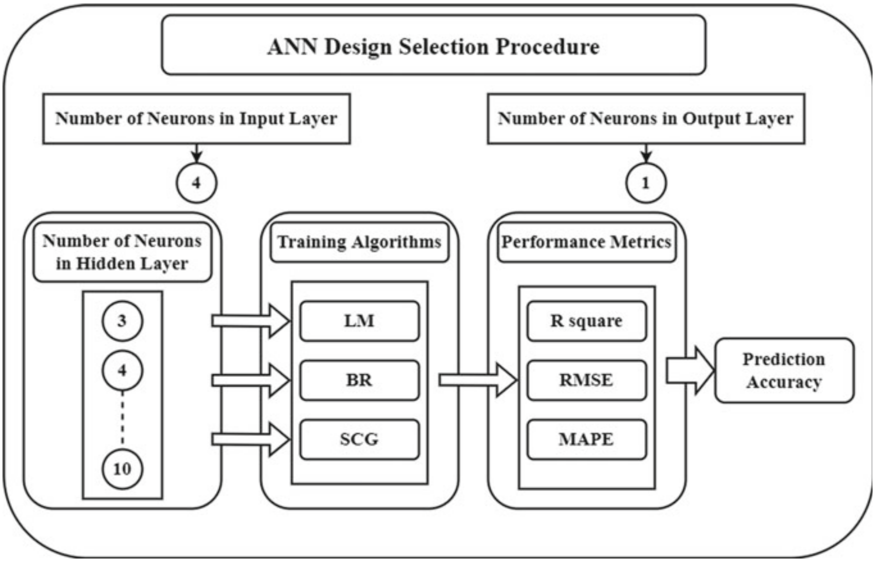

Fig. 1 ANN design selection procedure

the drilling of Glass Fibre-Reinforced Polymer composite material. To make the machining process environmentally friendly, there is a current trend of dry machining of difficult to cut materials [9–12].

In this present study, ANN models for prediction of main cutting force during the dry turning of DSS were built using various architectures and training algorithms. The models with the best performance were finally selected. The models consisted of one input layer with four neurons, one hidden layer with variable number of neurons and one output layer with one neuron. Three training algorithms, namely Levenberg–Marquardt (LM), Bayesian regularization (BR) and scaled conjugate gradient (SCG), were used independently by varying the neurons in the hidden layer from 3 to 10. Three evaluation metrics, namely R square, Root mean square error (RMSE) and mean absolute percentage error (MAPE), were used to evaluate the performance of these models. Finally, the predicted values were compared with the actual experimental values in the validation stage. The model having the best prediction accuracy was finally selected. Figure 1 shows the ANN design selection procedure.

2 Materials and Method

The following sections cover the experimental process followed in the study as well the modelling carried out for Artificial Neural Network.

Table 1 DSS composition

C (%)	Cr (%)	Ni (%)	Mo (%)	N (%)	Mn (%)
0.02	22.30	4.55	3.18	0.15	1.18

Table 2 Independent turning variables

Code	Turning variables	Levels and values		
		– 1	0	1
A	Speed of cutting (m/min)	80	100	120
B	Rate of feeding (mm/rev)	0.1	0.2	0.3
C	Depth of cutting (mm)	0.5	1	1.5
D	Radius of tool nose (mm)	0.8	1.2	1.6

2.1 Experimental Process

The experiments were conducted on Standard Duplex Stainless Steel S32205 (UNS). Microstructural phase analysis of Duplex Stainless Steels indicate that they contain approximately fifty per cent austenite and fifty per cent ferrite [13]. The physical properties of these steels are mixture of the properties of these two grades. However, due to their high yield and tensile strength, rapid work hardening rate, likeliness for the formation of built-up edge, low thermal conductivity and high fracture toughness, they are categorized as difficult to cut materials [13]. Spectro chemical testing of the material was carried out for detection of the constituents. The results of this test are given in Table 1. Hot-rolled circular rods, with 34 mm diameter and 150 mm length, were machined on MTAB Max Turn Plus + CNC turning centre. This machine used with the FANUC controller has up to 6000 rpm spindle speed and 7.5 KW power ratings.

Kistler 9257 three component piezo-electric dynamometer was used for tangential or main cutting force measurement. Chemical vapour deposited triple layer coated, i.e. titanium carbonitride, aluminium oxide and titanium nitride and cemented carbide cutting tool inserts of Sandvik make with designation SNMG 120408 MR 2220, SNMG 120412 MR 2220 and SNMG 120416 MR 2220 were used for the turning operation. The tool holder was of Echain brand with designation ESDNN 2525 M12. Selected turning variables with their values are as given in Table 2.

2.2 Artificial Neural Network (ANN) Modelling

An ANN is a data processing and modelling tool, which was evolved during the search process for mathematical modelling of human learning process. The studies on this technique started in nineteen forties with the modelling of neurons. This was later applied in various fields. ANNs can correlate input data having single or multiple features with the output data having single or multiple features. The most important advantage is that they are capable of learning and using different learning algorithms. In the present study, ANN models for prediction of main cutting force during the turning of DSS were built using various architectures and three training algorithms namely, Levenberg–Marquardt (LM), Bayesian regularization (BR) and scaled conjugate gradient (SCG). Forty-eight experimental trials were conducted according to the parameter settings given in Table 3. The measured values of the main cutting force for these trials are also given Table 4.

Table 3 Experimental settings for independent variables, used as input matrix during training stage of the ANN

Sr. No	A (m/min)	B (mm/rev)	C (mm)	D (mm)	Sr. No	A (m/min)	B (mm/rev)	C (mm)	D (mm)
1	100	0.3	1.5	1.6	25	100	0.3	1	1.6
2	80	0.2	0.5	1.6	26	80	0.1	1	1.2
3	120	0.3	1	1.6	27	120	0.1	1	1.2
4	120	0.1	0.5	1.6	28	80	0.3	1	1.2
5	80	0.1	1.5	1.6	29	120	0.3	1	1.2
6	100	0.1	0.5	0.8	30	100	0.1	0.5	1.2
7	120	0.2	1.5	0.8	31	100	0.3	0.5	1.2
8	80	0.1	1	0.8	32	100	0.1	1.5	1.2
9	80	0.3	1.5	0.8	33	100	0.3	1.5	1.2
10	120	0.3	0.5	0.8	34	80	0.2	0.5	1.2
11	120	0.1	1.5	1.2	35	120	0.2	0.5	1.2
12	80	0.3	0.5	1.2	36	80	0.2	1.5	1.2
13	100	0.2	1	1.2	37	120	0.2	1.5	1.2
14	100	0.2	0.5	0.8	38	100	0.2	1	1.2
15	100	0.2	1.5	0.8	39	100	0.2	1	1.2
16	80	0.2	1	0.8	40	100	0.2	1	1.2
17	120	0.2	1	0.8	41	120	0.3	0.5	1.6
18	100	0.1	1	0.8	42	120	0.3	1.5	1.6
19	100	0.3	1	0.8	43	120	0.1	1.5	1.6
20	100	0.2	0.5	1.6	44	100	0.1	0.5	1.6
21	100	0.2	1.5	1.6	45	100	0.1	1.5	1.6
22	80	0.2	1	1.6	46	100	0.1	1.5	0.8
23	120	0.2	1	1.6	47	120	0.1	0.5	0.8
24	100	0.1	1	1.6	48	100	0.1	1	1.2

Table 4 Measured values of main cutting force, used as output matrix during the training stage of ANN

Sr. No	Fx (N)	Sr. No	Fx (N)	Sr. No	Fx (N)	Sr. No	Fx (N)	Sr. No	Fx (N)	Sr. No	Fx (N)
1	830.1	9	1234	17	371.4	25	568.6	33	1046	41	326.1
2	176.4	10	501.5	18	221.6	26	348.6	34	336.7	42	704.1
3	496.7	11	488.7	19	506.5	27	339.6	35	321.6	43	320.1
4	115.1	12	417.9	20	225.2	28	696.1	36	747.3	44	75.58
5	383.1	13	541.6	21	607.8	29	673.8	37	736.4	45	321.4
6	199.6	14	155	22	416.8	30	194.1	38	530.8	46	400.8
7	744.5	15	561.8	23	391	31	391.2	39	537.2	47	149.8
8	349.7	16	371.6	24	280.9	32	458.4	40	531.8	48	330.6

3 Results and Discussion

During the training stage of the ANN model developed for main cutting force, three different learning algorithms, namely LM, BR and SCG, were used to determine the optimum learning algorithm. Also, the optimum network architecture was determined by using various architectures, consisting of three to ten neurons in the single hidden layer. Three performance evaluation metrics, namely R^2, RMSE and MAPE, were used to evaluate these network architectures. The performance of these networks under the previously mentioned metrics is represented in Table 5.

Figure 2 depicts the R square performance of various networks. It was evident from this figure that a network with five neurons in the hidden layer and trained using BR algorithm (NN13) had the highest value of R square.

Figure 3 depicts the RMSE performance of various networks. It is evident from this figure that a network with six neurons in the hidden layer and trained using LM

Table 5 ANN performance under different evaluation metrics

	R^2			RMSE			MAPE		
Hidden neurons	LM	BR	SCG	LM	BR	SCG	LM	BR	SCG
3	0.9812	0.9900	0.9585	66.037	50.112	99.224	1.896	0.920	11.626
4	0.9897	0.9945	0.9263	50.450	37.609	132.426	1.632	0.289	8.274
5	0.9885	0.9955	0.9731	54.127	33.880	81.795	0.789	1.415	3.930
6	0.9955	0.9896	0.9929	33.723	53.215	42.801	1.329	0.926	1.800
7	0.9843	0.9912	0.9862	61.248	48.673	58.877	2.019	2.359	2.321
8	0.9853	0.9949	0.9839	60.219	36.500	63.380	3.891	0.878	3.730
9	0.9702	0.9932	0.9851	83.793	41.150	62.189	1.745	0.065	0.656
10	0.9903	0.9949	0.9714	51.034	35.725	88.023	0.623	1.682	5.664

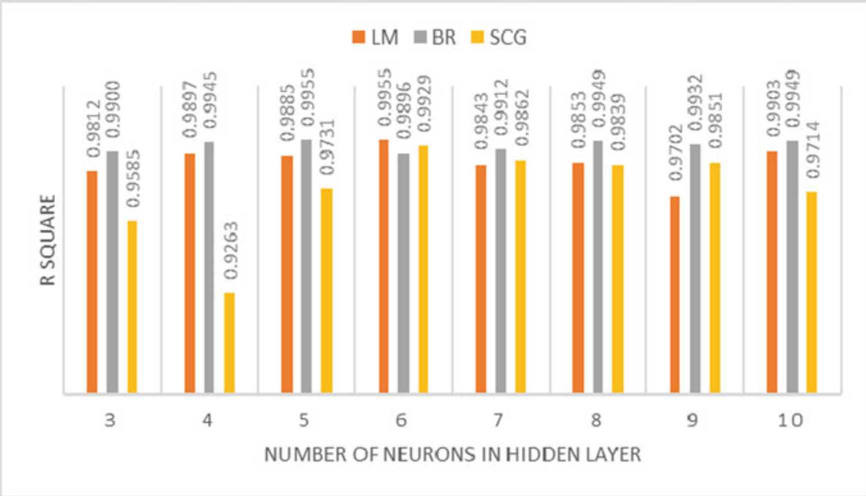

Fig. 2 R square performance of various networks trained with LM, BR and SCG

algorithm (NN6) has the lowest value of RMSE and thus the best performance under this metrics.

Figure 4 depicts the MAPE performance of various networks. It is evident from this figure that a network with nine neurons in the hidden layer and trained using BR algorithm (NN17) has the lowest value of MAPE and thus the best performance under this metrics.

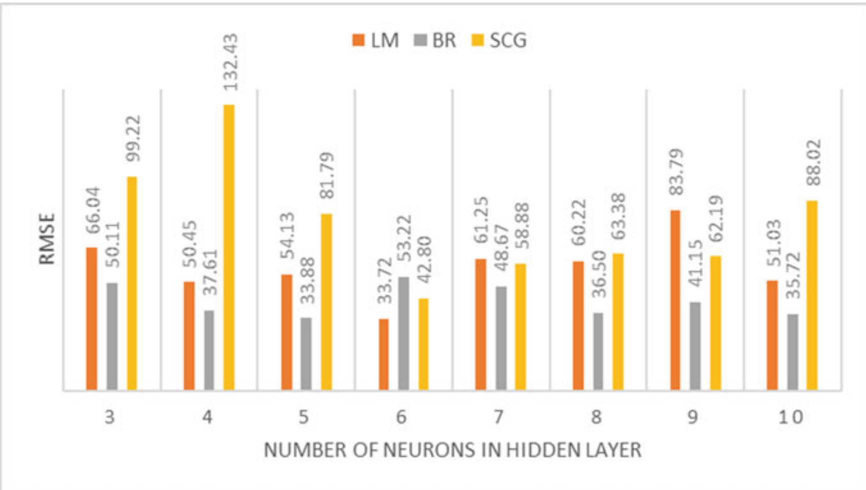

Fig. 3 RMSE performance of various networks trained with LM, BR and SCG

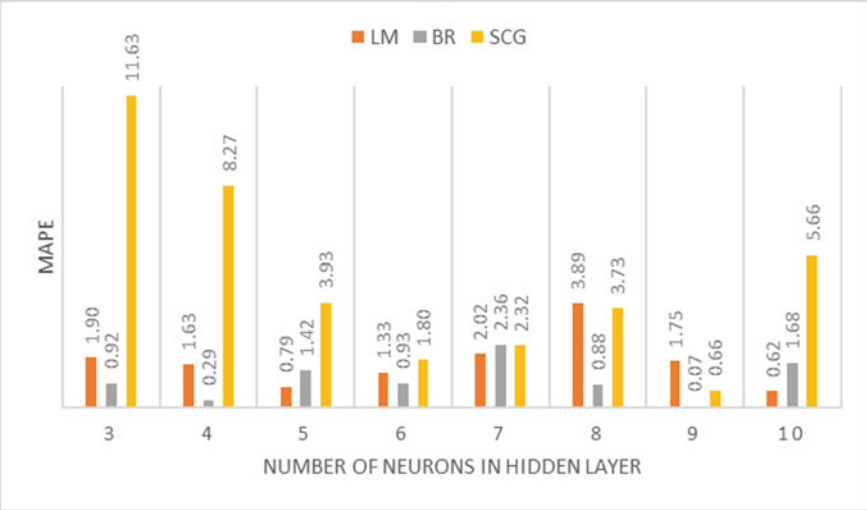

Fig. 4 MAPE performance of various networks trained with LM, BR and SCG

Since three different networks having different architectures and trained using different training algorithms had the best performance under these evaluation metrics, it was necessary to test their prediction accuracy by conducting validation trials. The results of these trials are displayed in Table 6.

It is visible from Table 6, that a network having 9 neurons in the hidden layer and trained using BR algorithm has highest average prediction accuracy of 99.96% and thus the best network for prediction of main cutting force during the turning of DSS.

Table 6 Prediction accuracy calculation for the three best performing networks

Sample	Measured force (N)	NN13		NN6		NN17	
		Predicted force (N)	% Accuracy	Predicted force (N)	% Accuracy	Predicted force (N)	% Accuracy
E1	326.10	318.35	97.62	328.04	99.40	326.10	100.00
E2	704.10	697.41	99.05	677.39	96.21	704.07	100.00
E3	320.10	364.39	86.16	363.98	86.29	320.08	99.99
E4	75.58	67.98	89.95	132.03	25.32	75.70	99.84
E5	321.40	367.90	85.53	364.67	86.54	321.63	99.93
E6	400.80	370.41	92.42	401.90	99.73	400.85	99.99
E7	149.80	163.51	90.85	164.05	90.49	149.72	99.95
E8	330.60	334.19	98.91	342.09	96.52	330.74	99.96
Average % Accuracy		92.56		85.06		99.96	

4 Conclusion

ANN models for prediction of main cutting force during the dry turning of DSS were developed as part of this study. Forty-eight experimental trials were conducted using various settings of the input parameters, and the main cutting force was measured using dynamometer. The ANNs consisted of four neurons in the input layer, three to ten neurons in the hidden layer and one neuron in the output layer. Three training algorithms, namely Levenberg–Marquardt (LM), Bayesian regularization (BR) and scaled conjugate gradient (SCG), were used for the training purpose, and three performance evaluation metrics were used for measuring the performance of these networks. Finally, the prediction accuracy of the best performing networks was calculated in the validation experiment. The network having nine neurons in the hidden layer and trained using BR algorithm displayed the highest average prediction accuracy of 99.96% and thus proved to be the best network.

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Impact of Process Parameters on Machining-Induced Micro-Hardness in Dry End Milling of Inconel 625 Using Coated Tool

Ramesh Rajguru and Hari Vasudevan

Abstract Super alloys, such as nickel-based alloy Inconel 625, are capable of maintaining their excellent mechanical properties, even after extended contact with high temperatures. The class of super alloys was mainly developed for the components of aircraft turbine engines as well as turbo-superchargers and many other industrial uses, such as oil and petroleum refineries, chemical plants, gas turbines and rocket engines. However, they are difficult to cut during the machining process and induce high micro-hardness on machined surface. Machining-induced micro-hardness has been generally recognized as one of the key factors among all surface integrity parameters. Micro-hardness measurements are considered significant in the determination of wear and corrosion resistance as well as to obtain an in depth understanding of machining-affected region. This study was carried out to investigate the machining-induced micro-hardness of Inconel 625, during the end milling under dry environments with ultra-hard coating. ANOVA in combination with mean effect plot was applied for the analyses of micro-hardness. ANOVA results indicated the R^2 value as 98.16%, very close to 1, implying that the model terms are significant. Cutting speed and depth of cut were observed as the prime factors on machining-induced micro-hardness. Minimum micro-hardness (266 HV) was obtained at a higher feed per tooth, lower cutting speed, higher depth of cut and positive radial rake angle.

Keywords Micro-hardness · Inconel 625 · Milling · PVD TiAlSiN coating

1 Introduction

Inconel 625, a heat treatable nickel chromium iron alloy has demonstrated to be one of the most versatile alloys with unique properties, including outstanding resistance

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to creep, corrosion, especially oxidation and carburization, high strength as well as stiffness at elevated temperatures. However, it is difficult to machine the alloy due to superior mechanical properties, leading to declining levels of machinability as well as lower ranges of cutting speed. As milling operation, particularly the end milling process is extensively used in aerospace applications, a finishing operation, with specified dimensional tolerances and surface quality, is very much needed. Higher quality of machined surfaces generated are considered important and essential in manufacturing. The degree and in depth micro-hardness of machined surfaces depend on many factors such as cutting conditions, cutting and tool geometry parameters and properties of material being machined. Therefore, it becomes important to know as to how the changes of cutting conditions influence the machining-induced micro-hardness in the end milling of Inconel 625 as well as undercutting and tool geometry parameters.

Raykar et al. [1] conducted a turning operation on Inconel 718 to analyse the micro-hardness of the machined surface and the degree of work hardening under a high pressure coolant. They pointed out that micro-hardness of machined surface is 1.11 times the bulk micro-hardness. Further, they also found the base material micro-hardness at a depth of approximately 270–300 micron, for all work piece. Kadam and Pawade [2] conducted a high-speed turning operation on Inconel 718 under dry, water vapour and chilled air machining environments for the assessment of surface integrity in term of micro-hardness of the machined surface through degree of work hardening under machined surface. They revealed that the coolant, steam imparted low degree of work hardening in contrast to the turning under chilled air and dry environments. Rajguru and Vasudevan [3] investigated influence of tool geometry on surface integrity aspects such as surface roughness, micro-hardness and residual stress. They pointed out that micro-hardness of the top layer was higher due to high rate of the work hardening during machining of Inconel 625.

Vasudevan et al. [4] conducted a turning operation to optimize machining parameters on Inconel 625 under dry conditions with coated carbide inserts. They concluded that dry machining could be carried out in the precision machining industries with the successful implementation of essential measures. Xavior et al. [5] studied the machinability of Inconel 718 under three different cutting tools, namely PVD TiAlN carbide, cubic boron nitride and ceramic with high-speed machining and pointed out that PVD TiAlN carbide tools cannot be used at speeds above 60 m/min. Halim et al. [6] investigated the effect of high-speed milling of Inconel 718 under dry and cryogenic environments on tool wear and chip morphology. They revealed strong influence of cutting conditions on the chip morphology such as distorted and darker colour under dry condition.

Thakur et al. [7] highlighted a sustainable alternative, using multilayer PVD TiN/TiAlN coating tool, on dry machining of nickel-based super alloy. The results revealed that the machining characteristics of nickel-based super alloy was found superior under the dry machining, using PVD TiN/TiAlN coating tool. Further, the work hardening at machined surface as well as sub-surface under dry conditions was comparable with flood cooling conditions. Makhesana et al. [8] conducted a machining operation on Inconel 718 to investigate the effect of cutting conditions, namely dry, flood and minimum quantity liquid on micro hardness. They concluded that no substantial variation was observed in the micro-hardness, as against the base material with cutting conditions. According to literature of Chaabani et al. [9], dry coolant generates a harder and large work hardening layer, as compared to a conventional coolant during the machining of Inconel 718. A research study by Xu et al. [10], on machinability of Inconel 718, investigated the influence of rake angle on micro-hardness of machined surface and they concluded that the positive rake angle produces less work hardening on machined surface and minimum sub-surface deformation.

In the machining of a heat treatable nickel chromium iron alloy Inconel 625, which has numerous applications in manufacturing industries, the establishment of efficient cutting and tool geometry parameters has been a problem, as a result of high rate of work hardening and huge amount of heat generation. Also, the cutting tool coating is applied in many cases to improve dry machining in the machining process. Advanced tool coating such as TiAlSiN play a key role in the sustainable alternative of cutting fluid, notably during the machining of nickel-based super alloys. It promotes an eco-friendly green machining environment of high speed machining of nickel-based super alloy as well [11]. In this context, this study was conducted to investigate the machined induced micro-hardness of Inconel 625 during the end milling, under dry environments with ultra-hard coating.

2 Experimental Procedure

A heat treatable nickel chromium iron alloy such as Inconel 625 was considered as the work piece in the current investigation. The test samples were of rectangular size of 150 × 50 × 6 mm^3. Four controlling factors were selected such as feed per tooth, cutting speed, depth of cut and radial rake angle with two levels and are presented in Table 1. The experiments were conducted at various cutting conditions as per the L_8 orthogonal array, and the experimental setup is depicted in Fig. 1. The range of standard helix angle was between 30 and 45° for most of the end milling process, due to sharpness and cutting edge strength. To improve the machined surface quality and to reduce the cutting force, machining of difficult to cut material could be achieved by using variable pitch milling end mill cutter. Therefore, solid carbide PVD-TiAlSiN coated cutter with four teeth was used as the cutting tool. Milling of nickel-based super alloy often requires more rigid and robust equipment, as compared to the milling of carbon steels. Hence, machining were performed using MAXMILL PLUS+ CNC machine at the Advanced Machining Centre of Walchand College of Engineering, Sangli, Maharashtra, India. The measurement of micro-hardness was carried out with Vickers digital micro-hardness tester. Experimental conditions with factors and responses are depicted in Table 2.

Table 1 Factors and their levels

Factors designation	Factors	Units	Levels	
			1	2
V_c	Cutting speed	m/min	50	90
f_z	Feed per tooth	mm/tooth	0.05	0.17
a_e	Radial depth of cut	mm	0.2	1.0
γ	Radial rake angle	°	5	13

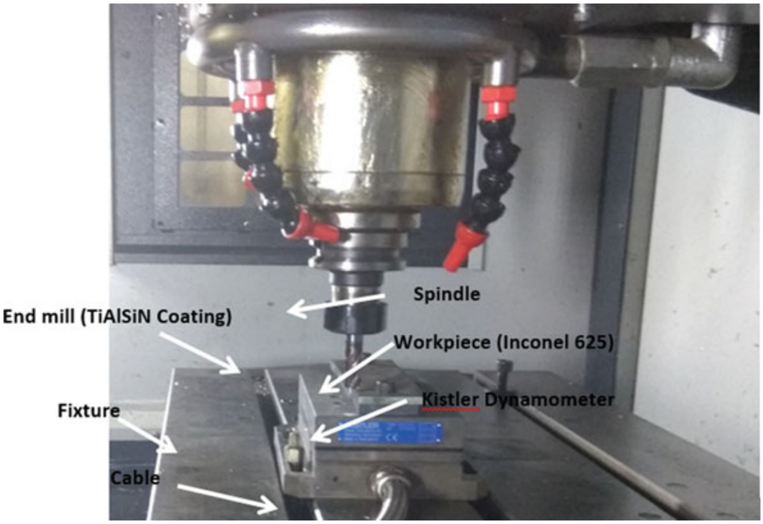

Fig. 1 Experimental setup

Table 2 Experimental plan with factors and response

(V_c)	(f_z)	(a_e)	(γ°)	Micro-hardness (μm)				
m/min	mm/ tooth	mm	°	50	100	150	200	250
50	0.05	0.2	5	304	293	278	274	258
50	0.05	1.0	13	274	260	248	243	240
50	0.17	0.2	13	295	288	285	281	280
50	0.17	1.0	5	266	254	253	245	233
90	0.05	0.2	13	344	343	339	334	331
90	0.05	1.0	5	305	303	300	296	297
90	0.17	0.2	5	321	310	302	300	298
90	0.17	1.0	13	305	275	259	298	228

3 Results and Discussion

The analysis was performed to investigate the influence of the controlled factors on top layer of the machined surface and sub-surfaces micro-hardness up to 250 μm. Mean effect plot and analysis of variance for machine induced micro-hardness results were obtained using Minitab software. Figure 2 depicts the pattern of the micro-hardness plots at different experimental conditions.

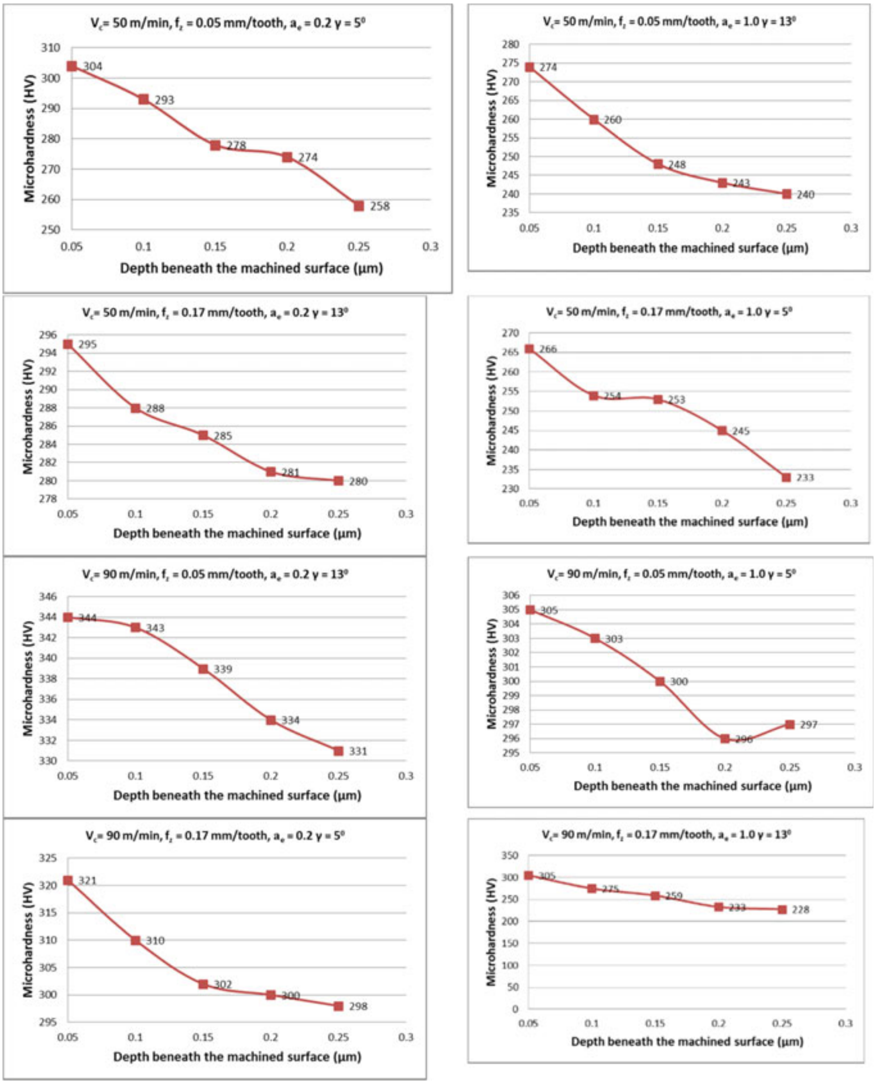

Fig. 2 Variation of micro-hardness at different cutting conditions

Table 3 Analysis of variance results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
V_c	1	2312.0	2312.0	2312.0	88.36	0.003
f_z	1	200.0	200.0	200.0	7.64	0.070
a_e	1	1624.5	1624.5	1624.5	62.08	0.004
γ	1	60.5	60.5	60.5	2.31	0.226
Error	3	78.5	78.5	26.2		
Total	7	4275.5				
R-Sq = 98.16% R-Sq(adj) = 95.72%						

It can be seen from Fig. 2 that the micro-hardness is higher closer to the top layer and it decreases underneath the surface layer up to 250 μm, because of the reduction in the work hardening. Further, the value of micro-hardness, being just below the machined surface is higher and it could be attributed to high amount of heat at cutting zone and severe plastic deformation. A blend of higher level of cutting speed and radial rake angle, along with lower level of feed per tooth and depth of cut results in maximum micro hardness of 344 HV, as a result of high amount of work hardening rate.

Analysis of variance for machine-induced micro-hardness results is presented in Table 3, and it revealed that the micro-hardness is significantly influenced by the cutting speed and radial depth of cut, followed by feed per tooth and radial rake angle. Cutting speed and depth of cut influenced the micro-hardness with a contribution of 54.075 and 37.99%, respectively, as compared to other process parameters. ANOVA table indicates the R^2 value as 98.16%, which is very close to 1. It implied that the model terms are significant. Higher value of 'F' in ANOVA table indicated that the effect of design parameters is large, as compared to the error. Hence, the cutting speed which showed the highest 'F' value has more influence on the process response.

To demonstrate the influence of process variable on micro-hardness, the main effect plot of micro-hardness was plotted and is depicted in Fig. 3. Mean effect plot of micro-hardness revealed that the micro-hardness increased as the cutting speed is increased from 50 to 90 m/min, as a result of high amount of work hardening rate. The effects of other two parameters were seen as moderate.

4 Conclusion

End milling experiments were performed as part of this study to investigate the influence of the controlled factors on machined surface and sub-surfaces of micro-hardness up to 250 μm on Inconel 625, under dry environments with ultra-hard coating. The micro-hardness was analysed using the analysis of variance and the main effect plot. A blend of higher level cutting speed and radial rake angle, along with

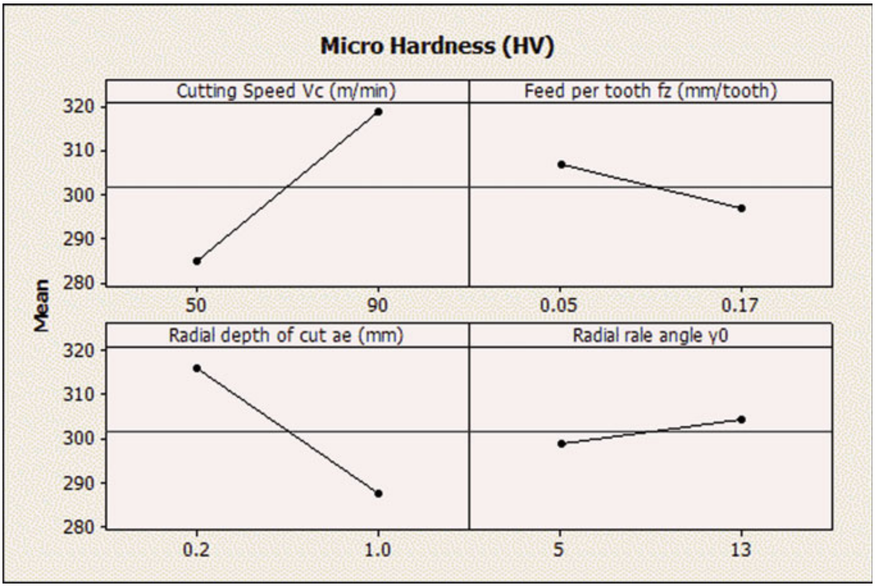

Fig. 3 Mean effect plot for micro-hardness

lower level of feed per tooth and depth of cut resulted in maximum micro-hardness of 344 HV, close to machined surface. Analysis of variance for machine-induced micro-hardness results revealed that the micro-hardness is significantly influenced by the cutting speed and radial depth of cut with a contribution of 54.075 and 37.99%, respectively. The experimental results revealed that the minimum micro-hardness (266 HV) was observed at lower cutting speed (50 m/min), radial rake angle (5°), higher feed per tooth (0.17 mm/tooth) as well as higher radial depth of cut (1.0 mm).

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Design

Design and Development of Vacuum Frying Machine for the Production of High-Quality Fried Products

Amit Choudhari, Pavan Rayar, Sunil Shimpi, Neel Pawar, and Satish Ambetkar

Abstract The advancements in technology today are leading people toward a prosperous future, but the abrupt shift to a busy lifestyle is causing anorexia, and as a result, people are more susceptible to several diseases. Fried meatballs, chicken, chips, beans, and countless more fried foods are famous due to their advertised high nutritional content, mouthwatering flavor, and crunchy texture. However, using such fried products has many health risks that most people are unaware of; instead, consumption is increasing at a high rate per year all over the world. The oil-fried foods are more likely to have high levels of acrylamide, a carcinogen that can cause harmful effects. Vacuum frying is the greatest alternative since it dramatically reduces the amount of this acrylamide substance without significantly altering the nutritional value of the raw product, including food products like potato, carrot, apple, mango chips, etc. It has become essential to keep producing products tailored for the customer's needs in the constantly developing world of technology, where new products are continually being introduced with a wide range of features. The vacuum frying machine's design strategy is not well understood due to a lack of data. Therefore, this paper examines the design and development of a vacuum frying machine from its current model to a new, improved model while taking into account customer needs, safety requirements, serviceability, user-friendliness, and the addition of new functions without lowering the machine's quality or ramping up its cost for small–scale industries.

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1 Introduction

Deep-fat frying is one of the most common and oldest methods of food preparation. As a result of this technique, items with a unique flavor–texture combination are created [1]. For example, Potato chips have an oil level of 35 to 45 g/100 g (wet basis), which gives them a distinct texture-flavor combination that makes them so appealing [2–4]. There are a variety of chips available in the market but if we just concentrate on potatoes then the potato chips retail sales in the United States are estimated to be around $6 billion per year, accounting for roughly one-third of total market sales [2]. The usage of frying oil has expanded dramatically in recent years, as indicated by global annual production exceeding 20 million tons [5]. Consumers, on the other hand, are highly aware of the health implications of the food's oil content. The increased incidence of heart dysfunction, hypertension, cancers, diabetes, and obesity is thought to be due to increased oil intake from fried foods [6, 7]. Due to customer concerns about oil absorption in fried foods, a significant study has been focused on techniques to decrease oil absorption in fried foods in recent years. For fried potatoes with reduced oil content but desired texture and flavor, vacuum frying is a best alternative [5]. High-quality dried fruit and vegetables can be produced with vacuum frying in a lot less time than they would be using traditional air drying. Typically, material processing under reduced pressure ensures a frying process where quality degradation, such as browning and fading of the material, can be avoided [8]. Additionally, processing at low temperatures and pressure prevents frying oil from degrading and oxidizing, ensures that a minimal amount of oil penetrates the material, and results in a product with high shelf-life stability [9]. A few of the oldest ways of food preservation, dehydration is a crucial part of the food processing process. The most used drying technique in the food sector is traditional air drying. In this situation, air characteristics including temperature, relative humidity, and air velocity have a significant impact on both material and air drying kinetics [10]. During air drying, dried products' colors change significantly [11, 12].

By looking at the market size of the vacuum frying technology and continuous development of intelligence manufacturing [13–15] there are very few research papers available related to the design and analysis of the machine aspects. Therefore, this research paper is about the further development of the vertical vacuum frying machine which was designed and prototyped earlier. In the previous paper "Design and analysis of vertical vacuum fryer" more emphasis is given on the comparison of the conventional vacuum frying machine and vertical vacuum frying machine along with the design parameters and analysis [16]. Whereas this study is about the advancement of the vertical vacuum frying machine by adding more features along with the industrial safety requirements. After the continuous use of the machine, some the problems arise, such as the chips were not as crispy as needed, they were more elastic in nature, the opening and closing mechanism of lead were bulky, there was difficulty in the regular cleaning, in addition to that the pump gets heated when there is some leakage from the lead when the lead is not closed properly. By taking the advantage of the feedback from the customer some of the features are developed, also some new elements are added to make the machine more user-friendly along with the safety features. Aside from that, a small-scale vacuum processing plant is not available, which is a significant barrier for entrepreneurs, small businesses, and other organizations. Higher machine costs for vacuum processing are difficult to justify. Therefore, the current paper can help the small-scale industries and motivate them to come forward and start manufacturing of mini vacuum fryers.

2 Material and Methods

2.1 Constructional Feature of Vacuum Fryer

Figure 1 shows the connection between the oil container, vacuum chamber, positioning of valves, and control modules. The reason for providing a separate oil container provide various unique features to the machine such as the de-oiling processes can be carried out itself inside the outer chamber [17], the cleaning of the chamber becomes easy, the oil comes in contact with the raw material only when required vacuum has been achieved inside the vacuum chamber which prevents the chips to become saggy. The detailed information related with the specific components of the machine are given in the following section.

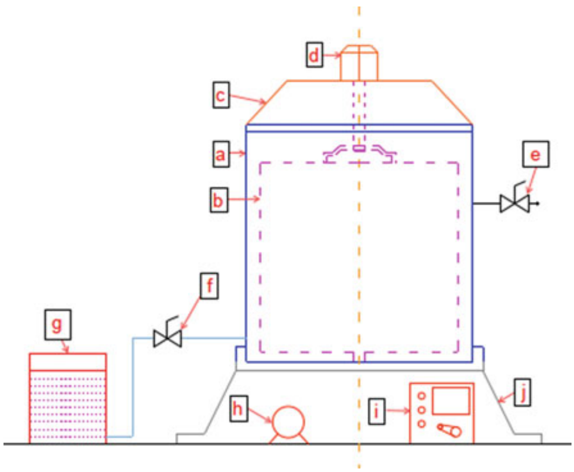

Fig. 1 Schematic diagram of the Vacuum frying machine setup (a) Outer shell (b) Inner shell (Bucket) (c) Lead (d) DC motor (e) Pressurization valve (f) Circulatory valve (g) Oil container (h) Vaccum pump (i) Control panel (j) Supporting table

2.2 Outer and Inner Shell

The outer shell which is also known as outer chamber is designed to withstand a vacuum pressure of up to 10 Torr (~8 Mpa absolute). The material choice is quite significant in terms of cost and design; therefore, stainless steel SS316L, a material which can sustain high temperatures and vacuum pressure, is the ideal choice for the outer shell. The inner shell, commonly known as the bucket, is designed such that it spins continuously during frying, resulting in consistency in the final vacuum fried product. The inner shell (bucket) has a slot in its insulated handle where the motor shaft is momentarily linked.

2.3 Lead with the Modified Design Having a DC Motor

The earlier developed Vertical vacuum frying machine [16] has a very bulky construction of lead mechanism since a DC motor and an epicyclic gear train were put on top of it to rotate the entire inner shell. In the development stage the lead design is very light, it is because of the change in the arrangement of motor shaft connection with the inner shell. Since the motor is here directly concentrically coupled to the inner shell, the epicyclic mechanism is eliminated, which greatly reduces the overall weight of the lead. The bucket is positioned below the lead as illustrated in Fig. 1 and is prime moved by a DC powered motor 200 W. Having total weight of 250 gm.

2.4 Pressurization Valve

As illustrated in Fig. 1, the outer shell is attached with the pressurization wall (annotated as e). This valve's sole function is to pressurize the entire shell and return it from vacuum to atmospheric pressure. It is a manually operated gate valve that ensures air particles flow from the outer atmosphere to the shell's interior after frying, bringing the shell to atmospheric pressure and providing better isolation. The reason for selecting the gate valve is its cost as compared to the ball valve and the vacuum inside the chamber in not too high which makes the choice easy.

2.5 Circulatory Valve

Circulatory valve is positioned as depicted in Fig. 1 between the outer shell and Oil container (annotated as f). It is a directional control valve that is solenoidal operated and operates in accordance with the control signal from the control panel. It aids in the oil flow from the oil container into the shell at the beginning of the frying process and aids in returning the oil from the shell to the oil container once the frying process is complete.

2.6 Oil Container and Vacuum Pump

The oil container (annotated as g) and vacuum pump (annotated as h), as shown in Fig. 1. are used to store oil and create the vacuum inside the shell, respectively. A separate oil container is provided by keeping in mind the standard cleaning requirements and for maintenance. A 0.5 HP vacuum pump is connected to the shell, enough to create a 10 torr of vacuum inside the outer shell.

2.7 Control Panel and Supporting Table

As per the Fig. 1 illustration, there is a control panel (annotated as i and a supporting table (annotated as j). The control panel controls the circulatory valve, which is built to remain closed until the necessary vacuum is established inside the shell. From a safety standpoint, this prevents oil from entering the chamber until all parameters align with the intended state. The shell's total weight is supported by a sturdy base with bolted legs to the ground.

3 Working

The working of the machine is very simple which starts with filling of inner chamber which is also known as bucket. The raw materials, such as potatoes, carrots, ladyfinger, onion, and mango chips, are put into the bucket before the machine is turned on. Once the inner chamber is loaded with material, it is placed inside the outer shell, and the lid is closed. Verifying whether the assembly is correctly sealed before turning on the machine is crucial. A safety function that sounds an alarm if the vacuum within the shell does not begin to form after 10 to 15 s of starting time has been included to ensure that the lead is adequately covered. To overcome this difficulty while designing the current machine the oil container is provided separately with a circulatory valve. The solenoidal operated gate valve (Circulatory valve) in this design allows the oil to move from the oil container to within the shell when the required vacuum is established inside the shell. Since the pressure inside the oil tank is higher than the pressure inside the shell, the oil flows upward without needing additional energy or a pushing device. Several products' frying times can be determined using the control panel, and a custom time can also be set. The inner shell spins during the frying process to ensure product homogeneity. Once the product inside the inner chamber gets vacuum fried the heating coils gets shut off and the pressurization valve opened manually. Since the shell is at a higher elevation than oil container due to the static pressure differential, the oil returned to the oil container after the pressurization valve opened to equalize the pressure to the atmosphere. Same time the circulation valves also open which allows the oil to flow back from vacuum chamber to the oil container, hence one cycle gets completed. The same cycle is repeated again for the other raw products to get high-quality vacuum fried chips.

4 Results and Discussion

4.1 Design and Development

The modified vertical vacuum frying machine is depicted in 3D in Fig. 2. The initial draft of this study report [16] includes a thorough analysis of the vacuum chamber. According to Fig. 3, the outer chamber measures 12 inches in diameter and 12 inches in height, with a 3 mm thick shell made up of SS316L steel. While initial examining this chamber on Ansys, it was found that the highest and lowermost portions (near the base) are where the greatest tensions are developing. Therefore, by including stiffeners in the new design, the likelihood of failure is decreased.

Deep-fat frying is done using vacuum frying technology, which operates at low pressure [~60–200 Torrs or 8–26 kPa abs] [18]. Vacuum frying reduces the boiling point of the food's water, minimizing the loss of product quality features [3]. Because the food is fried at a lower temperature and with less oxygen present than in conventional deep-fat frying methods, the natural color and flavor of the fruits and vegetables can be kept better [19, 20]. The acrylamide content comparison between vacuum-fried and traditionally fried chips is shown in Fig. 4 [1]. The line graph makes it obvious that the amount of acrylamide grows as frying time and temperature increase. According to Fig. 3a and b, it is clearly visible that when frying time and temperature rise, the amount of acrylamide present also rises dramatically, but this decreases when the identical potato chips are cooked in a vacuum. To get high-quality goods

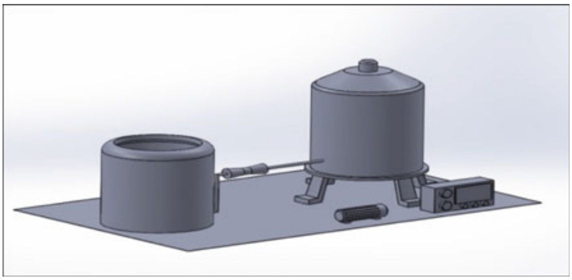

Fig. 2 Schematic of 3D model of vertical vacuum frying machine

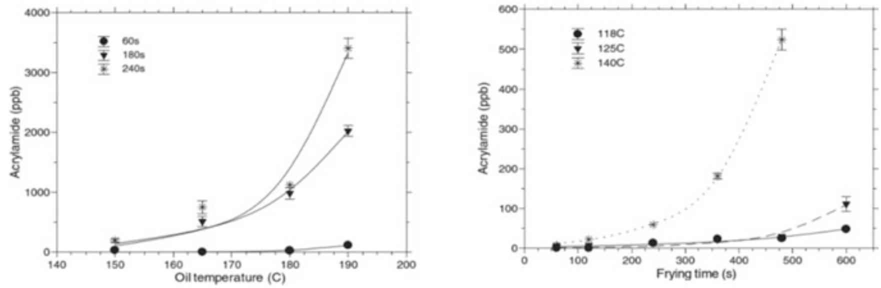

Fig. 3 The effect of oil temperature and frying time on acrylamide content in potato chips **a** traditionally fried chips at different oil temperatures **b** In a vacuum (10 torrs) for different frying time [1]

from the vacuum frying machine, it is crucial to adjust the frying temperature and time. The temperature and time of frying can be easily controlled with the vacuum frying machine's current design, and data may be recorded for future enhancements. The required optimum vacuum condition varies from raw material for example the best condition for frying potato chips is 10 torr, mango chips (8–10 kPa absolute, pineapples (10 kPa absolute), guava chips (9 kPa absolute), [21] jackfruit (100 mbar) [22], etc. Since most of the products are ranging in 10 to 200 torr vacuum condition, therefore the outer chamber is designed for 10 torr vacuums.

4.2 *Stress Analysis*

As shown in Fig. 4, there are two analysis were carried out for optimization, first with 3 mm thickness of the vacuum chamber and second with 4 mm thickness for the same vacuum condition that is 10 torr. Model is created in ANSYS 18.1 version, Shell 63 element type is used and following material properties are used for SS 316L Material (MOE is reduced to account Temperature effect), vacuum condition 10 torr, temperature 200 °C, load on the lead 200 N. Boundary condition plot (all DOF (Rotational and translational)) are anchored and acceleration due to gravity 9.81 m/s^2 is applied. By comparing the von Mises stress plots (Fig. 4b and e), it is seen that for 3 and 4 mm thickness case both are coming in the same range and maximum stress generated is 54.87 Mpa whereas the allowable pressure for the SS316L at 200 °C temperature is 120 Mpa. Also the displacement plots are almost similar to each other and less than 5 mm hence both designs are safe (As per API 650 Annex S guidelines). By comparison of the results it can be concluded that if 3 mm thickness of vacuum chamber is used for the above mentioned vacuum condition instead of 4 mm thickness 25% of the material can be saved as a result the cost of the machine will reduce drastically.

