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TECHNICAL PAPER

The application of TRIZ on natural fibre metal laminate to reduce the weight of the car front hood

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Abstract

Fibre metal laminate is a lightweight material consisting of metal and composites bonded together. The application of natural fibre metal laminate is examined in this study, with the intention to reduce the weight of the car front hood and in turn, to reduce the weight of the vehicle. This would also help to reduce engine gasses emissions using less fuel and help to reduce the effects associated with global warming. The study highlights several limitations with this material and the importance to determine the appropriate and effective solutions using fibre metal laminate. The application of the TRIZ method is applied to solve several problems that may occur during the utilisation of natural fibre metal laminate as the car front hood. TRIZ is a systematic tool that can assist in solving problems and recommending inventive and effective solutions. By applying the TRIZ method, the contradictions associated with using natural fibre metal laminate as the car front hood are identified using "If", "Then", and "But" keywords to determine the parameters used for the selection of the 40 Inventive Principles via the TRIZ contradiction matrix. Three contradictions were identified and specific solution ideas determined via the application of the TRIZ method. The method also provided several other solutions for the contradictions. The TRIZ solution principles used to generate the specific solution ideas were: #40 composite material, #1 segmentation, #3 local quality, #37 thermal expansion, #2 taking out and #11 beforehand cushioning.

Keywords TRIZ · Natural fibre · Fibre metal laminate · Car front hood

1 Introduction

Greenhouse gas emissions, such as carbon dioxide (CO_2), methane and ozone found in the atmosphere, are recognised as being the main causes of global warming. Many activities contribute towards the production of greenhouse gases such as industrialisation, power generation, heat production, agriculture, forestry and transportation. The 2016 report on the trends in global CO_2 emissions [1] highlighted that in 2015, carbon dioxide emissions caused by road transportation increased primarily because of a 4.1% increase in diesel fuel consumption. Mandatory legislation released by the European Union (EU) stated that from 2015 onwards, all new cars registered in the EU should not emit more than 130 g of CO_2 per kilometre (g CO_2/km). The figure for CO_2 emission is equivalent to fuel consumption of approximately 5.6 l of petrol per 100 km (l/100 km) or 4.9 l of diesel fuel per 100 km [1, 2]. In conjunction to that, automobile manufacturers have made significant efforts to comply with the legislation to maintain their competitiveness in their respective target markets. The reduction in CO_2 emissions produced from an engine can be achieved by enhancing the engine's fuel economy, improving the vehicle's autonomy or by reducing the overall weight of the vehicle. Weight reduction improves fuel efficiency by approximately 6–8% for each 10% of reduced weight [3].

A large sheet of metal consisting of an outer and inner panel covering the car's engine is known as the car's front hood. The design of the car front hood must satisfy varying requirements based on style, safety, structural needs, transportation performance, fuel consumption, costs, quality and reliability [4]. Several research studies have been conducted to optimise the car front hood. Teng and

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Ngo [5] performed a study to investigate ways to optimise the thickness of the car front hood in relation to the safety of pedestrians. Ganeshpure and Bhope [6] analysed static and free vibration characteristics associated with the car front hood. Avalle et al. [7] investigated the aspects associated with pedestrian safety by utilising a numerical and experimental method on a lightweight car front hood. Several studies have examined weight reduction of the car front hood using new material compositions and including hybrid composite [8], aluminium sandwich sheet [9, 10] and natural composite [11]. According to Hamacher et al. [12], the reduction of the front car hood's weight can contribute to the front structural weight of the vehicle and achieve a more balanced static axle load distribution.

Over the last few decades, the demand for fibre metal laminate (FML) has increased due to its high performance and lightweight structure. FML is a lightweight material currently applied in various fields such as aviation, aerospace, maritime, defence and several other industry sectors. FML is a hybrid composite material constructed from interlacing layers of thin metals and fibre reinforced adhesives [13], having excellent physical and mechanical properties compared to monolithic metal structures [14]. Several studies have examined FML properties. Şen et al. [15] considered the design optimisation procedure for FML based on crack initiation. Hu et al. [16] observed FML based on carbon fibre reinforced polyimide, thereby possessing excellent thermostability. Abdullah et al. [16] examined FML based on fibre reinforced thermoplastic observing good adhesion between the aluminium and fibre reinforced thermoplastics achieved using sulphuric acid anodising surface-pre-treatment. Also, Sivakumar et al. [17] investigated the effects of processing parameters during the formation of a glass reinforced polypropylene-based sandwich structure with the results indicating the potential for it to replace monolithic aluminium.

While many researchers have examined FML, the number of studies carried out is limited with respect to FML based on natural fibre reinforced composite. Ishak et al. [18–20] determined a suitable natural fibre reinforced composite and thermoplastic matrix for FML using the Multiple Criteria Decision Making (MCDM) method by selecting kenaf fibre and polypropylene. Vasumathi and Murali [21] studied the bending impact and axial loading of jute FML using aluminium and magnesium alloys. The results confirmed the benefits of using Carbon Jute Reinforced Magnesium Laminate (CAJRMAL) instead of Carbon Jute Reinforced Aluminium Laminate (CAJRALL) in applications requiring the use of low weight materials. Sivakumar et al. [22] conducted an impact study on oil palm empty fruit bunch (OPEFB) FML observing that the OPEFB FML structure had excellent flatwise impact properties compared to 2 mm thick monolithic aluminium. Ng et al. [23] investigated fatigue performance of a hybrid FML structure with four different hybrid layups incorporating kenaf and glass fibre. It was observed that the hybrid laminate with kenaf/glass composite improved fatigue performance. Fazilah et al. [24] defined the tensile properties of woven kenaf fibre reinforced polypropylene hybrid aluminium composite with different fibre loadings and fibre orientation. The study observed that tensile strength increases when applying an increment of fibre loading and with 45° fibre orientation. Also, Gonzalez-Canche et al. [25] examined the mechanical properties of FML-based aramid fibre reinforced polypropylene, observing that tensile properties increased by $\sim$ 230 and $\sim$ 400% compared to composite laminate and aluminium sheet.