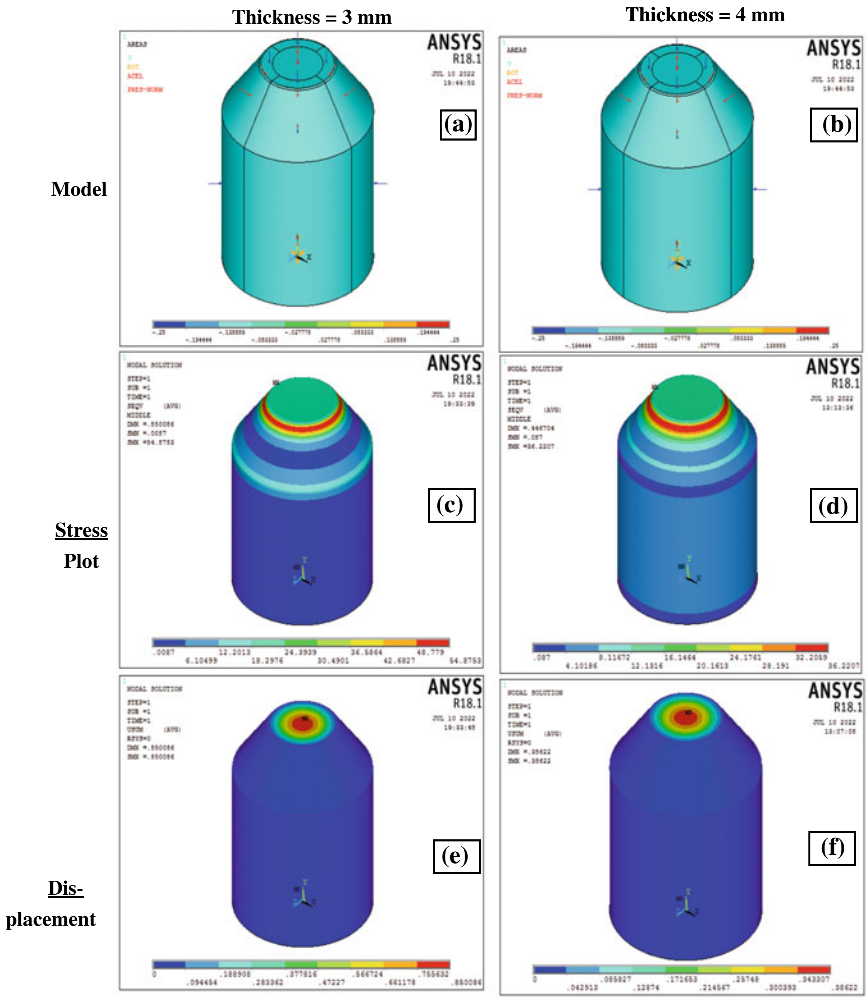

Fig. 4 Analysis of outer shell of vacuum fryer under vacuum of 10 torr with **a** 3 mm thickness, **b** 4 mm thickness of stainless steel 316L material, **c** stress developed in 3 mm shell and **d** in 4 mm shell, **e** shrinkage observed in 3 mm shell, and **f** in 4 mm shell

4.3 Design and Development of Circulatory and Pressurization Valve

The system's design with free flow becomes essential since no external energy is required to obtain the discharge of frying oil from the oil container to the vacuum chamber. The system should be built so that the static pressure within the oil container is always higher than the major and minor frictional losses that occur during flow without interrupting the flow. It can be easily calculated by the Bernoulli's principle,

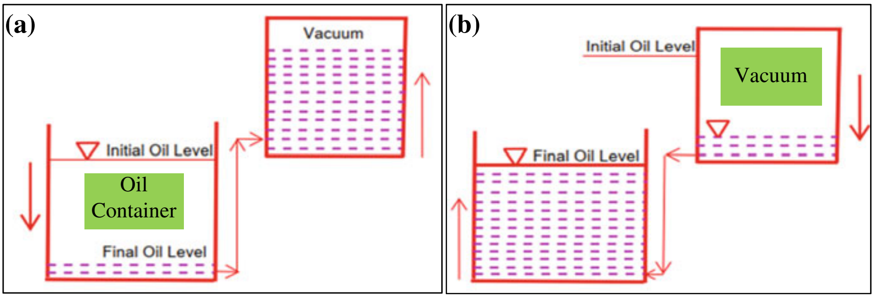

Fig. 5 The supply and return of frying oil: **a** from oil container to the vacuum chamber **b** from vacuum chamber to the oil container because of the pressure difference

let us consider the two points (1) and (2) (As per Fig. 5) which are at outlet of the container and inlet of the vacuum chamber so,

$$\frac{p}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{p2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_L \tag{1}$$

where H_L is total loss of head = Major loss (due to friction) + minor loss (due to circulatory valve) ($H_L = H_f + H_l$), P_1 and P_2 are the pressure, V_1 and V_2 are velocity and Z_1 and Z_2 are the static head at the inlet of oil container and vacuum chamber, respectively.

At any time to flow the frying oil from oil container to the vacuum chamber following condition should match,

$$\left(\frac{P_1 - P_2}{\rho g}\right) + \left(\frac{V_1^2 - V_2^2}{2g}\right) + (Z_{1-}Z_2) \geq H_L \tag{2}$$

Since the oil is viscous, the viscosity of the oil will also come into picture which can be easily considered by taking loss of head under consideration with viscous flow. The loss of head due to viscous flow is given by,

$$h_f = \frac{\pi \Delta P D^4}{128\mu L}$$

The volume flow rate of the frying oil from the oil container toward the vacuum chamber is given by,

$$Q = \int_A \vec{V} \cdot \mathrm{d}A = \int_0^R u.2\pi r \mathrm{d}r = \int_0^R \frac{1}{4\mu}\left(\frac{\partial P}{\partial x}\right)\left(\left(r^2 - R^2\right)\right) \cdot 2\Pi r \mathrm{d}r \tag{3}$$

where u is the velocity of the oil through the pipe. Since the one side of the pipe is connected with the oil container and other is with vacuum chamber this pressure difference is sufficient to overcome easily the losses due to friction therefore the oil will flow easily toward the vacuum chamber during the filling process. Now once we will have the flow rate it's easy to select the size and type of the circulatory valve. Since one side of this valve is going to be in vacuum so most suitable type of the valve for isolation purpose during vacuuming will be gate valve. The factor that is most useful in determining the type of valve to use for a given application is the flow characteristic. This characteristic is the relationship between the flow rate through the valve and the valve stem travel as the latter varies from 0 to 100%. Each valve's internal layout greatly affects the flow characteristics [23].

The inherent flow characteristic, which is identified in laboratory conditions with a consistent pressure drop through the valve, is the feature that is often plotted to get the idea of flow characteristics. The inherent equal percentage property can be explained using the following equation:

$$Q = Q_M R^{\left(\frac{x}{T}-1\right)}$$

where Q = Flow rate (GPM), x = Valve Position (in.), T = Maximum Valve Travel (in.), Q_M = Maximum Flow rate (GPM), R = Valve Rangeability (Range varies from 1 to 18 for gate valve)

$$C_V = \frac{Q}{963}\sqrt{\frac{s_g T}{P_i^2 - p_0^2}}$$

where oil's specific gravity is S_g. The value of C_v will decide the sizing and the selection of the valve. By trial-and-error method substituting the values of discharge, pressure drop, head loss we can calculate the value of C_v. Lesser the C_v value better the design and keep its value between 0.1–0.3. After calculation it is found that the best suitable size of the gate valve suited for this application is varying from 25–30 mm.

There is almost negligible amount of loss in the line of pressurization valve, so the design is not crucial. Any gate valve with the good sealing capability can be selected in the size range of 15 to 25 mm size.

4.4 Design and Development of Lead

Although the lead's design is thought to be the simplest, it is crucial from the operator's perspective. The lead opens and frequently closes while the consumer uses this equipment; hence the preliminary design needs to be improved. The epicyclic gear grain was installed on the previous lead, which tripled the weight overall compared to the current configuration. With the DC motor included the lid weighs only about 1200 g.

4.5 Design of Oil Container

A rectangular shape of the oil container is used instead of cylindrical so as to maximize the volume of the oil in the container and make sure the height of the oil in container should be as low as possible. Low height of oil in container helps in the fast draining of the used oil from the vacuum chamber to the oil container because of the less back static pressure. The size of the container is 250 × 250 × 400 mm and is made up of the SS 316 material.

5 Conclusion

Consumers want products that improve their overall well-being and health; however, even health-conscious consumers are unwilling to give up organoleptic properties. Vacuum frying is extremely important for future fried food manufacturing especially vacuum fried vegetable and fruit's chips. The design results found in the present study confirmed that for a cylindrical chamber having size 12 inch diameter and 12 inch height subjected to vacuum of 10 torr, 3 mm thickness of SS316L material will be best suitable for this application. For oil circulation and pressurization the best suitable valve for vacuum with lowest cost is gate valve and 25–30 mm valve can be selected for the circulation of frying oil and 15–25 mm for pressurization valve to repressurize the chamber to atmospheric pressure. One limitation of the vacuum frying process is that the initial investment for vacuum frying processing is significantly higher than for conventional frying. For future scope, researchers should find an alternative method for the production of vacuum inside the chamber which will significantly reduce the total cost of manufacturing and can be expanded at large scale. Aside from that, there is room for improvement in the fundamental process modeling of vacuum frying, which includes the steps and changes that occur during the process.

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Comparison of Methods for Predicting Muscle Activations and Knee Joint Contact Forces During Squatting Using OpenSim

Rohan Kothurkar, Ramesh Lekurwale, and Mayuri Gad

Abstract Musculoskeletal modeling and simulation software available give a non-invasive prediction of joint contact forces. However, the results are very sensitive to optimization techniques and model choice. In this study, muscle activations and knee joint contact forces (KJCF) were predicted for squatting using two different optimization techniques along with two musculoskeletal models. OpenSim 4.2 was used to simulate squatting using motion capture data and ground reaction forces. Electromyography (EMG) signals were filtered, rectified, normalized, and compared with predicted muscle activations. Good agreement was observed between predicted muscle activations using OpenSim and the EMG with few exceptions using both models. KJCF showed a significantly large difference using both models and optimization techniques. The study demonstrates the sensitivity of results to optimization techniques and model choice. The study also shows the incapability of musculoskeletal models to predict KJCF during squatting.

Keywords Squat · OpenSim · Knee joint contact forces · Musculoskeletal model

1 Introduction

In the human body, an extremely complex and highly loaded joint is the knee joint. Different treatment choices and clinical results require knowledge of knee joint contact forces [1]. In squatting, peak Tibiofemoral (TF) contact forces are significantly higher than in normal walking [2–5]. Two commonly used methods to estimate KJCF are mathematical modeling, and direct experimental measurement in vivo

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using telemetry. In a previous review, we compared different techniques to estimate knee joint contact forces [6] where large variation was observed in peak TF KJCF using mathematical modeling which ranges from 2 to 9 times BW. Whereas peak TF contact forces during squatting measured by instrumented knee implant range from 2.1 to 3 times body weight (BW).

More accurate predictions can now be made using musculoskeletal modeling and simulation software than with two-dimensional mathematical modeling. It is possible to measure knee load using musculoskeletal modeling tools like OpenSim, MSIM, Anybody, BodyMech, LifeModeler, etc. OpenSim [7] is open-source software that offers two optimization strategies for musculoskeletal modeling and simulation, Static Optimization (SO) and computed muscle control (CMC). Results using CMC and SO are different and optimization techniques should be validated with experimental activations [8]. Moreover, very less consistency was observed among different musculoskeletal models [9]. OpenSim models show good accuracy in predicting KJCF for walking [10, 11] but large errors were observed during squatting [12, 13]. Several studies have compared CMC and SO for walking [14, 15] sit to stand [16] some suggest SO is superior while others suggest a choice should be made after validating with experimental data.

This study has two goals regarding knee joint contact forces (KJCF). The first is to compare muscle activation estimations during squatting using two different OpenSim models and two different optimization techniques with measured muscle EMG. The second is to identify the approach to predict KJCF during squatting using two different OpenSim models and two different optimization techniques as well as to compare results with KJCF measured by instrumented knee implant.

Two different models are Rajagopal [17] and Catelli [18]. Both models feature the same muscles, muscle characteristics, and neutral pelvic position, but Catelli updated and implemented new wrapping surfaces to enable it to replicate movements involving deeper bending of the knee and hip.

2 Methods

The study's experimental data were all given by the publically available fifth Grand Challenge Competition to Predict in vivo Knee Loads [1]. The data included kinematics, ground reaction forces, EMG signals, and in vivo knee contact forces for a patient who had a tibial implant measuring force installed (for a male of 75 kg, 180 cm height, implanted knee: left). Data consists of 4 squatting trials from which we considered the second in our analysis. Available.c3d file was converted to OpenSim compatible.mot and.trc file format using MATLAB R2021a. EMG signals were extracted using a biomechanical toolkit, Mokka [19]. OpenSim 4.2 was used for simulating squatting movement using Rajagopal and Catelli musculoskeletal models. The model was then scaled for a subject using skin markers placed on the boney landmark. Inverse kinematics (IK) analysis was then performed to estimate the angles of the joints. The Residual Reduction Algorithm (RRA) is then performed to lower the impact of errors in modeling and marker data processing. SO toolbox which reduces the squared sum of the muscle activations each time used to determine muscle activation and forces. A CMC tool that combines static optimization with proportional derivative control was also used to find muscle activation and forces. Joint Reaction analysis is then performed to predict KJCF in a tibial frame of reference to align the axis with contact forces measured in the instrumented implant (Fig. 1). Guidelines [20] provided in the literature were used for simulations.

Using MatLab scripts, a fourth-order low-pass filter with a cutoff frequency of 6 Hz was employed to filter motion capture data and ground response forces [21]. EMG signals were rectified, band-pass filtered between 10 and 300 Hz, then low pass filtered using a 4th order Butterworth filter at 6 Hz using MatLab scripts [21]. Across all trials, EMG data were normalized to the maximal value of muscle EMG. We also compared the computed muscle activity to the subject's actual EMG data over the % squat cycle. MATLAB R2021a was used to analyze the data. Predicted KJCF by SO and CMC were compared with measure forces using instrumented knee implants. The coefficient of determination (R2) and root mean square (RMS) error were computed between measured and predicted KJCF. Additionally KJCF errors were also calculated using relation (Eq. 1) [12].

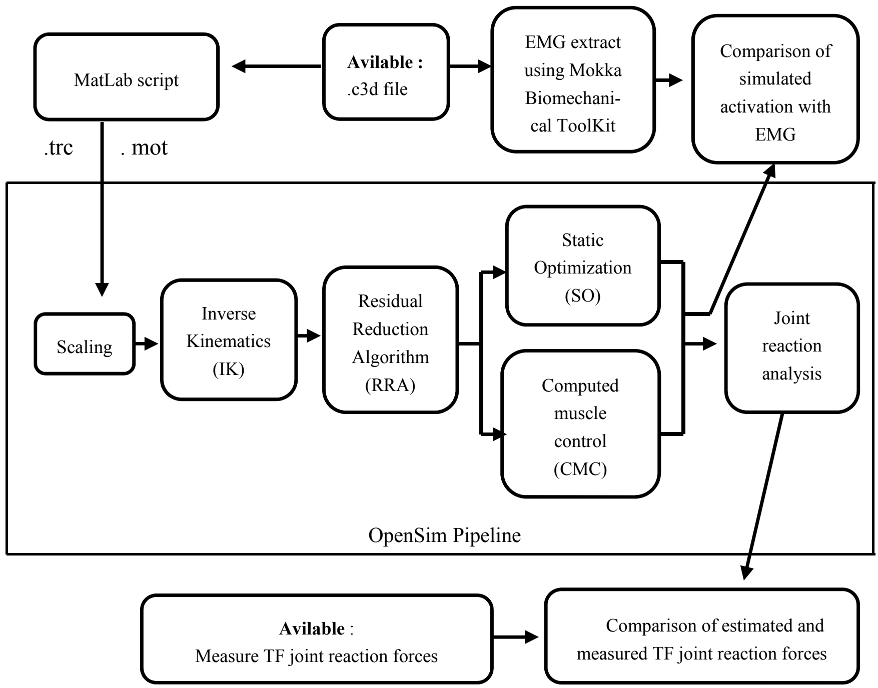

Fig. 1 Workflow of the study

$$\% \text{ KJCF Error } = \frac{\text{KJCF(Predicted)} - \text{KJCF(Measured)}}{\text{KJCF(Measured)}} \times 100 \quad (1)$$

3 Results

Measured EMG signals and predicted muscle activations were compared (Fig. 2). Good agreement between the trends in predicted muscle activations using CMC and the EMG measurements for vastus lateralis, rectus femoris, vastus medialis, tibialis anterior using both Catelli and Rajagopal model was observed. However, there were remarkable differences in predicted muscle activity and EMG of gluteus medius, gluteus maximus, and biceps femoris long head. According to measuring error brought on by influence from other soft tissues, the discrepancy in gluteus muscle activations may exist. Activation in muscle using CMC and SO shows similar trends except for rectus femoris and tibialis anterior where CMC activations show good agreement with measured EMG. The agreement between muscle activations using Catelli and Rajagopal model wasn't noticeably different for considered muscles, with the exceptions of semimem and gluteus maximus.

Hip and knee flexion angles correlated with percent KJCF errors (Fig. 3). Both models overestimate KJCF during most of the cycle except it underpredicts at the initial stage. KJCF error increased with an increase in knee and hip flexion angle.

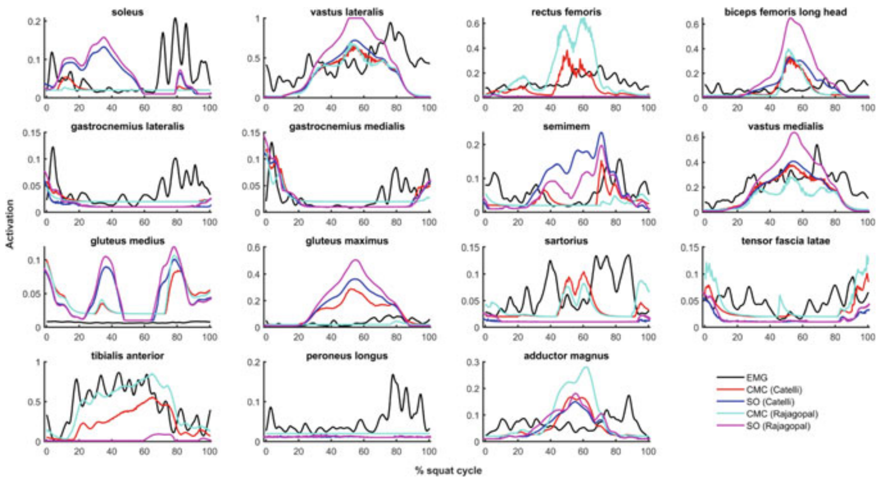

Fig. 2 Comparison between predicted muscle activations vs measured EMG for soleus, vastus lateralis, rectus femoris, biceps femoris long head, gastrocnemius lateralis, gastrocnemius medialis, semimem, vastus medialis, gluteus medius, gluteus maximus, sartorius, tensor fascia latae, tibialis anterior, peroneus longus, adductor magnus

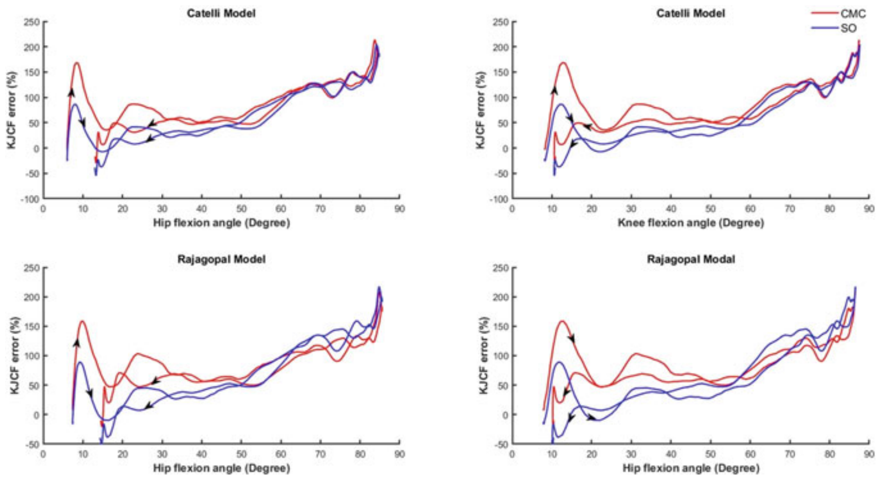

Fig. 3 Plotting the hip and knee angles during a squat against the estimated total KJCF error percentage

Table 1 Comparison of optimization techniques and musculoskeletal models

Optimization technique	RMS error % BW (R^2)	
	Catelli model	Rajagopal mModel
CMC	107.67 (0.81)	102.5 (0.82)
SO	103.5 (0.82)	111.9 (0.83)

Significantly large errors were observed between predicted and measured KJCF for both models (Table 1). A large difference was observed between predicted and measured KJCF along all axis (Fig. 4). Peak total contact force was 7.4 BW using CMC and 7.2 BW using SO for the Catelli model furthermore 7.3 BW using CMC and 7.5 BW using SO for the Rajagopal model compared to measured 2.75 at the deepest squat.

4 Discussion

We aimed to identify an approach to predict KJCF during squatting using two different optimization techniques of OpenSim. Two different musculoskeletal models were used for understanding the effect of wrapping surfaces on KJCF and muscle activations. The findings show that, for both musculoskeletal models, KJCF and muscle activation, except for femoris and tibialis anterior activations, are not significantly different. Similar results were obtained in previous studies [12, 13] where SO is used. The addition of wrapping surfaces in the Catelli model results in higher anterior contact forces (Fig. 3). We have also used the "Gait2392_simbody" model

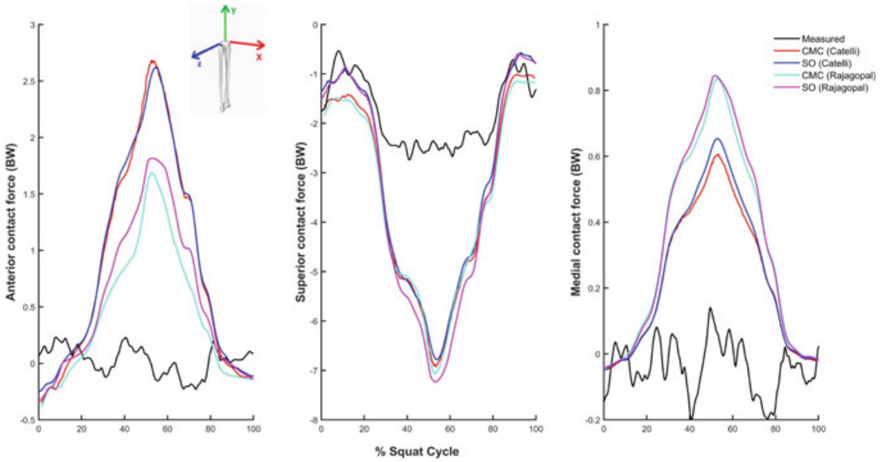

Fig. 4 Predicted and measured knee joint contact forces which are normalized to BW in anterior (X), superior (Y), and medial (Z) direction

for simulating squatting but it was observed that muscles were crossing the femur and pelvis and the anterior contact force was comparatively more than the superior contact force due to the absence of wrapping surfaces. Reasons for high KJCF were discussed [13] in a previous study shows that utilizing OpenSim, the ability of musculoskeletal models to predict KJCF is limited. Moreover, the muscle parameters of Rajagopal and Catelli models are based on healthy young individuals but measured KJCF using an instrumented implant is of elderly subject. Another hypothesis is that people with knee replacements may not benefit from the default cost function for SO, minimization of the squared activation, because their coordination patterns may differ from those of a normal knee. Furthermore, it was reported that KJCF changes with change in the SO approach [10, 22]. Similar results were obtained in the previous study [23]. EMG-driven toolbox [24] available may further improve results and should be evaluated by performing such studies. Previous studies have shown that EMG-driven modeling gives more accurate predictions of contact forces for walking [25].

This study does have some drawbacks. In CMC and SO, default parameters were used. Analysis was performed using only one subject. The scaling and IK were done through a marker-based system, which can lead to significant measurement inaccuracies[26].

5 Conclusion

In this study we observed large errors predicting KJCF for squatting activity using two different OpenSim musculoskeletal models and two different optimization techniques. Errors might be due to different activation patterns, musculotendon parameters, and optimization techniques. No significant difference in the results using SO and CMC was observed but CMC gives a more accurate activation pattern than SO. We suggest choosing an optimization method after comparing predicted muscle activations with EMG signals. Further research is demanded to comprehend the reasons for the very high difference between measured and estimated KJCF using OpenSim. After improvements in models, estimated KJCF and kinematics can be used as input boundary conditions during knee joint implant design.

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Seal Face Design of Dry Running Seal Assembly to Reduce Gas Leakage

Samip Purohit, Adeen Shaikh, and Mehul Prajapati

Abstract Mechanical seal designs have always been a challenge, as there are various working conditions related to the seal. Hydrostatic load, mechanical load, surface roughness, seal film thickness, physical and chemical nature of the working fluid have affected the seal design. The paper examines the development of non-contacting dry gas seal face with rotating groove technology that has a longer life span than mechanical seals. The performance of the seal is predicted by comparing the design from the data used to determine the forces that affect gas seals with the experimental data, and the results are discussed.

Keywords Spiral groove · Gas face seal · Gas film stiffness · Leakage rate

1 Introduction

Fluid hydrodynamic pressure operates on a non-contact and steady seal faces. The secondary seal, stator, rotor, rotor seat and elastic component make up the gas seal. For gas seal face, design calculations different seal parameters are selected. The force analysis is studied, and sealing performance is evaluated based on set conditions. For a dry gas face seal, filtering, dehumidifying, and saving the heat flux are required to ensure the long-term continuous functioning of auxiliary system (pumps and compressors). It is also necessary to consider the design of an auxiliary system.

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2 Process of Seal Design

As a non-contacting seal, the gas face seal should have a long service life as no wear occurs on its face. Weightage in balancing the force in gas seal design can yield more accurate results than the design of mechanical seals. The working principle, design parameters and the design process of the contact mechanical seal differ from the dry gas seal. To make designs successful, the balance ratios or area ratios are considered. Seal ring balance radius is directly linked to force balance in the design [1].

2.1 Design Conditions

As per the requirement from the customer, the design conditions are listed below:

Material	SiC/C
Sealing medium	Air
Mounting diameter	Ø 114.88 mm
Maximum outside diameter	Ø 174 mm
Seal pressure	0.2281 MPa
Ambient pressure	0.1013 MPa
Spin speed	10,380 RPM
Operating temperature	370 ºK
Dynamics viscosity	0.00002161 kg/ms

2.2 Seal Face Size

Figure 1 shows the gas seal face and forces acting on different parts of the assembly.

F_o = opening force; F_c = closing force; F_p = sealing medium force; F_{sp} = spring force; F_{fric} = friction force; d_b = balancing diameter; D_o = shaft diameter; d_i = inner diameter of the rotor; d_o = outer diameter of the rotor [3].

2.2.1 Seal Clearance

The actual nominal clearance is 0.3–2 μm based on surface roughness and waviness of seal faces. It is necessary for the film thickness to be 2–5 μm in order to prevent any contact wear between seal faces. Leakage rates increase with film thickness. The selection of sealing clearances of 3 μm is set [4].

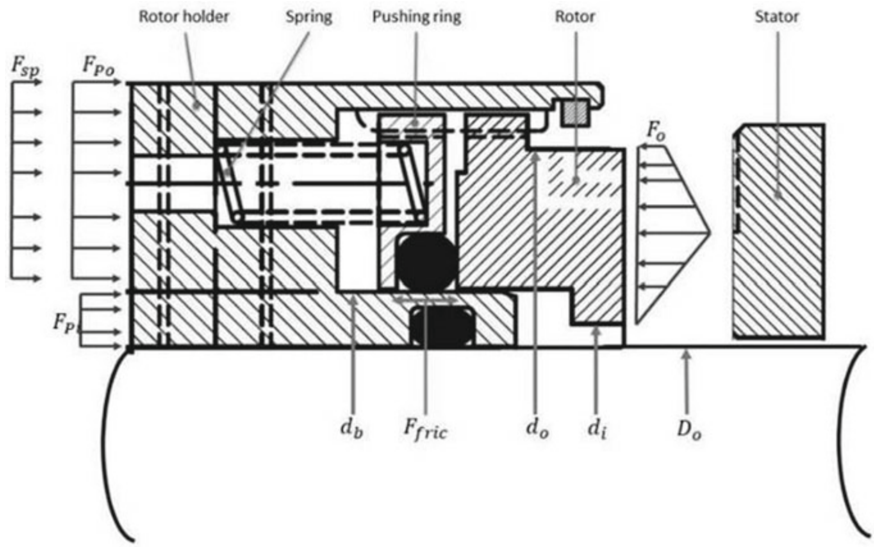

Fig. 1 Gas face seal structure [1, 2]

2.2.2 Seal Face Width

Face width as a macroscopic parameter of a gas seal is difficult to guarantee the flatness and perpendicularity of a large face. Installation errors or central errors can also result in non-parallel faces. A sealing with an excessively large radial dimension would easily deviate from the end face. A narrow seal face will not produce the desired hydrodynamic effect. As the hydrodynamic grooves are processed on the seal face, its face width should be wider than the contact mechanical seal under the same conditions [4].

2.2.3 Seal Face and Shaft Sleeve Clearance

Figure 2 depicts the structural dimensions of the seal friction pair design. Based on the shaft diameter (D_o) and the width, inner diameter and outer diameter of the end face are determined. The shaft sleeve and rotating ring do not move relative to each other, but the clearance between them is $e_1 = 0.5-1$ mm to ensure floatability. The clearance also compensates for the effect of shaft vibrations, deflections on the shaft sleeve and the stator. The stator ring and shaft sleeve move relative to one another. To reduce the error caused by radial vibration, the stator ring and shaft sleeve should have a gap of $e_2 = 1$–2 mm. The stator ring and the sealing chamber do not move relative to each other, and the general gap value is $e_3 = 0.5-1.5$ mm. Smaller gap value should be selected for O-ring to avoid failure on higher seal pressure. The gap value corresponds to an increase in the extrusion failure of the O-ring as the hardness

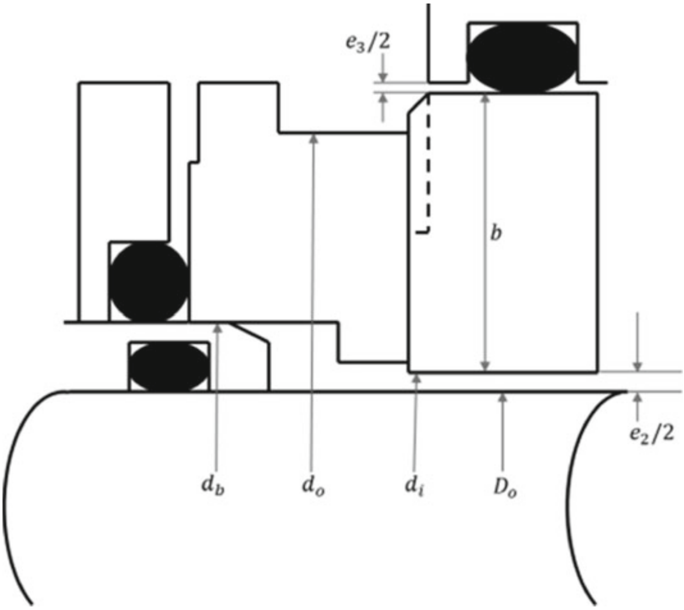

Fig. 2 Main structural dimensions of the seal friction pair [1]

of the chosen O-ring increases. If the selected O-ring has a large diameter, then the gap value corresponding to its extrusion failure will be greater [4].

Sections 2.2.1 and 2.2.2 illustrate selection of face width $b = 19.36$ mm and seal clearance $h_o = 3$ μm. As a result, the inner and outer diameters must match the installed inner diameter of 114.88 mm and 112.8 mm, respectively, in the design condition.

A seal's internal diameter is determined by

$$d_i = D_0 + e_1 + 1\ \text{mm} = 112.88 + 0.96 + 1 = 116.84\,\text{mm},$$

Outer diameter of seal face

$$d_o = 116.84 + (2 \times 19.36)\ \text{mm}\ = 155.56\,\text{mm}$$

2.2.4 Face Groove

The direction of the gas flow is affected by the fluid hydrodynamic groove that is formed on the rotor ring or stator ring during seal operation. When the seal is operating, these grooves may produce fluid hydrodynamic pressure. The spiral groove chosen for the face groove is shown in Fig. 3. Table 1 shows the calculated and analyzed values of the spiral groove geometric parameters based on the given design conditions [4].

a. Opening force

As a result of the distribution of pressures resulting from the radial pressure flow and the circumferential velocity flow of the gas film, the seal face at contact experiences an opening force as follows [5, 6].

$$F_o = \int_0^{2\pi}\int_{0.5d_i}^{0.5d_o} pr\mathrm{d}r\mathrm{d}\theta = \int_0^{2\pi}\int_{0.5\times 58.42}^{0.5\times 77.78} 0.2281r\mathrm{d}r\mathrm{d}\theta \tag{1}$$

$$F_o = 1889.55\ \mathrm{N}$$

b. Closing force

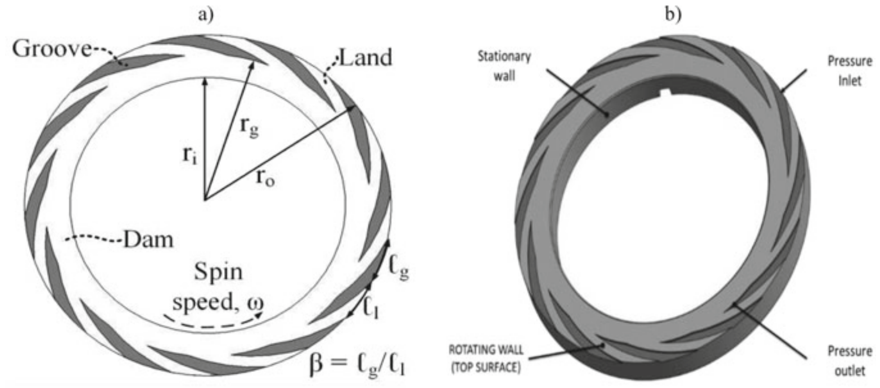

Fig. 3 **a** Schematic dry gas seal stator and **b** stator [6]

Table 1 Dry gas seal geometry

Parameter	
Medium	Air
Inner radius, *R*i (mm)	58.42
Outer radius, *R*o (Mm)	77.78
Groove root radius, *R*g (mm)	69.0
Spiral angle, *A* (Degree)	15
Ratio of groove to land, *B*	1
Groove number, *N*	12
Groove depth, h_g (mm)	5.0
Film thickness, *H* (mm)	3.05

A sealing friction pair's closure force comes from the friction between its faces. The sealing fluid's pressure F_p is exerted on the rotor ring's sealing face from the back (balance diameter of upper surface force and lower surface force). Spring force Fsp acts on the backside of the rotor ring. Friction force Ffric of the O-ring and inertial force of the friction pair during motion make up the closing force acting on the seal faces. O-ring friction and the inertial force produced by the friction pair during motion approach equilibrium in the stable condition and are not taken into account. Closed force is equal to spring force and medium pressure when designing [5, 7].

$$F_c = F_{sp} + F_p = F_{sp} + F_{po} + F_{pi} \tag{2}$$

where the pressure F_p of the sealing medium is separated into two parts (equilibrium diameter: the closing force F_{po}, caused by the action of the sealing medium, and F_{pi}, caused by the action of ambient pressure) [5, 7. Their expressions are

$$F_{p_o} = p_o \frac{\pi\left(d_o^2 - d_b^2\right)}{4} = 1515.97\text{N} \tag{3}$$

$$F_{p_i} = p_i \frac{\pi\left(d_b^2 - d_i^2\right)}{4} = 164.58\text{N} \tag{4}$$

$$F_c = 1889.55\text{N}$$

The spring force's main job is to overcome the secondary seal's friction and inertia and make sure the face of the seal closes when no pressure is applied.

2.2.5 Balance Diameter

The balance diameter is the boundary between the medium pressure and the ambient pressure, which directly influences the closing force [1]. The sealing force and opening force in the design must be balanced to ensure non-contact operation. Choosing a 5.45 mm as O-ring diameter and based on experimental measurements, when the compression ratio is 10%, the friction generated on the unit contact length is 240.72 N/m (according to GB/T 7757.2-2006 (standard for O-Rubber Seal Ring for Mechanical Seal)).

The friction generated by the O-ring can then be estimated as

F_{fric} = Unit length friction × length = 240.72 × π × (0.05842 + 0.07778) = 103 N.

Twice as much frictional force is required for the spring force $F_{sp} = 2\ F_{fric} = 206$ N;

The balance diameter calculated according to equation is

$$d_b = \left[\frac{\pi \left(p_o d_o^2 - p_i d_i^2 \right) + 4(F_{sp} - F_o)}{\pi (p_o - p_i)} \right]^{0.5} = 125.38\,\text{mm} \tag{5}$$

2.3 Design of Rotor Dimension

Seal rings typically use soft or hard matching methods for the friction pair. As axial flotation rings, rotors are used, and relatively soft seal materials are used. In essence, the rotor face width is equal to the sealing face width *b*. Figure 4 shows the seal ring's geometric structure and main dimensions. Rotor dimensions include axial and radial dimensions [8].

2.3.1 Design of the Radial and Axial Dimension

The radial dimension design between the rotor and the shaft is shown in Fig. 4, so the main radial dimension design of the rotor can be carried out in accordance with Table 2 [9].

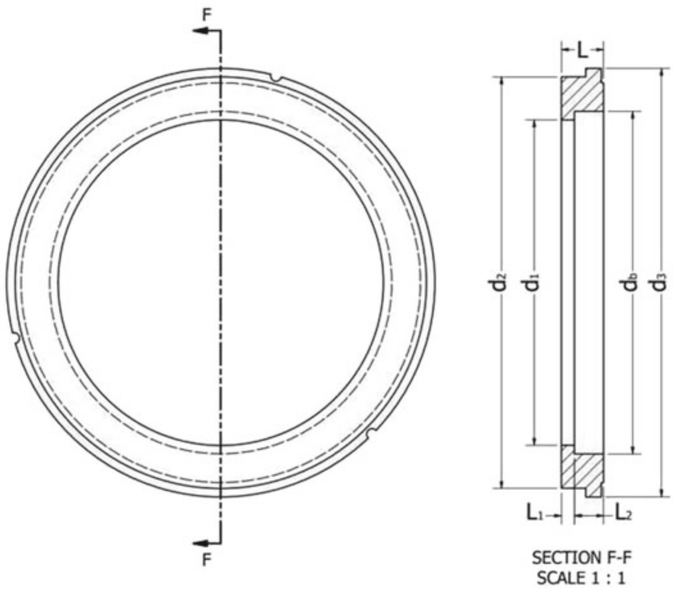

Fig. 4 Schematic diagram of rotor structure

Table 2 Dimensions of the rotor's geometrical structure

No	Design Size	Calculation expression	Data
1	Axial size l_1	–	4.76 mm
2	Axial size l_2	–	10.66 mm
3	Axial size l	$l = l_1 + l_2$	15.42 mm
4	Rotor's internal diameter when mounted at the shaft shoulder (d_o)	$d_o = d_b$	Ø 125.38 mm
5	Size of the rotor's inner diameter at its shaft or sleeve d_1	$d_1 > D_o + e_1 + 2\,\text{mm}$	Ø 119.14 mm
6	Rotor face outer diameter (d_2)	$d_2 = d_b + 2b$	Ø 150.64 mm
7	Rotor diameter d_3	$d_3 = d_2 + 2t$	Ø 156.88 mm
8	Rotor O-ring	Dia of O-ring = balancing dia	Choose a 125.38 mm O-ring internal diameter

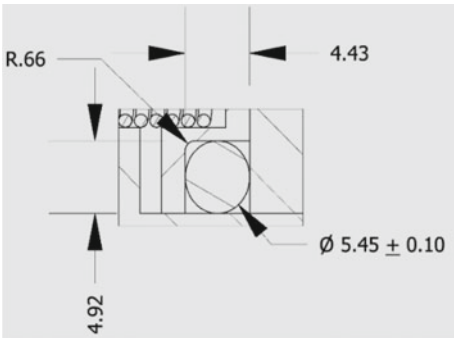

Fig. 5 Mounting dimensions of rotor O-ring

2.3.2 Rotor O-ring

According to GB/T 7757.2-2006 (O-Rubber Seal Ring for Mechanical Seal), the O-ring and its installation structure are selected, as shown in Fig. 5. Diameter of O-ring section $d^{'} = 5.45 \pm 0.10$ mm. Take groove depth $t = 4.92$ mm and groove width $B = 4.43$ mm, then the compression rate of O-ring = (5.45–4.92)/5.45 = 9.8%.

Further, the rotor structure dimensions as shown in Fig. 4 can be determined, as listed in Table 2 [9].

2.4 Stator Structure

Figures 6 and 7 show the schematic diagram of stator stricter.

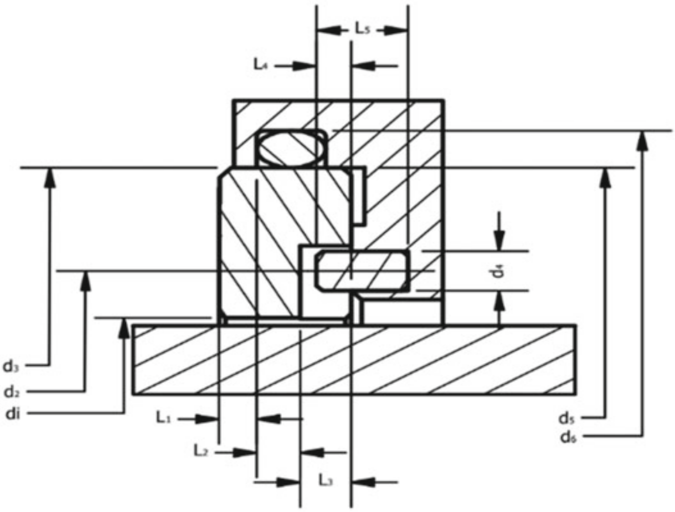

Fig. 6 Schematic diagram of stator structure size [8]

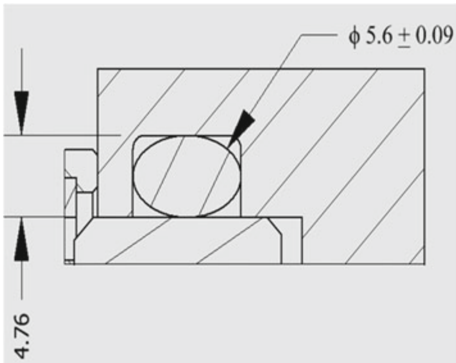

Fig. 7 Mounting dimensions of stator O-ring

For this stator structure, the primary size design guidelines are as follows:

(a) Stator axial dimension—The installation of the O-ring is the primary consideration for the static ring's axial structure dimension. The principle axial dimension design of the stator is given in Table 3.
(b) Radial dimension design—The main radial dimension design of the stator is given in Table 3 [4, 9].
(c) Stator O-ring—Section diameter of O-ring $d_0 = 5.6 \pm 0.10$ mm. The groove depth $t = 4.76$ mm and the groove width B = 7.55 mm, the compression ratio of O-ring = (5.6–4.76)/5.6 = 15%.

Table 3 Stator size design [9]

No	Design dimension	Calculation expression	Value
1	Axial size L_1	–	4.10 mm
2	Axial size L_2	–	4.76 mm
3	Anti-transfer groove depth L_3	–	5.58 mm
4	Total length of stator l_S	$l_S = L_1 + L_2 + L_3$	14.44 mm
5	Pin length L_5	$L_5 = 10 - 12\,\text{mm}$	10 mm
6	Length inserted in stator L_4	$L_4 = 3 - 5\,\text{mm}$	3.78 mm
7	Inner diameter of stator d_i	$d_i = D_o + e_2$	116.84 mm
8	Outer diameter of stator d_3	$d_3 = d_i + 2b$	155.56 mm
9	Location of pin, d_2	$d_2 = d_i + 6 - 8\,\text{mm}$	128.98 mm
10	Radial clearance between stator and gland $e_3/2$	$e_3/2 = 0.2–0.5$ mm	0.25 mm
11	Inner diameter of the joint between the stator and the gland d_6	$d_6 = d_3 + 2t$	165.08 mm
12	O-ring inner diameter at gland d_5	$d_5 = d_3 + 0.2 - 0.5\,\text{mm}$	155.76 mm
13	Diameter of the stator guard pin d_4	$d_4 = 8–10$ mm	10 mm
14	Stator O-ring	–	Select the O-ring inner diameter of ϕ155.76 mm

3 Gas Film Stiffness

A variation in gas film stiffness per unit changes the opening force of the gas film, which is correlated with the stability of the gas seal. General gas face seal design can make use of a constant gas film stiffness without disturbance frequency as the parameter of groove-type selection and optimization [4, 9].

$$K_z = -\frac{\Delta F}{\Delta h} \tag{6}$$

where Δh is the change of the gas film thickness values corresponding to the gas film force change ΔF [9]. When calculating, $\Delta h = (0.001 - 0.01)h_o$,

$$K_z = 4.696 \times 10^{12}\text{N/m}$$

The more stable the seal operates, the greater the stiffness and the smaller the variation of face clearance (signaling the stronger anti-interference ability of the seal).

4 Leakage Rate

Sealing performance is characterized primarily by the leakage rate. Leakage rates are influenced by rotational speed, pressure, temperature, gas viscosity, and the geometry of the seal surface [7, 9]. Volume leakage rate based on isothermal gas lubrication is given by

$$Q = \int_0^{2\pi} P\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial r}\right) r\,\mathrm{d}\theta = 8.55 \times 10^{-5}\mathrm{m}^3/\mathrm{h} \tag{7}$$

Leakage rate of design seal was $8.55 \times 10^{-5}\mathrm{m}^3/\mathrm{h}$.

5 Conclusion

The leakage rate of spiral-shaped bidirectional groove dry gas seal is found to be 8.55×10^{-5} m^3/h at 10,380 rpm and 3.05 μm gap under given operating conditions. By further decreasing the gap, a greater influence of the groove is exerted upon hydrodynamic lift, thereby increasing the load carrying capacity. Moreover, any increase in temperature and speed increases the power loss and leakage through the contact.

The closing force should ideally be determined by the minimum seal gap, thereby reducing leakage and sustaining power losses. However, there is a practical limit in reducing the film thickness, governed by the topography of contacting surfaces. The approach is to reduce the chance of direct boundary interactions, thus reducing friction and wear.

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Analysis of Railway Box Bridge for the Efficient Movement of Trains and Locomotives

Sarika Modak, Pramod Belkhode, Prashant Maheswary, and Kanchan Borkar

Abstract The recent development in the trains and locomotives improve the efficiency of the movement of trains and locomotives. The approach suggested the comparison of the structural analysis of the railway box bridge using the manual method and the Staad Pro. The RCC box type bridge is selected for the analysis which is approached with the design and structural analysis consists of structural elements such as top, bottom, and side wall of slab were designed to withstand the maximum bending moment considering the maximum ultimate load criteria by varying the different loads such as dead load and live load. The analysis results into the time consuming with the quite complex analysis related to complex structure. The result obtain is in good agreement with the computational method.

Keywords Railway · Bridge · Locomotive · Structural · Design

1 Introduction

Development in the construction industry is achieved worldwide particularly bridge construction [1, 2]. Present literature highlights the replacement of the conventional bridge with the help of rapid development in the technology. The major interchangeable includes the popularity of box bridges with the efficient dispersal of congested traffic, economic considerations, and aesthetic desirability has increased the popularity of box type bridges [3–5]. Structural efficiency, serviceability, better stability, and economy in construction result the used of bridge systems. Minimizes weight with maximum stiffness with high capacity makes the construction of bridge is efficient form it performs the advanced analysis for many years to better understanding the behavior of all types of box bridges, the results of these various research works are scattered and unevaluated [6]. Analysis proves that more improvement on the straight and curved box bridges is highly desired which divulged the attention toward aiming a present study. The paper highlights the analysis and design of box type minor railway

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bridges which would be help to the bridge engineers to understand the behavior of box bridge [7–9].

2 Geometry of Box Bridge

- All the dimensions that have been decided for the designing of a bridge are as follows:
- 1. R.C.C. twin box No. of boxes = 2
- Span = 4.5 m
- Clear height = 2.25 m
- Top slab thickness = 0.25 m
- Bottom slab thickness = 0.25 m
- Side wall thickness = 0.25 m
- Unit weight of concrete = 25 kN/m^3
- Unit weight of soil = 20 kN/m^3
- Modulus of subgrade of soil = 250,000 kN/m^2/m
- Coefficient of earth pressure at rest = 0.5
- Total cushion on top = 0.0 m
- Thickness of wearing coat = 0.065 m
- Carriageway = 2 Lane
- Grade of concrete = M25
- Grade of steel = Fe415 (Fig. 1).

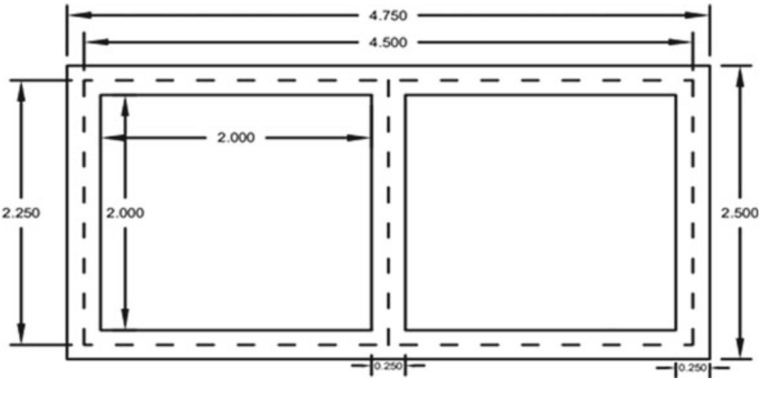

Fig. 1 Cross section of bridge [9]

3 Methodology

Structural analysis incorporates the fields of mechanics and dynamics as well as the many failure theories [10–12]. From a theoretical perspective, the primary goal of structural analysis is the computation of deformations, internal forces, and stresses.

- Kani's method
- Slope Deflection Method.
- Moment Distribution Method.

3.1 Calculation of MDM Method

Given data:

1. Span of bridge = 4.5 m
2. Clear height = 2.25 m
3. Top slab thickness = 0.25 m
4. Bottom slab thickness = 0.25 m
5. Side wall thickness = 0.25 m
6. Unit weight of concrete = 25 kN/m^3
7. Unit weight of soil = 20 kN/m^3
8. Thickness of wearing coat = 0.065 m.

Load calculations.

Total load on top slab = Self wt. of slab + External dead load + External live load.

A. Self wt. of top slab = 0.25 × 25 = 6.25 kN m^2
B. External dead load

   1. Self wt. of slap = 0.25 × 25 × 1 = 6.25 kN/m^2
   2. Self wt. of wearing coat = 0.65 × 22 × 1 = 1.43 kN/m^2
   3. Dead load = b × d × γ = 2.25 × 0.25 × 25 = 14.06 kN/m^2

      Total dead load = 14.06 + 6.25 + 1.43.

      Total dead load = 21.75 kN/m^2.

C. Calculation of live load.

According to IRC, Bridge rule appendix XII (a)

Live load = 42.25 kN/m^2

$$\text{Total load on top slab } (w) = 6.25 + 21.75 + 42.25 = 70.25 \text{ kN/m}^2$$

Coefficient of Earth Pressure

$$\text{Ka} = 1 - \text{Sin}\emptyset = 0.297$$
$$1 + \text{Sin}\emptyset$$

Lateral pressure due to (DL + LL).

=total vertical load × ka.

=64 × 0.297.

=19 kN/m^2.

Lateral pressure due to soil = ka × soil × h.

=0.297 × 20 × 2.25.

=18.365 kN/m^2.

Lateral pressure at top = 19 kN/m^2.

Lateral pressure at bottom = 19 + 13.37 = 32.37 kN/m^2

Distribution Factor (df): Df = K/Ek Realtive Stiffness (k) = I/L.

KAD = I/L = 1/2 = 0.5

KAF = KAF = 1/2 × I/L = 1/2 × 1/2 = 0.25.

3.2 Analysis of Box Bridge Using Staad Pro Software

Effective Width Calculation (Fig. 2):

$b_{\text{eff.}} = \alpha.a.(1 - a/\text{l0}) + b1$ where

α = a constant depending upon the ratio b/l0 let's take 2.6

a = min distance from support.

l0 = effective length of bridge (2.25 m).

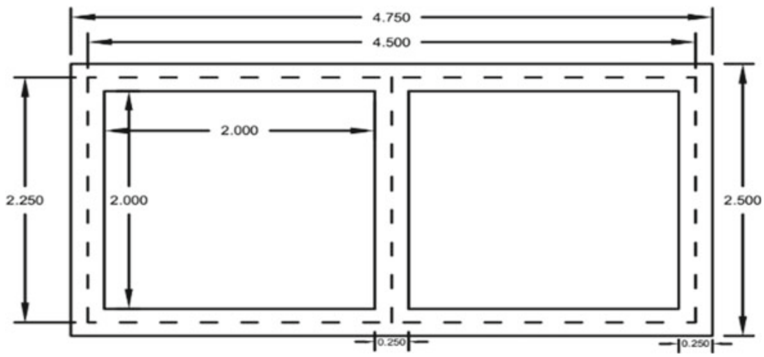

Fig. 2 Geometry of box bridge [9]

$b1$ = breadth of loads over the deck slab after 450 dispersion through wearing coat.
Therefore,
For 40 Ton Boggie.

$b1 = 0.81 + 2 \times 0.065 = 0.94$ m.
For 70R Tracked load.

$b1 = 0.84 + 2 \times 0.065 = 0.97$ m.

4 Load Intensity Calculation

For 70R Track: track load above slab 1 Impact factor = 25% (Table 1).
For 70R Track: track load above slab 2 Impact factor = 25% (Table 2).

5 Results and Discussion

The analysis of the box bridge is calculated using the manual approach and computational approach which is further compared and indicates that StaadPro is much higher than that of manual approach [13–15]. This is due to the fact that Staad Pro keeps much higher factor of safety than prescribed by the code in order to ensure that the structure is safe [16, 17].

6 Conclusion

The critical sections considered are the center of span of top and bottom slabs and the haunch and at the center and haunch of the vertical walls since the maximum design forces develop at these sections due to various combinations of loading patterns. The study shows that the maximum design forces developed for the loading condition when the top slab is subjected to the dead load and live load and sidewall is subjected to earth pressure and surcharges, and when the culvert is empty. It was observed that computational method (Staad Pro) was much more competent than Moment Distribution Method (MDM) in term of efficiency of result and time consumption.

Table 1 Load calculations

	LOADS	a (m)	$b1$ (m)	b_{eff} (m)	$b_{eff}/2$ (m)	Next wheel load	Dispersion width	Load intensity	Unit
Start of UDL	437.5	0.00	0.97	0.970	0.485	2.060	0.970	98.694	kN/m
Mid of span	437.5	1.125	0.97	2.433	1.216	2.060	2.246	42.619	kN/m
End of UDL	437.5	0.00	0.97	0.970	0.485	2.060	0.970	98.694	kN/m
	437.5	0.35	0.97	1.738	0.869	2.060	1.738	55.068	kN/m

Table 2 Load calculations

	LOADS	a (m)	$b1$ (m)	b_{eff} (m)	$b_{eff}/2$ (m)	Next wheel load	Dispersion width	Load intensity	Unit
Start of UDL	437.5	0.350	0.97	1.738	0.869	2.060	1.738	55.068	kN/m
	437.5	1.125	0.97	2.433	1.216	2.060	2.246	42.619	kN/m
	437.5	0.00	0.97	0.970	0.485	2.060	0.970	98.694	kN/m
	437.5	1.125	0.97	2.433	1.216	2.060	2.246	42.619	kN/m
End of UDL	437.5	0.00	0.97	0.970	0.485	2.060	0.970	98.694	kN/m

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CFD Analysis of Air-Swirl Burner

Rishika Patel, Shital Patel, and S. N. Teli

Abstract Computational fluid dynamics has an extended application in the field of fluid flow analysis. This paper encompasses various temperature and pressure profiles which are obtained for understanding the process of combustion in burners. Application of burner is ranged from the domestic to critical aerospace power use. The entire process of combustion has the temperature and pressure as its critical parameters which are obtained in this study. Hence, the simulation is been carried out for air-swirl burner for various fuel–air mixtures, namely stoichiometric, rich, and lean for specific boundary condition to generate their respective temperature and pressure profile. Using these profiles, further instabilities in the combustion process can be identified and worked upon for further analysis.

Keywords Combustion · Air-swirl burner · Equivalence ratio · Non-premixed combustion · CFD

1 Introduction

Computational fluid dynamics (CFD) has become a standard supporting tool exercised for design, optimization, and troubleshooting of various engineering applications specially to simulate combustion and other complex processes [1]. It is a commanding tool whose application is extended to conduct detailed analysis of the combustion process in various burners. The most important phenomenon in a burner is combustion. There are many types of burners out of which the extensively used the natural gas burner. Studies have been revolving around which fuel and oxidizer to use for more power output and less emissions. The process is focused to be most efficient, and such that the emissions are as less as possible. Many researchers are

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occupied in developing reliable technologies for a hydrogen-based energy infrastructure, since hydrogen represents a carbon-free energy vector for energy-storing and combustion, as stated by the International Energy Agency (IEA) [2]. Methane-air combustion is considerably simpler than that of higher hydrocarbons; a detailed mechanism still involves many elementary reactions and species [3]. Experiments followed by simulations were conducted to observe the efficiencies, emissions, and flame stabilities of burners [4]. Some studies were conducted to optimize the burner by studying the results of variations of ratio of air to fuel mixture, mass flow rate of the mixture, velocity, mass fractions of oxygen, propane, and butane [5]. Some researchers emphasized more on designing the burner such that the combustion that takes place is very efficient, and emissions are very minimal [6]. In this study, the burner chosen is the air-swirl burner. The paper presents the combustion process in the burner as well as compares the results when the fuel-air mixture is stoichiometric, rich, and lean.

2 Methodology

To study the process of combustion, the model chosen is the air-swirler burner. The model has been made in the software SOLIDWORKS. The simulation software used is ANSYS Fluent. The three basic steps in CFD are as follows [1]:

1. Meshing
2. Solving the equations
3. Post-processing

2.1 Geometry

Table 1 presents the dimensions of the burner modeled. Figure 1 demonstrates the model which will be imported to ANSYS for further simulations. The model is cylindrical in shape with a helical air-swirler. The swirler plays an important role as it helps in the mixing of air and fuel well for the combustion to take place efficiently. There is well defined fuel and air inlet for the fuel and oxidizer to flow through [2, 3]. The combustion chamber after the swirler is where the mixture ignites.

Table 1 Dimensions of the burner

	Value
Outer diameter (mm)	100
Inner diameter (mm)	30
Length of the combustion chamber (mm)	450
Swirl angle of the swirler (°)	45

Fig. 1 Geometry

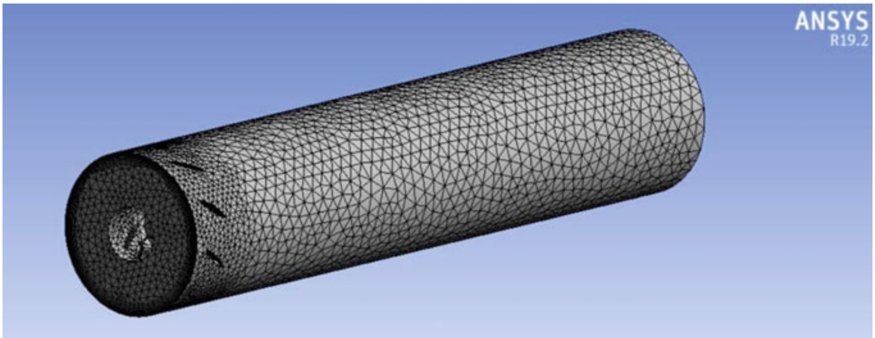

Fig. 2 Mesh of the burner

2.2 Meshing

The meshing is done in ANSYS software. For meshing, automatic method was used with sizing of 0.5 mm in the mixing area for more accurate results and inflation on the outer wall. The meshing has 115,135 elements. The meshing at the junction id made more finer to obtain better and accurate results. Figure 2 explains the meshed geometry in ANSYS.

2.3 Models Used for the Simulation

The type of solver used is pressure based and steady. The viscous model used is K-Epsilon standard with standard wall function [3].

Table 2 No. of cases to be run

	Equivalence ratio
Simulation 1	Phi = 1 (stoichiometric condition)
Simulation 2	Phi < 1 (fuel lean condition)
Simulation 3	Phi > 1 (fuel rich condition)

The species transport model with non-premixed combustion model is chosen. In non-premixed combustion, the fuel and oxidizer separately travel and mix in the combustion chamber and later ignite there. The fuel used in this burner is methane, and the oxidizer is air. The simulation is carried on with different ratios of the fuel and oxidizer; namely stoichiometric, rich, and lean mixtures. The chemistry state relation is chemical equilibrium. Table 2 delineates the cases taken into consideration in this study.

2.4 Boundary Conditions

Suitable boundary conditions of mass flow rate are input at the fuel and air inlet. The turbulent ratio and intensity used are 10 and 5 %, respectively. Table 3 displays the boundary conditions at the air and the fuel inlet of the burner.

Table 4 shows the fuel and air composition considered for the combustion in the burner.

Table 5 encompasses the different mass flow rate for the considered fuel of all the three cases. For air, the mass flow rate is kept constant for all the three cases.

Table 3 Boundary conditions

	Mass flow rate (kg/s)	Temperature (K)	Gage pressure (atm)
Air inlet	0.05	400	0
Fuel inlet	0.003	300	2

Table 4 Fuel and oxidizer composition

Heading level	Fuel	Oxidizer
CH_4	1	–
O_2	–	0.23
N_2	–	0.77

Table 5 Conditions for different cases

	Fuel mass flow rate (kg/s)	Equivalence ratio	Nature
Simulation 1	0.003	1	Stoichiometric
Simulation 2	0.002	0.69	Lean
Simulation 3	0.005	1.72	Rich

2.5 Results

Figure 3 demonstrates profile for the temperature obtained of all the three conditions. Part (A) shows the temperature variation for stoichiometric condition. The maximum and minimum temperature are 2760 K and 300 K, respectively. We can see that the combustion chamber temperature is near to 2000 K. Part (B) shows the temperature variation for the lean condition. The maximum and minimum temperature are 2560 K and 300 K, respectively. In the lower part of the combustion chamber, maximum temperature is observed, while the rest is approximately at 1770 K. Part (C) displays the temperature profile for the rich condition. The maximum and minimum temperature observed are 2820 K and 300 K, respectively. Most part of the combustion chamber is found to be with maximum temperature. We can, hence, compare the temperature variations for all three cases.

The results of the simulations are as follows:

Figure 4 demonstrates the pressure profiles at the outlet. The profile is almost uniform in all the three cases. The part (A), (B), and (C) represent the stoichiometric, lean, and rich mixture condition. The pressure has reduced in the stoichiometric and lean condition, whereas it has increased in case of the rich condition.

3 Conclusion

This paper encompasses comparison of the simulations for three mixtures, viz., stoichiometric, rich, and lean. The model used non-premixed and the swirler helped the fuel and oxidizer to mix properly to make the combustion more efficient. We can conclude that the maximum temperature was 2820 K obtained in the rich condition, and minimum was 1770 K found out to be in the lean condition. Furthermore, we can see the spread of the temperature in the combustion chamber and the junction where the fuel mixes the air. The pressure profiles helped us conclude the pressure drop during the combustion which is also a very important parameter. Further studies could be to implement premixed combustion model and predict the NOx emission rate.

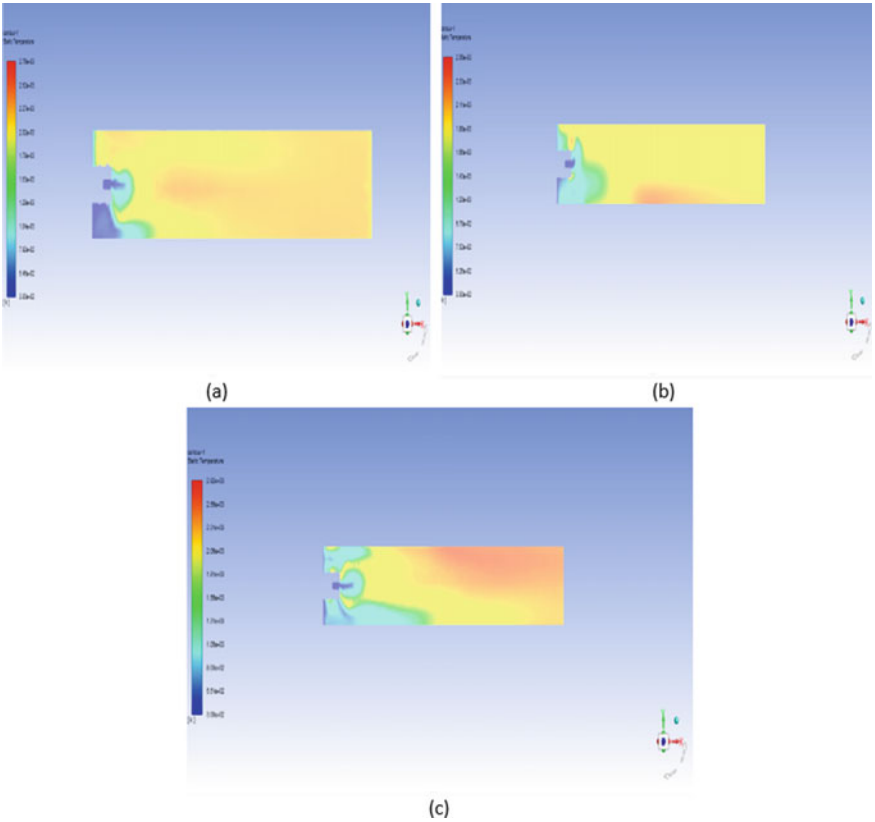

Fig. 3 Temperature profiles of **a** stoichiometric, **b** lean, **c** rich mixture

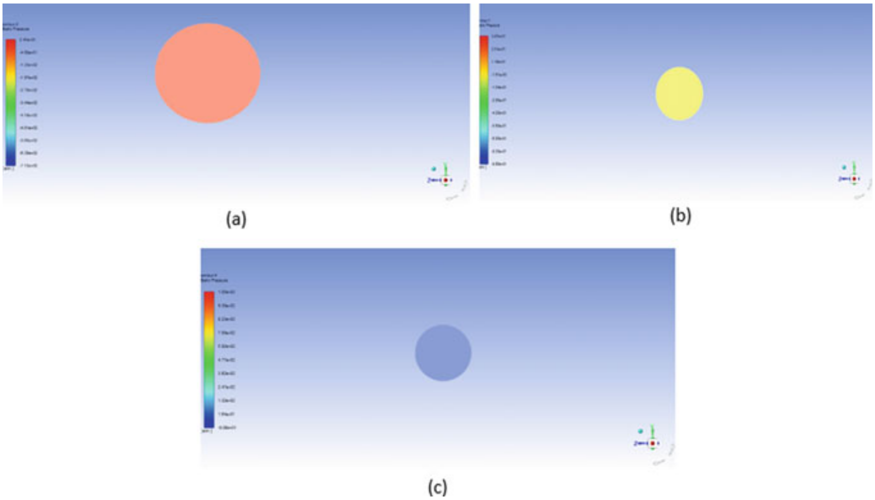

Fig. 4 Pressure profile at the outlet **a** stoichiometric, **b** lean, **c** rich mixture

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Design of an Electronic Continuously Variable Transmission Actuation Mechanism to Optimize Efficiency

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Abstract In today's industry, conventional CVTs are being replaced by E-CVTs due to various advantages, such as high efficiency and ease of tuning. Despite these advantages, actuation in E-CVT has been an area, lacking proper research and development. Thus, the design of a highly performant actuation mechanism was carried out and is presented in this paper. The proposed actuation mechanism involved the use of a power screw coupled stepper motor system. Different methods of force transmission were proposed for both the driving and driven pulley of the E-CVT. Corresponding calculations were done and CAD modeling was performed in Solidworks to conceptualize the design. In addition, FEA was performed on the components in ANYSYS Workbench to verify the viability of the design. As a result, the mechanical losses were seen reduced significantly due to low rotational inertia, low noise and low heat generation. It also resulted in an improved lightweight as well as compact E-CVT, with an increased life cycle over the conventional mechanical CVTs.

Keywords Electronic continuously variable transmission · Mechanical design · FEA · ANYSYS · Actuation mechanism · Power screw · CAD modeling · Custom CVT · Solidworks

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1 Introduction

A continuously variable transmission (CVT) is an automatic transmission that can change seamlessly through a continuous range of gear ratios. A CVT achieves infinite gear ratio flexibility by using two opposing cone-shaped pulleys with a belt that runs between them. Gear ratios change as the pulleys move closer and further apart, causing the belt to move up and down changing the diameter of the belt and altering the gear ratio based on the power needed in real time.

The CVT can be tuned to ensure that it engages at the torque peak of the engine, and it starts shifting out at the power peak of the engine. This results in the engine staying at the power peak, resulting in maximum acceleration. The tuning of a CVT depends on its actuation mechanism. The actuation mechanism of a mechanical CVT has a large number of components and the tuning process is complex. The system under consideration in this study was designed as per an All-Terrain Vehicle (ATV) designed and built by the college ATV team, which competes in the annually held BAJA SAE INDIA competition. This competition tests the overall performance with equal importance given to every aspect of the vehicle in rough terrain conditions. The components on which the performance of the E-CVT depends on are the flyweight mass, the stiffness of the primary and secondary springs and the cam profiles.

As compared to a Mechanical CVT, in the case of an Electronic CVT (E-CVT), the actuation and tuning depend only on the controller logic which can be optimized quickly. Thus, the time required for tuning the CVT reduces by a lot. The number of components also reduces and the assembly becomes lighter. Due to the reduced number of rotating components, the heat loss and the inertial loss decreases resulting in an increased overall efficiency. Using an electronically actuated CVT results in increased cost effectiveness due to no expenditure for manufacturing of components for the tuning of the CVT. Using an E-CVT brings in several such advantages and it was therefore felt pertinent to take up the design of an actuation mechanism for E-CVT. This study therefore is an attempt to design such an assembly to optimize efficiency and tuning time.

2 Literature Review

While assessing the issue, the goal was to review various papers concerning different types of actuation mechanisms proposed by authors. Research studies pertaining to both mechanical and electronic CVT were analyzed in detail. Pertaining to the shift from mechanical to electronic actuation, the initial preference was to look for a solution in electro-pneumatic or electro-hydraulic actuation systems in the erstwhile clutch systems and these were found to have been discussed by few researchers [1, 2]. In [1], highlighted many salient points regarding hydraulic actuation systems but due to the inefficient nature of a conventional hydraulic system in a dynamic setup like a CVT, other options were looked for in this study. On reviewing [2], it was decided to use an electro-mechanical actuation system. Once the type of actuation system was decided, the work for conceptualizing the system begun.

Various electro-mechanical actuation systems were explored by different authors [3–5], which aided the current study in conceptualizing the proposed design. Cholis et al. [6] discussed an actuation mechanism for the primary pulley in great depth in [6], which also helped the adopted approach with the development of proposed mechanism in the current study. The lack of research literature in the area of actuation of the driven pulley compelled this study to design the proposed mechanism. Designing various components with a top to bottom approach was done, wherein the assembly was conceptualized and broken down into smaller components, which were then designed by referring to the standards mentioned in [7].

3 Methodology

The actuation mechanism consisted of the following components:

- Trapezoidal power screw for conversion of rotation motion of stepper motor into linear motion for the sheave movement
- The power screw connected to the fork assembly which would transmit the linear motion to the sheaves
- Fork assembly consisted of the rollers, which would be in contact with the sheave.

The force required for the actuation of primary sheave was much greater than that of the secondary sheave, and the selection of motors was based on it resulting in extremely bulky motors. Hence, a fork lever arrangement was selected in the primary for the transmission of force with a mechanical advantage.

3.1 Construction and Working

The motor mount was fitted on the engine block for the primary accounting for the various clearances. An adapter connected the motor shaft and power screw for efficient torque transmission. Nut translated on the power screw was limited by a jam nut. The fork assembly was supported by the pivot and bearing housing on the CVT input shaft. The roller and roller bearing were press fitted on the fork. A detachable slotted link connected the fork and sliding nut. For high force, mechanical advantage using pivot mechanism was used. A processing unit signaled the stepper motor to rotate by a certain angle. This in turn rotated the power screw and the nut translated, applying a force at the end of the fork lever. A moment was transmitted by the fork to the roller and the roller was in point contact with the movable sheave and could rotate freely. Small contact area and free rotation also eliminated any heating issues.

For secondary, the selected stepper motor was mounted on the gearbox of the ATV for rigid support. The output of the stepper motor was connected to the trapezoidal

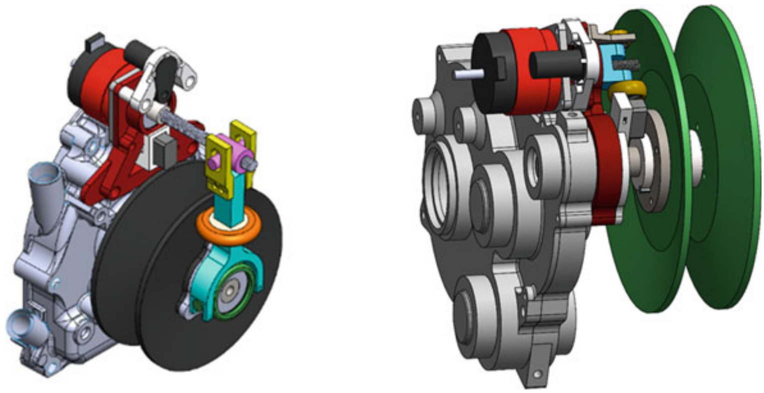

Fig. 1 E-CVT primary sheave assembly (left), secondary sheave assembly (right)

screw and the nut arrangement via, a motor adaptor. The motor mount also housed the bearing to support the motor shaft to avoid sudden reaction load from the secondary sheaves to motor axle, resulting in protection from impact loading. The nut had two rollers mounted on it to avoid relative motion between the stationary nut and rotating sheave surface. These roller mounts and the nut were integrated into a component called 'Integrated Nut'. Integrated nut rotation was prevented using the guide path. The processing unit signaled the stepper motor to rotate by a certain angle. This in turn rotated the power screw and the integrated nut translates, applying a force to the sheaves through the rollers. The final CADs for both, the primary and secondary sheaves, are as shown in Fig. 1.

3.2 *Design of Lead Screw and Nut*

The force required for the axial displacement of the movable sheave of the secondary pulley was considerably high. Hence, an M8 single start lead screw with 2 mm pitch was selected based on industry standards for medium grade applications. The general equations for power screws have been referenced to 6 of [7] and they have been modified for the given use case. The final equations used for the calculation of axial force and length of lead screw are as shown below and the design parameters for the calculations are given in Table 1.

$$\text{Rotational Input Power} = \text{Linear Output Power} \tag{1}$$

$$\therefore \text{MA} * \text{Torque} * \text{RPM} * 2\pi/60 = F_{\text{axial}} * \text{Velocity} \tag{2}$$

Table 1 Design parameters for lead screw and nut calculations

	Primary	Secondary
MA	2.1	1
F_{axial} (N)	5200	3500
Nut length	30	15
Sheave travel	26.54	17.5
Sheave distance	15.7	0
Adaptor length	20	20

$$\text{Since, Velocity} = \text{RPM} * \text{Pitch}/60,000 \quad (3)$$

$$L_{\text{screw}} = (\text{Adaptor Length})/2 + \text{Sheave travel} + \text{Nut length} + \text{Sheave Distance} \quad (4)$$

By substituting known values from Table 1 in Eqs. (1), (2), (3), (4) we get,

$$\begin{aligned} \text{Torque(primary)} &= 1.015\,\text{Nm} \\ L_{\text{screw}}(\text{primary}) &= 82.24\,\text{mm} \\ \text{Torque(secondary)} &= 1.12\,\text{Nm} \\ L_{\text{screw}}(\text{secondary}) &= 42.5\,\text{mm}. \end{aligned}$$

3.3 Design of Motor Mount

Engine block was chosen as the mounting point for the primary and the gearbox was chosen as the mounting point for the secondary. After Finite Element Analysis, the motor mount was further strengthened.

3.4 Design of Fork and Nut Assembly

The fork and nut assembly were designed considering the strength and ease of assembly. Slotted guide was provided on the fork to accommodate for the change in pivot length during the motion. The slotted end of the fork was then split into three parts for the assembly.

Table 2 Material characteristics

Material	Yield strength (MPa)	Density (kg/m^3)	Cost (per kg) in Rs.
EN-24 steel	550	7850	110
EN8 steel	415	7850	105
AISI 9310 steel	690	7850	120
Cast iron	350	7150	80
Al-6061	280	2700	300
Al-7075	540	2700	650
Mild steel	250	7850	80

Table 3 Material selected

Part	Material used	FOS
Motor mounts	EN-24	2–2.5
Fork	EN-24	2
Bearing housings	Mild steel	3
Roller wheels	Brass	2

4 Material Selection for Various Components

Table 2 enlists the different materials that were considered for various components of the actuation mechanism. Motor mounts experienced very high forces. Possible options were aluminum alloy (7000 series) or steel alloys (En series). Here, steel alloys were considered to optimize deflection criteria and cost. Also, since the mount was not a rotating component, losses associated with it were also small and hence selecting an expensive material (Al-alloy) would not be cost effective.

Since the fork was used to transmit force, it experienced the highest level of stress and deformation. Hence, En series of alloy steel was used for fork material.

Stress generated on the bearing housing was not high. Hence, it would be made from mild steel due to its ease of availability and machinability.

The roller wheel was machined using brass since it has properties such as wear resistance and ease of machinability which were favorable for this application. The final materials selected for all the components are mentioned in Table 3.

5 Analysis and Discussion

Static structural analysis was performed as a part of Finite Element Analysis for all the components. After modeling the various components, the CAD models were imported into ANSYS Workbench. Material Properties were assigned and the mesh was created with minimum element size, as 4 mm to balance the accuracy of the

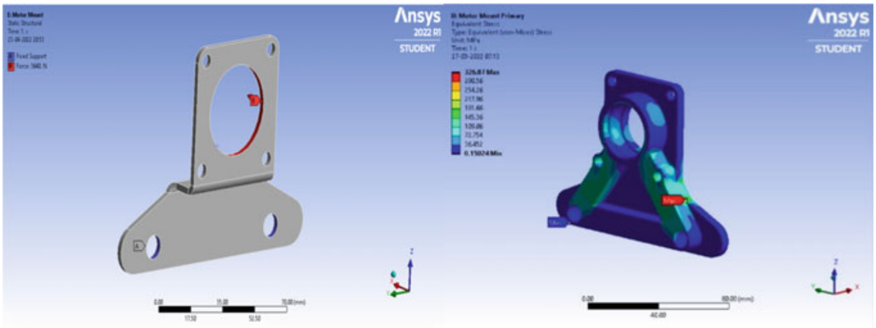

Fig. 2 Loading condition on first iteration (left); final design stress distribution (right)

results and computational time. The required forces were applied to the components, and the solution for von Mises stress was then obtained.

5.1 CVT-Primary Mechanism

Analysis of Motor Mount. The force distribution on the motor mount for the primary sheave is as shown in Fig. 2 (left). Due to the failure, the design methodology was changed from using sheet metal to a metal block. The stress analysis for the final design of the motor mount is as shown in Fig. 2 (right).

The motor mount's final design had a FOS of 2.08 and hence the design was finalized.

Analysis of Fork and Nut Assembly. Finite Element Analysis was performed on the initial design and it was further strengthened based on the results. The loading conditions can be seen in Fig. 3 (left) and the stress distribution can be seen in Fig. 3 (right).

The optimized design of the fork and nut assembly had a FOS of 2 and hence the design was finalized.

5.2 CVT-Secondary Mechanism

Analysis of Motor Mount. The force distribution on the motor mount for the secondary pulley is as shown in Fig. 4 (left). The stress distribution was improved by redesigning the motor mount. The analysis of the motor mount with the gearbox is as shown in Fig. 4 (right).

The motor mount had a FOS of 2.3 and hence the design was finalized.

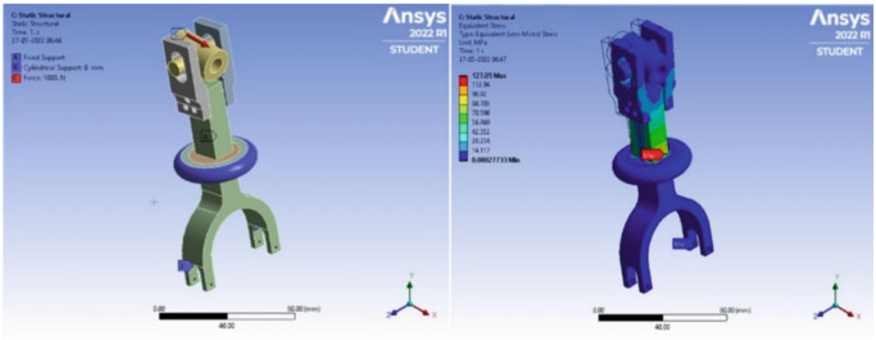

Fig. 3 Loading condition (left); stress distribution (right)

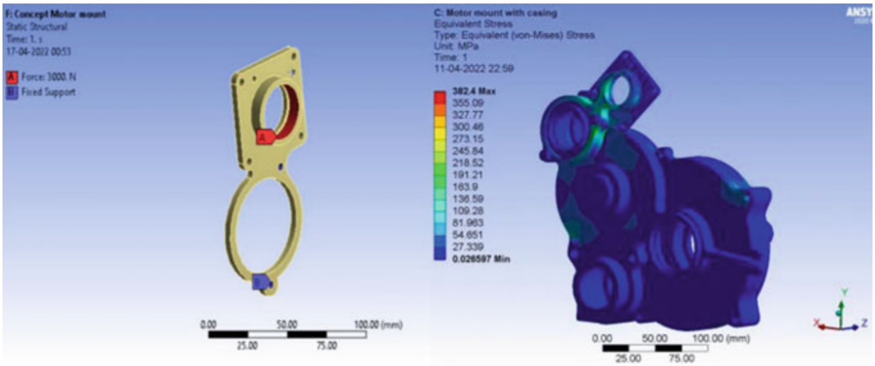

Fig. 4 Loading condition on first iteration (left); final design stress distribution (right)

Analysis of Integrated Nut. The force distribution for the integrated nut is as shown in Fig. 5 (left). It was assumed that the force distribution between the upper roller and lower roller is equal. The stress distribution is as shown in Fig. 5 (right).

The integrated nut assembly had a FOS of 2 and hence the design was finalized.

6 Conclusion

The design of the E-CVT has resulted in the following and has brought out potential possibilities for future. After consideration of various actuation methods, a power screw mechanism was used in the design to actuate movable sheaves on the primary as well as secondary side. Due to high force requirement of the primary side, a lever-based fork was developed to achieve 2 stage mechanical advantage. En-24, mild steel, brass, hardened steel and Al-6061-T6 were the materials used in various applications to maintain a minimum FOS of 2. ANSYS workbench was used as the

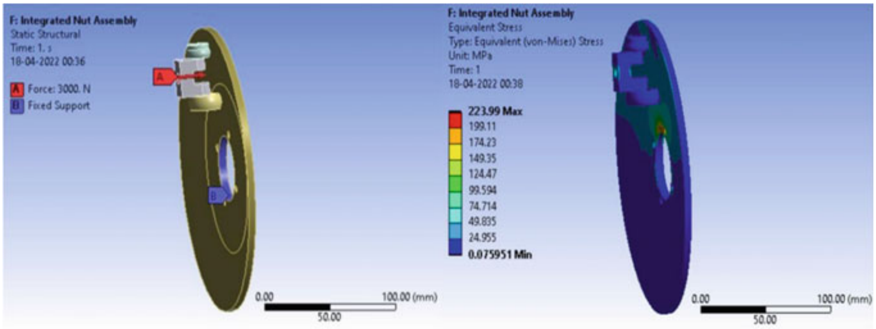

Fig. 5 Integrated nut loading condition (left); stress distribution (right)

Finite Element Analysis tool to validate stress and strain induced. The mechanical losses were reduced significantly due to low rotational inertia, low noise and low heat generation due to the electro-mechanical actuation. A balance between the strength and weight of the component was ensured during the material selection process. This also resulted in an improved lightweight as well as compact and increased life cycle over the conventional mechanical CVTs.

Further research in the materials could be carried out to reduce the losses generated in the sheave and the wheel. Alloys which are lightweight, cost efficient and having lower heat conductivity could be used to reduce the losses thereby making the mechanical subsystem more efficient. Although the losses generated due to heating have been greatly reduced, CFD analysis could be done for the entire enclosure, which would aid in further minimizing the heat generated using the laminar flow inside the CVT casing.

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Design and Development of Electromagnetic Braking System in Automobiles

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Abstract The disc or drum brakes are used in a conventional braking system. Any vehicle's braking system is required to slow or stop its movement. Brake systems in automobiles were used in response to high comfort and safety standards under various operating conditions. A magnetic braking prototype model is developed and examined in this study to improve the braking system in automobiles. The experimental results observed that increasing the electric current generates an electromagnet which creates drag force and causes the vehicle speed to be slow down. The aim of the electromagnetic braking system is to reduce brake failure and prevent accidents on the road. It also minimizes braking system maintenance. This system has the benefit of being able to be installed in any vehicle with simple transmission and electrical system adjustments.

Keywords Braking system · Electromagnetic · Automobile

1 Introduction

Friction is the most common technique of converting kinetic energy into heat in brakes, however, other methods may be used. The most common issue with conventional braking systems is that it generates heat and causes wear and tear. In an electromagnetic braking system, the braking is accomplished through frictionless concept, hence no heat is produced.

The electromagnetic brake is a driving system that uses magnetic flux to stop the vehicle. Electrical energy is used to create a magnetic field to produce eddy currents in electromagnetic brakes. These brakes depend on a continuous flow of electrical energy to function and any interruption in that supply may fail the system. The electromagnetic braking system minimizes braking distance when compared to a regular braking system.

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The brake is actuated by magnetic force in an electromagnetic braking system. The electromagnet is coupled to a shaft via a disc that is fixed on the frame. When electricity is provided to the coil, the current running through it generates a magnetic field across the armature, which pulls the armature to the coil. As a result, the system generates a torque, and the vehicle finally comes to rest. Permanent magnets do not require any sort of energy source and may operate in a wide range of environments [1].

1.1 Literature Survey

Several literatures have been found in the topic of electromagnetic braking systems. According to a recent study, the magnetic braking is most reliable braking mechanism compare with other type of braking technology.

The magnetic braking effect is mainly concerned by the amount of eddy currents generated in the revolving disc positioned among the magnets in the magnetic braking system. Researchers provided the relationship for the electromagnets and the revolving disc and the generation of eddy currents [2].

An experiment involving the diameter, the radius, and the thickness of the disc, still supports variation in their values due to their relationship. It determines the basic construction of magnetic brakes by performing a straightforward experimentation with a bronze strip stretched between two magnetic poles [3].

Most of earlier studies focused on understanding the electromagnetic fields process and creating methods to determine the magnetic braking force on rotating discs. In view of an engineer, it is required to design of braking system configuration with real-world applications, the braking force controlled to achieve the design goals, and the braking structure stabilized while it is in use.

2 Mathematical Model

It uses sophisticated electromagnetic and thermal phenomena despite being a relatively simple mechanism. Therefore, empirical evidence is particularly important in theory of computation.

In the literature on eddy current brakes, there are three models discussed [4–6]. In Smythe's method [4], the rotating component is treated as a disc with a finite radius, and a reflection approach is used to obtain a closed-form solution that is tailored to the geometry of the issue. The first step is to figure out how much induction of magnetic (B) generated by right-circular cylinders that induce eddy currents in a disc.

After computing the function, which indicates the current flowing from a point to the edge of the rotating disc any cross-sectional region, it is possible to calculate the torque by integrating the radial component of current, the electromagnetic induction, and the arm lever, then integrating across the surface area of the pole piece. Due to the demagnetizing effect, the flow of eddy current is short-circuited through the permeable pole parts of the electromagnet, consequently the overall flux would be.

$$\phi = \phi_0 - \frac{\beta^2\gamma^2\omega^2\phi}{R} = \frac{R\phi_0}{R + \beta^2\gamma^2\omega^2} \tag{1}$$

where ϕ_0 is magnetic flux piercing through the disc at rest and $\frac{\beta^2\gamma^2\omega^2\phi}{R}$ is demagnetizing magnetic flux acquired through dividing the electromagnet reluctance by the demagnetizing magnetomotive force.

The braking torque's integration yields the following result:

$$T = \omega\gamma\phi^2 D = \frac{\omega\gamma R^2\phi_0^2 D}{\left(R + \beta^2\gamma^2\omega^2\right)^2} \tag{2}$$

where

- T torque of the brake
- ω angular velocity
- γ $10^{-9}/\rho$
- ρ volume resistance of the disc
- Φ_0 flux penetrating the disc at rest
- D constant coefficient dependent on the positioning of poles
- R electromagnet reluctance
- β constant coefficient.

In contrast to experimental curve, this model works effectively on low speeds while decreases too quickly on high speeds. According to asymptotic behaviour, the torque falls off in the high-speed area more quickly than ω^{-1} in contrast to experimental results.

Smythe noted that all these performances might be caused by additional factors, so that the level of magnet iron saturation which will conflict with the expected relationship between magnetomotive force and flux (ϕ) and may adjust Eqs. (1) and (2).

In contrast to Smythe's technique, Schieber modified a common method of approach for a rotating system [5]. The following is the result at low speed only:

$$T = \frac{1}{2}\sigma\delta\omega\pi r^2 m^2 B_z^2\left[1 - \frac{\left(\frac{r}{a}\right)^2}{\left\{1 - \left(\frac{m}{a}\right)^2\right\}^2}\right] \tag{3}$$

where

- σ electrical conductivity of rotating disc
- δ thickness of rotating disc sheet

ω angular velocity
π coefficient constant
r radius of electromagnet
m distance between the pole face centre and the disc axis
a radius of the disc
B_z Magnetic flux density for z component, z-axis is electromagnetic pole centre path.

The formulation of equation is utilized in low-speed applications. At low speeds, Schieber's calculation is quite similar to Smythe's, and the concept applies to both rotating disc and linearly moving strip. The high-speed region is not investigated by Schieber.

According to inventions of Schieber and Smythe, Wouterse worked to come up with an effective solution for both the high-speed and low-speed regions [6]. The following expression is proposed by Wouterse for low speed:

$$F_e = \frac{1}{4}\frac{\pi}{\rho}D^2 d B_0^2 c v$$

$$c = \frac{1}{2}\left[1 - \frac{1}{4}\frac{1}{\left(1+\frac{R}{A}\right)^2\left(\frac{A-R}{D}\right)^2}\right] \tag{4}$$

where

Fe braking force
v speed.

The further variables are evaluation-based constraints that can be calculated using different eddy current brake types. In low-speed region, the formula fully concurs with Smythe's conclusion. Three important aspects emerged from Wouterse's investigation into the air gap of magnetic field at various speeds:

(a) The field minimally differs from the zero-speed field at extremely low speeds.
(b) At the normal speed at which the maximum force is applied, the induction is significantly smaller than B_0.
(c) The magnetic flux density began to fall even more at higher speeds.

In response to the above study, Wouterse proposed the following solution for the high-speed province:

$$\mathrm{Fe}(v) = \widehat{\mathrm{Fe}}\frac{2}{\frac{vk}{v} + \frac{v}{v_k}}$$

$$\widehat{\mathrm{Fe}} = \frac{1}{\mu_0}\sqrt{\frac{c}{\xi}\frac{\pi}{4}D^2 B_0^2}\sqrt{\frac{x}{D}}$$

$$v_k = \frac{2}{\mu_0}\sqrt{\frac{1}{c\xi}\frac{\rho}{d}}\sqrt{\frac{x}{D}} \quad (5)$$

where

- ρ disc material specific resistance
- ξ the ratio of zone region width to air gap in the distribution of asymptotic current near poles
- D diameter of soft iron pole's
- c total resistance of the disc contour to the disc under-pole contour section resistance
- v the rotating disc's tangential speed, considered at the pole's centre
- B_0 air gap induction
- v_k critical speed
- x air space between the pole surfaces which includes disc thickness or a coordinate that is perpendicular to the air space
- d disc thickness
- R distance between the disc's centre and the pole's centre.

3 Design of Electromagnetic Braking System

Figure 1 illustrates the proposed design of an electromagnetic braking system. The system uses current via a battery or an AC source. The braking pads are activated with help of an electromagnet through power source in order to stop the vehicle. Figure 2 represents electromagnetic braking system block diagram.

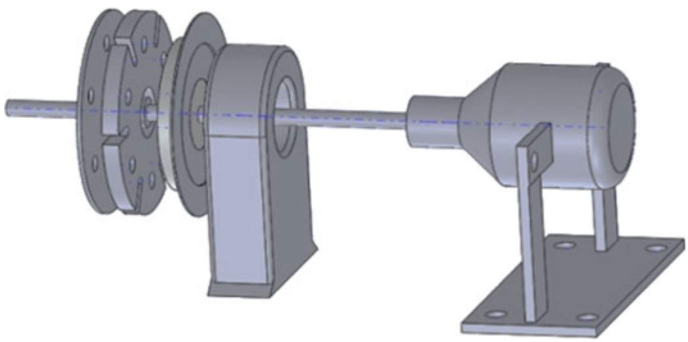

Fig. 1 Design of electromagnetic braking system

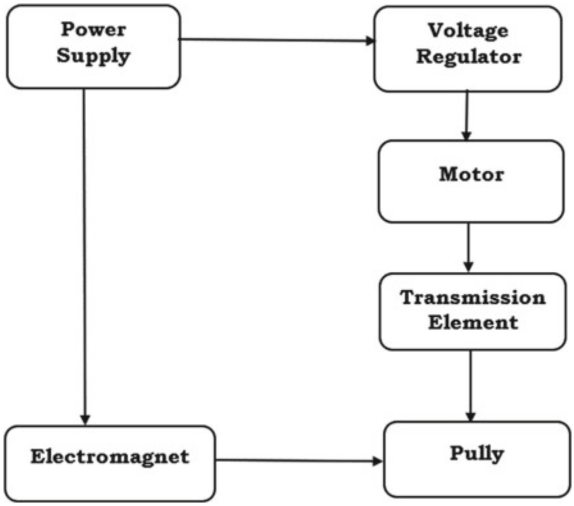

Fig. 2 Block diagram of electromagnetic braking system

4 Experimental Setup

In this experimentation, the electromagnet braking system was developed and tested for braking as illustrated in Fig. 3. The motor is attached to the wheel on one side by a shaft, and an electromagnetic plate is attached to other side of the wheel. The iron core of the electromagnetic disc is permanently fastened over the drum.

The experimental reading is taken as the disc's rotational speed with the motor and the stopping time when the electromagnet is operating, and the motor power source is cut off. The experimental results are illustrated in Table.1. Figure 4 shows the performance of system during experimental work.

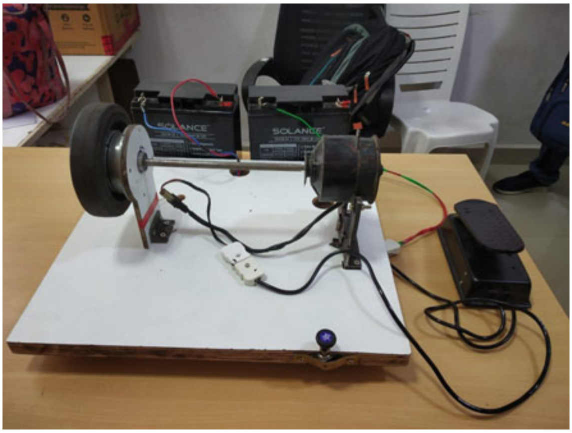

Fig. 3 Block diagram of electromagnetic braking system

Table 1 Experimental results: speed versus stopping time

S. No.	Speed (rpm)	Stopping time (s)
1	500	1
2	1000	1.5
3	1500	2
4	2000	2.6

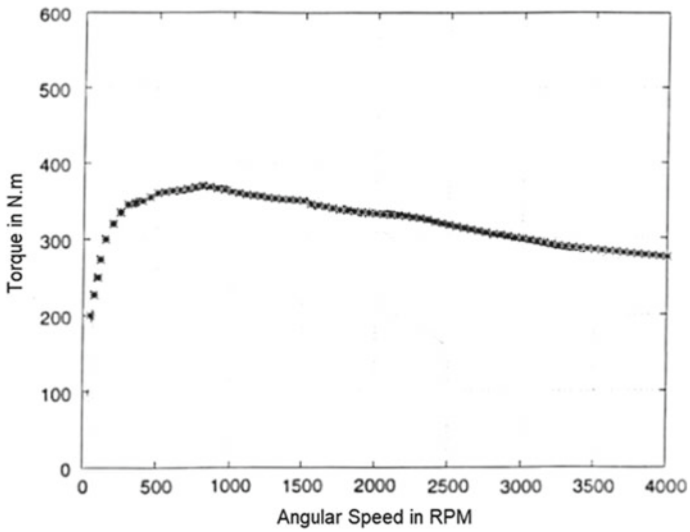

Fig. 4 Performance of the system during experimental setup

The motor is rotated the wheel. The speed controller allows for the variation of speed by reducing or increasing the motor's speed and altering the rate at which the wheels rotate. This speed is controlled by varying the current provided to the motor, which is done via a speed control switch. The load placed on the motor determines its speed; the motor runs at a low speed when there is a heavy load, and the motor runs at a high speed when the load is low. Rotation of the wheel is accomplished by the motor, which is connected to it through a shaft. The shaft connects to the wheel to the motor, which turns the wheel. The wheel rotation is tracked by the speed sensor.