The inherent properties of natural fibre and its use could potentially help with reducing weight, being cost-effective, being environmentally friendly, a renewable source, biodegradable, recyclable and in gaining carbon credits [21, 26]. Compared to aluminium, FML is about 30% lighter than aluminium [22] and 70% lighter than steel [27]. Therefore, to reduce the weight of the car front hood, FML based on natural fibre reinforced composite is used; refer Fig. 1. However, there are enormous challenges when applying natural fibre reinforced composite FML as the car front hood since the strength and stiffness of natural fibre are low compared with synthetic fibres [28, 29].

TRIZ is a powerful tool helping to guide engineers and designers to understand and solve problems [30]. Mastura

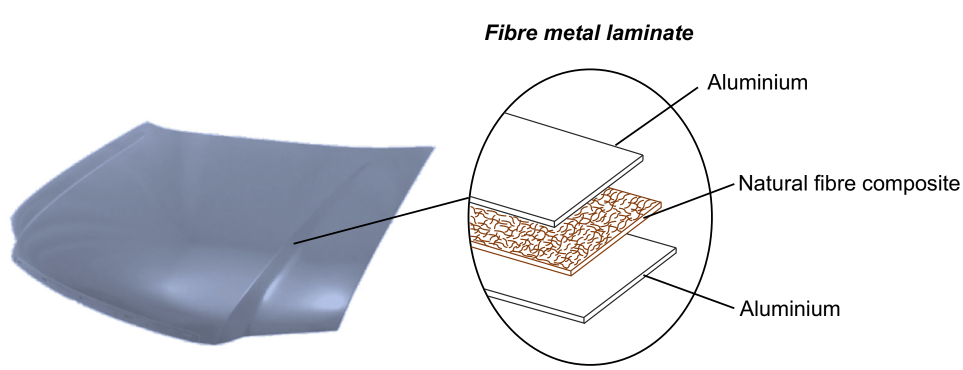


Fig. 1 Utilization of natural fibre metal laminate for car front hood

et al. [31] studied the design strategy for the design concept of a hybrid biocomposite automotive anti-roll bar using TRIZ. The TRIZ method proposed several solutions to increase the stiffness of the anti-roll bar without increasing the weight of the bar. The modern design of the hybrid biocomposite automotive anti-roll bar reduced the maximum displacement by 22.5%, eventually improving stiffness.

Ng and Jee [32] examined the difficulty in turning the milling machine control knob. The existing control knob would cause occupational injuries and musculoskeletal disorders to the operators given the excessive amount of force required to rotate the control knob. The TRIZ method was applied to redesign and to develop an ergonomic milling machine control knob. The innovative design produced and reduced the amount of pinch force by approximately 72% for males and 55% for females.

Sun et al. [33] studied the folding structure of bicycles. The aim of the study was to change and modify the shortcomings of traditional folding bicycles making it much faster than conventional folding bicycles. There were three contradictions that were noted in the study. These included the conflicts between the folding speed and structural stability, the weight, stress and reliability and, finally, the applicability of the target population and complexity. By applying the TRIZ method, the three contradictions were solved by selecting the most relevant principles. Principle #3 local quality resolved the conflict between the folding speed and structural stability. Principle # 1 segmentation resolved any conflict between weight, stress and reliability, and principle # 15 optimisation resolved the conflict between the applicability of the target population and complexity.

Furthermore, the TRIZ method can be integrated with other tools such as Quality Function Deployment (QFD), the Technology Acceptance Model (TAM), the morphological chart and with several other tools. Research carried out by Mansor et al. [34] on an automotive spoiler applied kenaf polymer composites to achieve a lightweight advantage while maintaining the structural strength of the car spoiler. The TRIZ method was used during the initiation of the concept design stage while for the development stage, the TRIZ method was integrated with the morphological chart.

Yihong et al. [35] achieved a new design of wall materials incorporating the TAM, QFD and TRIZ methods. The TAM method was utilised to identify user intentions and the level of demand to use the new materials and the collected information was then converted into the design requirements using QFD. The TRIZ method was primarily focused on identifying and resolving the various problems associated with user demands and market needs.

The case studies discussed herein clearly confirm that the TRIZ method can be practically applied to problem-solving areas, leading to innovative and creative solutions. Integrating the TRIZ method with other tools for problem-solving makes the method more convincing. Therefore, the aim of this study is to apply the TRIZ method on natural FML for the car front hood to generate inventive solutions for the enhancement of vehicle performance.

2 Methodology

Teoriya Resheniya Izobretatelskikh Zadatch (TRIZ) is a tool used for inventive and effective solutions and was chosen to help and guide in developing the conceptual design for the application of FML as the car front hood. The method was developed by Genrich Altshuller and his team, through analysing more than 3 million invention patent documents that predicted breakthrough solutions to various problems [36].

TRIZ has grown as many researchers study this method and has evolved after Altshuller. In 1991, Salamatov [37] has proposed the laws of evolution, called Wave Model. Then, in 2001, Zusman and Zlotin [38] proposed the Directed Evolution model. Cavallucci [39] has integrated the TRIZ Laws of Engineering Systems Evolution into the design process. TRIZ has further evolved with the development of the Evolutionary Potential [40], Evolution Trees [41] and Network of Evolutionary Trends [42] and still growing.