5 Conclusion

In comparison with conventional braking systems, the electromagnetic braking technology is more efficient. When an emergency brake is applied to a conventional braking system, it results in a lot of slipping and a lot of braking distance. When an emergency brake is used, the electromagnetic system is designed to reduce braking distance and slippage. Finally, the magnetic braking system is totally controlled by electricity, which allows the operation to be completed rapidly.

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Comparative Study of Maldistribution on a AEL Design of Shell and Tube Heat Exchanger Using Conventional and Inline Nozzle Position

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Abstract Maldistribution is the uneven distribution of the mass flux through the various tubes of a shell and tube heat exchanger. A numerical comparative study between the AEL type of shell and tube heat exchanger (SHTE) with conventional nozzle position and an inline nozzle position has been done at various inlet velocities of 3.31, 5 and 7 m/s. It was concluded that as the inlet velocity increased the maldistribution also increased for both the designs of heat exchanger. Also the maldistribution was always greater for header with inline nozzle than the conventional nozzle position.

Keywords Maldistribution · SHTE · Nozzle position

1 Introduction

Maldistribution is nothing but the non-uniformity of the mass flux through the tube bank of a SHTE. Maldistribution is caused mainly due to the design parameters of a shell and tube heat exchanger such as the header type, nozzle position, tube layout and the boundary conditions. For a shell and tube heat exchanger having a velocity deviation less than 5% with respect to the mean flow would be considered as a shell and tube heat exchanger with uniform flow distribution [1]. Many applications of a conventional shell and tube heat exchanger are based on the assumption that the mass flux distribution is uniform across the tube bank, which is not practical as claimed by Bejan and Krauss [2]. Flow maldistribution is an unavoidable phenomenon and has severe implications on the thermal and mechanical performance of heat exchangers [3]. Maldistribution in the tubes connected to the header is caused by the exchanger

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geometry features or by actual operating conditions. Maldistribution in tubes reduces the efficiency and the performance of the heat exchanger [4, 5].

The gross flow maldistribution in turbulent flow can be quantified by relating it to the overall pressure drop across the tube bank and the dynamic head of the entering the header [6]. The pressure drop across the tube bank is contributed by the pressure drop at the inlet, pressure drop in the tubes and the losses taking place at the exit of the tube. The correlation for the pressure drop across the tube bank was given Sadik et al. [7]. Flow maldistribution can also be caused due to size variations between the channels caused due to manufacturing tolerances or poor manifold design of the exchanger [8]. As per the report of Collier, the flow maldistribution causes local erosion in high velocity areas and also causes fouling in those regions which are stagnant [9]. These in turn reduce the overall efficiency of the heat exchanger.

A statistical model was developed by Mohammadi and Malayeri [10] for predicting the maldistribution in the tube side of a single pass shell and tube heat exchanger. The effect of flow maldistribution on the heat duty of a shell and tube heat exchanger was analytically studied by Chowdhary and Sarangi [11]. If the number of transfer units (NTU) was small that the flow maldistribution has a little impact on the heat duty of the heat exchanger and vice versa.

The objective of this study is to find out the maldistribution in the two geometries at three different velocities and to compare the maldistribution through the two geometries.

2 Model Description

2.1 Physical Model

The geometry of the shell and tube heat exchanger with the conventional nozzle position and an inline nozzle position was prepared using ANSYS ICEM CFD. The geometrical specifications for the shell and tube heat exchanger are as mentioned in Table 1.

Figure 1 indicates the geometry used for simulation. A number of part names were created such as the inlet, outlet, header wall, flat wall and tube wall for giving the boundary conditions during the solver setup.

Figure 2 indicates 77 interiors created at the center of the tubes in order to capture the mass flux through them.

2.2 Meshing

The meshing of the geometry was done using ANSYS ICEM CFD. Initially, the surface mesh was created using robust/octree algorithm. The surface mesh so

Table 1 Geometrical specifications of the heat exchanger

Sr. No.	Geometry	Specification
1	Header type	Flat end
2	Header inner diameter	304.8 mm
3	Number of tubes	77
4	Tube thickness	1.65 mm
5	Tube outer diameter	19.05 mm
6	Nozzle inner diameter	66.64 mm
7	Length of nozzles	212 mm
8	Tube pitch	25.4 mm
9	Tube lengths	1518 mm
10	Tube layout	Triangular (60°)
11	Fluid circulated	Water
12	Fluid viscosity	0.001003 kg m/s
13	Fluid density	998.2 kg/m^3

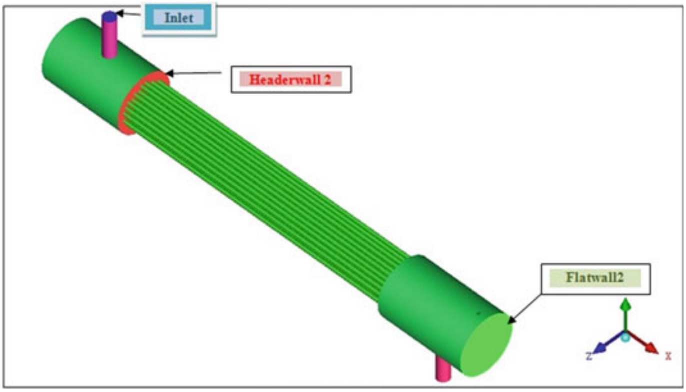

Fig. 1 Geometry of flat face header with conventional nozzle position of a AEL shell and tube heat exchanger

obtained was further meshed into 3D using prism mesh. In order to capture the viscous effects near the walls, curved surfaces were meshed with two layers near the boundaries. A grid independent test was done using coarse mesh, medium sized mesh and a fine mesh. Based on the results of the test, the medium mesh was chosen for further simulations.

The number of nodes obtained in the conventional exchanger was 6,33,611, while with the inline position the number of nodes obtained was 6,32,593. The minimum mesh quality obtained in the conventional case was 0.26, while that for the inline position the minimum mesh quality was 0.3. Figure 3 indicates the mesh for the heat exchanger with inline nozzle position.

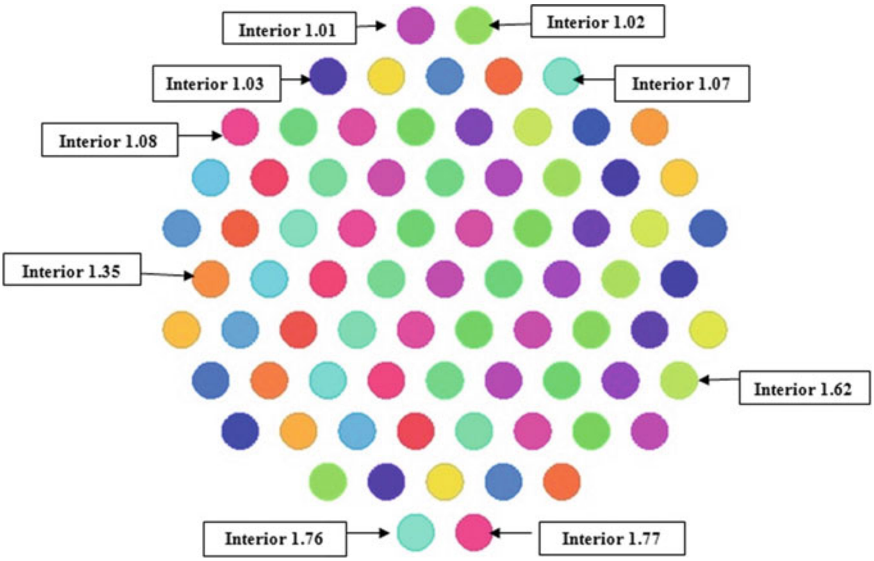

Fig. 2 Interiors created at the center of tubes to capture the mass flux

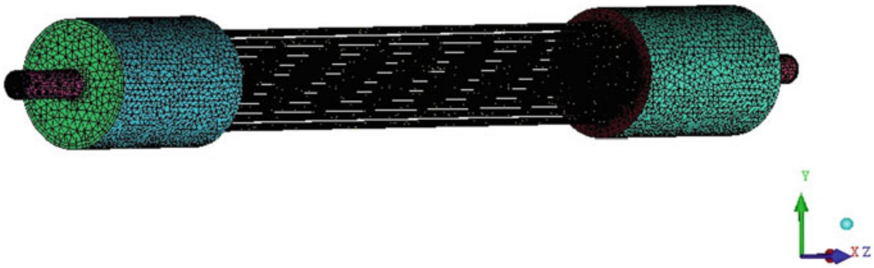

Fig. 3 3D mesh for inline position

2.3 Solver Setting

The solver used for the simulation was ANSYS Fluent 14.5. Solver specification used were three dimensional, pressure based and for a steady state. The viscous model used was $k - \omega$ as it is best suitable for complex geometries. The energy equation was kept off.

For the inlet boundary condition, velocity inlet was used and for outlet the pressure outlet at zero-gage pressure was used. For the inlet wall, outlet wall, tube walls and the header walls no slip boundary condition, stationary and with a surface roughness 0.5 was used.

The pressure velocity coupling used was SIMPLE algorithm. The momentum, turbulent kinetic energy, turbulent dissipation rate was set for second order upwind scheme.

3 Results and Discussion

3.1 Validation of the Simulated Result

The simulation was carried out in Fluent 14.5, and the results were obtained after the convergence taking place. To check the correctness of the simulated results, the analytical results for pressure drop in [7] were compared with that obtained from simulated results. The pressure contours across the tube banks were obtained using Z planes at locations of the tube banks. Figure 4 shows the pressure contour at location $Z = 0$ for conventional nozzle position for inlet velocity of 3.31 m/s.

The simulations were carried for three inlet velocities at 3.31, 5 and 7 m/s for and the results were compared the analytical method for conventional position. The deviation between the numerical results and the analytical results was very less, and hence, the simulations can be considered as validated and can be used for further post processing. Table 2 shows the comparison between the numerical and analytical pressure drop across the tube bank for three inlet velocities.

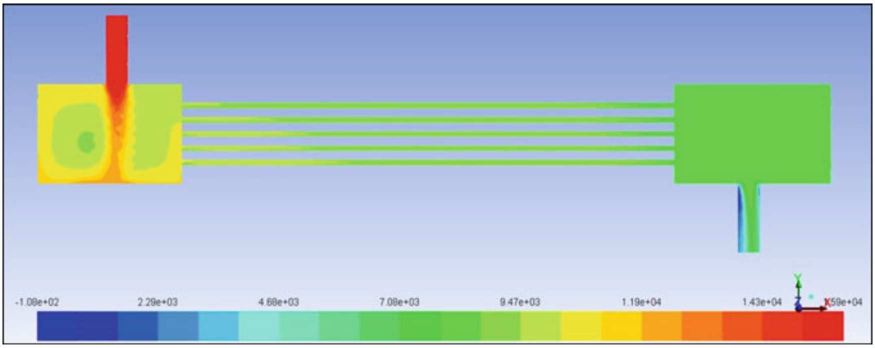

Fig. 4 Pressure contour at $Z = 0$ position

Table 2 Numerical and analytical pressure drop for conventional position

Inlet velocity	3.31 m/s	5 m/s	7 m/s
Analytical pressure drop (Pascal)	2035	4430	8212
Numerical pressure drop (Pascal)	2136	4683	7916
Percentage pressure difference	4.7	5.4	3.7

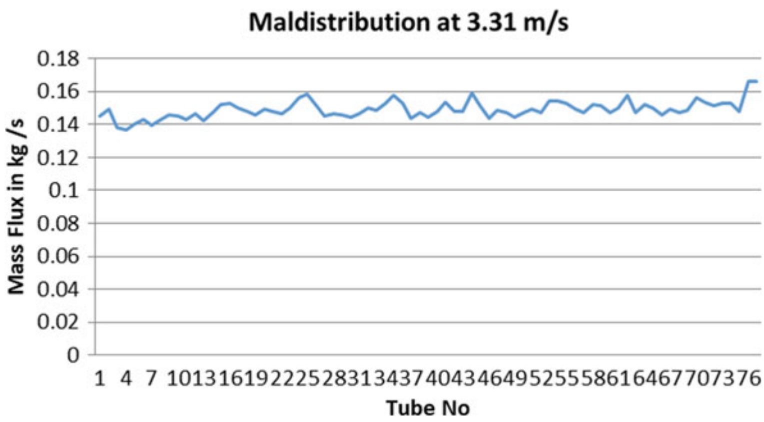

Fig. 5 Maldistribution in tube bank for conventional position at inlet velocity of 3.31 m/s

3.2 Maldistribution Analysis

To get the exact value of the mass flux across each tube of the heat exchanger, 77 interiors were created at the center of the tube as shown in Fig. 2. They were numbered row wise starting from the top row and in the left to right direction as shown in Fig. 2. The flux report was generated in FLUENT in order to get the mass flux through these interiors.

3.2.1 Flat Header with Conventional Nozzle Position

Figure 5 indicates the mass flux distribution for conventional nozzle at an inlet velocity of 3.31 m/s.

The mass flux in tube no 1 and 2, i.e., the top row is almost equal. Also the mass flux in the tube no 76 and 77, i.e., the bottom most row is almost the same. The mass flux increases down the rows as can be seen from Fig. 5. The mean mass flux was 0.149079481 kg/s, while the total mass flux is 11.47 kg/s. The mass flux deviation for each tube was calculated with respect to the mean mass flux. The summation of the magnitude of the mass flux deviation through each was 0.29883205 kg/s.

Therefore, there exist a 2.6% of mass flux deviation with respect to the total mass flux through the tubes.

3.2.2 Flat Header with Inline Nozzle Position

Figure 6 indicates the mass flux distribution for inline nozzle at an inlet velocity of 3.31 m/s.

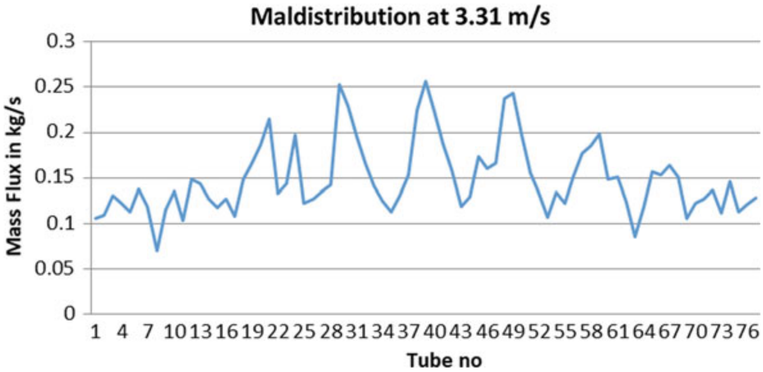

Fig. 6 Maldistribution in tube bank for inline position at inlet velocity of 3.31 m/s

The mass flux in the tube no 76 and 77, i.e., the bottom most row is almost equal. The mass flux was maximum in the centermost tube, i.e., tube no 39. The mass flux decreases in the form of concentric circles from the center tube to the tubes located radially outwards. The mean mass flux was 0.149004727 kg/s, while the total mass flux was 11.47 kg/s.

The mass flux deviation for each tube was calculated with respect to the mean mass flux. The summation of the magnitude of the mass flux deviation through each was 2.342679179 kg/s.

Therefore, there exist a 20.42 % mass flux deviation with respect to total mass flux through the tubes.

3.2.3 Overall Maldistribution Analysis

Table 3 shows the maldistribution analysis for the conventional as well as the inline nozzle position for three inlet velocities of 3.31, 5 and 7 m/s.

Both the cases were iterated for the three velocities, and the following results were concluded. The maldistribution for the conventional position is less compared to the inline at all velocities. Also the maldistribution for a particular case increases as the inlet velocity increases as can be seen from Table 3.

Table 3 Overall maldistribution

Sr. No.	Geometrical specification	Maldistribution at different velocities		
		3.31 m/s	5 m/s	7 m/s
1	Conventional (kg/s)	0.2988	0.4888	0.7666
	% Difference	2.60	2.82	3.15
2	Inline (kg/s)	2.3426	3.6688	5.9436
	% Difference	20.42	21.17	24.5

4 Conclusions

The amount of maldistribution in the various tubes is a function of inlet velocity or the Reynold number, i.e., as the inlet velocity increases the amount of mass flux deviation increases for both the geometries.

The mass flux is more in the lower rows for heat exchanger with conventional nozzle position, while in case of heat exchanger with inline nozzles the mass flux is more at the center most tubes and then decreases outwards in the form of distorted concentric circles.

The amount of mass flux deviation increases with the inlet velocity for heat exchanger with conventional nozzle position as can be seen from Table 3, while in case of heat exchanger with inline nozzle position it increases drastically with the inlet velocity.

Also there exist a huge difference in the mass flux deviation between the SHTX with conventional nozzle and the shell and tube heat exchanger with inline nozzles at all the given velocities as can be seen from Table 3.

The lowest mass flux deviation occurs in case of flat header with conventional nozzle position, while the highest is seen in the flat header with inline nozzle position for all the velocities.

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Design and Analysis of a Compliant Displacement Amplification Mechanism

Jay Mistry, Elroy Menezes, Prathamesh Indulkar, and Greegory Mathew

Abstract Compliant mechanisms are a new class of high-performance mechanisms which transmit motion and energy through elastic deformation. Due to its monolithic construction, light weight and precise motion, it is preferred over traditional mechanisms. This paper discusses the design of a compliant displacement amplification mechanism using the parametric model. The mechanism consists of two key sections—the input section and the output section. For the input section, the parallel motion flexure design using semi-circular hinges was used. For the output section, two designs viz. with FLEX-16 hinges and with dyad hinges were considered. Mechanisms with these hinges were nonlinearly analyzed using ANSYS Mechanical APDL. Design with dyad hinges was finalized for the output section based on inferences from the FEA results.

Keywords Compliant mechanisms · Parametric model · Displacement amplification

1 Introduction

A compliant mechanism transmits motion and energy through elastic deformation. It gains its mobility from the deflection of flexible members and relies less on movable joints [1, 2]. A traditional mechanism has members which are joined using pin joints or sliding joints, while a compliant mechanism has members which deflect

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Table 1 Material properties of polypropylene

Parameter	Density (kg/m^3)	Young's modulus (GPa)	Poisson's ratio	Cost (Rs/kg)
Values	900–1000	3–5	0.42	700–800

in the intended direction and transfer motion. The idea of using compliant mechanisms has opened doors to more efficient and precise [3] mechanisms which have unibody design. The number of components required for a compliant mechanism can be considerably less than for a rigid version of the same mechanism. In addition, compliant mechanisms are usually planar and can be fabricated easily from plane sheets of material.

2 Materials and Method

A compliant mechanism can be designed by using various methods such as pseudo-rigid model [4–6], topology optimization model [7, 8] and parametric model [9]. A parametric model of design and analysis is a method in which certain features of the component are selected as parameters of the design to facilitate quicker iterations as compared to the traditional method of analysis. This method helps to automate the design process and reduce the total design time. It is independent of manual calculations, has a high accuracy and is also easier and faster to create multiple iterations. The parametric method using FEM was, therefore, selected to design the compliant mechanism.

A compliant mechanism can be fabricated using plastics such as polylactic acid (PLA), polyurethane (PU), polypropylene (PP), acrylonitrile butadiene styrene (ABS) and metals such as aluminum. However, PP was selected as it provides better strength despite having a lower density, can be machined using CNC milling, is cost effective and in case of 3D printed components, it has been observed that polypropylene components provide better compliance as compared to those with other materials like PLA, ABS, PU, etc. Material properties of PP are provided in Table 1.

3 Design and Analysis

3.1 Design of the Input Section

The input section of the mechanism should act as a load bearing support. It should have a unidirectional motion and should transfer load smoothly over a limited range of motion. Considering the above functions, a parallel motion flexure mechanism was selected. Two semi-circular hinges were arranged in series to provide the constrained

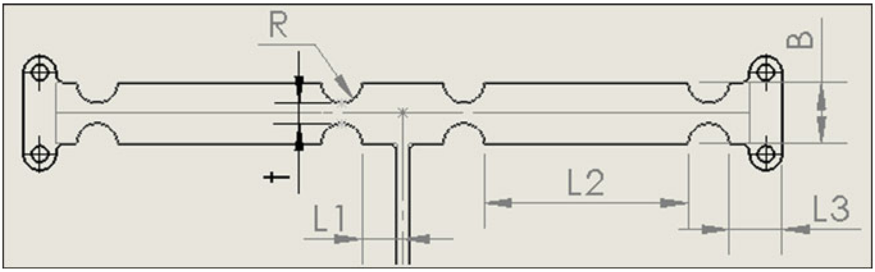

Fig. 1 Parallel motion flexure mechanism

Table 2 Input section—parameters and values

Parameter	h	T	R	B	L1	L2	L3
Values (mm)	7.5	2	5.5	10	10	50	5

vertical motion and also to eliminate the transverse shift. The parallel motion flexure mechanism is shown in Fig. 1 while its parameters and values are specified in Table 2.

3.2 Design of the Output Section

The second requirement of the compliant mechanism was to have a mechanism which converts the unidirectional input displacement to rotational displacement and indicate the applied load. This could be achieved by using a mechanism with Flex-16 hinge or a mechanism with dyad.

The design with Flex-16 hinge comprised of 16 flexures that radiated outward from the center of the joint, four intermediate rigid arc shaped shuttles, one vertical flexure between the two innermost shuttles and two rigid ends for fixing the hinge. Flex-16 would actuate when one end was fixed and a moment was applied on the other end. The radial flexures acting in series allowed for large angular displacement by dividing the stress and displacement among the individual flexures. The lengths of the flexures were designed to be as long as possible in order to reduce stresses and also to be small enough to fit within the size envelope of the hinge and avoid contact with other flexures during hinge displacement. The two innermost intermediate rigid shuttles were connected by a vertical flexure to provide both axial stability and sufficient rotation. The outer intermediate rigid shuttles increased stability during rotation and could accommodate four flexures per quadrant. Figure 2 depicts the mechanism with Flex-16 hinge.

The parameters used to define the keypoints in ANSYS Mechanical APDL are specified in Table 3. The design consisted of total 28 parameters of which 20 parameters were based on the configuration of the hinge. F1 to F8 are ratios, T1, T2 are out

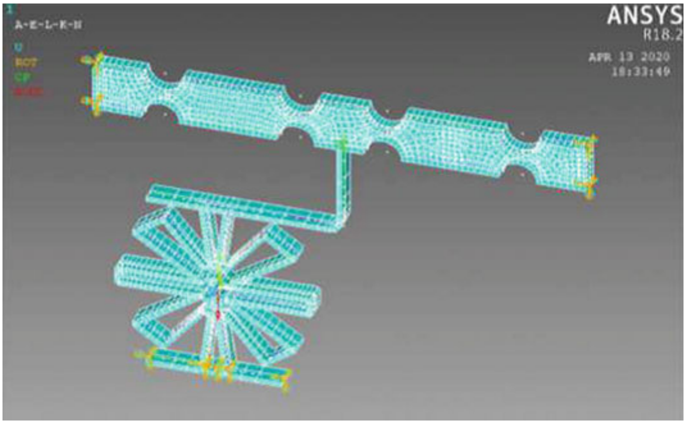

Fig. 2 Complaint mechanism with Flex-16 hinge

Table 3 Parameters and values for the mechanism with Flex-16 hinge

Parameter	R	T1	T2	W	A1	A2	A3	A4	A5	A6
Value	20 mm	1 mm	1 mm	5 mm	7°	22°	34°	45°	56°	57°
Parameter	A7	A8	F1	F2	F3	F4	F5	F6	F7	F8
Value	85°	90°	1.05	0.29	0.94	1	0.15	1	0.15	1

of plane thickness, while W is in-plane thickness. These parameters are explained in detail in [10].

3.3 FEA Analysis of Design-1

The Young's modulus, Poisson's ratio and density of the material (PP) were 300 MPa, 0.42 and 900 kg/m^3, respectively. The element type was BEAM 189. The number of keypoints, elements and nodes was 97, 726 and 2109, respectively. The number of fixed supports was 3, and the load along the negative Y-axis was 20 N. Figures 3 and 4 indicate the induced stresses and the deformation. The maximum stress and the deformation observed were 0.473×10^{11} N/m^2 and 1.05 mm, respectively. The simulation results show that the amount of deflection of the end pointer was inadequate for the required displacement amplification. The hinge was designed to rotate about the center, but it was observed to be rotating from the side. To correct this, a rod element connecting the central link and the point of application of the load would need to be added, however, it will result in a non-planar mechanism. In addition, if the vertical load exceeds the limit, it will compress the mechanism and further restrict the displacement amplification. To eliminate these drawbacks, the Flex-16 hinge was replaced by a compliant 4-bar dyad and a pointer. These two elements provided the necessary displacement amplification. The series connected elastic hinges were kept as it is to provide the necessary constrained vertical motion. The compliant dyad building block, CDB, consisted of two beams connected in series. The beams had different lengths (l_1 and l_2) and different orientations. The length of the second beam was normalized such that l_2 norm $= l_2/l_1$.

The mechanism with dyad is shown in Fig. 5. The design consisted of 20 parameters (Table 4) of which seven (pertaining to the parallel motion flexure) were

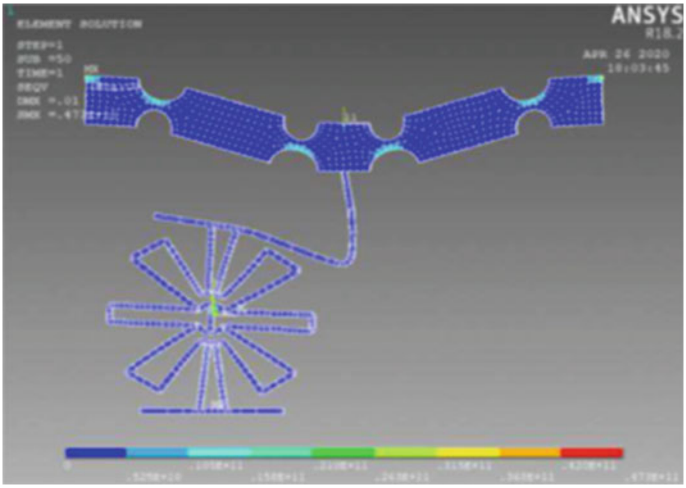

Fig. 3 Von Mises stresses (Nodal) for the design with Flex-16 hinge

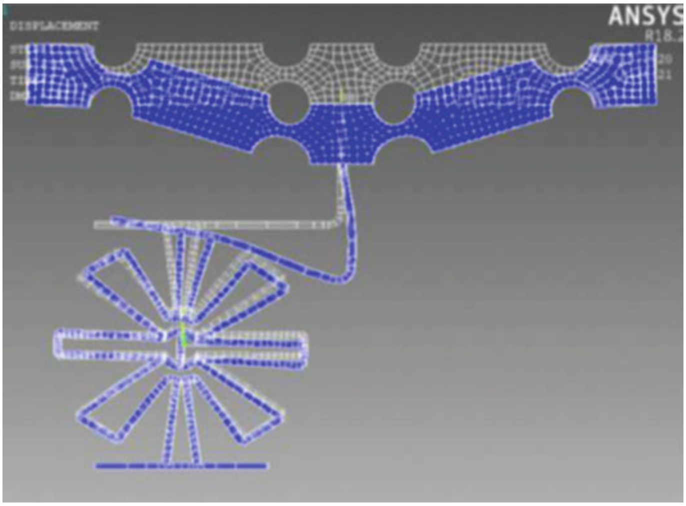

Fig. 4 Deformation (Nodal) for the design with Flex-16 hinge

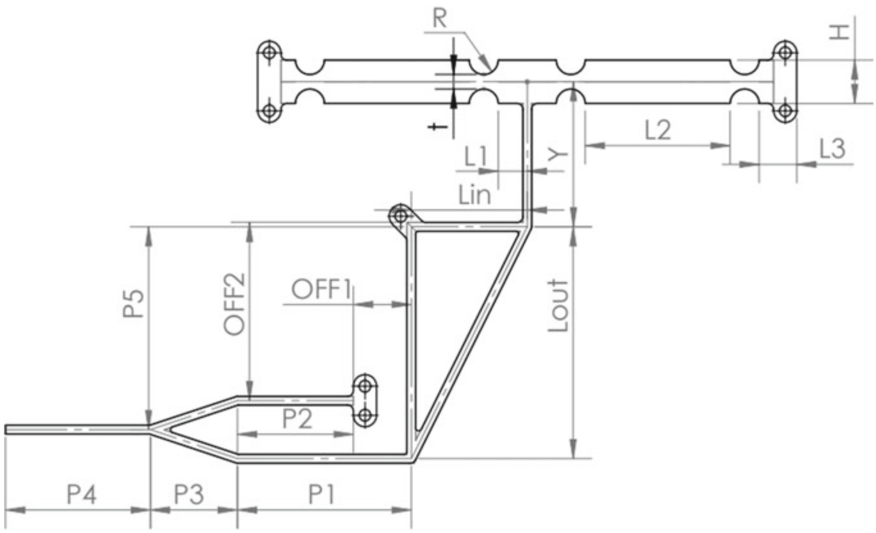

Fig. 5 Complaint mechanism with dyad

Table 4 Parameters and values for mechanism with dyad

Parameters	W1	T1	Lin	Lout	Off1	Off2	X	Y	H	R
Values (mm)	5	3	40	80	20	60	40	50	13	5.5
Parameters	P1	P2	P3	P4	P5	L1	L2	L3	T	B
Values (mm)	60	40	30	50	70	10	50	5	2	5

redundant. They were used in order to maintain the configuration. A total of 47 keypoints were provided. The necessary displacement amplification was achieved through geometric advantage. The compliant pointer added on to the displacement amplification and provided the necessary indication on an approximate linear scale.

3.4 FEA Analysis of Design-2

The properties of the material, the element type and the applied load were same as that for the mechanism with Flex-16 hinge. The number of keypoints, elements and nodes was 101, 945 and 2115, respectively. The number of fixed supports was 4. Figures 6 and 7 indicate the deformation and the induced stresses. Taking into consideration the equivalent Von Mises stress, it was observed that the max stress was obtained on the curved surface of the flexure hinge. The maximum stress and the deformation observed were 15.1×10^6 N/m^2 and 52.16 mm, respectively.

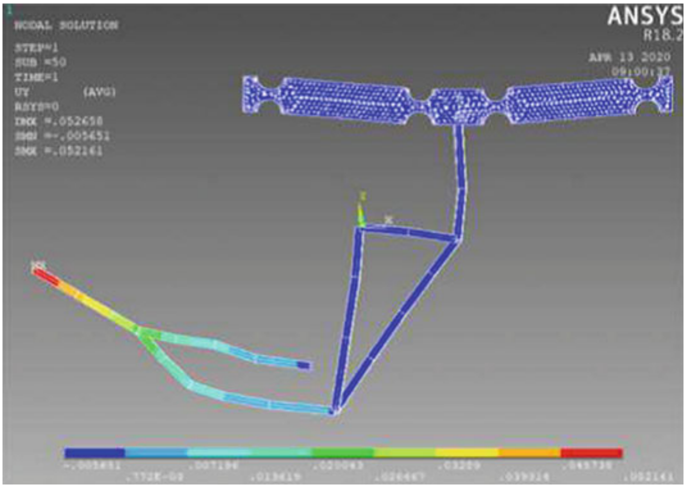

Fig. 6 Deformation (Nodal) for the design with dyad

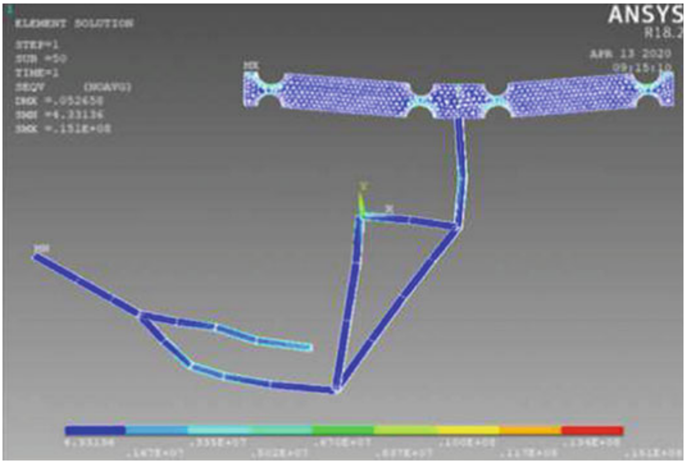

Fig. 7 Von Mises stresses (Nodal) for the design with dyad

The output data (deflection of end pointer) from ANSYS was plotted against the applied load to determine the stiffness and the linear characteristics (load vs deflection) of the mechanism. It is clear from Fig. 8 that an approximate linear relationship exists between the applied load and the deflection. Such a linear relationship proves that the entire mechanism has a constant geometric stiffness even at large deflection. The mechanism with dyad is completely planar. It has led to a 40% increase in output for the same loading condition along with a 60% reduction in the number of parameters and a 50% reduction in the number of links.

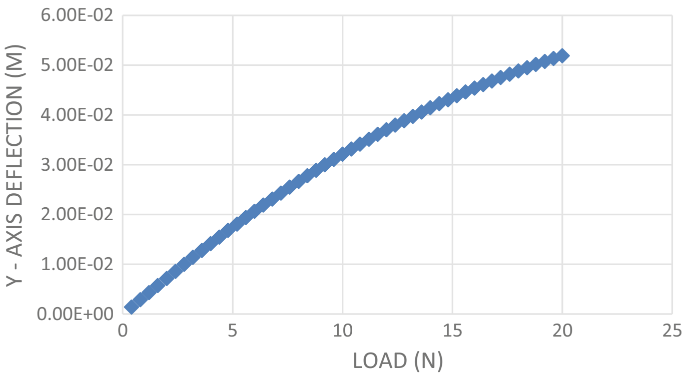

Fig. 8 Load versus deflection

3.5 Optimization of Parallel Motion Flexure

The parallel motion flexure was further optimized by replacing the semi-circular hinge with corner filleted hinge of square shape as shown in Fig. 9. For the same loading condition, an increase of 10% in the output deflection was noted. The deflection observed was 57 mm while it was 52 mm previously. An amplification of 7% was observed for the same input. The new amplification was 10.7 times as compared to the previous amplification which was 10 times. The optimized mechanism with filleted corners thus provided better compliance, improved manufacturability and reduced the overall material requirement.

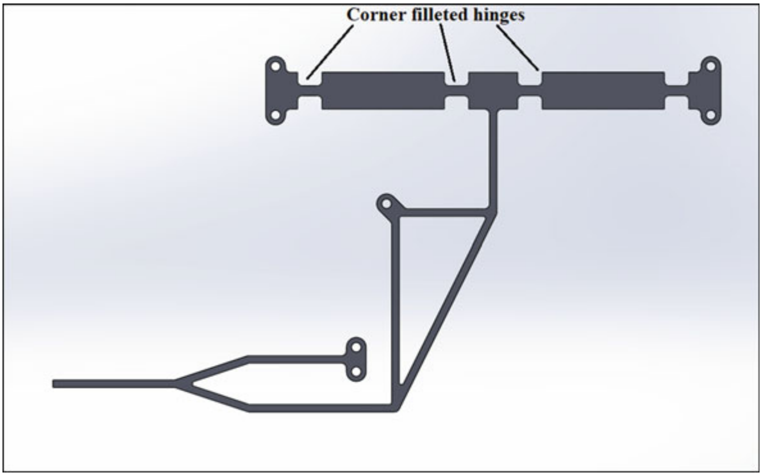

Fig. 9 Optimized mechanism with corner filleted hinge

4 Conclusion

A displacement amplification mechanism was designed successfully after three iterations. The parametric model of design method was chosen for designing the mechanism after reviewing literature related to design of compliant mechanisms. The first design explored the possibility of using Flex-16 hinge with semi-circular flexure hinges connected in series. The flexure hinges provided the necessary vertical stiffness, however, the Flex-16 hinge provided only a limited displacement amplification. The second iteration of the design consisted of a 4-bar compliant dyad and a compliant pointer. With this combination, the required displacement amplification was achieved. A parametric finite element model of this design was created, and the parameters were optimized to achieve better results. Iterative nonlinear finite element analysis was performed to check the required deformation and the induced stresses. Based on the slope of the load vs. deflection graph, the stiffness was predicted to be 350.88 N/m. As the nature of the graph was linear, the mechanism can be successfully used in weighing machines to measure the true weight of an object. In the third iteration, the semi-circular hinges were replaced by corner filleted flexure hinges. The design provided a displacement amplification which was approximately 10.7 times the input displacement. The induced stresses for this design were well within permissible limits.

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Design and Development of an Indexing Drill Jig for Currency Counting Machine

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Abstract The study involves the designing of a custom drill jig to manufacture a crucial component of currency counting machines. A drill jig is a work-holding device that holds, supports and locates the workpiece and guides the drill bit to perform the drilling operation. The holes to be drilled are equidistantly located along the lateral curved surface of the cylindrical workpiece. Indexing refers to a process of quick and accurate location of a workpiece or fixture in a number of specific positions. An indexing plate type indexing mechanism was developed to drill all five holes without the need of clamping and unclamping the workpiece multiple times. The components were designed, assembled and drafted using Solidworks. Height gauges were used to determine the positioning of the drilled holes with respect to the face of the workpiece. Go/no-go gauge was utilized to verify the diameter of the drilled holes. Implementing indexing drill jigs significantly improved the accuracy of the position at which the holes were being drilled. The consistency of the manufactured components and the rate of production of the housing were also significantly improved.

Keywords Drill jig · Indexing mechanism · Pivoted lever mechanism

1 Introduction

A currency counting machine is a machine that counts money either stacks of banknotes or loose collections of coins. The project completed consisted of creating an indexing drill jig for manufacturing of a key component (housing) of the currency counting machine. The machine can be customized to be operated in auto or manual

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mode. This machine can count 150–200 notes in one setting depending on the condition of the notes at an extremely fast counting speed of 4 s per 100 notes. In addition to counting the notes at an extremely fast rate, it can also detect the authenticity of the notes.

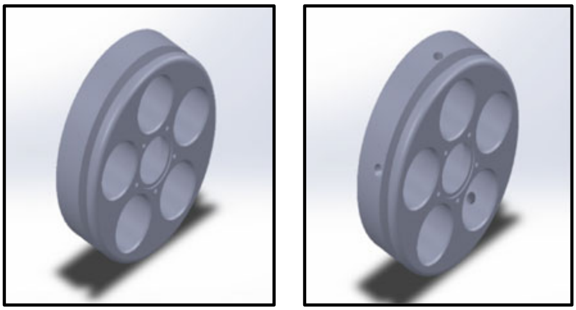
The machine works based on vacuum. The centre shaft which is housed in the centre of the housing is connected to a vacuum pump. Five fingers are housed inside the circular holes present on the housing. A DC motor is connected to the housing with through a planetary gearbox. When the machine is turned on, the vacuum pump turns on, the suction force of the vacuum pump is calibrated so that only one note is sucked towards the finger. The DC motor rotates the housing which in turn makes the five fingers revolve around the centre of the housing. As each finger revolves, it carries one note with it. The scanning is done through using a beam of light. The interruption in light beam caused by the passing note helps machine to make counts. The project consisted of manufacturing a custom drill jig for manufacturing of the housing of the Godrej Swift Turbo currency counting machine.

2 Methodology

A drill jig was to be manufactured for a circular workpiece. The workpiece was a key component (part name-housing) of the currency counting machine and 5 holes of 6 mm diameter were required to be machined accurately at distance of 16 mm from the front face right in line with the circular cut-outs as indicated in Fig. 1. Since the holes were to be drilled on a curved surface, drilling on the exact plane and maintaining the required tolerances was extremely difficult without the use of a customize jig. Even the slightest inaccuracy can result in an air leak and as the note counting machine relies on vacuum to move the notes, the accuracy of the entire machine can be compromised.

In addition to the dimensional inaccuracies, the process time was extremely long which significantly decreased the accuracy of, not only the drilling process but of the entire manufacturing cycle.

Fig. 1 Workpiece and drilling positions



Workpiece After drilling operation

2.1 Design Approach

- Researched about drill jigs and indexing mechanisms.
- Selected and designed the indexing mechanism and related components.
- Designed the locators and mounting mechanism.
- Designed the bush and top plate.
- Designed the remaining auxiliary components.
- Made continuous improvements to the design to improve ergonomics and decrease process time.

First the drill jig was designed and checked for the optimal indexing mechanism for this jig. For this specific drill jig, the indexing plate type method of indexing was the most optimal and simple solution for machining the equally spaced holes on the periphery of the workpiece [1, 2]. In this type of indexing mechanism, the workpiece is located and clamped on an accurate indexing plate which moves along with the workpiece.

Second Location—In this jig, the workpiece is located using three locating mechanisms. The first type is the cylindrical locators used to locate the workpiece with respect to the indexing plate. As the primary requirement of this operation is to drill five holes along the length of the workpiece perfectly in line with the five holes on the face of the workpiece, the location of the workpiece with respect to the indexing plate is the most important parameter of this jig. To achieve this, three cylindrical locators were used [3]. The slot and key mechanism was designed to make sure that the workpiece was perfectly aligned with the drill bush when the key was engaged.

The third is the pair of thrust bearings used for mounting the indexing plate and workpiece to the mounting plate. Mounting the indexing plate and workpiece to the mounting plate using a bolt was possible, but that would have constricted the indexing plate completely [4]. In that case, the worker would have had to loosen the bolt and fasten it again after drilling each hole. Hence, this was not the ideal solution as the cycle time for each workpiece would have been unnecessarily long. Thrust bearings were chosen to provide axial locking whilst also allowing the indexing plate to rotate freely. The centre of the drill bush was required to be 16 mm from the face of the workpiece at a height of 20 mm from the drilling surface.

The completed design was reliable and functional; however, there were several ways in which it could be improved to decrease the operation time even further and make the working even more ergonomic. Spring-loaded mechanism for the indexing key was implemented to improve the efficiency of the design [5].

2.2 Design Iterations

Design 1

In this design shown in Fig. 2, a spring housing was designed which would house a return spring that would compress when the key was pulled out and expand back to its original length once the tip of the key lined up perfectly with the slot in the indexing plate, resulting in the indexing key getting re-engaged automatically.

A fork like automotive manual transmission was used to disengage the indexing key. The design of the key was accordingly altered to house the fork and the spring. This fork was connected to a bell crank which was then connected to pull rod. This mechanism allowed the worker to disengage the indexing key just by pulling the pull rod towards him.

However, there were some flaws in this design. Bell cranks cannot provide purely translational motion. The worker would have had to pull the rod in an arc to disengage the key. Modifying the bell crank to do so would make the system more complex and increase the costs. To eliminate these flaws, second design was developed.

Design 2

A new mechanism was designed where a simple horizontal lever was used instead of the bell crank assembly as shown in Fig. 3. The key, spring and spring housing were carried forward from the previous design. The fork was extended in length and pivoted around an M6 bolt. A new mount was designed to house the pivoting bolt as well as to mount the fork. Additionally, the last 50 mm of the fork was given a knurled finish to provide good grip.

The operator will line up the workpiece with the locators and tighten the bolt and washer to fit the workpiece firmly onto the jig. The operator will then drill the first hole by guiding the drill bit through the bush. After the first hole has been drilled, the operator will use his left hand to pull the lever towards him. The lever will pivot around the M6 bolt of the fork mount and push the key backwards into the spring

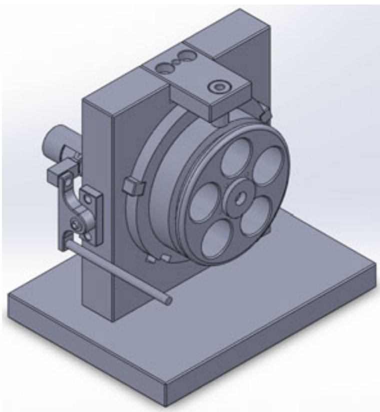


Fig. 2 Bell crank and pull rod mechanism

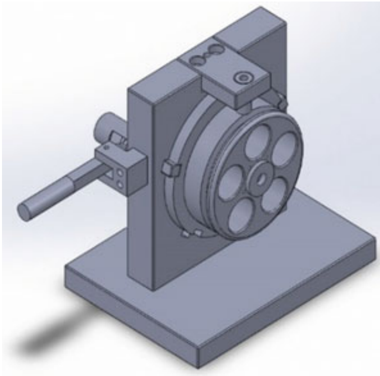


Fig. 3 Pivoted lever mechanism

Table 1 Comparison of the two spring-loaded mechanisms

Design 2	Design 1
Pivoted lever mechanism	Bell crank mechanism
More ergonomic	Less ergonomic
Simpler construction	Complicated construction
Consists of fewer components	Consists of more components
Lower cost	Higher cost

housing resulting in the disengaging of the key and compression of the spring. The operator will then use his right hand to rotate the indexing plate. When the key lines up with the next slot, it will automatically be re-engaged with the help of the spring force. The operator will then drill the second hole. This process will then be repeated three more times to drill the remaining holes.

Table 1 depicts the comparison of the two design iterations done by using two spring-loaded mechanisms.

In conclusion, the pivoted lever mechanism was better than the bell crank mechanism in all categories and hence was selected as the final key actuation mechanism.

Material Selection

Low cost, high hardness, high toughness, high impact and wear resistance were the material requirements for the design. Table 2 depicts three materials shortlisted based on the requirements.

Drafting

After finalizing the design concept and creating CAD models and assemblies using Solidworks, the manufacturing of the parts was to be started. For the manufacturing to start, detailed drawing sheets for each and every part were drafted.

Table 2 Comparison of the materials selected

Material	Hardness (HB)	Fatigue strength (MPa)	Cost (Rs/kg)	Yield strength (MPa)	Density (g/cm^3)
OHNS	230	210	135	465	7.8
MS	30	195	90	650	7.8
AL 6061	95	96.5	280	276	2.6

Tolerances

The entire jig was analysed, and all the critical dimensions were identified. After analysing the critical dimensions, the tolerances for each component were decided. Maintaining intricate tolerances require extremely accurate machining processes such as wire EDM machining and cylindrical grinding.

Assembly

After the components had passed quality control and the lever mount and mounting plate had been successfully reworked, the assembly of the two jigs was initiated.

3 Results and Discussion

3.1 Trial Run

A trial run was performed after both the jigs were successfully assembled. The jig was mounted on a conventional drilling machine as shown in Fig. 4. The base plate was clamped to the table of the machine using T-slot clamps. A 6 mm drill was connected to the spindle. The spindle was then lowered through the bush to carry out the drilling operation. The lever was then used to actuate the indexing key and the next slot was selected. This process was further repeated thrice to drill the remaining holes.

3.2 Results

The diameter of the drilled holes for both the jigs was perfectly 6 mm. This indicated that the workpiece did not move at all when the impact loading of the drill bit coming in contact with the workpiece was exerted on the components of the drill jig. Hence, it was concluded that the jig was robust.

The distance of the centres of the holes drilled using both jigs from the face of the workpiece was measured using a Trimos height gauge. All the readings were within a range of 0.04 mm. Since the tolerance considered was 0.1 mm, both the jig passed

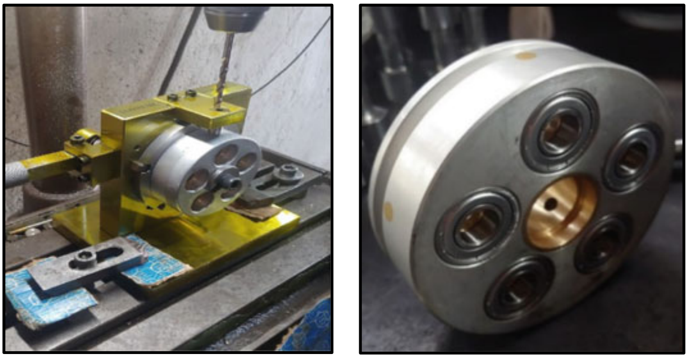


Fig. 4 Mounting of drill jig and assembly

the trial. After the trial, both the jigs were completely disassembled and coated with an anti-rust coating and the components were left to dry for a few hours. After the coating had dried completely, both the jigs were reassembled.

After completing the visual inspection, operator conducted another trial run to confirm the accuracy of the jig. The results of this trial were the same as the previous trial, and hence, both the jigs were approved. Both the jigs were immediately installed in the plant, and the manufacturing of the currency counting machine housings was started.

4 Conclusion

The drill jig was successfully designed, manufactured and delivered within the desired timeframe. The design of the jig was constantly improved over time by implementing various upgrades over time. These upgrades included

- Implementing spring-loaded indexing key mechanism to improve the ergonomics and efficiency of the drill jig,
- Using dowel pin for more accurate location of the bush with respect to the workpiece,
- Using C-washer instead of a regular washer to decrease the mounting and dismounting time of the workpiece by over ten seconds.
- Providing a slight taper to the locators to make the clamping and unclamping process of the workpiece easier and faster whilst also decreasing the wear and tear of the locators.