The TRIZ method consists of four steps: First, to define the specific issue or problem by identifying the gaps in the requirements and to determine the characteristics that should be improved or eliminated for faultless operations [43]. Second, to interpret the specific problem or issue into a general problem (e.g. engineering contradiction, physical contradiction, function model, substance field model) [44]. Thirdly, based on the general issue or problem, apply the solving principles belonging to TRIZ (i.e. contradiction matrix, the system of standard inventive solutions) to determine the general solution. Finally, to derive the specific solution from solving the problem based on the suggested TRIZ general solution. Figure 2 illustrates the TRIZ problem-solving method which classifies problems and solutions in seeking correlation that enables a set of generic problem-solving operators [45].

2.1 Contradiction

The contradiction is a constraint that arises from the obvious incompatibility of the desired features within a system [46]. The inventor of TRIZ Altshuller divided the contradiction into three types which are administrative,

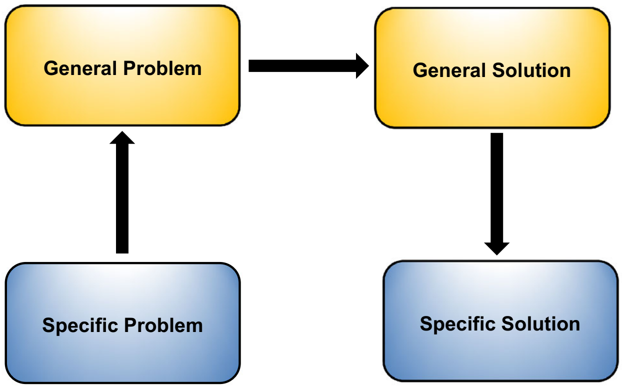


Fig. 2 TRIZ problem solving method

technical and physical contradictions. The administrative contradiction refer to something is required to make, to receive some result, to avoid the undesirable phenomenon, but it is not known how to achieve this result [47]. The administrative contradiction needs to be evaluated and re-stated as a specific technical or physical contradiction problem statement that can be solved [48]. The technical contradiction is a situation in which when an improvement of one of the system parameters will then lead to deterioration of another parameter [49] and the physical contradiction addresses the part of the technical contradiction centred on that parameter that has two opposite values at the same time [50].

2.1.1 Contradictions presented in natural fibre metal laminate for car front hood design

The main goal of this study is to achieve weight reduction in vehicles, to improve fuel efficiency and contribute towards the reduction of global warming. For this reason, FML has been selected as a potential lightweight material to reduce the weight of the car front hood due to its excellent mechanical properties and by sharing the advantages of using metals and fibre reinforced composites. Also, to gain further carbon credits, the natural fibre was chosen as the composite fibre reinforced layering for the FML. This is due to its low weight, cost-effectiveness, being environmentally friendly, a renewable source, biodegradable, and recyclable. However, there is a level of contradiction regarding the amount of effort required to apply natural FML as the car front hood due to the limitation of the natural fibre's mechanical properties. A contradiction occurs when any improvement against the system parameter is performed, which then leads to deterioration of the system.

To identify the problems of the natural FML car front hood system, a function analysis is constructed. Function analysis delivered the interactions between each component with a complete and simple visual, which could assist in a proper understanding of the problems and the potential solutions for the whole system [51], along with detailing of the components connections. Figure 3 illustrates the functional analysis of natural FML which details the interaction between each component.

Figure 3 depicts an overview of the function analysis and the application of natural FML as the car front hood and through this function analysis, we could model the problem using administrative contradiction, technical contradiction and physical contradiction. For this study, the contradictions are modelled as technical contradiction since it is easy to interpret the involved parameters to obtain the solution utilising 39 system parameters and to determine the appropriate solutions through the 40 Inventive Principles.

The car front hood is the main component to absorb the impact of any collision which will deform the vehicle's front hood. However, the reliability of the material is questionable since the strength and stiffness of natural fibre are both low compared with synthetic fibres. According to a study by Khalili et al. [52], the tensile strength of basalt FML is 280 MPa, while a further study carried out by Kuan et al. [53] identified that the range of tensile strength for environmental friendly FML is between 90 and 140 MPa. Therefore, to improve the stiffness of the FML structure, adding a layer of composite or metal is commonly applied to obtain the equivalent strength of the current material.

The next problem to be faced using natural FML car front hood is the thickness. Due to the thick layering of FML, the front hood may not completely closed due to the interference between the front hood and engine components. Moreover, according to Teng and Ngo [5] concerning the stiffness of the car front, the hood must be systematically optimised as some components in the engine compartment may be close to the motor vehicle's front hood surface.

Besides that another technical contradiction for the application of natural FML is the exposure to humidity caused by rain or mist. Since FML is a layering structure, the edge of the FML, especially the composite layering, is potentially vulnerable when exposed to humidity caused by rain and mist. Yousif and Ku [54] identified that natural fibre/polymer composites exposed to humidity and immersed in water could absorb moisture. Dhakal et al. [55] confirmed that the natural fibre's physical, mechanical and thermal properties are affected by moisture absorption.

3 Application of the TRIZ method

By applying the TRIZ method, the technical contradictions for utilising natural FML as the car front hood are identified using "*If*", "*Then*", and "*But*" keywords. According

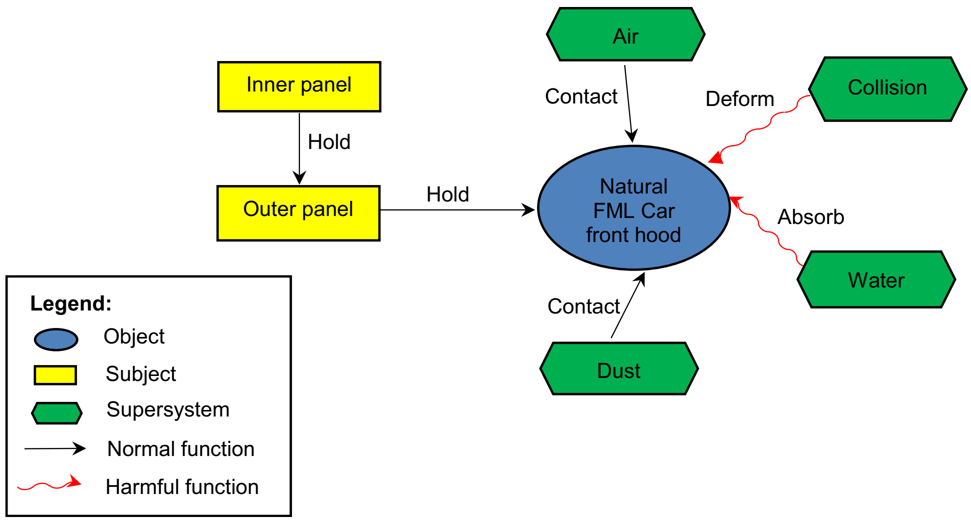


Fig. 3 Function analysis of natural FML utilization for car front hood

Table 1 TRIZ solution principles for contradiction 1

Improving features	Worsening features	TRIZ solution principles
# 1 mass of moving object	#5 Strength	# 28 mechanics substitution
		# 27 cheap short-living objects
		# 18 mechanical vibration
		# 40 composite material

to Kamarudin et al. [56], the keywords are beneficial for identifying the 39 parameters used for the selection of 40 Inventive Principles using the TRIZ contradiction matrix. Moreover, the formulation of "*If*", "*Then*", and "*But*" keywords makes the problem easier to understand and to identify the contradiction parameters [57]. A similar approach had been taken by Ong and Rahman [58] to improve the effectiveness in identifying the poor thermal dissipation device using electrical measurement. Kurata et al. [57] also used this technical contradiction to renew the streamlined process of a government service facility.

If: state the change made
Then: state what good happen
But: state what bad happen

The three main contradictory problems, identified using natural FML as the car front hood, are:

(i) Contradiction 1:
If applying a natural fibre composite layering of FML as the car front hood panel,
Then could reduce weight of the vehicle,
But the strength of the structure to absorb the impact energy better than actual car front hood during collision is unreliable.

The particular problems are defined using the "*If*", "*Then*" and "*But*" keywords and the statements are then translated to one of 39 System parameters to determine 'improving' and 'worsening' parameters. In contradiction 1, relating to the moving object, the improving parameter is #1 mass of moving object, while the worsening parameter is #5 strength. Strength as per the 39 System Parameters is the extent to which the object is able to resist changes in response to force [59]. The improving and worsening parameters will be referred to the Expandable TRIZ Contradiction Matrix 2010 to determine the proposed solutions by TRIZ. Table 1 shows the inventive solution principles recommended by TRIZ method. There are four recommended solutions that the designers could use to generate and gather ideas to solve the contradiction.

Even though FML is a composite sandwich structure, nevertheless, TRIZ method can optimise the FML hybrid composition and stacking configuration. For contradiction 1, solution principle #40 has been selected to generate specific solution ideas. Therefore, Table 2 shows the design strategy involving the composite composition to solve the problem, while Fig. 4 illustrates the specific solution idea to solve contradiction 1.

Nevertheless, after reviewing the list of 40 Inventive Principles, several additional solutions could be applied to generate specific solutions and ideas for contradiction 1. Table 3 shows the specific solution idea number 2 for contradiction 1, while Fig. 5 illustrates the solution idea.

(ii) Contradiction 2:
If increasing the thickness of the FML panel,

Table 2 Specific solution principles for contradiction 1

TRIZ solution principles	Solution description	Design strategy description
# 40 composite material	Change from uniform to composite (multiple) materials	Apply a hybrid composition by combining the natural fibre with synthetic fibre (glass, carbon or aramid fibre) at the impact point to enhance the strength to absorb impact energy

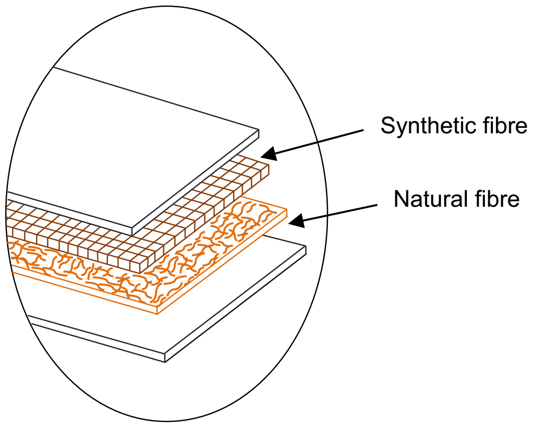


Fig. 4 Solution idea No. 1 for contradiction 1: hybrid composition

Table 3 Specific solution idea No. 2 for contradiction 1

TRIZ solution principles	Solution description	Design strategy description
# 1 segmentation	Increase the degree of fragmentation or segmentation	Vary the stacking configuration of the fibre reinforced composite in the FML layering to increase strength to absorb impact energy

Then could improve the stiffness of the car front hood,
But there is interference between front hood and engine components.

For contradiction 2, the improving parameter is #5 strength, while the worsening parameter is #32 ease of manufacture. Table 4 shows the inventive solution principles recommended using the TRIZ method. Table 5 describes the design strategy for contradiction 2, where #3 local quality has been selected as the solution to solve the problem. Figure 6 illustrates the solution idea for contradiction 2.