Both the jigs were used in two trial runs, and both provided stellar results exceeding the quality control requirements by a significant margin. These jigs were immediately installed in the plant and have been working flawlessly ever since. Using these indexing drill jigs to manufacture the component (housing-currency counting machine) has not only increased the production rate of the plant, but it has also improved the accuracy of the machined component. Using an indexing drill jig will also significantly decrease human errors caused during the drilling process. This indexing drill jig can also be modified in dimensions and used for performing drilling operations on other workpieces with similar requirements.

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Performance Testing of Parabolic Dish Type Solar Cooker with Dust Accumulation

Harshal Patil and Nishikant Kale

Abstract The limitations of fossils fuel are well known to all. It is necessary to find an alternative solution for fossil fuels. Renewable energy is always a ray of hope for a researcher as well as humankind. Solar cooking may be a small but very important contribution to saving conventional fuels. There are many solar cookers available in the market. Existing solar cookers have some drawbacks. The main concern of its performance, cost and availability for all time has been the focused points of this research. It has been found from the literature survey that low cost and efficient reflective material is very necessary for solar cookers. The performance of solar cooker is affected due to dust accumulation on reflector surface. In this paper, the parabolic solar cooker is analyzed by applying different reflective materials with the effect of dust. Anodized aluminum sheet, aluminum foil, silver-coated LDPE foil and polished aluminum sheets are used as reflective materials for the solar cookers. All these materials are available in almost all cities of India.

Keywords Solar cooker · Reflective materials · Parabolic dish · Performance · Effect of dust

1 Introduction

Cooking is the important daily activity in human life because we eat mostly cooked food, which is done by conventional energy sources [1]. Biomass fuel is obtained from plants or animal material, which leads to deforestation of land. Across the world, approximately more than three billion people depend on conventional energy sources [2]. The use of biomass stoves requires more time to cook and consumes more fuel [3].

Like all other developing countries in India, also there is heavy dependence to meet domestic and industrial energy needs. Nearly 36% of the primary energy consumption in India is for cooking. The energy scenario in rural areas in India is still grim. Using

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renewable energy sources to meet the energy needs is the solution. Solar energy is the most promising option as compared to other sources [4, 5].

India is a tropical country and has maximum sunny days in a year [6]. Energy from sun can be used directly or indirectly. Solar cooker is a device that uses only sunlight as a fuel.

Despite several advantages, use of solar thermal energy as a source for cooking is yet to gain popularity worldwide. It has mainly restricted to demonstrative levels only.

2 Dust Accumulation on Reflectors

The working of solar cooker is affected due to accumulation of dust. The accumulation of dust is influenced by various surrounding conditions. Most of solar cookers are kept in open atmosphere and that causes dust deposition with time [7].

The efficiency of cooker depends on the dimensions of dust particles accumulated on concern reflector of solar cooker. As the dust accumulation increases, the efficiency of the cooker decrease, and if the size of dust particle becomes smaller, performance also decreases as smaller particles restrict more radiation on sun facing surface. The different dust accumulation may include ash, soil, sand, etc. [8].

3 Materials

There are different types of material are suggested by researchers for building the solar reflector like household aluminum foil, low-density polyethylene, polished aluminum metal sheet, etc. Therefore, the critical study of dust on different reflective materials attracts the attention of researchers [9–14].

Hence, for present research work, household aluminum foil, low-density polyethylene (LDPE) sheet, thin polished aluminum metal sheet and anodized aluminum sheet are considered for performance testing of solar cooker. These reflective materials are readily available in the local market and collected for comparative study of solar cookers. All three materials are low cost as compared to advanced material, which is used in the existing solar cooker. All the material is purchased from local market of Amravati city. The cost details for materials are shown in Table 1.

4 Methodology for Assessment of Effect of Dust

Dust consists of particles having a size less than 500 μm in the environment that comes from various sources such as construction site, soil, dust storm and industries. Dust have seen or unseen particles. It includes floating and fallen particles [8].

Table 1 Properties and cost details for proposed reflective materials

Material	Thickness (μ)	Reflectivity (%)	Cost per m^2 sheet (Rs)	Durability
Aluminum foil	10.5	87	52	Few days
Silver LDPE foil	60	90	15	Few days
Thin polished aluminum metal sheet	710	86	267	Up to 3 years
Anodized aluminum sheet	700	88	971	Up to 5 years

Solar cookers are hampered by dust accumulation as it reduces performance. So, evaluation the effect of dust accumulation for a particular place required to be carried out to predict the performance and installation of various solar cookers [15].

To evaluate the performance of parabolic solar cooker with dust, standard dust sample was used as shown in Fig. 1. The salient specifications of this dust sample were evaluated in the laboratory by using specified test methods. The test report is shown in appendix. Table 2 describes the specifications of the dust sample used in this experimentation.

Fig. 1 Dust sample

Table 2 Specifications of dust sample

S. No.	Property of dust	Test result
1	Average fineness (%) (must be less than 10% as per IS 4031 (part 1): 1996 (R-2005)	6
2	Particle size (μ)	10
3	Density (gm/cc)	1.38
4	Specific gravity	3.12

Fig. 2 Two parabolic dish type solar cookers

5 Experiment Set Up

The two parabolic solar cookers having identical specifications were used for experimentation as shown in Fig. 2. The performance of the first was used as the reference for given operating conditions. All the modifications for judging the performance of reflective material were carried out on the solar cooker number two.

6 Reflective Materials with Accumulation of Dust

The effect of dust accumulation on the working of parabolic solar cooker was studied. Presented paper focused on four different reflecting material with accumulation of dust were tested such as anodized aluminum sheet, aluminum foil, low-density polyethylene sheet and polished aluminum metal sheet as shown in Fig. 3. The effect of dust accumulation was studied at three levels in terms of weight such as low, medium and high. The weight of the dust was measured with the help of weighing machine. Also, the reflecting surface gets wetted by wet cloth so that all the dust sticks on the reflective surface. The dust is spread uniformly on the reflecting surface by a multilayer flour strainer.

7 Testing Procedure for Experiment on Solar Reflectors

Performance of solar cooker has examined by standard measure given by Funk [16]. In this testing procedure, some uncontrolled weather conditions and controlled variable are kept in certain range throughout the experiment. All the experiments are conducted on terrace so as to eliminate the shadow problem. Latitude and longitude for the experimentation site are 20.88 and 77.73, respectively. Experiments conducted on sunny day of the month September and October 2021.

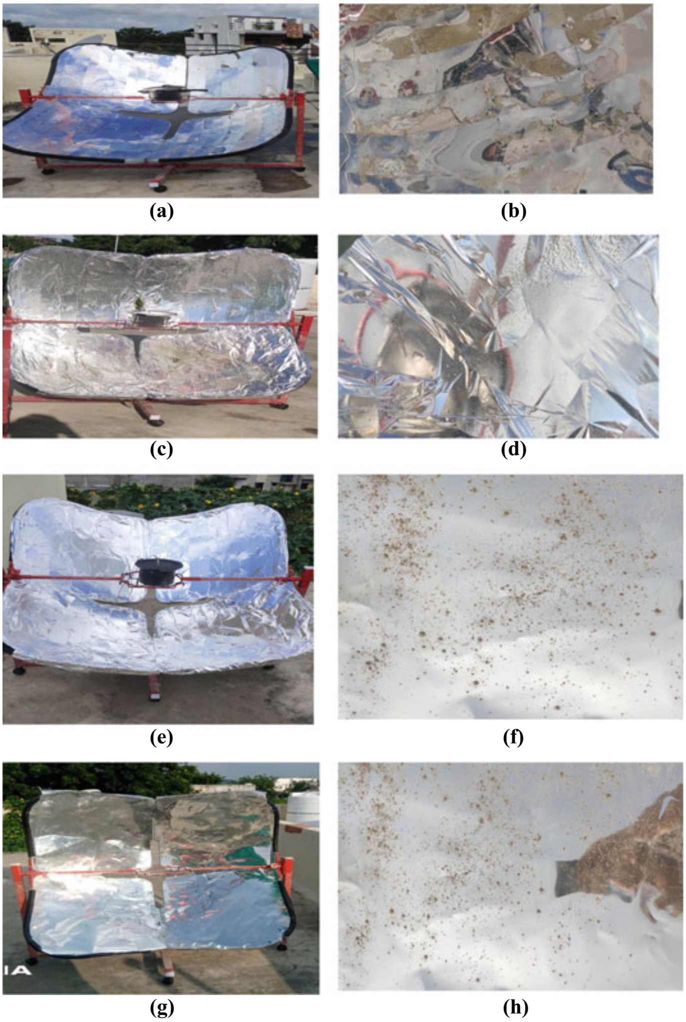

Fig. 3 Various reflective materials with and without dust accumulation, Anodized aluminum sheet (**a**, **b**), aluminum foil (**c**, **d**), LDPE sheet (**e**, **f**), polished aluminum sheet (**g**, **h**)

8 Tolerance of Various Reflective Materials to Dust

The effect of dust accumulation was tested with various reflective materials for the performance of the cooker. In this work, the performance of anodized aluminum sheet, aluminum foil, low-density polyethylene and polished aluminum sheet reflecting materials was studied with three levels of dust accumulations. The obtained observations were correlated with a standard solar cooker with no dust accumulation.

The performance of the parabolic solar cooker with standard reflecting material, i.e., anodized aluminum sheet, aluminum foil, low-density polyethylene and the polished aluminum sheet was tested with low dust (5 gm) on reflector for the average solar intensity of 638 w/m^2. Figure 4 shows the comparison of overall efficiencies for solar cooker with low dust accumulation for various reflective materials.

The working of parabolic solar cooker for the mentioned reflecting materials was then tested with dust accumulation with medium intensity (15 gm) for the average solar irradiance of 641 W/m^2. Figure 5 shows the comparison of overall efficiencies for solar cooker with medium dust accumulation for various reflective materials.

The working of the parabolic solar cooker for these four reflecting materials was further tested with high-intensity dust accumulation (25 gm) for the average solar irradiance of 640 W/m^2. Figure 6 shows the comparison of overall efficiencies for solar cooker with heavy dust accumulation for various reflective materials.

The entire series of experiments for studying the effect of dust on various reflective materials for range of solar insolation showed that performance of all reflective

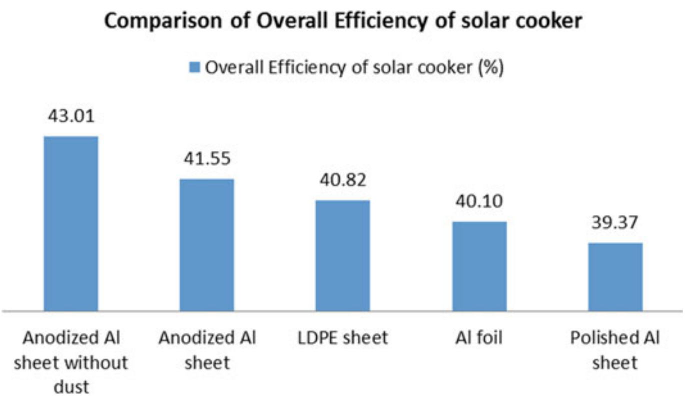

Fig. 4 Comparison of overall efficiency for parabolic solar cooker with low dust accumulation

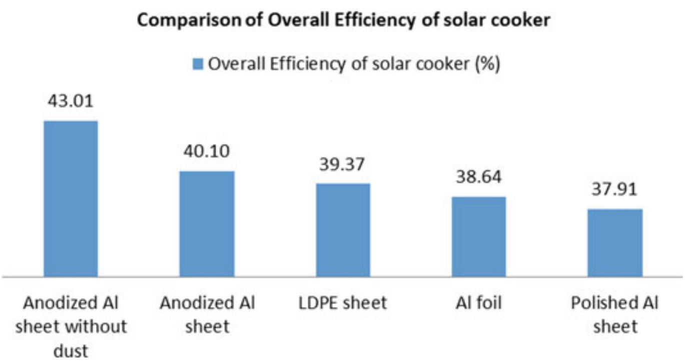

Fig. 5 Comparison of overall efficiency for parabolic solar cooker with medium dust accumulation

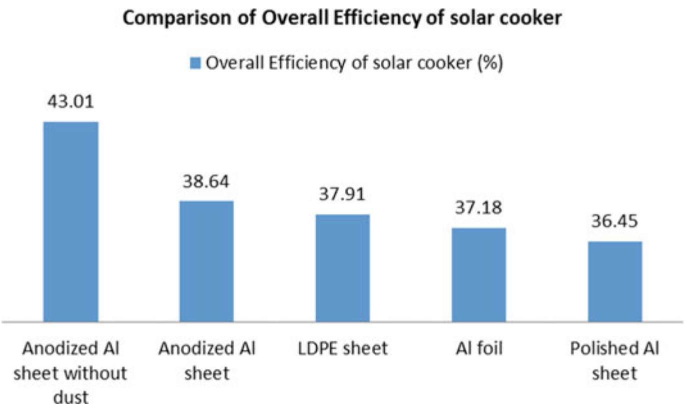

Fig. 6 Comparison of overall efficiency for parabolic solar cooker with heavy dust accumulation

materials deteriorated with dust accumulation. More the intensity of dust, more the performance deviates from the standard solar cooker.

It was observed that the reflective material polished Al sheet is most sensitive to dust accumulation, whereas anodized Al sheet is most tolerant to dust accumulation of any intensity.

9 Conclusion

When mild dust is accumulated on the reflector, the output of the parabolic solar cooker is reduced by 5%, 6.7% and 8.47%, respectively, for low-density polyethylene sheet, aluminum foil and polished aluminum sheet used as a reflecting material. For the medium intensity of dust accumulation, the performance of parabolic solar cooker is reduced by 8.4%, 10.1% and 11.8%, respectively, for low-density polyethylene sheet, aluminum foil and polished aluminum sheet used as a reflecting material. The performance of parabolic solar cooker with heavy dust accumulation is reduced by 11.8%, 13.5% and 15.2%, respectively, for low-density polyethylene sheet, aluminum foil and polished aluminum sheet used as a reflecting material.

It is observed that polished aluminum sheet is more sensitive than anodized aluminum sheet by 5.1% in all three levels of dust accumulation. So, a polished aluminum sheet is most sensitive to dust accumulation, whereas an anodized Al sheet is most tolerant to dust accumulation of any intensity. It is concluded that the LDPE sheet is the best solution for the other expensive reflectors.

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Performance Optimization of an Air Heater with Delta Flow Obstructions: A Taguchi Approach

Bronin Cyriac and Siddappa S. Bhusnoor

Abstract Air heaters are used extensively for space heating and drying agriculture products. Flow obstructions disturb the laminar sublayer formation and thus improve the performance of an air heater at the cost of additional pressure drop. In the present study, the design parameters (angle of attack—α, relative obstruction height—e/H, and relative obstruction width—b/P_t) of the delta flow obstructions were optimized using the Taguchi approach to maximize the thermal performance parameter (Nu) of the air heater with minimum pressure drop. The study reveals that the relative obstruction height (e/H) is the significant factor influencing the performance of the air heater, followed by α and b/Pt. A delta flow obstruction with $\alpha = 30°$, e/H = 0.25, and $b/Pt = 0.25$ is found to be the optimum combination of design parameters. Delta flow obstructions with optimum design parameters produce a thermal enhancement factor (TEF) of 1.76 in comparison with a smooth duct.

Keywords Air heater · Delta flow obstruction · Heat transfer enhancement · Taguchi method

1 Introduction

The reservoirs of various natural energy sources are depleting because of the increased energy demand. The increased use of energy is leading to the dissipation of natural energy sources, which in turn motivated various researchers to develop more effective methods and techniques to conserve energy [1]. Due to the poor heat transfer coefficient of air, the solar air heater's thermal efficiency is low [2]. Flow

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obstructions improve the thermal performance of air heater because of the creation of turbulence and better flow mixing [1]. Many studies have been carried out to study the thermal and hydraulic characteristics of a roughened air heater [3–12]. A summary of the previous work done on the analysis of air heater performance considering the effect of the geometry of obstruction and inclination of obstruction in the direction of flow is summarized in Table 1.

According to the literature studies, flow obstructions enhance the heat transfer properties of an air heater at the expense of pressure loss. However, the geometry and orientation of the flow obstruction have a significant impact on the thermal and hydraulic performance of the air heater. So detailed parametric analysis is required to find the optimum attack angles for improved performance of the air heater. Most of the researchers used conventional methods like optimizing one parameter at a time to optimize the geometry of the obstruction. But this method is inefficient compared to various scientific techniques like the Taguchi method. The objective of the present work is to optimize the geometry parameters of a delta flow obstruction to maximize the thermal enhancement factor (TEF) of an air heater using the Taguchi approach.

2 Materials and Methods

An air heater with delta flow obstruction was analysed using the numerical technique (CFD) for optimizing the geometrical parameters of the delta flow obstruction for maximizing the thermal enhancement factor (TEF) of the air heater. The CFD model was validated by comparing the CFD results of the smooth duct with results from empirical correlations and literature experimental results. The details of the materials and methods used in this study are explained in the below subsections.

2.1 Numerical Technique for Analysis of Thermal and Hydraulic Performance Parameter of Air Heater with Delta Flow Obstruction

For the present study, a rectangular channel (1200 mm × 300 mm × 50 mm) with a constant airflow rate (Re = 5000) was considered. The modelling of the domain and grid generation was done using ICEM CFD. The computational domain was modelled corresponding to one longitudinal pitch length (Pt) and half the duct width. The heat was supplied to the air from the bottom surface at the rate of 800 W/m^2, and the other surfaces were modelled as adiabatic walls. The symmetry boundary condition was applied to the left of the computational domain. Periodic boundary conditions were applied to the inlet and outlet, and the thermos-physical properties of air were considered constant corresponding to the inlet temperature of 300 K. The

Table 1 Literature summary on different obstructions used in air heaters

References	Type of obstruction	Re[a]	α[b]	e/H[c]	P/e[d]	Nu/Nu_0[e]	f/f_0[f]	TEF[g]
Ebrahim Momin et al. [3]	V-shaped ribs	2500–18,000	30–90	0.02–0.034	10	1.6–2		1.12–1.8
Tanda [4]	Transverse and V-shaped ribs	8900–36,000	45–90°	0.09–0.15	4–13.3			1–1.6
Karmare and Tikekar [5]	Square grit ribs	4000–17,000	60	0.035–0.044	12.5–36	1.9–2.25	2.33	1.39
Aharwal et al. [6]	Inclined rib	3000–18,000	60°	0.0377		1.4–2.6	1.8–2.8	1–1.8
Promvonge and Thianpong [7]	Triangular, wedge and rectangular shapes	4000–16,000				4.5–6.6	25–150	0.79–1.12
Thianpong et al. [8]	Isosceles triangular ribs	5000–22,000		0.13–0.26				0.86–1.32
Promvonge [9]	Multiple 60° V-baffles	5000–25,000	30–60	0.1–0.3	1–3	3.9	8.31	1.87
Chompookham et al. [10]	Winglet vortex generators	5000–22,000	60°	0.2	1.33			1.82
Promvonge et al. [11]	Longitudinal vortex generators	5000–22,000	30–60°	0.13	1.33	2.2–2.6	2.2–5.5	0.95–1.67
Tamna et al. [12]	Multiple V-baffle	4000–21,000	45	0.25	0.5–2			0.9–1.53

[a] Reynolds number
[b] Angle of attack
[c] Relative roughness height (Height of obstruction to height of duct ratio)
[d] Relative roughness pitch (Pitch to obstruction height ratio)
[e] Nu enhancement (Nusselt no of roughened surface to Nu of smooth surface of smooth surface)
[f] *f* enhancement (Friction factor of roughened surface to friction factor of smooth surface of smooth surface)
[g] Thermal enhancement factor

computational domain was discretized using unstructured tetrahedron mesh with prism mesh at the boundary.

The continuity, momentum, energy, and turbulence model were solved for the flow through the air heater using ANSYS Fluent 2019 R3. Realizable k-ε turbulence model with enhanced wall treatment was used for the analysis of the air heater. The COUPLED algorithm h used for pressure velocity coupling. Residue values less than 10^{-3} and 10^{-6} were used for velocity and continuity, respectively, for flow convergence.

2.2 Evaluation of Thermo-Hydraulic Performance Parameter Using Numerical Data

Flow obstructions improve the thermal characteristics of an air heater. But it also increases the associated pressure drop. So a term called thermal enhancement factor (TEF) suggested by Webb and Han [13, 14] was used to judge the true benefit of the flow obstruction. TEF helps in judging the true effectiveness of flow obstruction by taking care of both Nusselt number (Nu) enhancement and friction factor augmentation (f) in comparison with a smooth duct. A TEF value greater than one is considered beneficial.

$$\text{TEF} = \left(\frac{\text{Nu}_{\text{with obstruction}}}{\text{Nu}_{\text{smooth}}}\right)\left(\frac{f_{\text{with obstruction}}}{f_{\text{smooth}}}\right)^{\frac{-1}{3}} \tag{1}$$

2.3 Validation of the Computational Fluid Dynamics (CFD) Model

A smooth air heater was modelled and analysed for various flow rates (Re = 5000 to 20,000). The Nu and f obtained for the smooth duct from the CFD study for various Reynolds numbers were compared with the Nu and f obtained from standard empirical correlations given by Eqs. (2) and (3). The CFD results were compared with the published experimental results [15–17] to ensure the accuracy of the model.

Dittus–Boelter equation [18]

$$\text{Nu} = 0.023\ \text{Re}^{0.8}\text{Pr}^{0.4} \tag{2}$$

Modified Blasius equation [18]

$$f = 0.085\text{Re}^{-0.25} \tag{3}$$

Table 2 Taguchi factors and levels for the optimization of delta flow obstruction

Sr. No.	Design parameters	Levels		
		Level 1	Level 2	Level 3
1	Angle of attack (α)	30°	60°	90°
2	Relative obstruction height (e/H)	0.25	0.5	0.75
3	Relative obstruction width (b/P_t)	0.25	0.5	0.75

2.4 *Taguchi Approach for the Optimization of Delta Flow Obstruction*

Taguchi approach is an efficient tool for the design and optimization of engineering systems. It uses signal-to-noise ratio (SNR): nominal is best, lower is better, and larger is better for the optimal parameter combination. Larger is better SNR was used for the current study as the requirement is to maximize the Thermo-hydraulic performance (TEF). The SNR for larger the better is defined as [19] .

$$\mathrm{SNR} = -10\log\frac{1}{n}\sum_{i=1}^{n} y_i^2 \tag{4}$$

Taguchi factors and the levels considered for the study are listed in Table 2.

The angle of attack (α) is taken as the inclination made by the obstruction with the horizontal plane. The relative obstruction height is the ratio of the height of the obstruction (e) to the height of the duct (H). The relative obstruction width is the ratio of the width of the obstruction (b) to the transverse pitch length (P_t), where P_t is the distance between two successive delta obstructions in the transverse direction of the flow.

3 Results and Discussions

The effect of α, e/H, and b/P_t of delta flow obstructions on the performance of an air heater was studied using a Taguchi L_9 (3^3) orthogonal array. The geometry of the delta flow obstruction (α, e/H, and b/P_t) has been optimized to improve the performance of the air heater. The CFD model used for the optimization was validated by running the simulation for a smooth duct and comparing the results with standard empirical correlations and literature experimental results. The results of these studies are discussed in the below subsections.

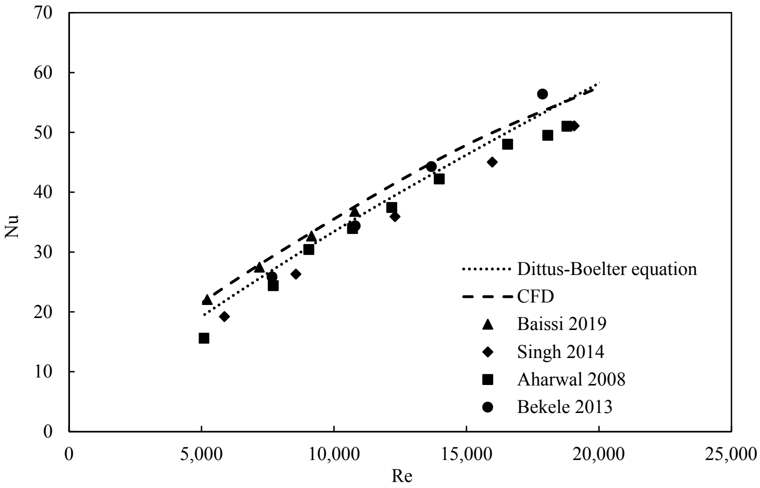

Fig. 1 Thermal performance parameter (Nu) of smooth air heater as a function of fluid flow rate (Re)

3.1 Validation of the CFD Model with Predictions from Empirical Correlations and Literature Experimental Results

For the validation of the CFD model, Nu and f of a smooth air heater were evaluated at various flow rates. The results obtained from CFD have been validated using the empirical correlations and literature experimental data as shown in Figs. 1 and 2, respectively.

The results obtained for Nu and f from the CFD are in good agreement with that of results from the Dittus–Boelter equation and modified Blasius equation with an average variation of 5.68% and 7.2%, respectively. CFD results also show a close relationship with the experimental data from the literatures.

3.2 Thermo-Hydraulic Performance Optimization of a Delta Flow Obstruction Using the Taguchi Method

The effect of α, e/H, and b/P_t of delta flow obstructions on TEF of the air heater was studied using a Taguchi L_9 (3^3) orthogonal array. Taguchi table with the Nu, f, and TEF obtained from the CFD are shown in Table 3.

The signal-to-noise ratio of the responses at various levels was found using Eq. 1. The effect of design parameters on the TEF when the design parameter changes from one level to another level is shown in Table 4 and plotted in Fig. 3.

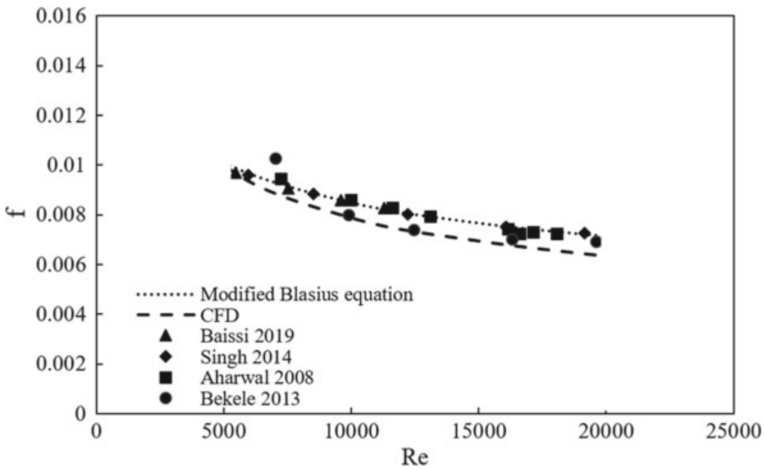

Fig. 2 Hydraulic performance parameter (f) of a smooth air heater as a function of fluid flow rate (Re)

Table 3 Design of experimental matrix and the results obtained from CFD for the air heater with delta flow obstructions

Test No	Factors			Results		
	α	e/H	b/P_t	Nu	f	TEF
1	30°	0.25	0.25	49.14	0.02	1.77
2	30°	0.5	0.5	45.97	0.05	1.28
3	30°	0.75	0.75	73.45	0.14	1.43
4	60°	0.25	0.5	44.72	0.02	1.54
5	60°	0.5	0.75	56.62	0.08	1.32
6	60°	0.75	0.25	54.57	0.05	1.49
7	90°	0.25	0.75	42.24	0.03	1.38
8	90°	0.5	0.25	38.44	0.03	1.24
9	90°	0.75	0.5	48.45	0.08	1.11

Table 4 Response of main effect plot for SN ratios

Level	α	e/H	b/P_t
1	3.391	3.838	3.438
2	3.215	2.143	2.265
3	1.869	2.494	2.772
Delta	1.522	1.695	1.172
Rank	2	1	3

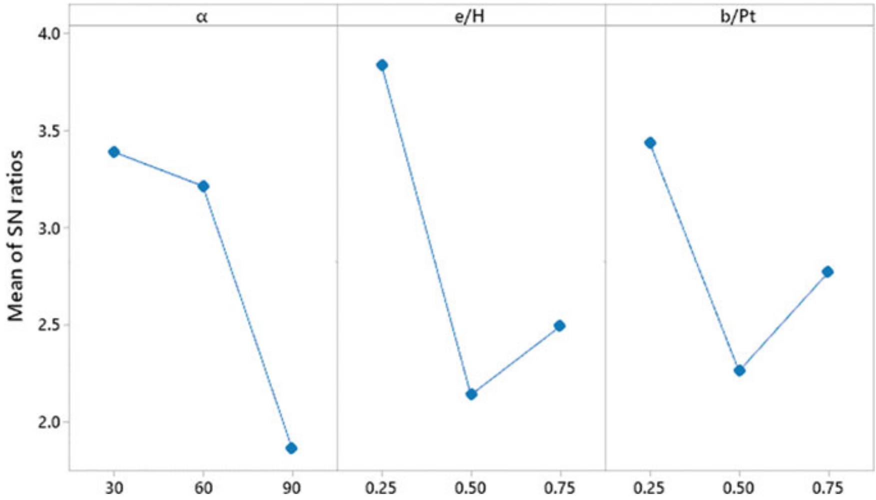

Fig. 3 Main effect plot for SN ratios (Larger is better)

The mean effect plot of SNR as shown in Fig. 3 shows that all the design parameters (α, e/H, and b/P_t) of the delta flow obstructions are having a significant impact on TEF. The factor that affects the response parameter the most is the one with the largest difference between the maximum and minimum SNR values. So, the relative obstruction height ($\Delta_{\text{max–min}} = 1.695$) is the most significant factor influencing the performance of the air heater, followed by the angle of attack ($\Delta_{\text{max–min}} = 1.522$) and relative obstruction width ($\Delta_{\text{max–min}} = 1.172$).

As per the SNR, a delta flow obstruction with $\alpha = 30°$, e/H = 0.25, and b/P_t = 0.25 is found to be the optimum combination of parameters to maximize the thermo-hydraulic performance (TEF) of the air heater.

All the configurations of the delta flow obstructions improve the thermal performance of the air heater (Nu) along with an increased friction factor (f) in comparison with a smooth air heater. The results from the study show that the delta flow obstruction with minimum angle of attack, relative obstruction height, and relative obstruction width is the best choice for maximizing the performance of an air heater. The higher values of the design parameters improve the Nusselt number but it also increases the associated friction factor. A delta flow obstruction with $\alpha = 30°$, e/H = 0.25, and $b/P_t = 0.25$ is found to be the optimum combination of parameters to maximize the TEF of the air heater. A delta flow obstruction with optimum design parameters produces a TEF of 1.77 with a Nusselt number (Nu) enhancement of 2.29 and a friction factor augmentation of 2.16 in comparison with a smooth duct.

4 Conclusions

The effect of α, e/H, and b/P_t of delta flow obstructions on the thermo-hydraulic performance of an air heater was studied and optimized numerically (CFD) using a Taguchi L_9 (3^3) orthogonal array. The relative obstruction height is the most significant factor influencing the performance of the air heater, followed by the angle of attack and relative obstruction width. A delta flow obstruction with $\alpha = 30°$, e/H = 0.25, and $b/P_t = 0.25$ is found to be the optimum combination of design parameters. A delta flow obstruction with optimum design parameters produces a thermal enhancement factor (TEF) of 1.77 in comparison with a smooth duct.

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Increase in Solar Panel Efficiency by the Use of Easy Mirror and Cooling Gadget

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Abstract Powered by solar cells, CPV has an advantage over non-concentrated photovoltaics as it requires fewer large solar cells for the same intensity output. Besides the duration and intensity of sunlight, the temperature also affects the overall performance of PV modules. This is because excessive temperatures will significantly reduce the output power. This research paper describes practical ways to improve the overall performance of solar panels using the valuable resource of using mirrors and cooling mechanisms. These reflectors are inexpensive, easy to install, and require no machinery or equipment to install. However, the CPV works effectively in concentrated light as long as the solar cell is kept cool by the heat sink. Experimental results show a significant improvement over the traditional sun panel output.

Keywords Solar panel · Simple mirror · Cooling system

1 Introduction

Solar energy is the conversion of electricity from the day to electricity, using photovoltaics (PV), colloquially using concentrated solar energy, or mixed. The Focused Photovoltaic Structure uses lenses or mirrors and a sun tracking system to focus a large area of sunlight into a small beam. Solar cells use the photovoltaic effect to convert light into electric state-of-the-art electricity. Centered photovoltaic (CPV) technology uses an optical system containing a cell to generate power [1]. CPV has an advantage over off-center photovoltaics as it requires a smaller amount of solar cells for the same energy output. In addition, sunlight intensity and temperature have a very positive impact on the overall performance of PV modules, as high temperatures significantly reduce the output power. This project describes a practical approach to improving panels using mirrors and cooling mechanisms. The solar power was initially fully utilized to power small- and medium-sized applications, from a solar-powered calculator to his home in a remote location powered by an off-grid rooftop

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PV array. A commercially concentrated solar energy flower was first developed in the 1980s [2]. As free solar energy dwindles, the variety of grid-connected solar structures has risen to the hundreds, and utility-scale solar power plants are being built with multi-megawatt loads. This white paper describes a rational approach to improving the performance of sun panels using mirrors and cooling mechanisms. These reflectors are cheap, easy to use, easy to apply, and eliminate the need to use a device. However, CPV works efficiently in concentrated heat as long as the solar cells are kept cool using some heat sinks [3]. Experimental results show that the baseline performance of the solar panel is significantly improved. Experimental measurements obtained with no reflector and no cooling, with reflector and no cooling, and with reflector and cooling are compared.

2 Literature

Rizwan Arshaad et al. (April 2014) describe a practical method to beautify the performance of sun panel through the usage of mirrors and cooling mechanism. Those reflectors are cheap, clean to handle, simple sufficient to use, and need no more system or gadgets to apply. But CPV performs efficiently in concentrated light so long as the sun cells are kept cool by way of some heat sinks. Experimental effects indicate considerable enhancement in ordinary output of sun panel.

Muhammad Bilal et al. (February 2016) illustrate sun strength conversion to electricity thru PV cells has grown to be extra preferred, but excessive rate of cells and lower efficiency have obstructed its use in growing international locations. One way to reduce the excessive cost in keeping with kWh of electricity is to beautify the overall performance of PV module systems. Low fee reflecting mirrors, lenses, and light focusing concentrators can be a very good solution. These mirrors listen the mild intensity over the entire surface of the panel. The effect is that the extra electrons are generated as a result, the output energy of the solar module will increases.

However, the effect of improved light radiation for longer time is the raised temperature of the panel, which could inversely lessen the open circuit voltage (Voc) and decrease the efficiency. To tackle this hassle, a proper cooling gadget can be needed to maintain the PV module's overall performance. This paper offers the contrast performance of a PV module without reflecting replicate and with reflecting mirror and manual monitoring. The values of brief circuit modern and open circuit voltage have been measured underneath unique conditions of monitoring. The output strength became calculated, and the values were obtained for different combinations. Findings from the experiments present that thru the use of concentrators, a 25% imply upward push of short-circuit (Isc) currents with solar monitoring may be executed. Effects additionally display that PV module with handiest monitoring gives higher output than the device without tracking, but the gadget with reflecting reflect and tracking gives greater output power. Appealing outcomes have been acquired with concentrators and mirrors set up with the PV module. With the assist of negligible energy consumption by way of concentrators and reduced complexity in comparison with solar monitoring, use of concentrator or reflecting mirrors would be competitively priced in comparison with sun monitoring. Similarly to that, setup of reflectors and concentrators is straightforward. They are cost-powerful, clean in addition, don't need any similarly preservation or other complex gadgets [4].

Alok Ranjan et al. (September 2015) centered on to increase output power the use of mirrors and as a consequence calculate the efficiency by way of taking readings in numerous daylight situations. PV panels have no moving parts and generally live with much less protection for two decades or greater. Landlords can add PV panels and save on their monthly electricity bills. Also, a utility company can create a large monthly "farm" of his PV panels to provide green energy per month. CPV is the amount of solar cells required for the same power generation, so it benefits from monthly voltaic concentrations. Due to this duration and sunlight depth, the temperature also has a great effect on his total output of his PV modules. This test provides a realistic estimate of the monthly increase in efficiency of the sun panel through the usage range of the mirror mechanism. However, the experimental effect shows a staggering increase in the normal production of solar panels [5].

3 Methodology

3.1 Reflecting Mirrors

The light reflected by the mirror is very fine and unique light mirror images due to moderate reflection across the solar panel, which increases the output current and rated voltage, thus improving the overall performance of the PV panel device improve. The following Fig. 1 illustrates reflecting mirrors methodology.

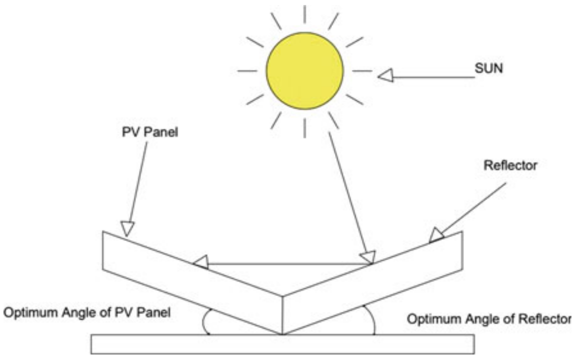


Fig. 1 Reflecting mirrors methodology [6]

3.2 Cooling Mechanism

Based on the study under focused solar radiation, the total output power of the solar cell is reduced by 50%, and the temperature rises from 46 to 84 °C. Therefore, a green cooler is very important to maximize the performance of your solar panel and protect your mobile from deterioration and damage. Solar modules can be cooled actively or passively.

3.3 Experimental Setup

The following approaches proposed to improve the performance of solar panel are mainly based on the experimental facts predicted by the measurements; graph is obtained from his three different strategies. Some of these readings transmit his indefinitely into the future for his three sunny days in April. This experiment uses silicon semiconductor monocrystalline solar panels. Iron body is modified to house solar panels and mirrors. This experimental technique uses the energy chiller to improve the overall performance of the PV module. A PVC plastic tube with a hole in the bottom is fixed to the frame of the sun visor so that he can supply water from the rubber tube as well from the water tank.

4 Design and Components

Structure Design: The following Fig. 2 created the solid model of frame using CAD software. Figure 3 shows the fabricated frame of solar panel display to perform experimental work (Table 1).

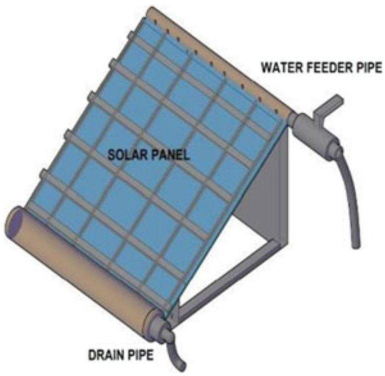


Fig. 2 CAD design of frame

Fig. 3 Fabricated frame of solar panel display specifications of various components: Drain pipe: Diameter = 4-inch, Length = 27 inch, Water feeder pipe: Diameter = ¾ inch, Length = 27 inch Ball valve: ¾ inch solar panel: 60*60 cm

Table 1 Specifications of solar panel

Model	TEL12P40
Panel type	Monocrystalline
Solar panel dimension (L*B) mm	660*500 mm
Short circuit current (A)	2.35 A
Maximum power voltage (V)	18.68 V
Open circuit voltage, Voc (V)	22.43 V
Maximum power current, (A)	2.20 A
PRICE	₹1900.00

Mirror: Dimensions of mirrors are 660*500 mm. Mirror is used for to consenter the solar radiation on to the panel. Thus, it will increase the power output, so here we used 660 × 500 mm mirror. This will mount on the frame.

PVC Pipes: PVC Pipe (3/4 × 27 inches): PVC pipe will be used to sprinkle the water on the panel. This pipe will have holes on its periphery on specific intervals.

Ball Valve (3/4 inch): This will be used to connect pipe to water tank. PVC Drain Pipe (4 inch): This pipe will be used as a stopper.

Water Tank: This will be used to store the water.

Electrical Accessories: Some of electrical accessories used in this project, such as multimeter, wires for the connection, solar disconnector, and infrared thermometer.

Overall Structure: Following Fig. 4 illustrates overall structure of the solar panel system with cooling effect.

Fig. 4 Overall structures

Fig. 5 Experimental setup for without concentration and cooling system

5 Data Analysis

5.1 Without Mirrors and Without Cooling

In this methodology, we perform experiment on only solar panel without using mirror and cooling system. And, following are the results of experiment. In this type, temperature of panel increases continuously, due to rising in temperature, panel efficiency decreases, and we obtained fairly low output as temperature increases. Following Fig. 5 illustrates experimental setup for without cooling and concentration.

5.2 With Mirrors

In this methodology, we perform experiment on solar panel with using mirror. By using mirrors concentration on solar panel increases and thereby increasing output of

Fig. 6 Experimental setup for cooling system

panel. And following are the results of experiment. In this type, temperature of panel increases continuously, due to rising in temperature, panel efficiency decreases, and we obtained fairly low output as temperature increases, but due to more concentration, output of this methodology is fairly more as compared to first methodology.

5.3 With Cooling

In this methodology, we perform experiment on solar panel with active cooling system. By using cooling system, temperature of panel decreases considerably. In this method, we try to keep temperature of panel in the range of 38 °C to 45 °C. As in this temperature range, we obtain more output as this range is standard range to obtain fair results. To keep temperature of panel in specified range, we cooled the panel for every 10 min. And once the temperature range is obtained, we stopped the cooling, and after that, the readings are taken. And output is fairly good than the other two methods. Output voltage is also in minimum range. Following fig illustrates experimental setup for with cooling (Fig. 6).

6 Experimental Work

With mirror, without cooling, with mirror, with cooling effect, and time measured value by temperature observation factor, the changes are made accordingly as given in Table 2.

The overall performance of a photoelectric mobile is measured in phrases of its performance at turning sunlight into strength. Much of the mild energy is meditated or absorbed by way of the fabric that makes up the mobile. Because of this, a normal commercial photovoltaic cell has efficiency between a low of five% to a high of 20%. On common most effective approximately one-sixth of the daylight putting a

Table 2 Observation table

Sr	Time	Without mirror and without cooling				With mirror				With cooling			
		Temp	V	A	P	Temp	V	A	P	Temp	V	A	P
1	11.00	38	20.3	2.21	448	38	204	2.21	45.08	39	204	2.19	44.67
2	11.15	39	20.1	2.23	448	40	202	2.23	45.04	41	206	2.20	45.32
3	11.30	40	19.7	2.26	445	43	203	2.22	45.06	41.5	210	2.22	46.62
4	11.45	42	19.5	2.28	444	43.2	205	2.20	45.1	42	209	2.30	48.07
5	12.00	41.2	19.3	2.30	443	44	205	2.21	45.30	42.3	208	2.31	48.04
6	12.15	45.5	19.2	2.26	433	45.5	206	2.22	45.73	42.5	209	2.32	48.48
7	12.30	50.2	19.1	2.28	435	50.5	206	2.25	46.35	42.2	212	2.31	48.97
8	12.45	65.63	18.9	2.26	427	65.2	204	2.29	46.71	42.6	210	2.33	48.93
9	13.00	64.78	18.9	2.25	425	64.2	197	2.30	45.31	42.5	209	2.3	48.07
10	13.15	64.79	18.7	2.25	420	64.5	195	2.32	45.24	42.9	211	2.3	48.53
11	13.30	64.7	18.7	2.24	418	64.7	195	2.32	45.24	43.1	208	2.29	47.63
12	13.45	64	18.8	2.24	421	64.1	194	2.31	44.81	43.1	209	2.28	47.65
13	14.00	63.5	18.7	2.21	413	63.2	192	2.31	44.35	43.2	208	2.23	46.38
Average			19.22	2.25	432		200	2.26	45.33		208	2.27	51.86

photovoltaic or sun cellular generates strength. The following fig illustrates circuit diagram of solar panel (Fig. 7).

Efficiency is calculated by output divided by input. So here, Input = power received from sun by solar panel. So, Input = Area of solar panel/solar irradiance at STC For given solar panel, Area = 660*500.

Solar irradiance at STC = 1000 W/m^2.

Input power = 660*500/1000, Input power = 330.

Now, Output = power developed by solar panel in terms of wattage.

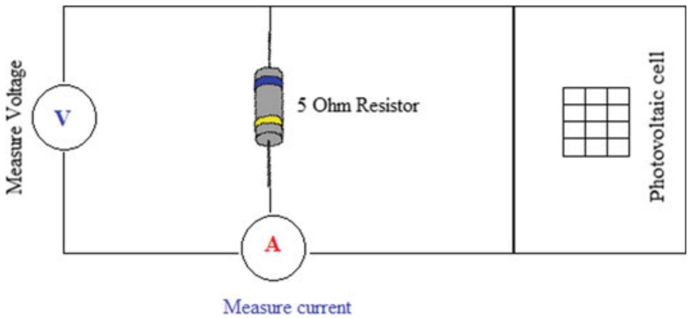


Fig. 7 Circuit diagram of solar panel [6]

Table 3 Observation table of efficiencies of all three methods

S. N.	Method of experiment	Efficiency (%)
1	Without concentration and cooling system	13.11
2	With concentration	13.80
3	With cooling system	15.71

So here we have taken average power of each method and calculated the results Without Concentration and Cooling System:

Efficiency = (Output/ Input) *100 Efficiency = (43.27/330) *100 Efficiency = 13.11%.

With Concentration Efficiency = (Output/Input)*100Efficiency = (45.33/330) *100 Efficiency = 13.80%.

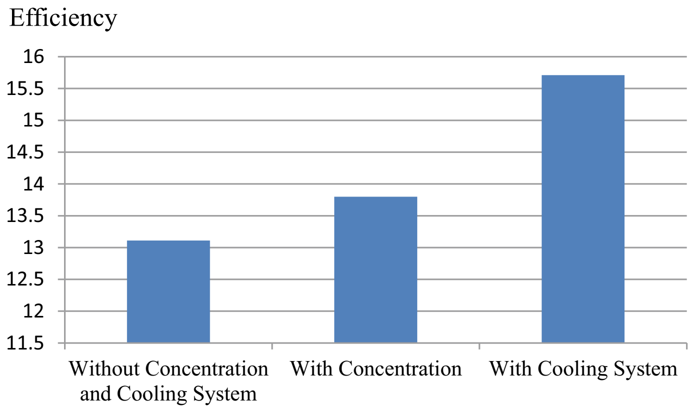
With Cooling System: Efficiency = (Output/ Input) *100 Efficiency = (51.86/330).

*100 Efficiency = 15.71% (Table 3).

7 Result

From above Graph 1, we can say that cooling of panel greatly effects on efficiency of solar panel as efficiency increased considerably more as compared to other two methods.

1. Without concentration and cooling and
2. With concentration.



Graph 1 Comparison efficiency versus types of solar system

Using concentration efficiency of solar panel increases by 0.69%. Whereas, using cooling system efficiency of cooling system increases by 2.6%.

8 Conclusion

The results of experiments using the chiller to increase the efficiency of solar panels are very encouraging. The cooling consumption is higher than the other two. The output power of the easy solar panel without mirror is 43.27 w, the solar panel with mirror is 45.33 w, and the cooling consumption is 51.86 w. Without any concentration and cooling system, we analyzed that due to increasing temperature of solar panel open circuit voltage of panel decreases due to this power output decreases. Hence, efficiency of panel decreases. Using concentration, efficiency is increased but not up to great extent and efficiency is limited. But using cooling system, open circuit voltage of panel increases as temperature of panel decreases due to which efficiency is increased. And increase in efficiency is more as compared to other methods. Hence, cooling system is more advantage able. Therefore, from obtained result, we can conclude that use of cooling system for increasing efficiency is more advantageable than using mirror. By using concentration efficiency of solar panel increases by 0.69%. Whereas, using cooling system efficiency of cooling system increases by 2.6%.

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Structural Analysis of Endodontic Restorations

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Abstract An intraoral prosthetic called a dental prosthetic is used to repair intraoral flaws such as missing teeth, sections of teeth, and missing soft or hard elements in the jaw and palate. The dentistry specialty that focuses on dental prosthetics is called prosthodontics. These prostheses are utilized to restore mastication (chewing), enhance appearance, and facilitate communication. A dental prosthesis can be fixed to teeth or dental implants, suctioned into position, or held passively by the muscles around it. There are many materials which are commonly used for dental restorations, such as porcelain, zirconia, dentin, gold, and amalgam. The objective of this research is to compare prostheses made of ceramics and zirconia to find their breaking stress using Finite Element Analysis (FEA) and validate the results of FEA with experimental results.