(iii) Contradiction 3:
If applying a thick layer of natural fibre composite for FML panel as car front hood,
Then could increase the strength of the front hood,
But the edge of the FML is vulnerable and could expose the composite layering to humidity

For contradiction 3, the improving parameter is #5 strength, while the worsening parameter is #38 object affected harmfully factors. Table 6 shows the inventive solution principles recommended using the TRIZ method. Table 7 describes the design strategy for contradiction 3, where # 37 thermal expansion has been selected to solve the problem. Figure 7 illustrates the solution idea for contradiction 3.

Upon reviewing the list of 40 Inventive Principles, several solutions could be applied to generate the solution ideas for contradiction 3. Tables 8 and 9 show the specific solution ideas for contradiction 3, while Figs. 8 and 9 illustrate the solutions idea.

Fig. 5 Solution idea No. 2 for contradiction 1: stacking configuration

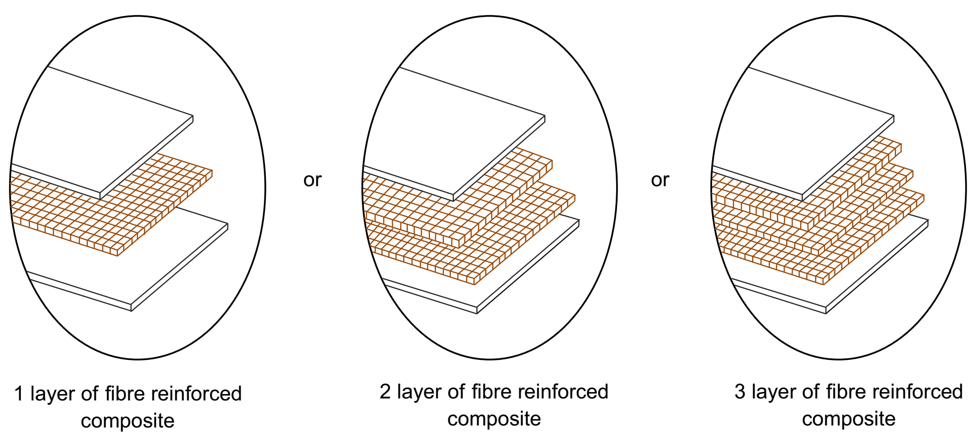


Table 4 TRIZ theory solutions for contradiction 2

Improving Features	Worsening features	TRIZ Solution Principles
# 5 strength	#32 ease of manufacture	# 11 beforehand cushioning # 3 local quality # 10 preliminary action # 32 colour changes

Table 5 Specific solution principles for contradiction 2

TRIZ solution principles	Solution description	Design strategy description
# 3 local quality	Change of an object's structure from uniform to non-uniform, change an external environment (or external influence from uniform to non-uniform	Natural FML car front hood could be shaped to facilitate and fit the engine compartment

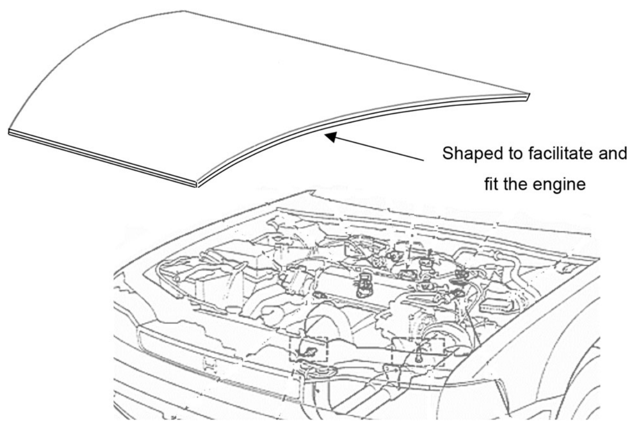


Fig. 6 Solution idea No. 1 for the contradiction 2

4 Results and discussion

To analyse the contradictions of natural FML, function analysis was used to investigate the interactions occurring between the components. By utilising function analysis, the affected or harmful components were defined and the problem definitions identified using "*If*", "*Then*" and "*But*" keywords. The words are compatible with the parameters that can be manipulated to obtain the recommended solutions for each contradiction. The 39 systems parameters were used to determine the improving and worsening parameters. Once the parameters were clearly stated, the contradiction matrix was used to identify the relevant inventive principles as listed in the 40 Inventive Principles which would help to guide the relevant parties to solve the problems.

The TRIZ method applied on natural FML to reduce the weight of the car front hood leads to three contradictions: impact, thickness and water absorption. Through using the TRIZ method for contradiction 1, principle #40 composite was the recommended solution along with a hybrid composition by combining natural fibre with synthetic fibre (i.e. glass, carbon or aramid fibre) at the point of impact and will enhance the strength to absorb impact energy during a collision. However, as a practical and useful tool used for problem solving and following a review of the 40 Inventive

Table 6 TRIZ theory solutions for contradiction 3

Improving features	Worsening features	TRIZ solution principles
# 5 strength	#38 object affected harmful factors	# 18 mechanical vibration # 35 parameter changes # 37 thermal expansion # 1 segmentation

Table 7 Specific solution principles for contradiction 3

TRIZ solution principles	Solution description	Design strategy description
# 37 thermal expansion	Use thermal expansion (or contraction) of materials	Apply shrink wrap by polymer plastic film. When heat is applied to the polymer plastic film, it will shrink tightly and cover the edge of the front hood

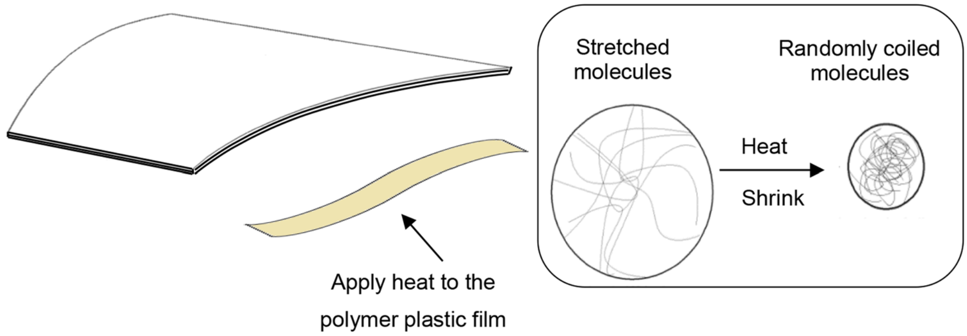


Fig. 7 Solution idea No. 1 for the contradiction 3

Table 8 Specific solution idea No. 2 for contradiction 3

TRIZ Solution Principles	Solution description	Design strategy description
# 2 taking out	Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object	Remove the excess layering at the edge of the FML to ease the hemming process to join the inner and outer closure layer together

Table 9 Specific solution idea No. 3 for contradiction 3

TRIZ Solution Principles	Solution description	Design strategy description
# 11 beforehand cushioning	Prepare emergency means beforehand to compensate for the relatively low reliability of an object	Apply the edge guard that will protect the open edge of front hood from humidity

Principles, there are potentially further solution principles that could be applied. Principle #1 segmentation was applied to increase the degree of fragmentation or segmentation by varying the stacking configuration of the fibre reinforced composite in the FML layering to increase the strength to absorb impact energy.

While for contradiction 2, to improve the stiffness of the front hood, the thickness of the FML panel should be increased. However, there is a problem regarding the distance between the front hood and the engine components. Through applying the TRIZ solution principles, principle #3 local quality was selected as the solution for the conflict. The design strategy was to shape the natural FML to facilitate and fit the engine compartment.

Contradiction 3 has several solutions where the solution obtained from the contradiction matrix was #37 thermal expansion. Polymer plastic film shrink wrap was applied to protect the edge of the FML from humidity which, when heat is applied to the polymer plastic film, will cause the film to shrink tightly covering the edge of the front hood. Another solution was #2 taking out, by separating an interfering part or property from an object. This is where excess layering at the edge of the FML needed to be

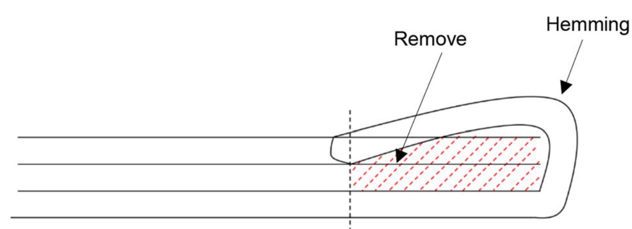


Fig. 8 Solution idea No. 2 for the contradiction 3

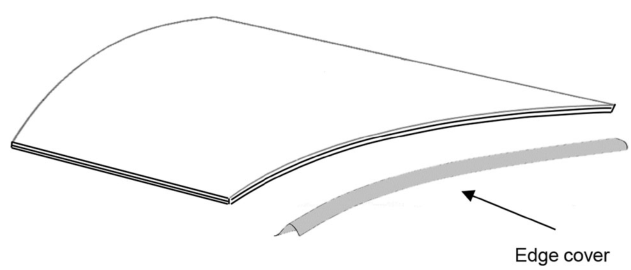
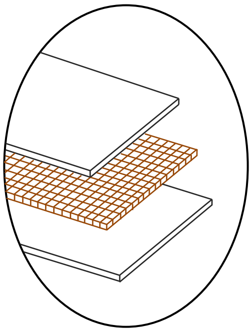
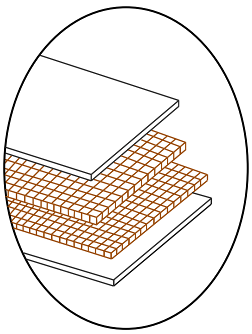
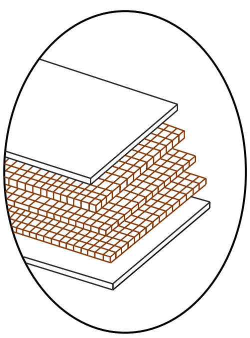


Fig. 9 Solution idea No. 3 for the contradiction 3

removed to ease the hemming process and to join the inner and outer closure layers together. Principle #11 beforehand, cushioning was an alternate solution for

Table 10 Overall weight, tensile strength and young modulus for each configuration

Configurations	Fibre weight fraction (%)	Fibre volume fraction (%)	Tensile strength (MPa)	Young modulus (GPa)
	14.78	10.54	58.81	4.40
	28.24	21.08	60.48	5.51
	40.51	31.61	58.36	4.13

contradiction 3 where the strategy was to apply an edge guard to protect the open edge of the front hood from humidity.

4.1 Determination of best specific solution

Based on contradiction 1, two specific solutions could, therefore, enhance the strength of the natural FML car front hood to absorb impact energy during a collision. Regarding recyclability and biodegradability, solution number 1 (combining natural fibre with synthetic fibre) was rejected as it does not meet the objective of this study which is to be environmentally friendly. According to solution number 2, several configurations can be selected to enhance the strength and to absorb impact energy. From these configurations, a further study was carried out to determine the appropriate fibre reinforced composite by determining the fibre weight fraction, fibre volume fraction, tensile strength and Young's modulus for each configuration. Results for the fibre weight fraction, fibre volume fraction, tensile strength and Young's modulus of each configuration are shown in Table 10.