Keywords FEA · Endodontic · Dental · Breaking stress

1 Introduction

Human teeth serve to mechanically break down food by cutting and crushing it so that it may be swallowed and digested. The four different tooth kinds that humans have—incisors, canines, premolars, and molars—each serve a particular purpose. Food is sliced by the incisors, torn by the canines, and crushed by the molars and premolars.

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The gums cover the tooth roots, which are located in the mandible (lower jaw) or maxilla (upper jaw). Teeth are made of multiple tissues with differing densities and hardness.

Due to proliferation of junk food and carbonated drinks, cases of dental cavities are increasing. There is a close relationship between oral health and general health. For example, effective mastication reduces the burden on the digestive system. Therefore, improving oral health is expected to improve general health.

Rekowa et al. [1] studied the relation between the crown material of tooth and its thickness and found that the crown material and thickness are of primary importance in the induction of stress magnitude. The study by Hojjatie et al. [2] suggested that orientation of the applied load has a more important effect on development of large tensile stresses than the occlusal thickness of ceramic.

Jiang et al. [3], studied stress distributions on various dental restorative materials. The study revealed that, the restorative materials exhibited similar stress distribution patterns under identical loading conditions. Rosentrit et al. [4] conducted study to evaluate the in vitro behavior of ceramic zirconia molar crowns by considering various core designs and marginal fit. The study showed that there is no effect of the in vitro performance on the variation of the gap thickness.

Al-Amleh et al. [5] studied the effect of thickness of porcelain and rate of cooling on residual stresses. The material used for the study was zirconia molar crown. It is concluded that the geometry of teeth and cooling rate have substantially different effects on residual stress profiles. Marit et al. [6] studied features of fractures on glass ceramic and zirconia-based dental restorations and found that regardless of the composition of the core material, all ceramic restorations fracture in similar ways.

Statistical analysis performed by Salameh et al. [7] revealed that specimens with fiber posts demonstrated significantly higher failure loads and favorable fracture pattern compared to the composite core buildup.

The objective of current research is to determine the stress levels due to mechanical loads in restored tooth by using FEA and validate the results of FEA using experimental results. The materials used for the analysis were zirconia and ceramic.

2 Forces Acting on a Molar Tooth

Various forces are applied to the teeth during mandibular movement and mastication. Because the tooth surfaces are curved or inclined, additional forces may be acting on them in addition to the vertical ones. The periodontal and alveolar tissues of the tooth work together to counteract these forces. Only vertical forces are involved when the surfaces are flat and parallel to the force of mastication. In curved surfaces, additional forces develop and may not be applied along the tooth's long axis. It is assumed that the cuspule planes are inclined planes.

When a force is applied perpendicular to a fixed horizontal surface, the resolving force applies an equal and opposite force perpendicular to the surface. The surface still responds at a right angle to the surface even if it is slanted at an angle to the

Table 1 Material properties

Sr. No.	Parameters	Ceramic	Zirconia
1	Elastic modulus	65–90 GPa	110 GPa
2	Poisson's ratio	0.3	0.22
3	Density	2.2 g/cm^3	5.68 g/cm^3

horizontal. As a result, when forces are applied to inclined planes, they are not in equilibrium.

3 Material Properties

The materials used for the analysis were zirconia and ceramic. Table 1 depicts some of the physical characteristics of ceramic and zirconium.

4 Commonly Used Teeth Terminologies

Surface that is distant from the face's midline is referred to as distal. The area of the face that is in contact with the lips or cheeks is called facial. The area closest to the lips is labial. Buccal refers to the area that faces the cheeks.

The tooth's anterior biting edge is called incisal. The tongue-facing surface is referred to as lingual. The portion of the face that is closest to the midline is known as the mesial.

The chewing surface of back teeth is called the occlusal. Proximal tooth surfaces are those that are close together (i.e., distal of lateral incisor and mesial of canine).

5 Finite Element Analysis

FEA is performed on both the materials used for the analysis. The software used for the analysis was ANSYS. In order to import the dental model into FEA software, the digitization of prototype model into numerical model was studied and generated using the CAD application. The numerical model is meshed using tetrahedral elements, and appropriate material properties and boundary conditions were assigned to this model. Finally, the model is submitted to solver for the analysis.

5.1 FEA of Ceramic

Figures 1 and 2, respectively, show the course and fine meshing of tooth model. As fine mesh model qualifies for the convergence test, it was used for the analysis. A tetrahedral element with mesh size of 2 mm was used. A force of 200 N was applied on the lingual surface of the tooth, and the bottom surface was fixed as shown in Fig. 3.

Figures 4 and 5 show total deformation and von-Mises stress on ceramic, respectively. The maximum deformation and von-Mises stress was found to be $9.65e^{-5}$ mm and 7.16 MPa.

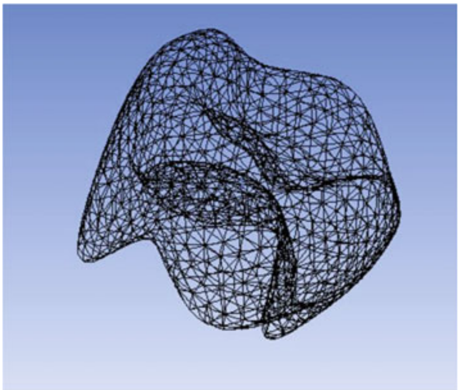

Fig. 1 ANSYS course meshing of ceramic

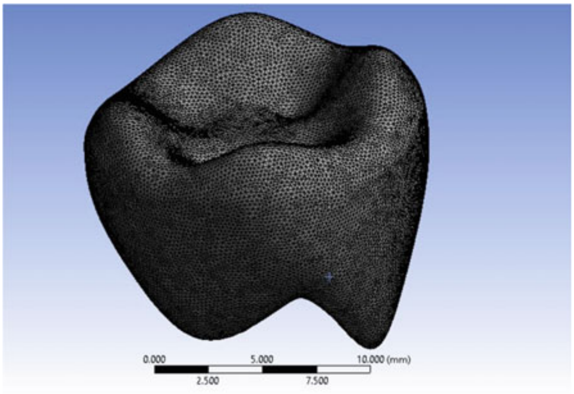

Fig. 2 Fine meshing of ceramic

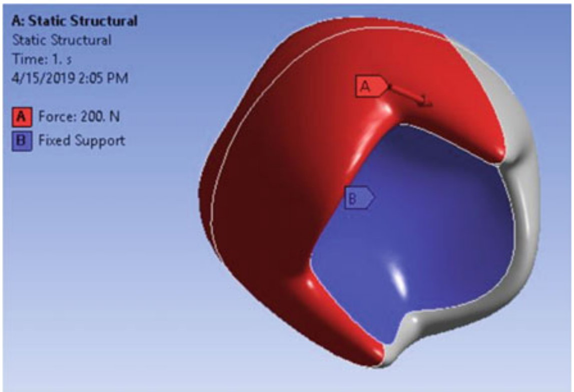

Fig. 3 Application of boundary conditions

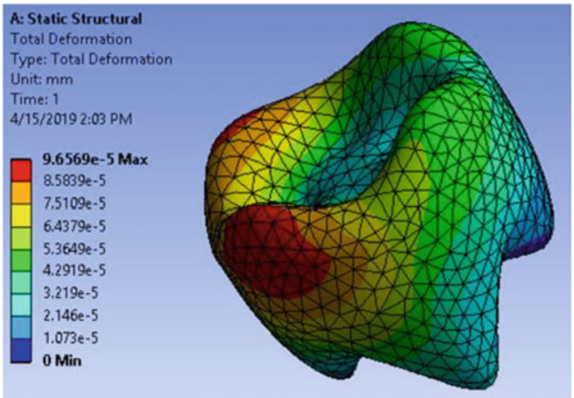

Fig. 4 Total deformation of ceramic

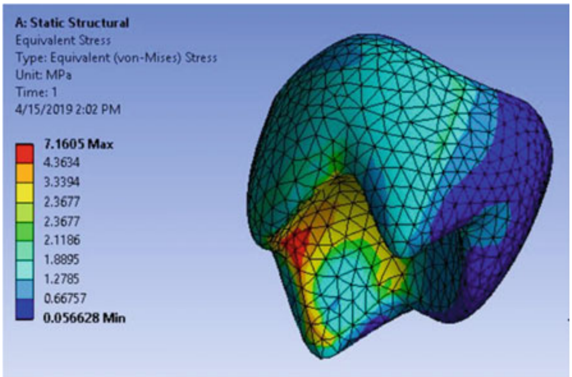

Fig. 5 Equivalent stress on ceramic

5.2 FEA of Zirconia

The meshed model and boundary conditions used for both the ceramic and zirconia are the same as shown in Figs. 1, 2, and 3. Also fine mesh model qualified for the convergence test was used for the analysis of zirconia.

Figures 6 and 7 show total deformation and von-Mises stress of zirconia, respectively. The maximum deformation and von-Mises stress was found to be $2.0869e^{-4}$ mm and 7.06 MPa.

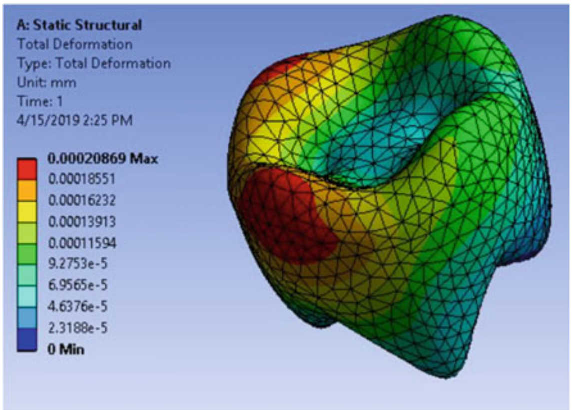

Fig. 6 Total deformation of zirconia

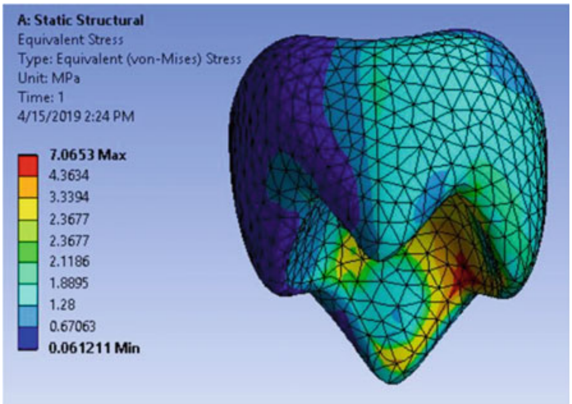

Fig. 7 Equivalent stress on zirconia

6 Experimental Testing

The testing was done for both the molar teeth of ceramic and zirconia to find the bearing strength on lingual surface of teeth. The compressive testing machine (CTM) was used to find the strength. The first step in testing the teeth was to measure the dimensions of teeth and find contact area, as contact area is required to input during testing. The dimensions of the teeth were measured using vernier caliper and are shown in Fig. 8.

As an example, the effective contact area calculation is shown for ceramic. The effective area can be approximated to a trapezium having two parallel lengths as 14 mm and 8 mm and height between two parallel sides as 10 mm. Therefore, effective area was (14 + 8) *10/2 = 110 mm^2. Therefore, the load acts on the area of 110 mm^2 (1.1 cm^2).

6.1 Experimental Testing of Ceramic Molar Tooth

A digital automatic compression testing machine of capacity 250 KN was used for the measurement of stresses. The effective area of tooth 1.1 cm^2 and pace rate of 0.1 KN/sec was given as input as shown in Fig. 9.

As shown in Fig. 10, to avoid motion of tooth while applying load on it and for firm holding of tooth, a plate containing tooth surrounded by cement is used. This plate is placed in compression testing machine on which another upper plate applies the load on tooth.

The load was applied on lingual surfaces for determining the breaking stress of the tooth. From the experiment, the breaking stress of ceramic molar tooth was found to be 80 MPa. Figure 11a shows the broken pieces of ceramic after the testing.

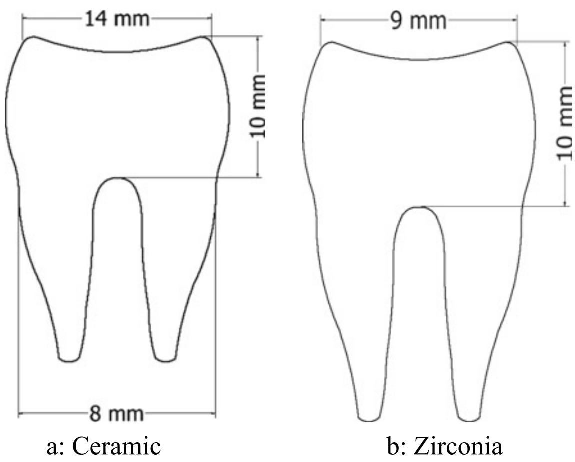

Fig. 8 Molar tooth dimension (contact area)

Fig. 9 Display of CTM

Fig. 10 Testing arrangement

6.2 Experimental Testing of Zirconia Molar Tooth

As explained in the Sect. 6.1, the testing of zirconia molar tooth was carried out in similar way. Based on the dimensions of the tooth, the effective area on which load acts was found to be 90 mm^2. This area and 0.1 KN/s as pace rate of loading was

a.Ceramic b. Zirconia

Fig. 11 Broken pieces of sample after testing

given as an input to CTM. The breaking stress for zirconia tooth was found to be 84.4 N/mm^2. Figure 11b shows the broken pieces of zirconia after the testing.

7 Conclusions

Numerous factors can be harmful to a tooth's health, and the consequences of multiple factors together can be detrimental. Oral health is at danger when a tooth or dentition has a structural flaw because the flaw cannot heal on its own. Dental prostheses, which are artificial devices, are therefore required to replace one or more lost natural teeth or to restore a damaged, unsightly, or malfunctioning tooth.

In this paper, the structural integrity was analyzed for two dental restoration materials, viz. ceramic and zirconia. The analysis was carried out using FEA, and the results of the FEA were validated by experimental results.

From the results of FEA, the deformation and stress for ceramic material were found to be 9.65e–5 mm and 7.16 MPa, respectively. For the zirconia, these values were 2.0869e–4 mm and 7.06 MPa. The analysis was also carried out by conducting test on CTM, and the breaking stresses of ceramic and zirconia were found to be 80 MPa and 84.4 MPa. As the results obtained by FEA were well within the limits of breaking stress, therefore the analysis was safe.

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Experimental Analysis of Sprayer for Horticulture and Orchards

S. D. Shelare, S. N. Waghmare, M. M. Yenurkar, and G. R. Jodh

Abstract This research paper intends to provide an analysis of the electric motor-operated heated triple pump (HTP) sprayer for a long range of jet discharge used in horticulture and orchards. The spraying is used to control the weeds, insects, and disorder subjected to crops, such as grass, fruits, and vegetables. This sprayer is assured by the HTP unit, which is driven by an electric motor. The HTP unit consists of three pistons which are referred to as "heated triple pistons" which move in a water suction chamber which sucks water from the formulation tank by the reciprocating motion of a triple piston. These triple pistons are connected together by means of a crankshaft in perfect coordination, and the rotational movement of the crank shaft is achieved by means of a pulley which is mounted on a crankshaft stop which is driven by an electric motor and power is delivered to the pulley by means of a V belt. The electric motor is rotated at 1400 RPM. The electric motor is single-phase operated and requires a 230 V to 240 V electric supply to run the electric motor, which has a frequency of 50 Hz. This HTP sprayer unit is used to achieve a high pressure of 10 bars to 30 bars, and a range of 1 m to 10 m is achieved by using this spring unit. This spraying unit can minimize non-uniform calibration of mist formation.

Keywords Sprayer · Horticulture · Agriculture

1 Introduction

The revolution in technology has made agricultural practices shift toward the automation in irrigation, pest control, soil conditioning, and tree growth regulation using various plant growth promotion sprays [1–5]. The liquid formulation spraying technique is employed for controlling diseases. Hydraulic sprayers are used to manipulate weeds, insects, and disorder in subject crops, ornamental, grass, fruits, and

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vegetables [6–8]. A massive range of producers supply tractor-mounted, pull-type, pickup-mounted, and self-propelled sprayers for a variety of varieties of spraying. Modern agriculture relies on technology and a fair share of such technology is involved in Indian agriculture. Agriculture spraying has proved to be a boon for crops if the spraying method employed is efficient [9–12]. The expensive expense of pesticides, as well as the necessity to safeguard the environment, motivates applicators should use caution while handling and spraying insecticides. Many application issues, according to research, are caused by poor sprayer calibration [13–16]. According to a North Dakota survey, 60% of pesticide applicators were either over or under applying pesticides due to errors in application method environmental conditions and the wrong way of spray machine selection [17–20]. The sprayers used in practice have calibration error, non-uniform mist formation, the large particle size of output mist droplets, high cost of operation, high requirement of human effort, and high fuel consumption. In present work, HTP sprayer was manufactured, and trail were carried out to check its feasibility. This spraying unit is capable to minimize non-uniform calibration of mist formation.

1.1 Various Spray Pumps Available in Market

Generally, farmers are more inclined toward cost-effective solutions and low-budget machines. Many companies had introduced low-cost spray pumps in the market, which are not effective in service and cost effectiveness, if analyzed for long-term use; here are some spraying machines available in the market which are commonly used in agriculture practice are as follows [21–27].

1.2 Knapsack Sprayer

It is a mechanically operated spray pump. So it required continuous human effort. This pump is carried on the back of the operator. Thus, it causes fatigue to the operator. It has 20 L formulation tank, which is very heavy to carry on the back of the operator. Pressure created in this pump is using plunger which is connected to the piston of the pump. Hence, it is not suitable for high pressure. It can spray only 45 L of formulation per hour.

1.3 Knapsack Pump

It is an engine-operated spray pump. Run on petrol so it involves the fuel cost. It may be 2 stroke and 4 stroke engine, which require regular maintenance. It has a separate chemical tank and fuel tank which increases the load. It can spray 8 L of formulation per minute, but tank refilling is a time-consuming and labor-oriented job. It has 20 L formulation tank, which is very heavy to carry on the back of the operator.

1.4 Mist Dust Sprayer

It is a kind of knapsack power sprayer. It is used to spray liquid chemicals in mist form and urea in granule form. It can spray dust powder from pesticides also.

1.5 Orchard Sprayers

It is tractor-mounted equipment suitable for a large area of land. Hence, farmers who are not having tractors cannot use them. It can spray plant growth regulators and foliar nutrients to orchard trees. It is very expensive. It can spray 54 L of formulation per minute. But diesel consumption of tractors increases with the increase in discharge, which is expensive.

2 Problem Analysis of Present System of Spraying Technique Used in Agriculture

The spraying technique employed in agriculture is generally based on traditional way of spraying by using low-cost sprayers. The maintenance of spraying devices leads to leakage, discomfort, exposure to poisonous chemicals, and human fatigue.

The main problems analyzed in spraying are:

- Manual sprayers used in vegetable and food grain category crops require continuous human effort to move the handle of plunger attached with the spray pump.
- Fuel-operated spray pump involves high fuel cost and high labor cost. This pump is generally carried on back by the operator. Hence, it causes fatigue.
- Fuel-operated pump available in market is not having long range output of spray mist.
- Fuel-operated pumps cannot be operated from a single place for large area of land.
- Spraying formulation in large quantities cannot be sprayed in small times in summer or rainy seasons, when the actual duration of working for labor having variable timings.
- In Indian farms, spraying is typically done with one of two types of spray pumps: manual operated spray pumps and fuel-powered spray pumps. Which is the most popular hand-held spray pump? A more serious disadvantage of a hand-operated

spray pump is that the operator cannot use it for more than 5–6 h without being fatigued.

- Whereas a fuel-powered spray pump requires gasoline, which is both expensive and difficult to get in rural areas. At the same time, it emits CO_2 as a pollutant that harms our ecosystem.
- In present times, various pumps available in the market, weather it is fuel operated or manually operated pumps, are not capable of spraying on the tall trees like mango, pomegranate, guava, custard apple, orange, etc. They cannot spray at a range of 600 m from a single place. It cannot spray formulation at a height of 10 m for fruit trees. It is very heavy to carry on the back of the operator. It is found that some spray pumps can spray at a higher rate but they are very expensive to buy. Some of the spray pumps available in the market operated on two strokes and four strokes petrol engine which exhaust CO_2 in the environment which causes global warming.

3 Material and Methods

In our proposed system, the assembly of the HTP sprayer is done on a mild steel frame which has dimensions of 1.2 feet by 3 feet in length and breadth. The frame is made by means of welding, and the mounting for the electric motor and HTP unit are made in the form of slots by which we can adjust our HTP unit and electric motor according to the length of the V-belt. The electric motor is tightened on the frame by means of nuts and bolts. The HTP unit rpm ranges between 800 and 1000, which is achieved by means of the electric motor.

3.1 Various Components of Proposed HTP Sprayer

This HTP sprayer unit consists of various types of components and its sub-components which are as follows:

3.1.1 HTP Sprayer

Specification: Its suction volume ranges from 10 Lit/min to 22 Lit/min. HTP sprayer has excellent pump speed ranging between 800 and 1200 rpm. Impressive output pressure ranging between 10 and 30 bar, which weighs about 8 kg in weight. Its body is made up of cast iron. For HTP sprayer, we have to use one liter of oil for lubrication.

3.1.2 Electric Motor

Specification: Heavy Duty 2 HP Single Phase Induction Motor, 4 Pole Cast Iron Body. It has copper winding and runs at 1440 rpm rotational speed. The electric motor requires a voltage range between 230 and 240 V. It is a single-phase type electric motor having a frequency of 50 Hz and foot mounting.

3.1.3 V-Belt

Specification: V-belt is a rubber belt used to drive an HTP sprayer with an electric motor. We select grade A type V-belt, based on our calculation.

3.1.4 Pulley

Specification: Pulley is used to transmitting power from the driver pulley to the driven pulley. Pulley has a trapezoidal cross section.

3.1.5 Suction Tube

Specification: Suction tubes are made up of rubber. It is 5 feet in length. Suction tubes are an important part of the HTP sprayer, suction pressure formulation from the formulation tank, which is huge in spraying applications.

3.1.6 Delivery Tube

Specification: It is made of solid plastic which makes it long lasting and durable. It is 50 Mtrs long durable five-layered pipe. The delivery tube can handle extremely high pressure, which helps in increasing the range of the HTP sprayer.

3.1.7 Spray Gun

Specification: The spray gun is made up of stainless steel. It makes the mist of tiny water droplets suitable for spraying. The spray gun has a regulating sprayer which helps in increasing or decreasing mist formation and the height of spraying formulation.

3.1.8 Pressure Gauge

Specification: A pressure gauge is a device that calculates the force exerted by a liquid or gas on a surface. It is a pressure gauge that is filled with liquid. It is glycerine-filled.

3.1.9 Regulating Valve

Specification: Regulating valve is given on the HTP unit to regulate the pressure of water. We can regulate water pressure by regulating the valve from low to high.

3.1.10 Output Valve

Specification: HTP unit has two put valves for spraying. The output valve delivers pressure outside of the sprayer for spraying.

3.1.11 Foot Valve with Strainer

Specification: Foot valve is used for suction of water from the water tank. Foot valve is installed at a pump or the bottom of a pipeline. Suction tubes are made up of rubber. It is 5 feet in length.

3.2 Economic Analysis of Sprayer

The economic analysis of prayer is done by comparing the HTP sprayer and the engine-operated spray pump on various aspects, because this can clear both the price of operation and the efficiency of both the pumps. In the Table 1, the comparison of both the HTP sprayer and the engine-operated speed bump is made.

3.3 Fabrication Cost

Fabrication is one of the most important parts of any assembly, because it combines all the components of any assembly into one piece, and that requires some cost, so the cost of our spraying unit is as given in Table 2.

Table 1 Comparison of both the HTP sprayer and the engine-operated speed bump is made in this table

SN	Point of comparison	HTP sprayer	Engine-operated spray pump
1	Cost	18,800	12,000
2	Discharge	22 LPM	7 LPM
3	Operation time	It can spray 6 times more than the conventional engine operated pump	It has only one valve is fitted It can only spray with 7 LPM capacity
4	Distance covered	600 m	50 m
5	Mode of operation	It can be operated from one place	It has to be carried on back by operator
6	Labor cost	2 labor required (1 operator, 1 spray man)	2 labor required 1 spray man 1 helper
7	Area covered in 1 h duration	3 Acre	0.5 Acre
8	Fuel required	No fuel required as it is electric motor operated	2 L/hr petrol + 100 ml oil Cost = 240 + 10 = 250 rupees
9	Cost of operation	Low 500 rupees per day	High 2 labor + fuel cost for 8 h = 500 + 2000 = 2500

Table 2 Cost of spraying unit

SN	Components used	Specification	No. of components	Cost of the component (in INR)
1	Motor	2 HP	1	5000
2	HTP sprayer	22 LPM	1	5000
3	Pipe	300 m	1	4500
4	Spray gun	Heavy stainless steel	1	700
5	V-belt	Grade A	2	600
6	Pulley (driven)	Cast iron	1	500
7	Base frame for mounting	Mild steel	1	1500
8	Labor			1000
		Total	9	18,800

3.4 Experimentation of HTP Sprayer

The experimentation of the HTP sprayer is done on fields in India and in Sawangi, which is located in Hingana Tahasil in the Nagpur district of Maharashtra, which is a state of India. The experimentation is done on orange trees by spraying them. In this experiment, we spray the orange trees This experiment demonstrates the

Fig. 1 Actual model of HTP sprayer

Table 3 Pressure in bars versus discharge in liter per minute for HTP sprayer

SN	Pressure (in bars)	Range (in meters)
1	1	0.5
2	2	1
3	3	1.5
4	5	2.5
5	7	3.5
6	9	5

effectiveness of the HTP unit, which can spray a minimum of 10 hectares of fruit farming land in an eight-hour shift. Figure 1 shows the actual model of HTP sprayer.

4 Result

The comparison pressure in bars and the discharge in liter per minute for HTP sprayer is done in following Table 3.

These are the results of our developed spraying machine which handles spraying load for minimum 10 hector area in working shift of 8 h per day. Jet produced for spraying to reach up to 10-m height and formation of uniform mist formation at the discharge. From a single place, the discharge pipe can be elongated and placed up to 1000 m. It has a low cost of operation. It is suitable for all crops like vegetable grains and fruit trees.

5 Conclusion

The electric motor-operated HTP sprayer is capable to create high discharge through a nozzle of the spray gun for the long range up to 3 m to 10 m. This machine does not require any type of fuel for combustion as its electric motor operated; hence, this machine does not create air pollution and noise. The suggested system's initial cost is higher than that of traditional sprayers, but due to its great efficiency and lack of fuel requirements, the system's operating costs are relatively low. The technology designed is utilized to spray fertilizer, insecticides, fungicides, and paint. The HTP sprayer can carry heated fluid and viscous fluid like plastic paints, emulsion, etc., so it can be used in industrial applications also. The spraying gun can develop a fine mist of very small droplet size as compared to other sprayers; hence, it is having high effectiveness in spraying any fluid.

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Computational Estimation of Air Flow Parameters of an Outdoor Air Purifier

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Abstract Air pollution has become one of the biggest threats to human health. Installation of an outdoor air purifier can be an effective measure to combat air pollution. For designing an efficient air purifier, estimation of air flow parameters and selection of an appropriate axial fan for creating air suction is of utmost importance. In this paper, an analytical method to calculate CFM and computational estimation of static pressure drop across the various filtering components of the purifier is discussed. Details of CFD analyses and the corresponding boundary conditions are also presented.

Keywords Air purifier · CFD · CFM · Residual plot · Static pressure

1 Introduction

Air pollution is one of the largest risks to human health. It is difficult to maintain air quality due to hazardous industrial and agricultural practices such as the release of untreated and impure air to the environment, and burning of agro wastes. Installation of an outdoor air purifier seems to be an effective measure to combat air pollution.

The basic elements of an outdoor air purifier are shown in Fig. 1. Polluted air enters the purifier through the skirt—the black apex cut pyramidal duct inlet (where the air is sucked in), flows through various filters in the square duct and then exits from the outlet. The skirt has a square section of 0.762 m × 0.762 m at the inlet, while the central duct has a square section of 0.3482 m × 0.3482 m. The various filters in the purifier through which air flows are the ionizer filter, ultraviolet photocatalytic oxidation process (UVPCO) filter, plasma filter, and high-efficiency particulate air (HEPA) filter. The ionizer filter consists of electrically charged needles, which are mounted at specific intervals within the base region of the skirt. Its working can be understood from [1] and [2]. A collector plate is placed at the bottom to collect particles that will drop out from the polluted air. The structure of the skirt and the

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ionizer filter is shown in Fig. 2. The UVPCO filter (Fig. 3) consists of aluminium plates (substrate) coated with TiO_2 and UV lamps that are inserted through the central hole in the assembled substrate layers. Its working can be understood from [3]. The plasma filter comprises two needles that are mounted facing each other within the same housing. Its working can be understood from [4]. HEPA filter is used to capture the dust particulates present in air. It is placed directly above the plasma filter. The structure of the plasma and the HEPA filter is shown in Fig. 4. The structure of the roof is shown in Fig. 5.

While designing an air purifier, selection of an appropriate axial fan for creating air suction is of utmost importance. Tube axial and vane axial fans are the most widely used fans for a confined duct. An appropriate fan can be selected by using the fan performance curve, if parameters such as CFM and static pressure loss are known. CFM stands for "cubic feet per minute" and is a measure of air flow, often used to describe the capabilities of heating, ventilation, and air conditioning systems [5]. In case of a blower or a fan, it indicates the quantity of air that can be moved per

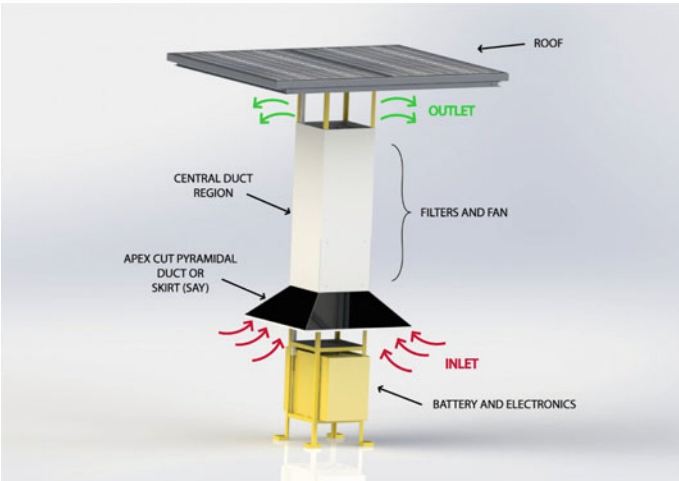
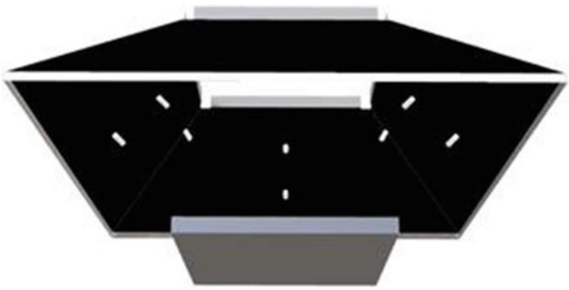


Fig. 1 Elements of an air purifier

Fig. 2 Structure of the skirt and the ionizer



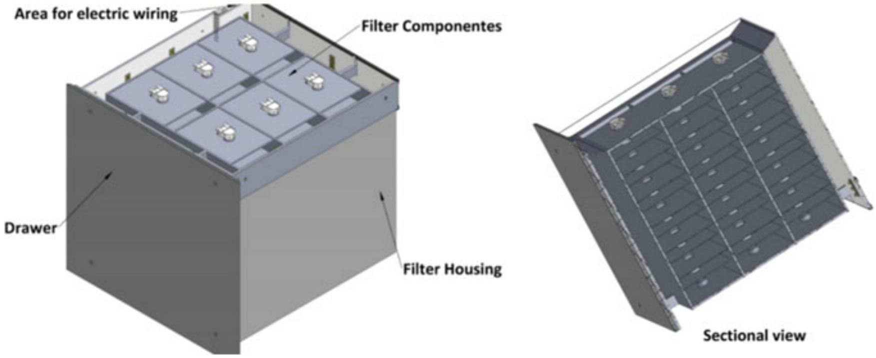


Fig. 3 Structure of UVPCO filter

Fig. 4 Structure of plasma and HEPA filters

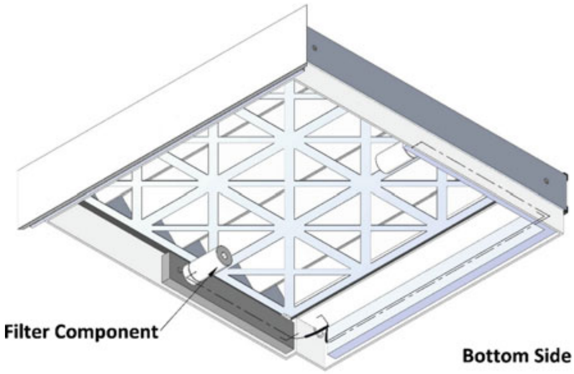
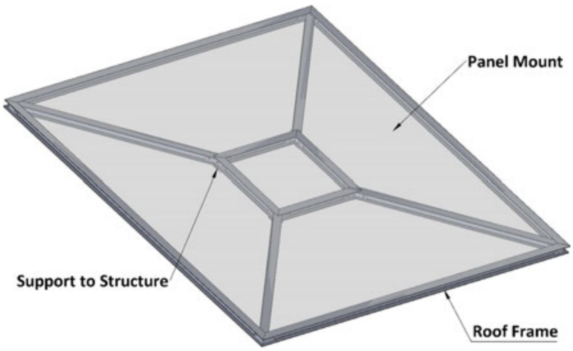


Fig. 5 Structure of roof



minute. Static pressure is the amount of pressure against which a fan has to push/pull air through the duct system. It is exerted equally on all four walls of a duct system [6]. The procedure for fan selection is explained in [7].

2 CFM Estimation for the Air Purifier

CFM is usually calculated by taking into consideration the volume of air to be cleaned in a particular time interval. Since the focus is on purifying impure air, control volumes of air around the buildings may be assumed to be sufficiently large. The various assumptions made for CFM estimation are:

- The buildings are arranged in a grid and are separated from each other by 20 ft.
- The air purifier is placed on the terrace of the central building in the grid.
- The polluted air needs to be purified once a day.

Considering a 12 storey building of height 120ft and width 50ft, which is situated on a plot with an area of 70 ft × 70 ft (Fig. 6), the amount of air which needs to be purified will be the volume of air within the empty space between the plot boundary and the building boundary.

Let V_1 be the volume of air between the plot boundary and the building.

Let V_2 be the volume of air above the building. Consider 5% FOS in air flow volume rate.

$$V_1 = (120\text{ ft} \times 50\text{ ft} \times 10\text{ ft}) \times 4 + (10\text{ ft} \times 10\text{ ft} \times 120\text{ ft}) \times 4$$

$$V_2 = 70\text{ ft} \times 70\text{ ft} \times 10\text{ ft}$$

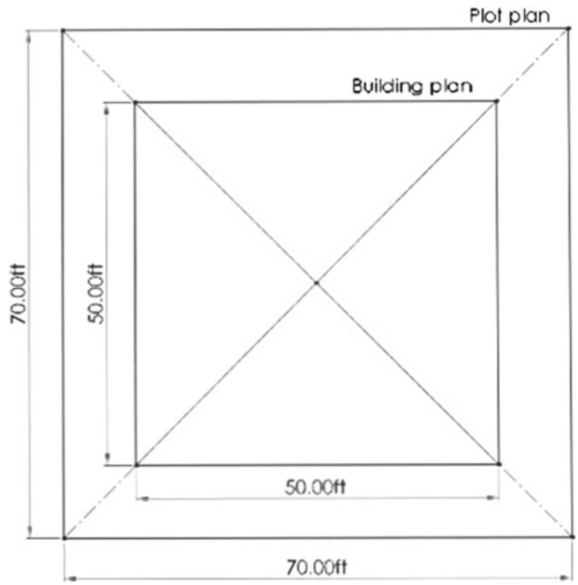


Fig. 6 Building and plot plan

$$\text{Total volume} = \mathrm{V}_1 + \mathrm{V}_2$$
$$= 337000\ \mathrm{ft}^3$$

$$\text{Air flow volume rate} = \frac{\text{Total Volume of air to be purified in a day}}{\text{Total minutes in a day}}$$
$$= \frac{337000}{24 \times 60}$$
$$= 234.03\ \text{CFM}$$
$$= 0.1110$$
$$= 0.1110 \times 1.05$$
$$= 0.1165 \frac{\mathrm{m}^3}{\mathrm{s}}$$

3 Static Pressure Drop Calculations

Static pressure is the resistance (friction) to airflow in a pipe, duct, hose, filter, hood slots, air control dampers, louvres, etc. It is measured in inches water gauge (in WG) or millimetres water gauge (mm WG).

Static pressure drop needs to be measured along every component that obstructs the free flow of air in the air purifier. The drop in pressure values, while flowing through the ionizer, UVPCO filter, plasma filter, HEPA filter, and the roof, can be estimated by using computational fluid dynamics (CFD) techniques.

The inlet air velocity at the duct plane (V_i) can be calculated by dividing the CFM value by skirt inlet area

$$V_i = \frac{\text{CFM}}{Duct\ c/s\ area}$$
$$= 0.9609 \frac{\mathrm{m}}{\mathrm{s}}$$

$$\text{Assuming an FOS of 10\%, } V_i = 1.1 \times 0.9609$$
$$= 1.06 \frac{\mathrm{m}}{\mathrm{s}}$$

The pressure drop values across the skirt, UVPCO, and the roof were calculated through CFD analyses. The details of the meshing parameters used for the analyses are.

- Maximum element size: 10 mm,
- Target skewness: 0.9,

- Meshing method: None,
- Smoothing: Medium,
- Growth rate: 1.2,
- Inflation: Smooth translation,
- Inflation translation ratio: 0.272,
- Inflation layers: 5.

3.1 Pressure Drop Across the Ionizer/Skirt

The inlet air velocity at the duct plane was calculated as 1.06 m/s. The velocity of air at the skirt inlet was then determined by using the continuity equation. Inlet velocity of 0.2 m/s at the skirt plane and outlet face pressure of 0 Pa were the boundary conditions for the analysis. The turbulence model was selected due to the converging area in the skirt. The resistance to air flow by the cylindrical needles (ionizer) in the skirt was neglected due to their small size (diameter of 20 mm and length of 61.5 mm). The other CFD solver parameters were:

- Pressure-based solver
- Velocity formulation: Absolute
- Time: Steady
- Gravity: $z = -9.81$ m/s^2
- Fluid: Air, Solid: Aluminium
- Model used: k-epsilon-Realizable with std. wall functions
- SIMPLE scheme
- Spatial discretization—Gradient: Least squares cell-based, Pressure: Second order, Momentum: Second-order upwind
- Turbulent kinetic energy: Second-order upwind
- Turbulent dissipation rate: Second-order upwind
- Solution controls—Under relaxation factors: Pressure: 0.3, Density: 1, Body forces: 1, Momentum: 0.7, Turbulent kinetic energy: 0.8, Turbulent dissipation rate: 0.8, Turbulent viscosity: 1
- Hybrid Initialization.

Scaled residuals plot provides an idea of the convergence of the solution and the closeness of the convergence. It also provides an indication of the solution stability [8]. The residuals plot for the ionizer (Fig. 7) indicates that the convergence for the continuity line, x, y, z velocity lines and the k, epsilon lines are below 1e^{-02} by the last iteration. Figures 8 and 9 show the total pressure contours at the skirt inlet and the outlet, respectively. Based on the CFD results, the pressure drop can be calculated as

$$\begin{aligned}\text{Pressure drop} &= \text{maximum Inlet plane pressure} - \text{minimum Outlet plane pressure}\\ &= 1.280 - 0.654\\ &= 0.626\ \text{Pa}\end{aligned}$$

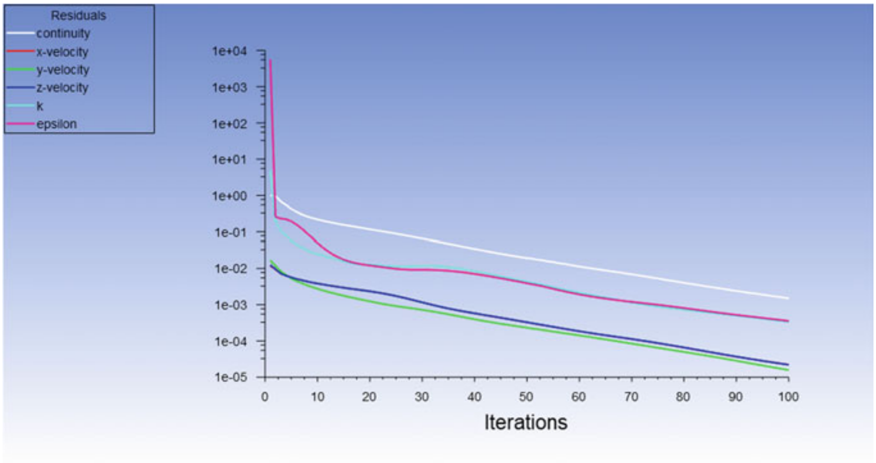


Fig. 7 Residual plot for skirt

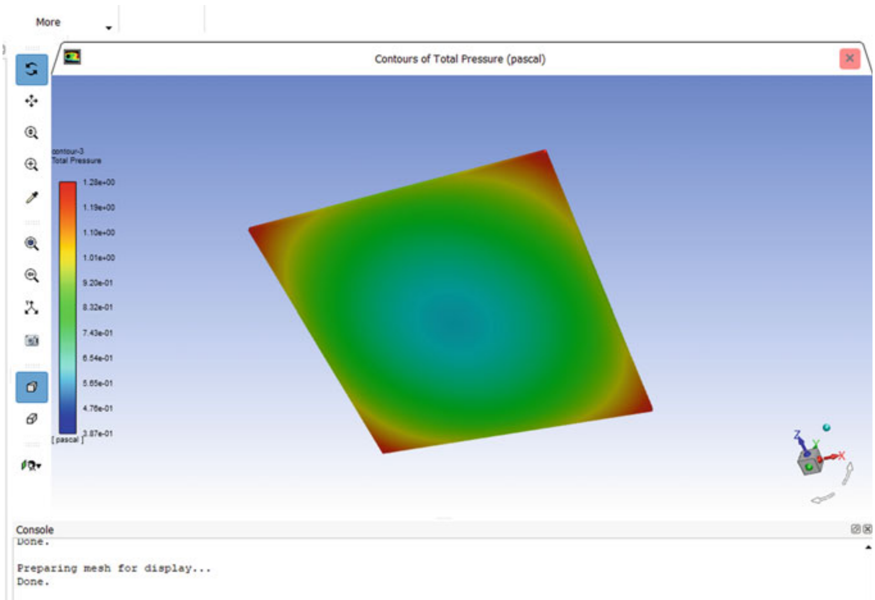


Fig. 8 Skirt total pressure contours near inlet

3.2 *Pressure Drop Across UVPCO*

Inlet velocity of 1.06 m/s and outlet face pressure of 0 Pa were the boundary conditions for the analysis. The turbulence model was selected for analysis due to the

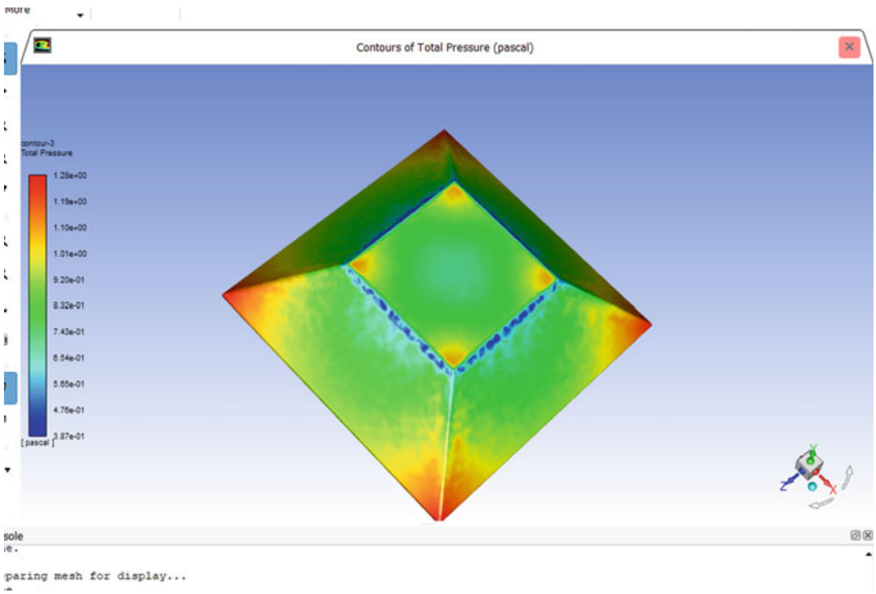


Fig. 9 Skirt total pressure contours near outlet

zig-zag flow paths in the UVPCO. The residuals plot for the UVPCO (Fig. 10) indicates that the convergence for the continuity line, *x*, *y*, *z* velocity lines and the *k*, epsilon lines are below $1e^{-01}$ value by the last iteration.

Based on the CFD results, the pressure drop can be calculated as 21.18 Pa. Figures 11 and 12 show the total pressure contours at the UVPCO inlet and outlet, respectively.

3.3 Pressure Drop Across the Plasma and the HEPA Filters

Value for the pressure drop across the HEPA filter was selected from literature. It was finalized to be 245.166 Pa [9]. The plasma filter consists of two cylindrical needles with a diameter of just 20 mm and a length of 42.5 mm. The resistance to air flow by the plasma filter was therefore not considered.

3.4 Pressure Drop Across the Roof

Inlet velocity of 1.06 m/s and outlet face pressure of 0 Pa were the boundary conditions for the analysis. The viscous laminar model was used for the analysis. The velocity boundary condition was specified at the indicated inlet plane (Fig. 13). The

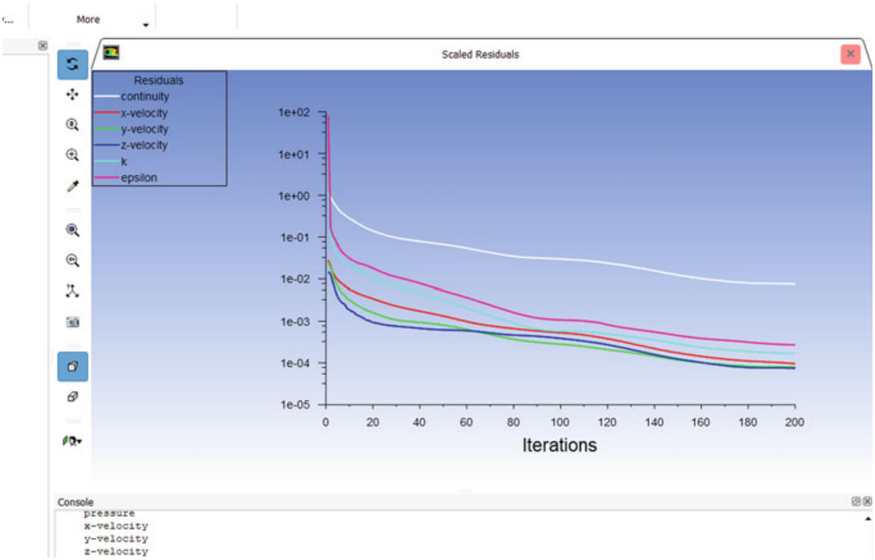


Fig. 10 Residual plot for UVPCO

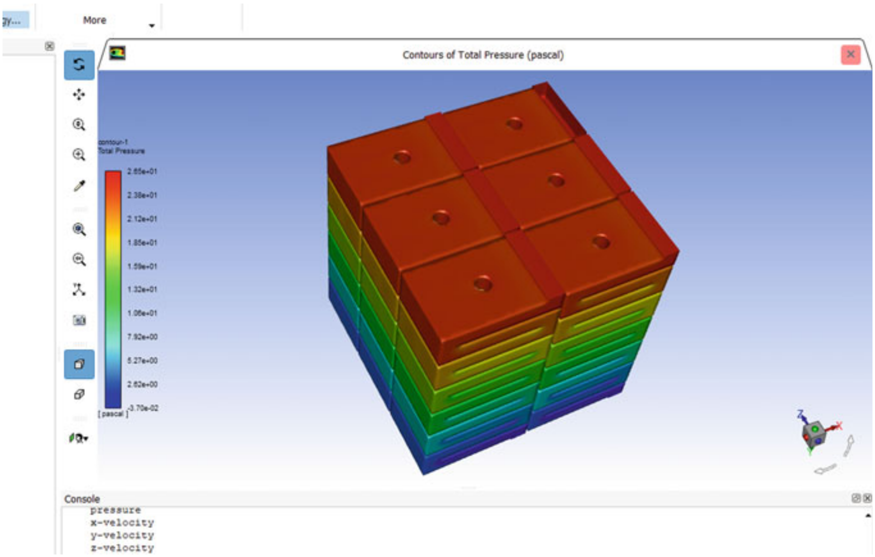


Fig. 11 UVPCO total pressure contours near the inlet

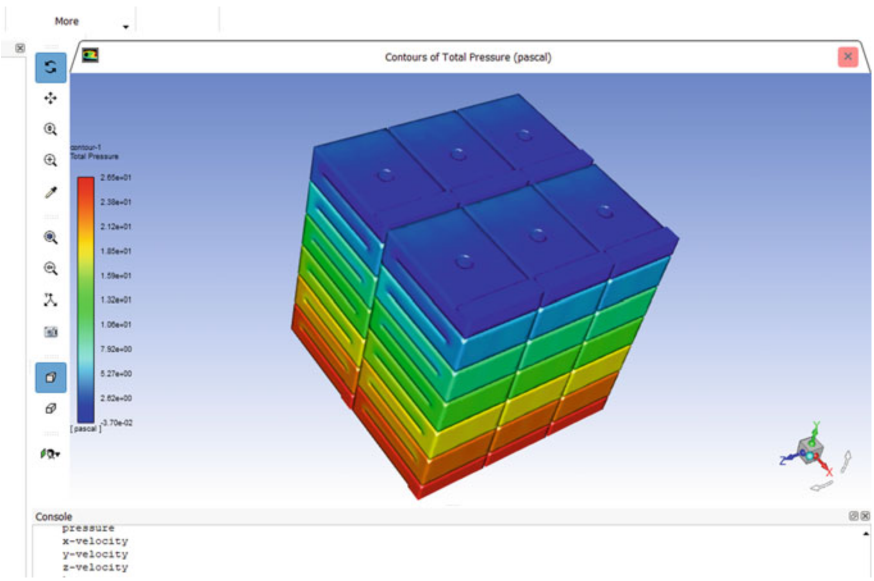


Fig. 12 UVPCO total pressure contours near the outlet

hatched region shows the space through which air flows after exiting the duct which includes 108.9 mm sides also open to atmosphere.