Based on the results shown in Table 10, 2 layers of fibre reinforced composite have better tensile strength and Young's modulus as compared to a single layer of fibre reinforced composite and 3 layers of fibre reinforced composite. Through the theory of rule of mixture, by adding the very high strength fibres to the low tensile strength matrix would increase the tensile strength of the composite if the interfacial bonding is good [60]. However, in this situation, 3 layers of fibre reinforced composite have a weak interfacial area between fibre and matrix. This is because, as the fibre loading increases, the weak interfacial area between fibre and matrix will increase and at the same

Table 11 Density of natural fibres and matrix [62, 63]

Natural fibre and matrix	Density (g/cm^3)
Kenaf	1.4–1.5
Flax	1.4–1.5
Hemp	1.4–1.6
Jute	1.3–1.5
Sisal	1.5
Polypropylene	0.899–0.920
Polystyrene	1.04–1.06
Polyester resin	1.2–1.5
Epoxy	1.1–1.4
Aluminium	2.68
Steel	8.05

Table 12 Weight for 3 mm thick panels

Material	Weight (g)
Steel	966
Aluminium	321
FML Hemp	120

time will decrease the wettability, which consequently decreases the tensile strength [61]. Therefore, for contradiction 1, 2 layers of fibre reinforced composite will be selected as the best stacking configuration of the fibre reinforced composite in FML, since this configuration has better tensile strength and Young's modulus as compared to other configurations. It is essential to determine the best solution between both specific solutions so that the utilisation of natural FML as the motor vehicle front hood can be acceptably accomplished.

4.2 Determination of weight reduction

This study was initiated to reduce the weight of the motor vehicle front hood, using natural FML. To determine the percentage of natural FML weight reduction compared to monolithic metal, the weight was compared from panels with dimensions of 200 × 200 × 3 mm. Natural FMLs were fabricated using composites panels with 2 mm thick sandwiched in between 2 layers of 0.5 mm thick aluminium. The composite panel consists of matrix combined with natural fibres. A list of natural fibres and matrix's density normally used in the automotive industry is shown in Table 11. A conservative weight calculation was done; the fibre with the highest density which is hemp with 1.6 g/cm^3 is selected and the composite is assumed to be fully fibre.

Based on Table 12, FML hemp is 30% lighter than aluminium and 80% lighter than steel. Therefore, it can be determined that natural FML can reduce the weight of the car front hood compared to steel and aluminium car front hood.

5 Conclusion

In this study, natural FML was used for the car front hood with the expectations being that this would reduce the weight of the vehicle, enhance the vehicle's performance and lessen carbon gas emissions of the engine indirectly helping to reduce global warming. To implement and utilise the natural FML as the car front hood is not an easy exercise due to the design complexities and limitations associated with natural FML. Besides, through this study also, it shows that a weight reduction of 30–80% could be achieved by utilising natural FML as compared to an aluminium and steel car front hood. Therefore, this study has shown that applying the TRIZ method can provide solutions and help to develop inventive and practical concepts and ideas.

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References

1. Olivier JGJ, Maenhout GJ, Muntean M, Peters JAHW (2016) Trends in global CO_2 emissions 2016. http://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf. Accessed 12 Jan 2017
2. Paltsev S, Chen YHH, Karplus V, Kishimoto P, Reilly J (2015) Impacts of CO_2 mandates for new cars in the European Union. http://globalchange.mit.edu/ Accessed 12 Jan 2017
3. Joost WJ (2012) Reducing vehicle weight and improving US energy efficiency using integrated computational materials engineering. J Miner Met Mater Soc 64(9):1032–1038. https://doi.org/10.1007/s11837-012-0424-z
4. Belingardi G (2010) Lightweight design of vehicle body a contribution toward greener environment. ACTA Teh Corviniensis Bull Eng 7(1):49–54
5. Teng T-L, Ngo V-L (2010) Optimization of bonnet thickness with respect to pedestrian safety. Proc Inst Mech Eng Part D J Automob Eng 224(12):1513–1526. https://doi.org/10.1243/09544070JAUTO1477
6. Ganeshpure AM, Bhope DV (2013) Static and free vibration analysis of a car bonnet. Int J Eng Res Technol 2(3):1–8
7. Avalle M, Belingardi G, Scattina A (2013) Numerical and experimental investigation of a lightweight bonnet for pedestrian safety. Int J Crashworthiness 18:29–39. https://doi.org/10.1080/13588265.2012.730214
8. Belingardi G, Scattina A, Gobetto E (2009) Development of an hybrid hood to improve pedestrian safety in case of vehicle impact. ESV Paper 09–0026:1–10
9. Rhee MH, Ryu Y-M, Kim KJ, Shin KS, Kim JH, Lee K-N (2009) Development of application technique of aluminum sandwich sheets for automotive hood. Int J Precis Eng Manuf 10(4):71–75. https://doi.org/10.1007/s12541-009-0073-5