The residuals plot for the roof (Fig. 14) indicates that the convergence for the continuity line, x, y, z velocity lines are below $1e^{+00}$ by the last iteration.

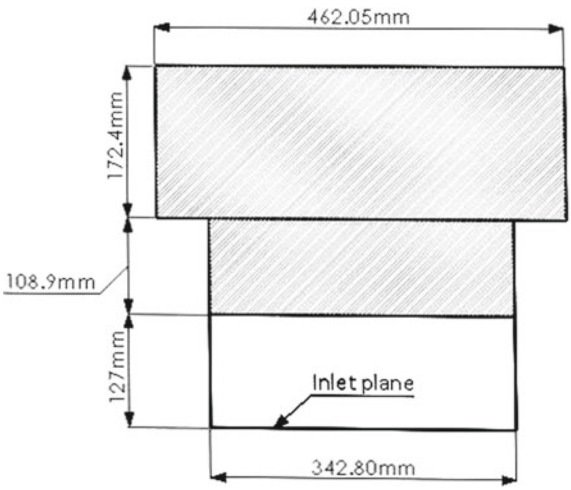


Fig. 13 Roof dimensions used in CFD analysis

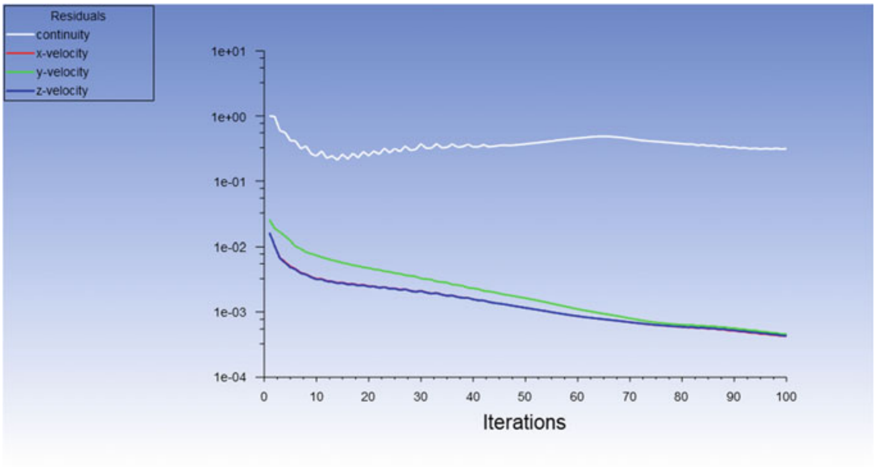


Fig. 14 Residual plot for roof

Figures 15 and 16 show the total pressure contours at the roof inlet and the outlet respectively. Based on the CFD results, the pressure drop can be calculated as 0.8753 Pa.

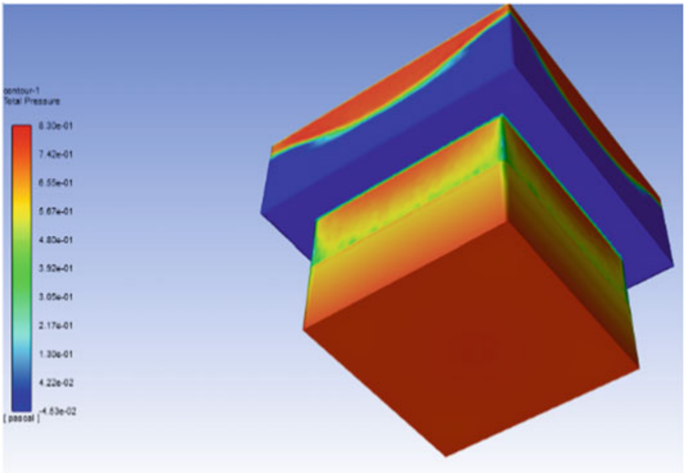


Fig. 15 Roof total pressure contours near inlet

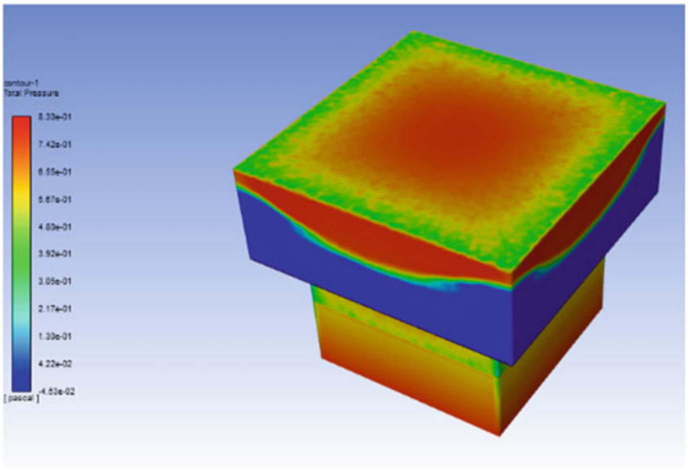


Fig. 16 Roof total pressure contours near outlet

3.5 Total Pressure Drop

The total pressure drop will be the net sum of pressure drops across the various filters and the roof.

$$\begin{aligned}\text{Total Pressure drop} &= 0.626 + 21.18 + 245.166 + 0.8753 \\ &= 267.8473\ \text{Pa}\end{aligned}$$

4 Selection of Inline Fan

Selection of an appropriate axial fan for creating the necessary air suction (to induce air flow) is of utmost importance for the efficient functioning of an air purifier. Based on the calculated static pressure of 267.147 Pa and the required air flow volume rate of about 234.03 CFM, Fantech Inline Centrifugal Duct (FKD 10XL) that offers static pressure of 1.5in (373.26 Pa) and 696 CFM [10] was selected for the air purifier.

5 Conclusion

Air flow parameters, such as CFM and static pressure losses, play a critical role in the design and functioning of an air purifier. By using control volume technique, the air flow volume rate required was estimated to be 234.03 CFM. The static pressure drops across various filters and the roof were determined using computational techniques. CFD analysis indicated that the fan static pressure was 267.147 Pa. Based on these parameters, Fantech Inline Centrifugal Duct (FKD 10XL) was selected for the air purifier.

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Computational Fluid Dynamics Analysis of Delta Wing

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Abstract The wing area with a triangular planar shape is called delta wings. The supersonic flow is, in many respects, completely different from the subsonic flow. These differences affect the design philosophy of supersonic and subsonic aircraft. This research addresses subsonic flow and design on delta wings. CFD is being used to improve the delta wing's efficiency in this project. An experiment necessitates the use of a design model, which is more time consuming and expensive than using CFD methods for the same purpose. A computational fluid dynamics model underpins the whole investigation. At different angles of attack of 0, 5, 10, 15, 20, the flow over a NACA0012 aerofoil is analysed in two dimensions. This analysis is performed by considering various parameters like temperature, pressure, and velocity using computational fluid dynamics using Software ANSYS2016.

Keywords Delta wing · Angle of attack · Computational fluid dynamics

1 Introduction

The wing area with a triangular planar shape is called delta wings. The supersonic flow is, in many respects, completely different from the subsonic flow [1, 2]. These differences affect the design philosophy of supersonic and subsonic aircraft. Our research addresses subsonic flow and design on delta wings. Supersonic aircraft usually have larger swept wings [3]. A special case with a triangular plan view is called a delta wing. For take-off and landing, delta wings are high-speed aircraft that fly at lower speeds [4, 5]. Also, in most situations, these planes fly at subsonic speeds most of the time and employ their supersonic capabilities only when necessary [6, 7].

It has been studied for a long time, but until the jet era when it was proven, no significant use was found. High-speed subsonic and supersonic flights are no problem for this propeller [8–10]. When it comes to lightweight aircraft like hang

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gliders, Rogallo's flexible wings have proved to be a useful design. The delta wing's unique aerodynamic and structural properties make it an excellent choice for aircraft. With and without additional stabilising surfaces, several design modifications have emerged throughout time [11, 12].

The aerodynamics of aircraft have been predicted for many years by the dynamics of computing fluids. Viscous flow calculations are common in cruise situations, but predicting nonlinear effects at higher angles of attack is much more difficult [13]. There are a number of challenges in performing these calculations, including the difficulty of correctly modelling turbulence and displacement for turbulent currents and strongly distributed flows, the need to use adequate numerical algorithms when flow asymmetry is possible, and difficulties in grid construction [14]. These issues have been considered and recommendations have been made to further improve high-angle prediction. Current predictability for high angular attack currents is discussed and solutions based on hybrid turbulence models are proposed. The following are other computational difficulties encountered in modelling the flow through a delta wing at high angles of attack [15, 16].

Computational methods for predicting the flow of interacting peaks have not yet been fully demonstrated. Researchers are still working on tools that allow for the quick calculation of vortex flows in complicated configurations [17–20]. It is difficult to model the onset of a vortex flow separating the boundary layer on a smooth surface. It is difficult to predict vortex breakup in vehicles with complicated configurations. The effects of scale, compressibility, and instability (such as asymmetry and oscillations of flow at vortex breakdown points) need to be addressed. Multidisciplinary studies are needed to further understand the impacts of vortex interaction. As a result of massively separated flows, traditional turbulence models fail to accurately anticipate the intensity and location of the central vortex core [21]. Extensive studies need to be conducted to demonstrate network convergence. With turbulence modelling mode, a precise CFD simulation of the full aircraft design is the ultimate aim.

Flow over the NACA 0012 airfoil was investigated by Patel et al. and found that at zero degrees of AOA, there is no lift force [8, 22, 23]. Even if drag force and drag coefficient values have risen, the rate of growth is far lower than the rate of increase in lift force. An airfoil called NACA 2412 is employed in this research, and the first number represents maximum camber in hundredths of a chord, while digits 2 and 3 indicate maximum chamber placement from leading edge in tenths of a chord [24, 25]. The final two digit represent maximum thickness in hundredths of a chord. Airfoil chord $c = 0.3$ m and airfoil span $l = 1.6$ m are used as the parameters for the design. For the experimental wing model, these dimensions were chosen, which are in line with the publicly available data from other test UAV samples in Vietnam as well. The fluid–structure interaction defined lift and drag forces [26].

Integration of surface pressure is the most common method for determining the lift and drag coefficients of an Euler CFD solution. For determining drag coefficients, this approach is not viable (all but one drag value was negative) [27]. In addition, two enormous forces in the flow direction are subtracted, which introduces inaccuracies. As a result, determining drag requires precise knowledge of pressure distribution

[27]. These two issues imply that a precise computing grid is required in order for a surface integration approach to be accurate, resulting in extended run times. They also aggregate multiple drag components into a single drag coefficient, which is another drawback.

Even in design concept, it is critical to understand how the aircraft's drag is generated so that the design may be more efficient. As a result of the surface integration technique's drawbacks, scientists have begun looking at other approaches to evaluating CFD-generated lift and drag coefficients. The Wake Integration approach is a method that may be used. The drag is calculated from the physical phenomena that creates drag forces in this technique [27]. This is accomplished by measuring the downstream vortex and entropy on a plane perpendicular to the flow [26]. The lift-induced drag causes the vortices, while the wave drag causes the entropy [28]. Since surface integration relies on grid resolution, this approach will be employed in this study since it isolates the drag components based on the physical processes that induce drag.

Therefore, in present work CAD model of Delta Wing is prepared. Also, the analysis of the various parameters like the temperature, pressure, and velocity have been carried out for checking the efficiency of delta wing on varying the angle of attack (0, 5, 10, 15, 20).

2 Materials and Methods

2.1 Wing Design Parameters

The wing parameters are crucial when it comes to wing design and analysis. The real wing analysis processes are provided by the wing parameter. Here are a few wing parameters to consider.

2.1.1 Wing Plan Form Area (S)

Use the formula for a Trapezoid to calculate the area of a tapered wing. The wing span is equal to the average chord length.

$$\text{Average Chord} = \frac{\text{Tip Chord} + \text{Root Chord}}{2}$$

$$\text{Wing Area} = \text{Average Chord} * \text{Wing Span}$$

Using the formula for a tapered wing, if the Delta Wing's Tip Chord is larger than zero inches, utilize the formula above. A triangle is formed when the Tip Chord is equal to 0.

$$\text{Wing Area} = \frac{1}{2} * \text{Root Chord} * \text{Wing Span}$$

2.1.2 Aspect Ratio (AR)

A wing's length and slenderness are measured by its aspect ratio. AR stands for "Aspect Ratio", and it is the square of a wing's span divided by its area.

$$\text{Aspect ratio} = \frac{S}{C}$$

2.1.3 Taper Ratio

An instrument's taper ratio (λ) tells you how close its root chord (cr) is to its tip chord (ct). By combining the separate section chords, the mean aerodynamic chord can be obtained.

$$\text{Taper ratio} = \frac{\text{Tip chord}}{\text{Root chord}} = \frac{Ct}{Cr}$$

2.1.4 Tip Cord (Ct)

Parallel to the plane of symmetry and at locations where straight leading or trailing edges meet the curvature at the tip of an airfoil. When the sweep is at its smallest, the tip chord of wings with variable sweep is measured.

2.1.5 Swept Angle

Swirled wings are wings that bend backward or forward from their roots instead of straight sideways.

2.1.6 Dihedral Angle

Fixed-wing aircraft wings and tailplanes are referred to as dihedral angles because of their upward angle from the horizontal. The term "anhedral angle" refers to a downward angle of a fixed-wing aircraft's wings or tailplane relative to the horizontal, also known as a negative dihedral angle.

2.2 *CFD Analysis*

2.2.1 Governing Equations

Unsteady Navier–Stokes equations in their conservation form are the set of equations that ANSYS solves. Unless otherwise noted, all of the following equations use static (thermodynamic) quantities. Computational fluid dynamics relies heavily on transport equations, which are instantaneous equations of mass, momentum, and energy conservation. Averaging the instantaneous equations results in extra terms for turbulence. Mass, momentum, and energy conservation equations may be stated in a stationary frame like this:

$$\text{Continuity Equation}: \frac{D\rho}{Dt} + \frac{\partial U_i}{\rho \partial x_i} = 0 \tag{1}$$

$$\text{Momentum equation}: \rho \frac{\partial U_j}{\partial} + \rho U_i \frac{\partial U_j}{\partial x_i} = -\frac{\partial P}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_i \tag{2}$$

where

$$\tau_{ij} = -\mu\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) + \frac{2}{3}\delta_{ij}\frac{\partial U_k}{\partial x_k} \tag{3}$$

2.2.2 Generalized Navier–Strokes Equation

The Navier–Stokes equations may be simplified by rewriting them in the form of the generic formula.

$$\frac{\partial(\rho\emptyset)}{\partial t} = -\nabla p + \mu\nabla^2 V + \frac{1}{3}\mu\nabla(\nabla V) + \rho J_b \tag{4}$$

When $\Phi = 1$, U j, T, We may derive the continuity equation, the momentum equation, and the energy equation from these. NSE is another kind of NSE.

$$\frac{\partial DV}{Dt} = -\nabla p + \mu\nabla^2 V + \frac{1}{3}\mu(\nabla V) + \rho J_b \tag{5}$$

Analytical equations are the Navier–Stokes equations finite difference, finite element, and finite volume approaches are common methods of discretization.

The "CFD procedure" is the assembly and solution of the system of algebraic equations to provide approximate solutions for all flow parameters across the wing after the purpose and CFD programmes have been selected. By integrating the fluid flow controlling equations across all solution domains (finite control volumes), an approximate solution may be found.

2.3 Selection of Aerofoil

In many ways, the aeroplane's airfoil is its beating heart. Flight speed, take-off and landing distances, stall and handling characteristics are all influenced by the airfoil's performance throughout all flight stages. Airfoil section is the second most critical wing characteristic, behind wing plan form area, according to this analysis. The movement of an aircraft is greatly influenced by the form of a component as critical as this. This design is referred to as an airfoil.

NACA-A64-208 or NACA-A64-204 are the parameters used in the design of airfoils. A new approach to airfoil design is provided by these six series. An F-16's airfoil is shown in the following figure: an F-16 aircraft's wing airfoil is designed using this airfoil, and the design is based on NACA airfoil selection criteria.

2.4 CFD Analysis

2.4.1 Pre-Processing

For the best accuracy, it is necessary to split our profile into as many little pieces as possible before performing meshing, which is known as breaking our profile into n number of small parts. This step deals with the issue geometry shown in Fig. 1a shows the geometry of delta wing and b shows meshing of airfoil.

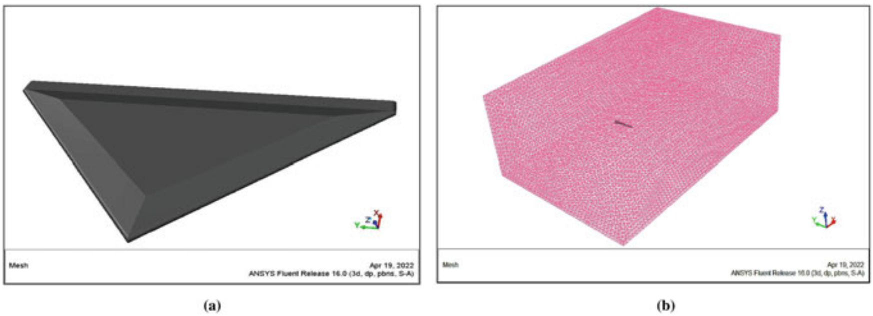


Fig. 1 Geometry of delta wing **b** Meshing

2.4.2 Solver

In this stage, the ANSYS—Fluent Software is used to specify all of the boundary conditions and input parameters that serve as a foundation for solving the issue and informing what data should be recorded throughout analysis (like Cl and Cd). Due of the high accuracy and speed of the second order scheme discretization, we chose this method. Semi-Implicit Approach for Pressure Linked Equation (SIMPLE) is the pressure–velocity coupling solution method which we employed in this investigation.

2.4.3 Post-processing

Steady state pressure-based solver is used for the CFD analysis of delta wing. Spalart–Allmaras (1eqn) strain/vorticity-based viscous model is used. Energy equation is also used for the simulation. Pressure far field boundary condition is used for the inlet and outlet with different Mach number (1.2 at sea level). Symmetry boundary conditions are used at middle plane to minimize the computation time. Pressure–velocity couplings are done with coupled scheme. Second-order upwind scheme is used for spatial discretization.

Figure 2 shows the contours for static pressure, velocity, and mach number.

2.5 Report Generation

Figure 3 shows the pressure, velocity, and temperature at 5-degree angle of attack.

Figure 4 shows the pressure, velocity, and temperature at 10-degree angle of attack.

Figure 5 shows the pressure, velocity, and temperature at 15-degree angle of attack.

3 Result and Discussion

Keeping in mind that we have 30 iterations to get each issue converged, we picked a broad range of angle of attack from 0° to 15° for NACA 64–208. Tables 1 and 2 show the coefficient of lift and coefficient of drag as aerodynamic properties. In addition to the pressure and velocity contours, this research focuses on comparing the lift and drag across a broad range of angle of attack (Table 3).

Figure 6 shows the coefficient of lift for NACA 64–208 seems to be exactly proportional to the angle of attack (0° to 15°) until the critical angle of attack, beyond which the coefficient of lift begins to decrease rapidly.

Air's properties vary along with the airfoil's form, which affects the airfoil's necessary lift and drag forces. The forces generated while an aircraft moves through

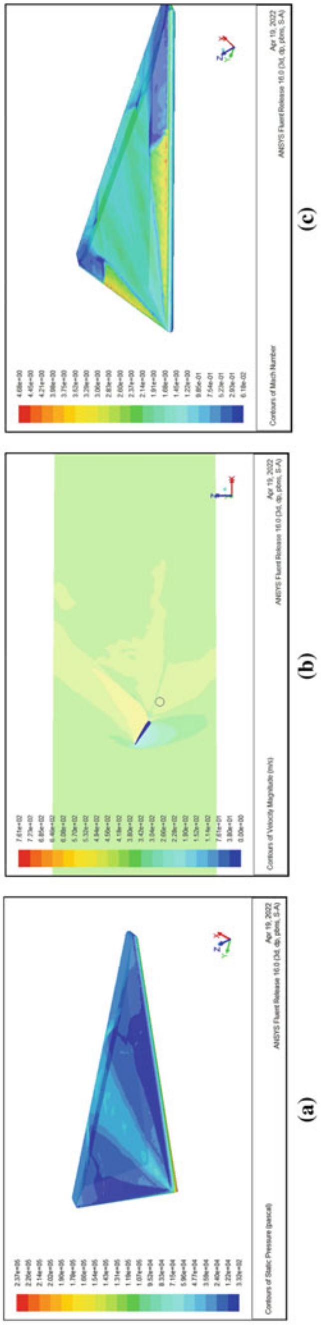


Fig. 2 Contours of **a** Static pressure in Pa, **b** Velocity in (m/s) and **c** Mach Number

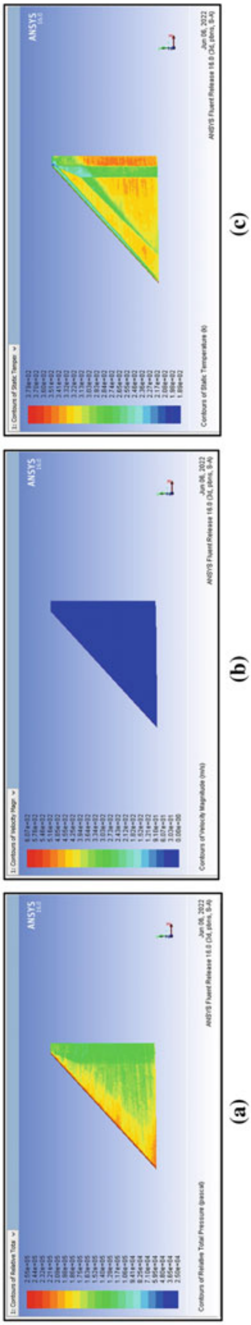
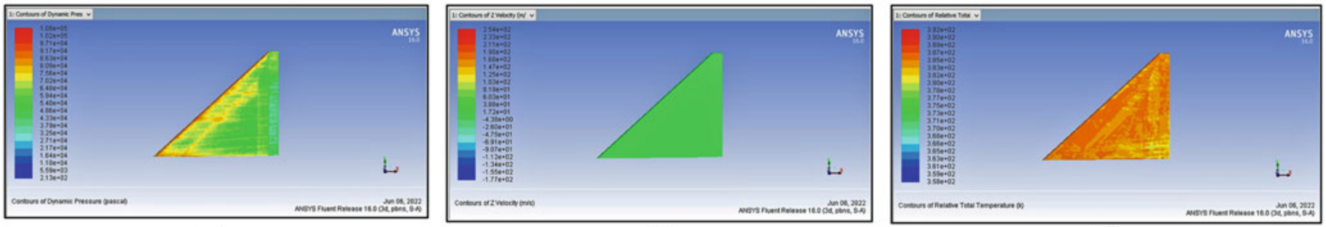


Fig. 3 **a** Pressure, **b** Velocity and **c** temperature at 5-degree angle of attack



(a) (b) (c)

Fig. 4 **a** Pressure, **b** Velocity and **c** temperature at 10-degree angle of attack

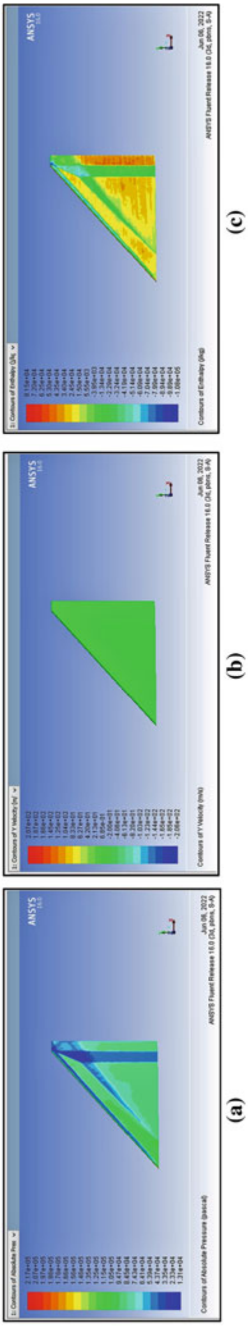


Fig. 5 **a** Pressure, **b** Velocity, and **c** temperature at 15-degree angle of attack

Table 1 Basic and optimizes values

Quantity	Optimal value	Basic	Relative difference (%)
Wing span (cm)	272.48	268.24	1.6
Wing area (cm^2)	22.42	21.6	3.7
Tip chord (cm)	14.15	13.52	4.6
Root chord (cm)	150.4	147.6	1.9
Aspect ratio	3.31	3.33	0.6
Thickness (cm)	7.31	8.12	10

Table 2 Initial design parameters

Quantity (cm)	Base value
Wing semi-span	134.12
Tip chord	13.52
Thickness	8.12
Front diagonal edge length	31.76
Leading edge radius	2.5
Rear diagonal edge length	40

Table 3 Input boundary condition

Input boundary condition	
Model	Spalart–Allmaras (1eqn) strain/vorticity
Inlet	Pressure inlet
Mach no	1.1 at sea level
Pressure of flow	1.013250 * 10^5 Pa (760 mm Hg)
Density of fluid	1.2250 kg/m^3
Fluid	Air
Outlet	Pressure-outlet

the air. For a successful flight, a positive angle of attack must be used to compensate for the lift force and weight distribution that are not in sync. This may be accomplished by adding a couple more aeroplanes to the mix. As a result, both the thrust and drag forces produce a restraining force in the same direction. Airfoil efficiency is determined by the ratio of lift coefficient to drag coefficient, which indicates how much lift can be gained for a given amount of drag. In order to have a greater lift-to-drag ratio, any aircraft must have a high coefficient of lift and a low coefficient of drag.

In order to achieve a greater lift-to-drag ratio without incurring any drag losses, the angle of attack must be increased up to a certain degree, as indicated by the lift-to-drag ratio.

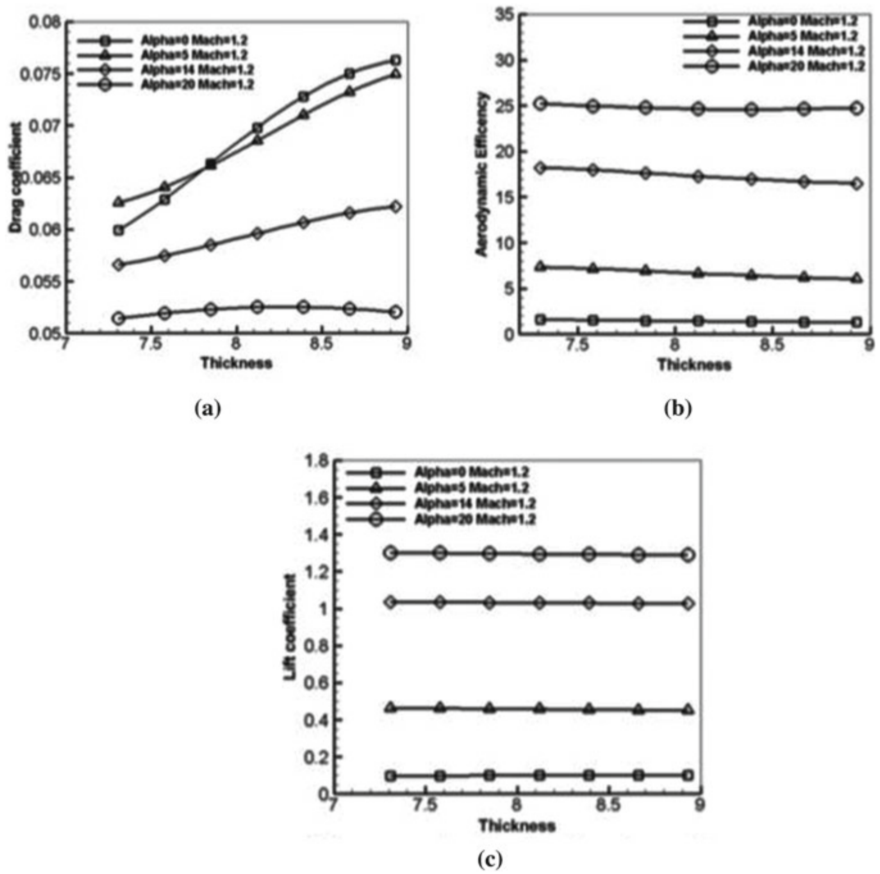


Fig. 6 Lift and drag coefficient at mach no. 1.2 and angle of attack 0, 5, 15

4 Conclusion

As the angle of attack increases, the optimization parameters temperature, pressure, and velocity all react linearly.

Roll stability tends to be more effective than directional stability in Delta aircraft, although the directional stability of a Delta is identical to that of a conventional aircraft. This is because the plane is small and has a swivel.

A delta wing's normal maximum lift angle of attack is 35 degrees, which is much greater than the angle for a two-dimensional airfoil. The delta wing, as a result, is best suited for aircraft with a high degree of maneuverability.

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Design of a Passive Assistive Exoskeleton for Improving Overall Worker Productivity in Industries

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Abstract The purpose of this paper has been to study and implement the design of a passive exoskeleton, specifically developed for industrial use and assess the potential effect of this exoskeleton on the reduction of physical loading on the body. The exoskeleton is a device with a clamp incorporated for mounting and transmission of forces onto the support. The proposed exoskeleton in the study uses only a passive mechanism to assist industrial workers. The unit was designed to assist industrial workers by reducing the carrying load of an object, weighing up to 500 N. This mechanical unit uses a sophisticated spring mechanism to divide the load and transmit it to the waist and within the chassis. The design consisted of a gravity compensation mechanism, i.e. 4-bar mechanism and springs to assist the motion. Exoskeleton designs, excluding hydraulic and electrical systems, use purely mechanical systems. Therefore, the entire system designed is simple, lightweight, inexpensive and easy to assemble. The target users are industrial workers, and hence, cost is the determining factor for this prototype. The material chosen was steel, which saves money, but also increases the effectiveness of the exoskeleton. Analysis was performed using software to ensure durability and functionality of the exoskeleton, and this could be further improved using finite element analysis.

Keywords Exoskeleton · Passive · Gravity compensation · Extension spring · Analysis

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1 Introduction

An exoskeleton is a machine that functions to support the human body in daily work and rehabilitation and increase the body's strength. The exoskeleton has many industrial uses and replaces certain types of tampering. Some handheld power tools, such as grinders, power cutters and saws are heavy and difficult to use for extended periods of time. Operators are often injured due to their weight, when using these heavy power tools.

Exoskeleton helps users/operators carry heavy loads. The exoskeleton can provide the force required to lift and hold heavy loads and there are two types of exoskeletons, such as active exoskeleton and passive exoskeleton.

An active exoskeleton is an exoskeleton that uses actuators, motors, sensors, etc., to give movement to a limb. A battery or external power source is required, when designing an active exoskeleton. A passive exoskeleton is one that does not use an external power source. Mechanical energy storage elements, such as springs can be used to store energy by expansion or compression. Spring energy can be used for weight acting on a load.

As of now, the collaborative robot industrial sector is the fastest-growing market for exoskeleton. They can reduce ergonomics issues, musculoskeletal injuries and fatigue, which are quite common disturbing factors to the workers as well as the companies in construction sites, factories, dry docks and warehouses. If not addressed, this could adversely affect the overall worker productivity in industries.

There are many exoskeleton designs in the market, some expensive and some not as effective as needed. For example, in one such design actuators were used along with the springs for the motion of exoskeleton, but as a part of the current study, an auxiliary passive upper extremity exoskeleton was designed to address the above-mentioned issues. The objective of this study was to make exoskeletons cheap, effective and wearable on the arm for the benefit of industrial workers. Exoskeletons are a great solution for carrying items for extended periods of time or carrying heavy loads.

1.1 The Following Considerations Were Taken up, While Creating the Design of the Exoskeleton

- The Exoskeleton must bear all weight on the waist.
- It must be able to be worn on at least one arm.
- They must be light and easy to manufacture.
- They must support a load of at least 10 kg.
- The design should provide enough freedom to move the arm in all directions.
- The design should be easy to assemble and safe for the user to use.

2 Literature Review

Extant literature review showed that though research has been going on in this area and many different mechanisms have been developed to provide support to parts of the body and for different applications, such as for defence, medical purposes and industrial purposes specific attempt to simplify the design, reduce cost and improve the efficiency of workers have not been taken up, especially in the Indian context.

Research has been performed in this area, which shows the benefit of using an exoskeleton and how wearing a right exoskeleton, designed for a specific task could reduce the risk of various injuries drastically and at the same time also help to increase the efficiency and productivity of the task. Study by Zurada [1] showed that even by performing simple tasks, such as manual lifting or manual material handling can lead to lower back disorder (LBD), and Bosch [2] showed that using a right exoskeleton could reduce the muscle activity by 35–38%, thereby reducing discomfort and also lower the risk of LBDs.

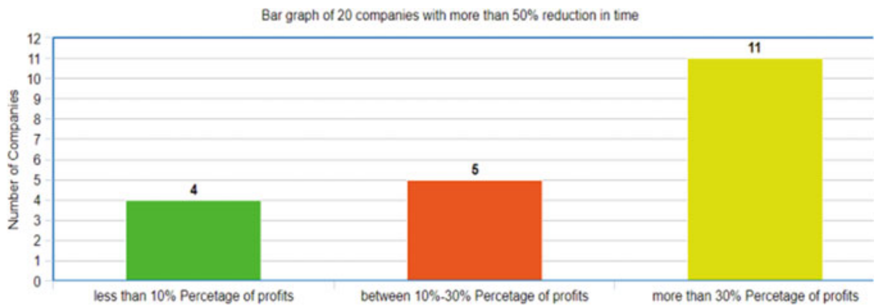
The proposed design in this study was made based on the extant literature, particularly the above studies, so as to lower the risk of injuries and to help improve the quality of the task by assisting people in manual tasks. Specifically, this study has focused on improving the design, efficiency, reducing cost and improving the mechanism mentioned in the existing studies.

3 Industrial Feedback

The R&D of exoskeletons in a developing country like India has numerous impediments. The first significant problem is minimal or zero government funding for such projects as research in this area is not prominent as well as cheap. India is a labour-based economy and unless it is economically beneficial to industries, they would instead use cheap labour to do the job, rather than use a mix of humans and machines. As a part of this study, a survey was conducted initially that targeted small businesses and factory owners or the people, who run them. This has been achieved through public surveys, physical surveys and market research. The data provided is from more than 130 different feedbacks. This survey only targeted people, who employed only unskilled labour. Various findings of this survey are summarized below. Out of the survey audience were companies with a turnover between 50 lakhs to 2 crores. Only the companies which employed unskilled labourers for menial repetitive work were included in the survey. The feedback from 30 unique companies was recorded and analysed to understand the target audience for the product. The working of the passive unit was explained to the company representatives and also how including it in their workforce would reduce labour fatigue, prevent work-related accidents and thereby increase production. Firstly, the proposed companies were asked about the amount of money they were willing to pay for the proposed new unit. Eighteen companies were ready to invest ten percent of their profits in the product, while only two companies were willing to pay higher than thirty percent of their profits to purchase the product. Ten companies were willing to pay in the range of ten to thirty percent of their profits for the same.

In addition to the price, depending on the work processes of the companies, the respondents were asked to estimate the reduction in time for their workflow. The type of work, number of exoskeleton units per worker, working hours and some other factors were factored in to estimate the efficiency of the unit. Twenty companies predicted a reduction of fifty percent reduction in work time. Seven companies estimated a reduction of ten to fifty percent in their work time. The remaining three companies estimated a 10% reduction in their work time.

The price data and efficiency achieved by the 20 companies were overlapped with more than fifty percent reduction in their work time. The result is shown in the following bar graph. The X-axis shows the price, the companies were willing to pay for the product, while the Y-axis shows the number of companies.



From the graph, it is clear that only four companies, which achieved more than 50% reduction in time were willing to pay less than 10% of their profits. Five companies were ready to pay between 10 and 30% of their profits, whereas the remaining 11 companies were willing to pay more than 30% of their profits.

3.1 Summary of Feedback

From the research and surveys, the accessible data was assessed to choose and design the course of this study. The extent of the research work was studied and evaluated. To meet everyone's demand, the target price of the companies that were willing to pay 10% of their profits were chosen. To achieve maximum efficiency, companies with a reduction time of less than 50% were selected. Hence, only four companies fell into the target area. These four companies remained as the target audience for the product. Based on the review outcome, it was decided to make the cost of the prototype the most crucial factor. It was planned to work towards developing a basic unit, so that even people without a technical background could easily understand the working and the assembly of the passive exoskeleton unit.

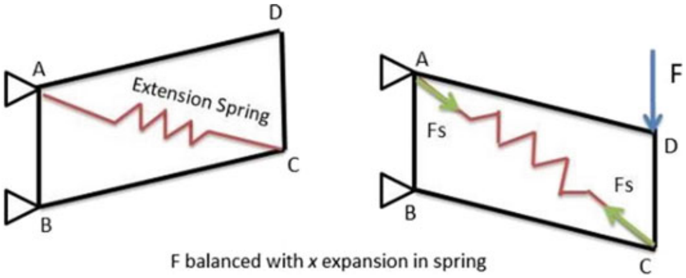


Fig. 1 4-Bar mechanism

4 Methodology

This machine was designed and built according to the procedure described in the study, G.E.A.R [3]. The design approach adopted was simple and fruitful and instead of using a torsional spring, a second tension spring was used to increase the load-carrying capacity and to make design more user friendly.

To create a passive upper limb exoskeleton, spring energy was the best way to generate the force needed to lift and hold heavy loads. The type of spring used in this design included tension spring.

4.1 4-Bar Mechanism

A 4-bar linkage mechanism with tension springs mounted diagonally was adopted for the design. Fix one limb and apply the load to the other limb was the strategy followed. The load causes the spring to stretch, and this extension generates energy inside the spring, which acts against the load. This mechanism was mainly used to help the arm move from the shoulder.

In Fig. 1, the AB and CD connections and the BC and AD connections have the same length (Figures are not drawn to scale). A and B are attached with pin joints. There is a tension spring between A and C. All links are connected by pins or swivel joints. When the load is applied perpendicular to D, the link DC would try to move down, resulting in some extension of the spring. The spring then expands until the load forces are balanced and after equalization, equilibrium is reached.

4.2 CAD Design

The following design was the final design created with the help of Solidworks CAD software. Figure 6 shows the fully assembled design. The design was carried out with all of the above goals in mind. The dimensions for the design were based on a standard scale and could be customized according to the need.

4.3 Design Components

Figures 2, 3, 4, 5 and 6 show various parts of the assembly and the assembly itself. The parts, which are not mentioned in the figures below are mentioned in the analysis part.

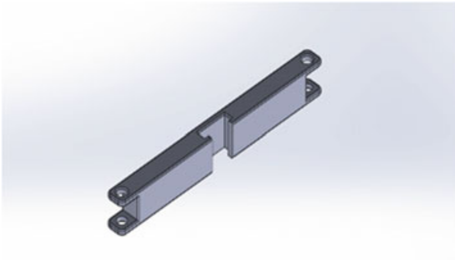


Fig. 2 Waist link

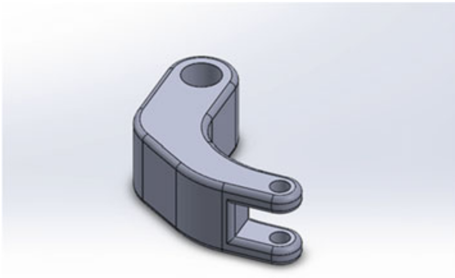


Fig. 3 Inter link

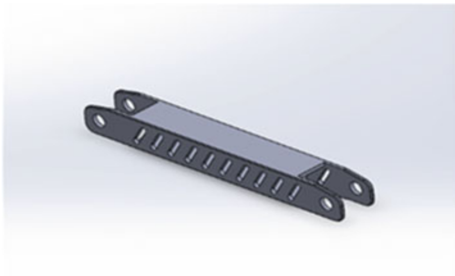


Fig. 4 4-Bar link

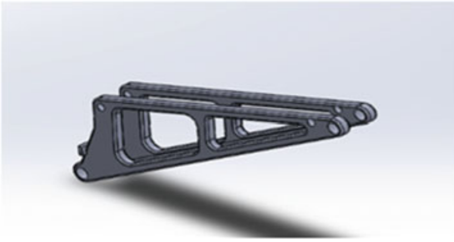


Fig. 5 Elbow link

Fig. 6 Complete assembly

5 Material Selection

For selecting the material for the exoskeleton frame, one of the most important considerations was the strength-to-weight ratio of the material. Higher ratio results in stronger and lighter parts. The index for maximizing strength-to-weight ratio is given in Eq. (1).

$$M_1 = \frac{\sigma y}{\rho} \tag{1}$$

$$M_2 = \frac{E^{0,5}}{\rho} \tag{2}$$

Another important consideration for selecting material for the exoskeleton frame was stiffness. The exoskeleton must be strong enough to withstand the applied load. However, at the same time, it should be stiff enough to not bend or buckle. The index for maximizing stiffness is given in Eq. (2).

Fracture toughness of the material was another property to be considered. In order to extend the fatigue life of the exoskeleton, the material must have high fracture toughness. The indicators that maximize fracture toughness are shown in Eq. (3)

$$M_3 = \frac{K_{1c}}{\rho} \tag{3}$$

$$Z = 10M_1 + 5M_2 + 3M_3 \tag{4}$$

For the best results, a new variable was defined, which included the performance indexes. It is given in Eq. (4).

The material that has the highest value of Z was considered to be the most appropriate material for the exoskeleton frame. However, other factors, such as ease of manufacture and cost were not included in it and would be considered for the final material selection. The numbers beside M1, M2 and M3 indicate the importance of the indexes in the material selection for the exoskeleton frame.

6 Analysis

An analysis of various components of the assembly was then performed. Parts were checked for the maximum load-carrying capacity, as to whether they are safe or not. As for this study, analysis was performed using a robust software and not actual mathematical calculations.

6.1 Software Used

As a part of analysis, softwares, such as Ansys 2022 R1 Student Version and hyperworks (for motion study) were used. The parts, which were not tested do not require analysis, as stress acting on them is not much, as compared to other parts and will be safe, if the other parts are safe. All the information regarding the links, constraints and the force acting on them are given below.

The results and the loading conditions for all the links are also mentioned below.

Table 1 Forces, torque and weight

Part name	Force applied	Constrain
Inter link	500 N	Fixed support at one end
Connector link F	500 N	Fixed support at one end
Elbow link	500 N	Fixed support at one end

Table 2 CAE analysis of various components: total deformation and safety factor

Part name	Max deflection (mm)	Factor of safety (minimum)
Inter link	0.01653	11.24
Connector link F	0.1336	2.9714
Elbow link	0.002811	15

6.2 Forces Acting on the Links

The assembly consisted of many parts and sub-assemblies. Different links have different degrees of freedom, but for the sake of analysis, the worst working conditions were taken and checked for the maximum carrying capacity, which is for 500 N of load. All links were fixed on one side, and the load was applied on the other side for the maximum capacity. Table 1 shows the forces applied, the torque generated as well as the weight on the links.

6.3 Results

The links did not fail and have yielded a factor of safety between 2.9 and 15, and the deflection was also negligible. These links were safe for the worst operating conditions (max 50Kgs). Other results are mentioned in detail in Table 2.

Analysis was performed using CAE software. Ansys was used for the structural analysis, and hyperworks was used for the motion analysis of the exoskeleton. All the parts were found to be safe under the loading condition of 500 N. Some results are mentioned in Figs. 7, 8, 9, 10, 11, 12 and 13. The design can be further improved by using precise mathematical equations, while deciding the final dimensions for the design. This design was made on a scale.

Analysis included the following parts:

- Inter link
- Connector link F
- Elbow connector.

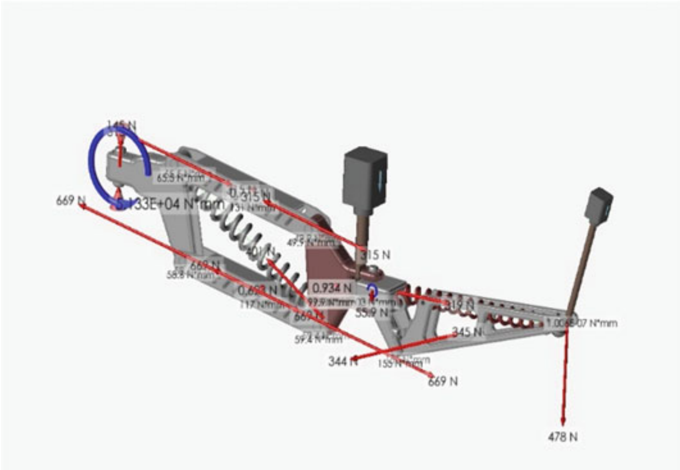


Fig. 7 Motion Study using HyperWorks

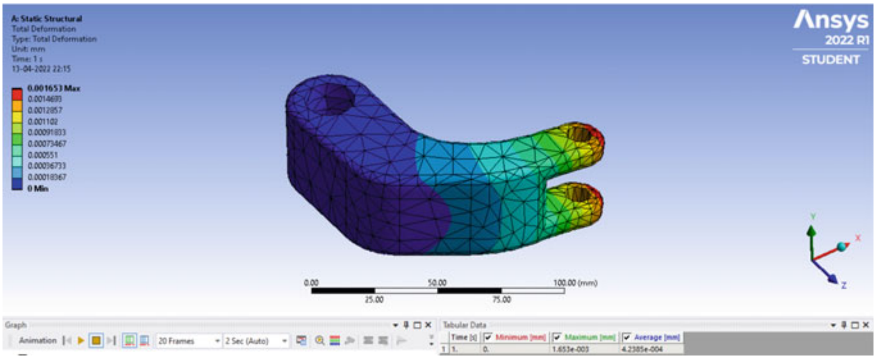


Fig. 8 Inter Link-Stress Analysis

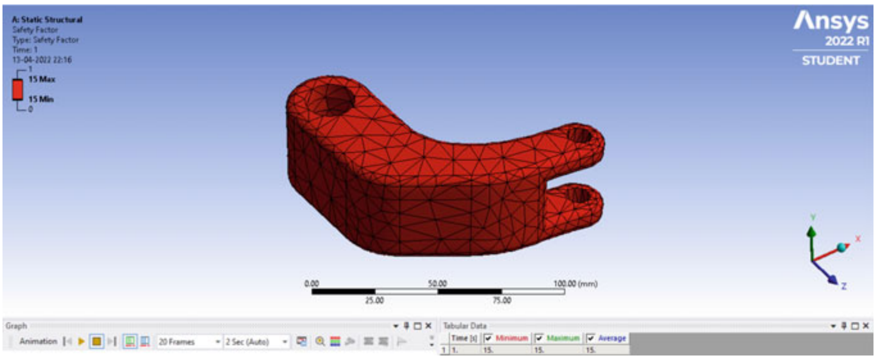


Fig. 9 Inter Link-Factor of Safety

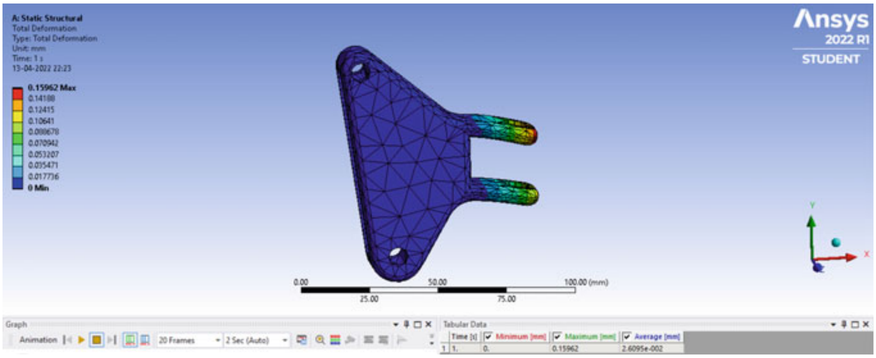


Fig. 10 Elbow Link-Stress Analysis

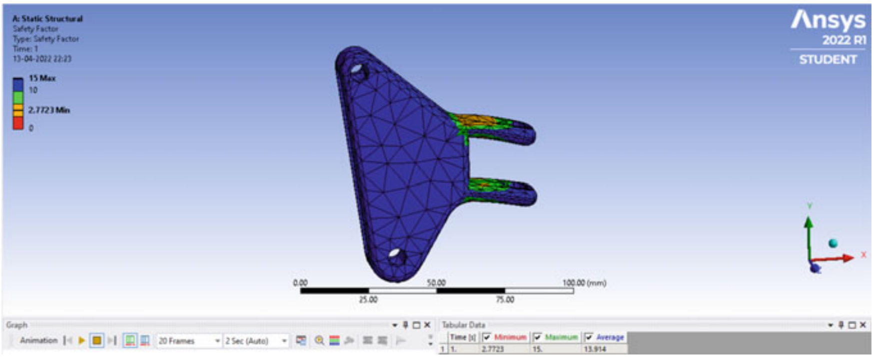


Fig. 11 Elbow Link-Factor of Safety

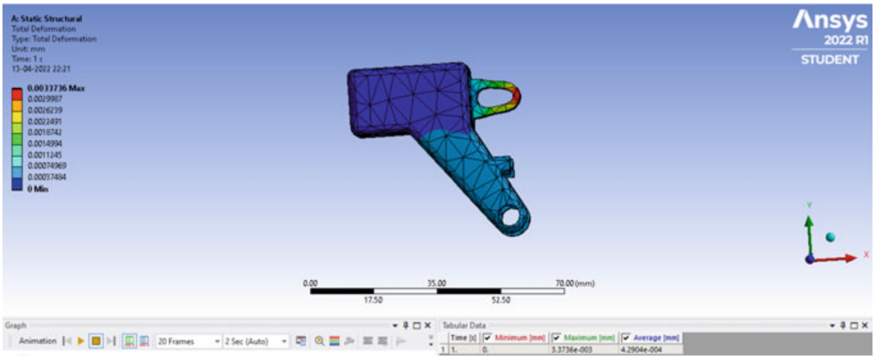


Fig. 12 Wrist Link-Stress Analysis

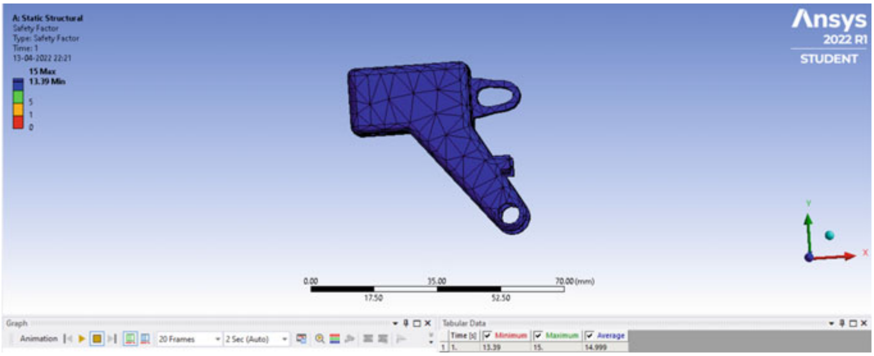


Fig. 13 Wrist Link-Factor of Safety

Figure 7 shows the force acting on each part of the exoskeleton, which were all less than 500 N. Hence, it was found that the design is safe for the 500 N load. Figures 8, 9, 10, 11, 12 and 13 show the deformation and safety factor values for components of the assembly.

7 Future Scope

The utilization of exoskeleton in Indian industrial sector is at the bottom level yet, but it is a low-hanging fruit for budding entrepreneurs. According to various research findings from across worldwide, the revenue of exoskeleton is expected to touch $5.8 billion by 2028, focused on the plan and appropriation of only passive exoskeletons that help to enhance human capacities. Though geologically, the exoskeleton market scope changes substantially across various regions.

For most people, technology makes things easier; but, for a person with a disability, it makes things practicable. India is where only individuals, who are incapacitated, get valid treatment from time to time. Due to huge fee of prostheses, only the higher earnings families can manage the cost. But in the near future in India, a higher growth rate will be encountered, because of factors, such as the growing population and increasing prevalence of stroke and spinal cord injuries, presence of a large pool of patients, increased disposable income and availability of government funding.

The design carried out in this study focused on this problem, and it was intended to make it cost-effective, so that it can be made available to more people, while not compromising on the quality. Future work may look at enhancing the capacity and other distinct features of the exoskeleton for still heavier applications.

8 Conclusion

Exoskeletons are a great solution for carrying items for extended periods of time or carrying heavy loads. As part of this study, an auxiliary passive upper extremity exoskeleton was designed. A CAD model was then developed, and static force calculations were performed to determine the force required for the spring. These forces were used to find a suitable spring design. The spring design could be customized according to the load capacity and the chassis was designed for a load capacity of 50kgs. The height could be adjusted with the exoskeleton closure of the bag, making it convenient to wear on the forearm. It was easy to assemble and carry and was also designed to not exceed 8 kg or 9 kg in weight. Finite element analysis could then be used to further reduce weight further and get more precise results.

This design could be used in industries for carrying heavy load and for using heavy industrial equipment for an extended period of time. The design was made keeping in mind that it can be manufactured easily, which heavily affects the cost. There was still further analysis needed to be done for this design. Finite element analysis could be used to find the stress and fracture areas, by which the design can be modified. It could also help in the size and weight optimization of the design. After the finite element analysis, the above analysis must be repeated, and model could be made more effective and precise. After that, the first prototype for the actual analysis of the exoskeleton is required to be built and if there are some glitches, they could also be fixed, thereafter.

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Design and Shape Optimization of a NACA0018 Airfoil Vertical Axis Wind Turbine for Highway Applications

Vedant Kale, Parth Shah, Simran Gupta, Yashashree Prabhune, and Vinit Katira

Abstract In the present work, the Helical Gorlov vertical axis wind turbine (VAWT) with NACA0018 airfoil is taken for study and optimization. The design, analysis, and optimization for maximum power generation along with taking considerations of the strength are studied. The theoretical calculations for power generated are done and validated using the CFD analysis. The model of the aforementioned VAWT is analyzed for flow and strength requirements using CFD and structural simulations. The VAWT can be implemented for electricity generation along highway medians contributing toward a clean energy environment.

Keywords Renewable energy · Wind energy · Wind turbine · Power generation · Optimization · CFD analysis

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1 Introduction

Due to steady rise in energy consumption, there is a need for increasing the energy production by harnessing the renewable energy sources. The studies have forecasted a 2 to threefold increase in energy demand by the year 2030 in India and around 63% of power is generated from fossil fuels [1]. In order to reduce the carbon footprint in the long run, it is imperative to adopt energy generation from renewable sources in small as well as large scale. The wind that is displaced by a moving vehicle on highways can be utilized to generate electricity with a vertical axis wind turbine (VAWT). Each vehicle on the highway offers an intermittent and uncontrolled source of wind power, which can be used to drive a turbine placed on the median. The primary objective of this study is to optimize the design of the VAWT and investigate the aerodynamic and structural parameters.

2 Literature Review

The previous studies have analyzed the effect of wind speed on the power generated for Savonious VAWT [2]. Niranjan et al. [3] assumed that the wind would hit all the turbine blades simultaneously and tested a scale model of VAWT. Michalewicz [4] conducted steady state analysis on Ansys Fluent for four different angular positions of VWAT. Subbaiah et al. [5] compared the rpm generated for a varying number of blades on the shaft and also concluded that the optimum angle of bend for the blades is 104–110 degree. Other studies analyzed and optimized the airfoil cross section of different types of VAWT using CFD tools [6–10]. Anthony et al. [11] investigated VAWT for low wind profile urban areas with an efficient low aspect ratio C-shaped rotor using Ansys software and proposed an involute-type rotor. The structural analysis for different materials of VAWT was done on CATIA software, and NACA2412 airfoil was selected for the analysis [12]. Sayed et al. [13] investigated the optimum angle of attack for blade profiles S825, S826, S830, and S831 for different wind speeds and highlighted that CFD tools can accurately predict wind turbine aerodynamic parameters. In order to compensate for irregular traffic, which can lead to intermittent wind flow, solar panel integration along with wind turbine generator was proposed and implemented [14]. Carrigan et al. [7] implemented a fully automated process for optimizing the airfoil cross section of VAWT. NACA 4 series airfoil is used for optimization because of availability of its key parameters. The generation of NACA airfoils, hybrid mesh generation, and unsteady CFD was coupled with DE algorithms. The project result was a 6% higher efficiency profile than the NACA 002. There is a scope for design optimization of Gorlov Helical VAWT on the basis of theoretical calculations and validation using CFD tools for different aspect ratios and helix angles.

3 Methodology

A Helical Gorlov vertical axis turbine was selected for shape optimization. The aspect ratio, helix angle, and turbine height are the parameters which significantly affect the performance of a VAWT. Considering the objective of placing the turbine on the medians of the highway, the turbine diameter and the turbine height are the restricting parameters. The turbine diameter was fixed to be 1.5 m. The number of blades was selected as 4, which is a trade-off between the power output and mechanical loads. Additionally, a higher power output implies a higher aspect ratio. The parameters considered variable such as the aspect ratio and helix angle are the ones that are considering for design iterations in this study. The CAD model was generated in Solidworks software, and analysis was done on Ansys software. The different configurations of turbine designs that are simulated for CFD results and analyzed are mentioned in Tables 1 and 2.

The airfoil NACA0018 was selected for analysis consisting of a closed contour is shown in Fig. 1. The CAD model of the turbine is shown in Fig. 2.

The CAD iterations are analyzed using Ansys software to further validate the calculation results. Along with the CFD flow simulation, the turbine was also subjected to loads due to rotation and wind velocity. Hence, the turbine was analyzed using both the simulations. The mesh configuration consists of tetrahedron elements with automatic meshing was implemented. This was to ensure efficient meshing at the tapered blade edges. The maximum element size was limited to 0.5 m. Mesh nodes = 112,778 and mesh elements = 68,701. The inlet flow wall was set according to the predicted actual direction of airflow with velocity of 12 m/s. All other walls are kept open to replicate real-time conditions with atmospheric pressure. No slip boundary condition was applied to the turbine blades. For the transient simulation settings, the time step chosen for analysis was 0.005 s, and the convergence criteria was 10e-6. The dynamic turbine performance is thus computed using the model as mentioned with the instantaneous torque output of the turbine. The material finalized was GFRP and the design was tested for structural requirements using a static structural analysis. The turbine supporting main shaft was considered as fixed support, and the turbine was subjected to the equivalent rotational velocity, and the results

Table 1 Variations of aspect ratios considered for analysis of wind turbine

Height (H) (m)	Radius (R) (m)	Aspect ratio (H/R)
0.75	1.5	0.5
1.0005	1.5	0.667
1.5	1.5	1

Table 2 Variations of helix angles considered for analysis of wind turbine

Radius (m)	Pitch (m)	Helix angle (degrees)
1.5	7.5	32.141
1.5	10	22.99

Fig. 1 CAD model of the Helical Gorlov vertical axis turbine

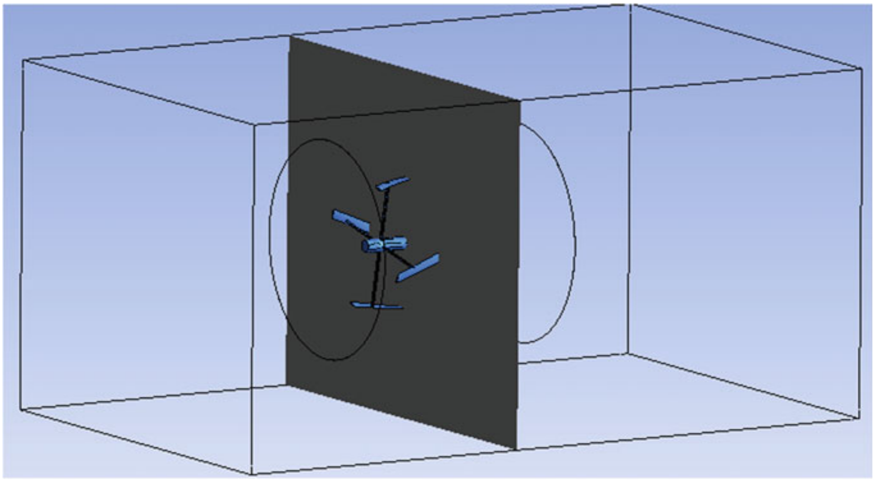

Fig. 2 Position of reference plane for monitoring the post processing data

were analyzed for stress generated and maximum deflection of the blades. The results were analyzed on the plane passing through the turbine region in the analysis setup as shown in Fig. 3. The transient turbine model was simulated for the power outputs, corresponding pressure and velocity plots around the turbine blades.

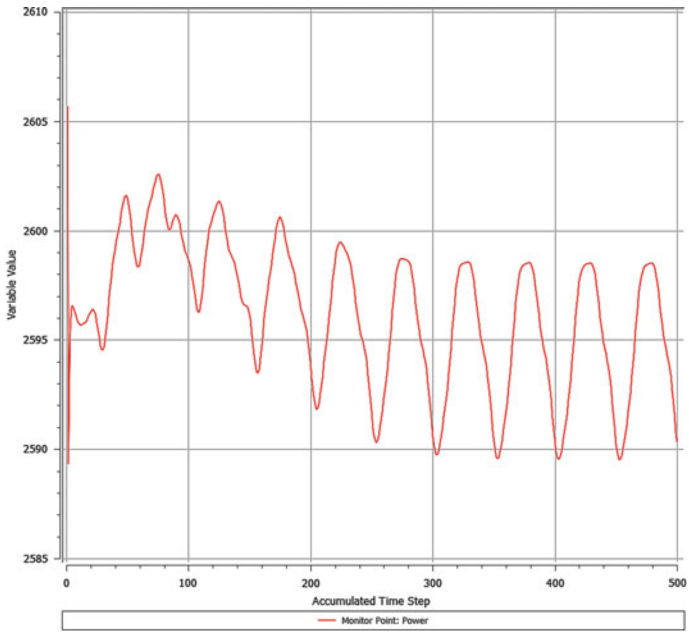

Fig. 3 Output power graph for aspect ratio 0.5

4 Results and Discussions

The airfoil NACA0018 vertical axis wind turbine having diameter of 1.5 m was simulated in Ansys software for aspect ratio of 0.5, 0.667, and 1. The power outputs are shown in Figs. 3, 4, and 5 for aspect ratio of 0.5, 0.667, and 1, respectively. It is clear from the plots that the cyclic nature of turbine power generation is taken into account, thus forming sinusoidal nature of graph at the end of convergence. The average power computed is from the graph at the end of convergence.

It is evident from the plots of power with respect to the aspect ratio that available power increases with the increase of the aspect ratio. This is due to a larger blade area which in turn increases rotational velocity. The theoretical and analysis power output comparison is as given in Table 3 below. The theoretical power is estimated using the Eq. 4.1, which is a function of the density of air (ρ), frontal area of the blade of turbine (A), and wind velocity (V).

$$P = \frac{1}{2}\rho A V^3 \tag{4.1}$$

The effect of aspect ratio on the pressure variation across the airfoil cross section was also simulated. However, the pressure plots show limited variation. This is due to constant airfoil parameters and wind flow properties. Therefore, due to the same

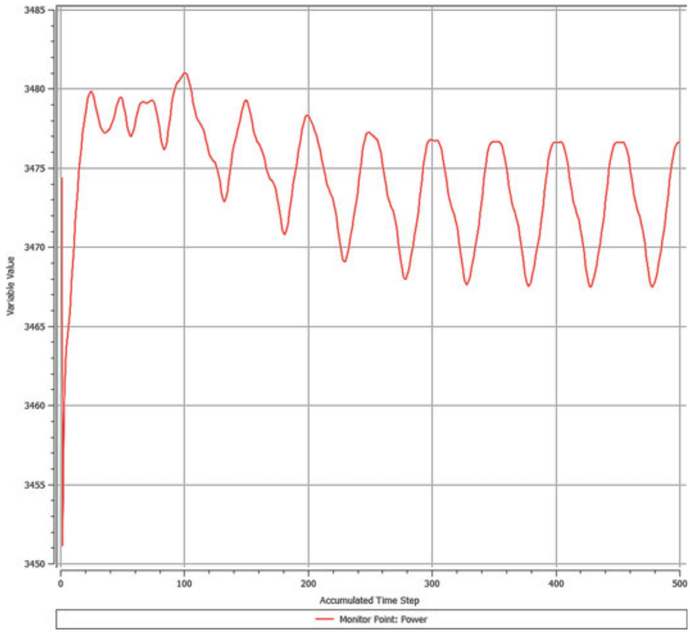

Fig. 4 Output power graph for aspect ratio 0.667

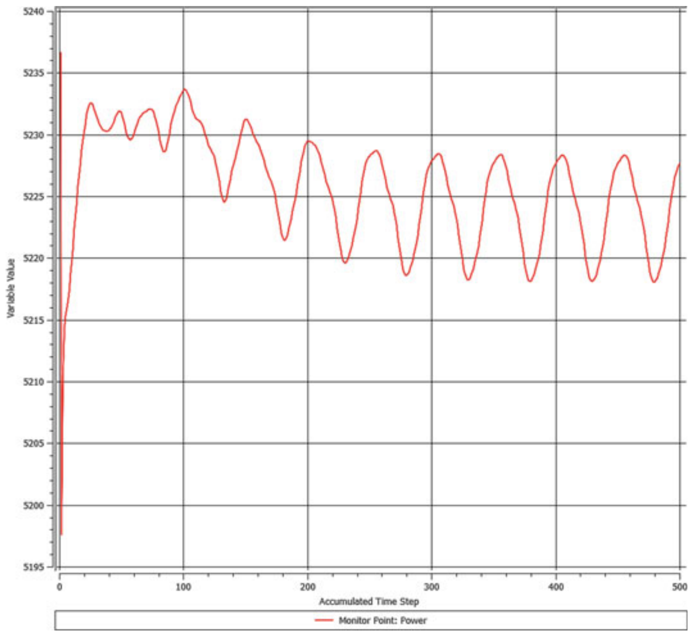

Fig. 5 Output power graph for aspect ratio 1

Table 3 Comparison of theoretical power output and analytical power output with respect to the aspect ratio

Aspect ratio	0.5	0.667	1
Theoretical power output (W)	2.463	3.284	4.77
Analytical power output (W)	2.59	3.475	5.225

NACA0018 airfoil profile used for simulations of different aspect ratios, there is a similar behavior of variation of air pressure over the blades which leads to the fact that the pressure plots is not a good metric for aspect ratio selection if the airfoil shape and wind characteristics remain the same. The velocity contours are also obtained for aspect ratio of 0.5, 0.667, and 1, and it is observed that aspect ratio of 0.667 provides the highest velocity as compared to aspect ratio of 0.5 and 1. Therefore, aspect ratio of 0.667 can be selected out of the three aspect ratios for optimum output.

The variation of helix angle was also simulated to note the variations in output power of the wind turbine. The simulations are performed for helix angles of 22.99 and 32.141. The results are shown in Figs. 6 and 7.

It is observed from the variations of output power with respect to helix angles of 22.99° and 32.141° that the helix angle of 32.141° provides marginally higher power as compared to helix angle of 22.99°.

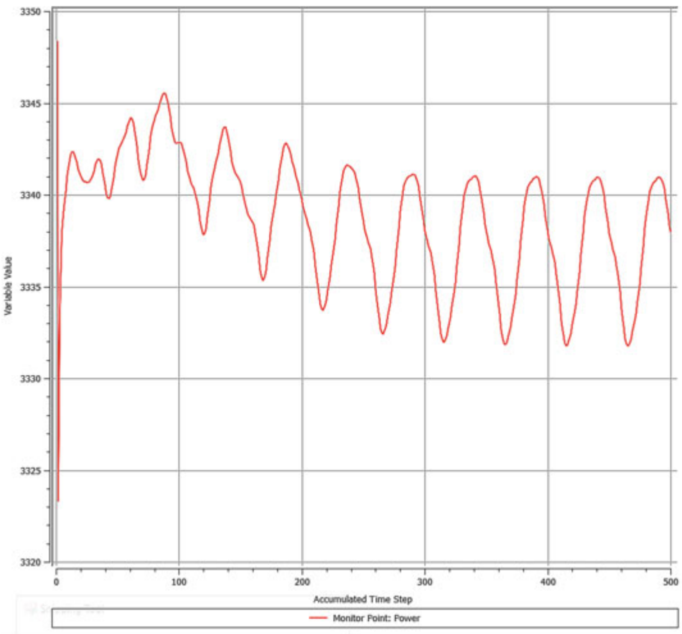

Fig. 6 Output power for helix angle 22.99°

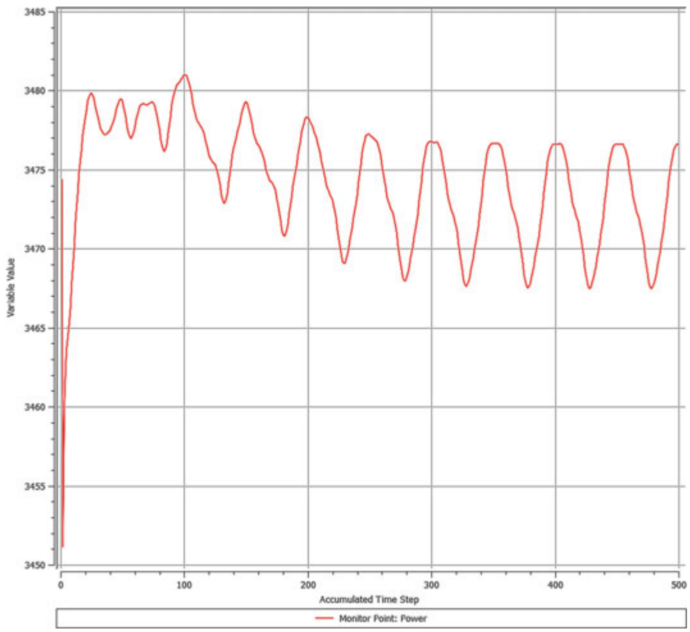

Fig. 7 Output power for helix angle 32.141°

The structural analysis was performed in Ansys software, and the stress and deflection were estimated for the airfoil NACA0018 vertical axis wind turbine. The material of the turbine blades was chosen as glass fiber-reinforced polymer (GFRP). The turbine blades is designed to be supported on two points to the main shaft. The expected maximum deflection is supposed to be at the blade center owing to its height. Maximum stress will be in turn generated at the supports and the blade tips as seen in the results. The maximum deflection and the stress generated are well below the ultimate limits of the GFRP material used. The variations of stress over the turbine blade and deflection are represented in Figs. 8 and 9.

5 Conclusion

The design optimization of Gorlov Helical VAWT was done on the basis of theoretical calculations performed. These calculations were further validated with the CFD analysis results. The results were analyzed initially on the basis of power output. This shows that as the aspect ratio increases, the power output of the given helical turbine also increases. This can be supported due to the fact that more the area of the blade available for power generation, more will be the increase in power output. Based on these observations, the priority of the designs iterated was aspect ratios 1, 0.667, and 0.5, respectively. Higher velocity at the rotor is preferred for maximum

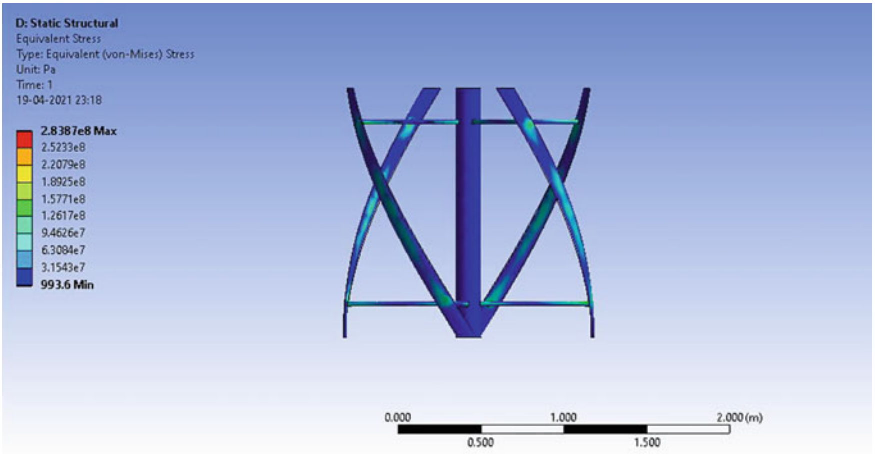

Fig. 8 Variation of stress over the turbine blade

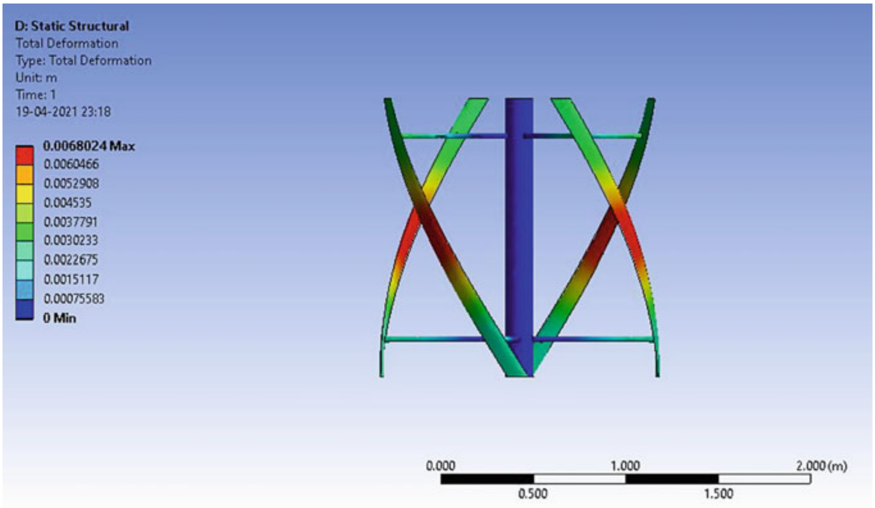

Fig. 9 Variation of deflection over the turbine blade

efficiency. Thus, the turbine design with aspect ratio 0.667 was chosen to be the optimum design. The pressure plots showed negligible variation primarily due to the fact that the airfoil and wind flow properties were the same for all the analysis results. This resulted in the same angle of attack and hence causing no significant difference in the pressure plots.

Further analysis was done for the variation in the helix angle of the turbine blades. It is evident from the results that the power generated decreased with decrease in the helix angle. The static structural analysis was done for the helical turbine with aspect ratio 0.667, and a helix angle of 22.99 degrees was finalized. The structural analysis showed a negligible stress concentrated on the overhang part of the blade for GFRP material. The values were justifiably lower than the ultimate stress limit of GFRP with an approximate FOS of 2–2.5 (considering the range of values available) The deflection was also found to be within considerable values and lower than the fracture limit of GFRP commercially used.

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Performance Optimization of Steam Ejector Using CFD Analysis

Abdullah Rumane and Shilpa Mondkar

Abstract The simplest devices are jet ejectors between all compressors and vacuum pumps. There are no moving parts, lubricants, or seals and are therefore considered to be the most reliable devices with low supporting costs. Factors affecting the performance of a jet ejector are molecular fluid weight, feed rate, tube length mixing, tube area, throat size, fluid speed, pressure rating, and temperature range. In this work, the optimization of jet ejector using CFD was carried out by creating a model and analyzing the multi-phase flow model of steam and water and the consequence of possible borderline environment on the clone answers using a commercial software of Ansys Academic 2021. The results show a 14.66% increase in the entrainment ratio of the fluids. The CFD results were compared to analytical model, and the deviation was calculated which was in the acceptable range, thus conforming to the reliability of CFD models. Lastly, a two-inlet nozzle was studied which gave an appreciable amount of entrainment ratio.

Keywords Steam jet ejector · Computational fluid dynamics (CFD) · Mass transfer · Nozzle

1 Introduction

Rising energy demand in international market is linked with industrial technological advancement which goes hand in hand with the population of the world, human growth, and pursuit of a higher standard of living. Multiple problems can arise from increased power consumption, which include emissions of greenhouse gases, global warming rapidity, and uprising demand for electricity. Generating new energy recovery policies, designing high-efficiency power tools, and substituting the devices

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that require excessive external load may be some adequate ways to diminish the need for global power urge. Several compressors and pumps have been replaced by ejectors in high-powered systems. Ejectors are basically composed of a nozzle, a suction inlet, a mixing chamber, and a diffuser. Its operating principle is based on the transfer of high-pressure flow to low-pressure flow without the need of outside work. However, ejectors have low efficiency than pumps and compressors and the jet ejectors are designed to execute optimal performance in certain operating environments. Within the ejectors, using numerical solutions, a comprehensive explanation of flow field is provided by a method called computational fluid dynamics (CFD). The CFD method has been demonstrated to be an effective tool for overcoming certain constraints of 1D mathematical methods. In recent years, the CFD tool has been used to precisely explore the impact of ejector geometry on its performance, also to study the distribution of flow within the ejectors, and to improve the geometric parameters of the ejector. In this research, the optimization of steam jet ejector was investigated in detail with the help of CFD and analytical model. A single inlet and multi-inlet models were developed and explored using multi-phase model of steam and water.

2 Literature Review

This unit deals with the research work in the area of jet ejectors available in the literature.

Patel [1] concluded that the results obtained through the analysis show that by reducing the steam inlet pressure, the outlet pressure condition remains the same, and therefore, the efficiency of the refrigeration plant is improved because less energy is required to generate motive steam pressure and temperature. Aravind [2] employed Spalart–Allmaras turbulence model which is able to predict the operating feature of steam ejector. Entrainment (ER) ratio has been found to increase with boiler saturation temperature reduction of the same superheat condition, evaporator temperature, and condenser pressure. The shocking position was found to recede as the condenser pressure increased. Entrainment rate was found to increase with decreasing throat width. It resulted in the moving downstream of the shocking position because of the reduction in the mass of primary fluid. Ruangtrakoon [3] compared experimental results with CFD. The mixing process inside the ejector was explained using Mach number contour lines. It was thereby concluded that the position of shock and angle of expansion of the motive fluid stream played a vital role in the performance of ejector. Varga [4] took working fluid was taken as water. Results show the existence of an appropriate rating, depending on the operating conditions. It has been found that although the efficiency of a nozzle can be considered permanent, the efficiency associated with suction, mixing, and diffuser ejector components depends on operating conditions.

A number of studies have been concluded; however, little to no research is available on the multiphase phase flow model of steam and water and also about the multi-inlet jet ejector systems. This research aims in fulfilling this research gap and also provides a detailed work on overall ejector efficiency, ejector component optimization, and their determination methods using computational and analytical method.

3 Problem Definition

Number of studies have been done considering single-phase model of water and steam, whereas miniscule of studies have been carried out involving multi-phase flow model of steam and water.

4 Objectives of the Research

The principal purpose of this investigation is to correct the configuration of traditional steam design using Ansys Fluent Academic 2021 R1 computational fluid dynamics program. There are three particular research objectives in this study:

1. Calculate optimal entrainment ratio.
2. Enhance neck segment, along with broadness & extent, the nozzle position, radius of inlet curve.
3. Evaluate efficiency of the optimum design.

The second goal intended is to ensure the validity of CFD modeling. The particular purpose of this investigation is to ensure the consistency of the CFD modeling by examining the consequence of potential boundary constraint on simulation solutions.

5 Materials and Methods

Methodology to be undertaken is as follows:—I. Literature survey. II. Problem identification. III. Modeling of geometry. IV. CFD analysis of the model. V. Calculation, result, and graphical representation. VI. Result analysis. After thoroughly undergoing the methodology described above, we will be in a comfortable position to address the lacunas in the current research domain and also to predict a design which outperforms the current research with the help of CFD analysis and numerical modeling. The flow composition of a steam jet ejector is as described below (Fig. 1):

Two inlets are provided wherein steam is taken through one inlet, and the propelled fluid is taken through another inlet. Both the fluids were mixed in the mixing chamber, and then they are flown out through a common exit.

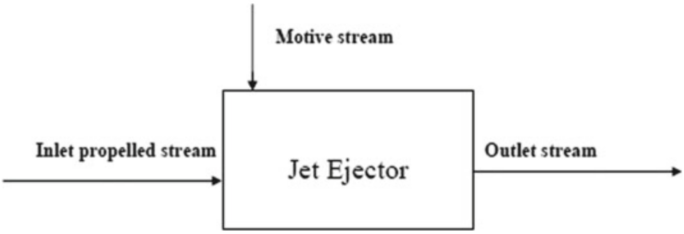

Fig. 1 Flow composition

5.1 Model Verification

The process of optimization was started by simulating the experimental model available in the literature by creating a CFD model and analyzing the data.

The geometry of the CFD model was initially set to simulate the AB and AG geometries of Huang et al. [5].

A 2D model was constructed in Design Modeler [DM], meshing of the model was done using Ansys Workbench, boundary conditions were applied for the multi-phase flow of the model, and 1000 iterations were performed. The following results were obtained.

Formation of a shock zone was seen in Fig. 2 in the throat area of the diffuser which led to decrease in the suction of the inlet-propelled fluid.

The entrainment ratio (ω),

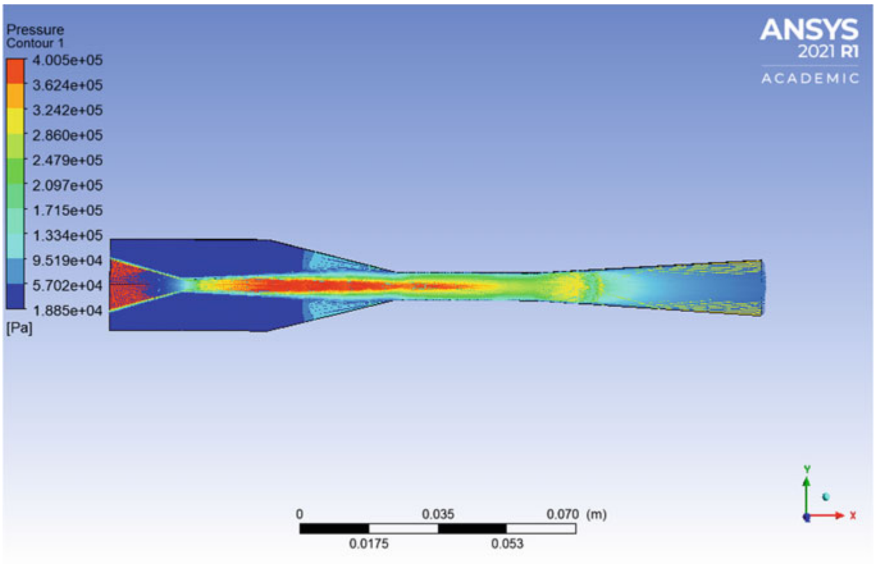

Fig. 2 Pressure contour of Axi-Symm jet ejector

$$\omega = \frac{\text{Mass flow of secondary fluid}}{\text{Mass flow of primary fluid}}$$
$$= \frac{3.5103\left(\frac{\text{kg}}{\text{s}}\right)}{8.2614\left(\frac{\text{kg}}{\text{s}}\right)} = 0.4249$$

Entrainment ratio calculated through experimental analysis (ω) = 0.4377.
Hence, %

$$\text{Error} = \frac{\text{Experimental}(\omega) - \text{Analytical}(\omega)}{\text{Experimental}(\omega)} \times 100$$
$$= \frac{0.4377 - 0.4249}{0.4377} \times 100$$
$$= 2.924\%$$

The error is in an acceptable range, thereby we can conclude that the CFD can be used to simulate the real-life conditions of steam jet ejector, and hence, the model verification is accomplished.

6 Optimization of Model

By varying the geometry, independent models were created.

6.1 Model A

After prototype creation, meshing was done with the help of Ansys Meshing software. All triangles method, refinement, edge sizing, and body sizing were used to create a suitable meshing and wherever required, fine mesh was used in order to capture the physics of the problem in detail. The boundary conditions of inlet steam were kept at 413 K temperature and 4 Bar, whereas that of water was kept at 303 K and at atmospheric pressure. 1000 iterations were performed (Fig. 3).

As clearly depicted in the above figure, there is a formation of vortices before the inlet part of the steam. This vortex causes the energy drop, thereby making the ejector inefficient to use. Also, a backflow can be seen at the outlet part in the diffuser section.

The entrainment ratio (**ω**),

$$\omega = \frac{\text{Mass flow of secondary fluid}}{\text{Mass flow of primary fluid}}$$

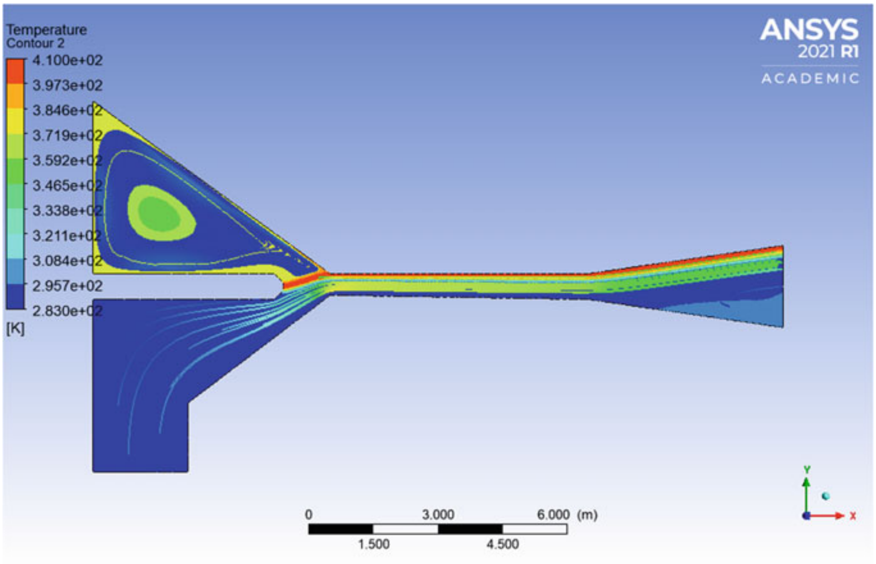

Fig. 3 Contour lines including temperature values

$$= \frac{4.452\left(\frac{\text{kg}}{\text{s}}\right)}{23.954\left(\frac{\text{kg}}{\text{s}}\right)}$$
$$= 0.1858$$

The mixing ratio (ω) of the two fluids is very less suggesting that the two flows are not intermingling.

6.2 Model B

Prototype with the dimensions as shown below was created in Ansys Design Modeler [DM]. The two phases were defined as a steam at 413 K at 4Bar pressure and water at 303 K at atmospheric pressure.

The temperature contour depicts a rather clear picture of the change in temperature at every interval. It also shows a recirculation zone toward the north section of the ejector. The temperature goes on reducing which is shown in the graph of Fig. 4.

The entrainment ratio (**ω**),

$$\omega = \frac{\text{Mass flow of secondary fluid}}{\text{Mass flow of primary fluid}}$$

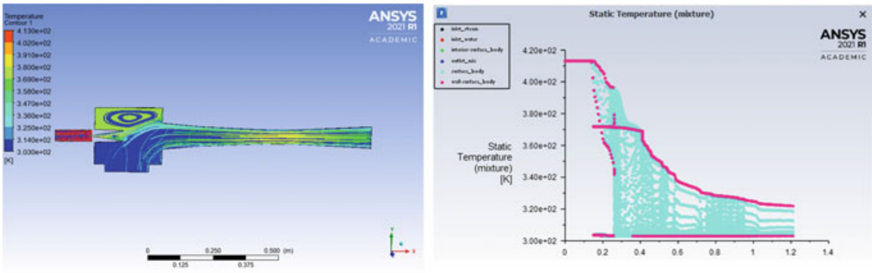

Fig. 4 Temperature contour and temperature graph

$$= \frac{4.5219\left(\frac{\text{kg}}{\text{s}}\right)}{9.0814\left(\frac{\text{kg}}{\text{s}}\right)}$$

$$= 0.4979$$

6.3 Model C

The single inlet in case of Model B was transposed into two inlets, i.e., multi-inlet flow. A design of a model was created using Ansys Design Modeler, meshing and named selection were done to the two-inlet steam ejector, a multiphase flow model was selected same as in case of Model B with exactly same boundary conditions, and solution was iterated. The following results were obtained.

The velocity reaches its maximum value in the mixing chamber. The plot of graphs in Fig. 5 shows relatively less recirculation zones due to proper mixing of the fluids.

The entrainment ratio (**ω**),

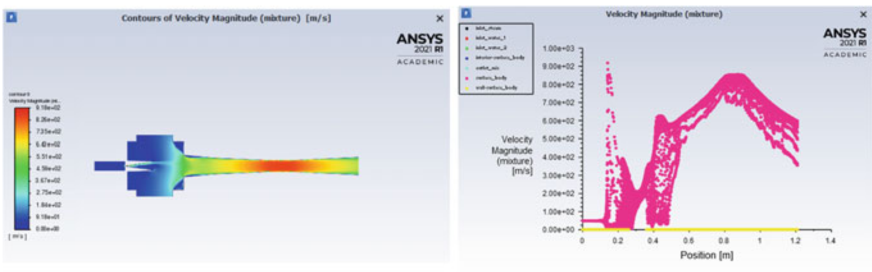

Fig. 5 Velocity contour and velocity graph

$$\omega = \frac{\text{Mass flow of secondary fluid}}{\text{Mass flow of primary fluid}} = \frac{7.528\left(\frac{\text{kg}}{\text{s}}\right)}{9.0814\left(\frac{\text{kg}}{\text{s}}\right)} = 0.8289$$

The mixing ratio of the two fluids was increased since the pressure drop at the exit of the nozzle caused both the inlet fluids to be sucked into the mixing chamber.

7 Mathematical Modeling

By applying mass, energy, and momentum (conservation equations), a quasi-1D mathematical procedure was used to compute outlet pressure, temperature, and efficiency of the jet ejector.

Outlet Steam Pressure (Po) [5].

$$P_0 = \left\{\left[\frac{1}{2}\left(m_s v_s^2 - v_0^2\right)\left(\frac{\gamma - 1}{\gamma}\right)\frac{MW}{R} + T_s m_s + T_w m_w\right] \times \left[\frac{(P_w + P_s)^{\frac{\gamma-1}{\gamma}}}{\left(T_s m_s P_w^{\frac{\gamma-1}{\gamma}} + T_w m_w P_s^{\frac{\gamma-1}{\gamma}}\right)}\right]\right\}^{\frac{\gamma-1}{\gamma}}$$

Outlet Temperature (T_0) [5].

$$T_0 = \frac{1}{2}\left(\frac{MW}{C_p}\right)\frac{m_s}{(m_s + m_w)}\left(v_s^2 - v_0^2\right) + \frac{(T_s m_s + T_w m_w)}{(m_s + m_w)}$$

Efficiency of the ejector (η) [5].

$$\eta = \frac{\frac{1}{2}(m_s + m_w)v_0^2 + m_w\frac{RT_w}{MW} + m_s\frac{RT_s}{MW} + m_w\left(\frac{\gamma - 1}{\gamma}\right)\frac{RT_w}{MW}\left[\left(\frac{P_0}{P_w}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\} + m_s\left(\frac{\gamma - 1}{\gamma}\right)\frac{RT_s}{MW}\left[\left(\frac{P_0}{P_s}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}}{\frac{1}{2}m_w v_w^2 + \frac{1}{2}m_s v_s^2 + m_w\frac{RT_w}{MW} + m_s\frac{RT_s}{MW}}$$

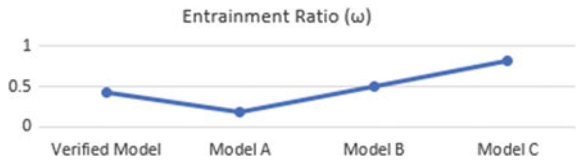

Fig. 6 Graph of entrainment ratio

Outlet steam pressure, temperature, and efficiency of the steam jet ejector were calculated by using the above-given formulas.

8 Results and Discussions

A good model will provide a high accuracy result and consumes the least computational resources.

8.1 Entrainment Ratio (ω)

The above-plotted graph shows the mixing ratio of all the four models. By comparing Model A with verified model, a −56.27% reduction in entrainment ratio is found out. Hence, Model A is the worst-case scenario and therefore is not suitable for application purposes. By comparing Model B with verified model, 14.66% increase is seen in the entrainment ratio which is acceptable, and hence, the geometry selected could therefore boost the output of ejector systems. On analyzing Model B with Model C, i.e., single inlet with multiple inlets, a staggering 39.93% increase is observed. Thus, if a single inlet is required, Model B should be selected, but if more entrainment ratio is needed, then Model C is to be selected and hence concluded that Model C is perfect for higher entrainment ratio use cases (Fig. 6).

8.2 Pressure, Temperature, and Efficiency

The efficiency of the ejectors is shown in Fig. 7. It is therefore seen that for a water and steam as a working fluid, and Model B outperforms both A and C. Thereby we can conclude that Model C has the highest entrainment ratio but the lowest efficiency as compared to Model B, because of the increase in inlets, the performance grading of the multi-inlet ejector reduces.

	Ejector Performance Parameters	CFD Analysis	Mathematical Modeling	% Error
Output Steam Pressure (P_0) [Bar]	Model A	0.4958	0.3844	22.46%
	Model B	0.5924	0.5266	11.10%
	Model C	0.5421	0.5049	7.36%
Outlet Temperature (T_0)[K]	Model B	322	314.73	2.25%
	Model C	316	308.44	2.39%

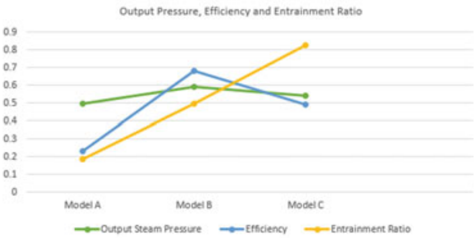

Fig. 7 Percentage error in the three models and graph of output pressure, efficiency, and entrainment ratio

9 Conclusion

In process industries, jet ejectors are extensively utilized as they have no moving parts and hence very low maintenance cost. However, jet ejectors have low efficiency as compared to the widely used pumps and compressors. Outcome of the research was to study the distinguished diameter of the nozzle, entrainment ratio, and the efficiency of the ejector. CFD software Ansys 2021 R1 (Student Version) was used in this research. Investigation revealed the dependability of CFD modeling, and the results support that it can provide excellent solutions that are in accordance with the analytical modeling and can further help in improving the design and overall output of steam jet ejector. The optimal geometry of high-efficiency steam jet ejector was determined. The research results indicate that the nozzle radius for steam inlet should be 1.335 mm for a 1199.01 mm length of entire ejector. A 14.66% increase in the entrainment ratio as compared to the existing single inlet ejector along with an efficiency of 0.68 was seen in the optimized model. The flow diagrams of the optimized model as seen in the various contours verify the multi-phase flow of the steam and water. This proves an impressive enhancement from a conventional steam jet ejector design.

Finally, a two-inlet steam jet ejector model is proposed along with their CFD and analytical modeling. The results convey a staggering improvement in the entrainment ratio but the efficiency was found to be decreased. Perhaps the performance ratio of multi-inlet jet ejector systems can be improved by providing mixing guideways which will help in giving higher compression ratio and thus increasing the overall output ratio.

10 Future Research

Although many works are available in the literature, further attempts are still needed. Optimization of steam jet ejector with multiple inlets should be further researched in order to obtain maximum efficiency. Research on the performance of single and multi-inlet ejector systems in cascading systems, i.e., series and parallel, should be studied.

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