10. Liu Q, Xia Y, Zhou Q, Wang J (2009) Design analysis of a sandwich hood structure for pedestrian protection. ESV Paper 09–0356(10):1–7
11. Kong C, Lee H, Park H (2016) Design and manufacturing of automobile hood using natural composite structure. Composite 91:18–26. https://doi.org/10.1016/j.compositesb.2015.12.033
12. Hamacher M, Wohlecker R, Ickert L (2008) Simulation of a vehicle hood in aluminum and steel. In: 2008 Abaqus users' conference, pp 1–16
13. Sinmazcelik T, Avcu E, Bora MO, Coban O (2011) A review: fibre metal laminates, background, bonding types and applied test methods. Mater Des 32(7):3671–3685. https://doi.org/10.1016/j.matdes.2011.03.011
14. Li X, Yahya MY, Nia AB, Wang Z, Lu G (2015) Dynamic failure of fibre-metal laminates under impact loading—experimental observations. J Reinf Plast Compos 35(4):1–15. https://doi.org/10.1177/0731684415616501
15. Şen I, Alderliesten RC, Benedictus R (2015) Design optimisation procedure for fibre metal laminates based on fatigue crack initiation. Compos Struct 120:275–284. https://doi.org/10.1016/j.compstruct.2014.10.010
16. Hu YB, Li HG, Cai L, Zhu JP, Pan L, Xu J, Tao J (2015) Preparation and properties of fibre metal laminates based on carbon fibre reinforced PMR polyimide. Compos Part B 69:587–591. https://doi.org/10.1016/j.compositesb.2014.11.011
17. Sivakumar D, Sivaraos Selamat MZ, Said MR, Kalyanasundaram S (2014) Effects of process parameters during forming of glass reinforced-pp based sandwich structure. Adv Environ Biol 8(8):3143–3150
18. Ishak NM, Sivakumar D, Mansor MR (2017) Thermoplastic matrix selection for fibre metal laminate using fuzzy vikor and entropy measure for objective weighting. J Eng Sci Technol 12(10):2792–2804
19. Ishak NM, Sivakumar D, Mansor MR (2016) Thermoplastic matrix selection based on entropy method for importance weight of criteria. In: Proceedings of Mechanical Engineering Research Day, pp 106–107
20. Ishak NM, Malingam SD, Mansor MR (2016) Selection of natural fibre reinforced composites using fuzzy VIKOR for car front hood. Int J Mater Prod Technol 53(3/4):267–285. https://doi.org/10.1504/IJMPT.2016.079205
21. Vasumathi M, Murali V (2013) Effect of alternate metals for use in natural fibre reinforced fibre metal laminates under bending, impact and axial loadings. Proc Eng 64:562–570. https://doi.org/10.1016/j.proeng.2013.09.131
22. Sivakumar D, Kathiravan S, Selamat MZ, Said R, Subramonian S (2016) A Study on impact behaviour of a novel oil palm fibre reinforced metal laminate system. ARPN J Eng Appl Sci 11(4):2483–2488
23. Ng LF, Sivakumar D, Zakaria KA, Selamat MZ (2017) Fatigue performance of hybrid fibre metal laminate structure. Int Rev Mech Eng 11(1):61–68. https://doi.org/10.15866/ireme.v11i1.10532
24. Fazilah MZN, Sivakumar D, Selamat MZ (2016) Tensile properties of woven kenaf fiber reinforced polypropylene hybrid aluminium-composite. ARPN J Eng Appl Sci 11(12):7823–7827
25. Gonzalez-Canche NG, Flores-Johnson EA, Carrillo JG (2017) Mechanical characterization of fiber metal laminate based on aramid fiber reinforced polypropylene. Compos Struct 172:259–266. https://doi.org/10.1016/j.compstruct.2017.02.100
26. Rocha Ferreira S, de Andrade Silva F, Lopes Lima PR, Toledo Filho RD (2016) Effect of natural fiber hornification on the fiber matrix interface in cement based composite. Syst Key Eng Mater 668:118–125
27. Sivakumar D (2011) An investigation into the forming behaviour of metal composites hybrid, Dissertation, The Australian National University
28. Matthews FL, Rawlings RD (1999) Composite materials: engineering and science. Woodhead Publishing Limited, Cambridge
29. Rout AKMJ, Misra M, Tripathy SS, Nayak SK (2015) The influence of fibre treatment on the performance of coir polyester composites. Compos Sci Technol 61(9):1–20. https://doi.org/10.1016/S0266-3538(01)00021-5
30. Gadd K (2011) TRIZ for engineers. Wiley, West Sussex, UK
31. Mastura MT, Sapuan SM, Mansor MR, Nuraini AA (2016) Design strategy for concept design of hybrid bio-composite automotive anti-roll bar using TRIZ. In: Mechanical Research Day, pp 60–61
32. Ng PK, Jee KS (2016) Design and development of an ergonomic milling machine control knob using TRIZ principles. Am J Appl Sci 13(4):451–458. https://doi.org/10.3844/ajassp.2016.451.458
33. Sun Q, Xie Q-S, Li Z (2013) Application of TRIZ methodology in solving technology conflicts of rapid folding bicycle. Appl Mech Mater 288:313–317. https://doi.org/10.4028/www.scientific.net/AMM.288.313
34. Mansor MR, Sapuan SM, Hambali A, Zainudin ES, Nuraini AA (2015) Conceptual design of kenaf polymer composites automotive spoiler using TRIZ and morphology chart methods. Appl Mech Mater 761:63–67. https://doi.org/10.4028/www.scientific.net/AMM.761.63
35. Luo Y, Shao Y, Chen T (2012) Study of new wall materials design based on TRIZ integrated innovation method. Manag Sci Eng 6(4):15–29. https://doi.org/10.3968/j.mse.1913035X20120604.635
36. Barry K, Domb E, Slocum MS (2015) What is TRIZ?. https://triz-journal.com/triz-what-is-triz/. Accessed 27 Sep 2016
37. Salamatov YP (1991) System of the laws of technical systems evolution. Chance to adventure. Karelia Publishing House, Petrozavodsk
38. Zusman A, Zlotin B (2011) Directed evolution: philosophy, theory and practice. Ideation International Inc., Southfield
39. Cavallucci D (2001) Integrating Altshuller' s development laws for technical systems into the design process. CIRP Ann Manuf Technol 50(1):115–120. https://doi.org/10.1016/s0007-8506(07)62084-8
40. Mann DL (2003) Better technology forecasting using systematic innovation methods. Technol Forecast Soc Change. 70(8):779–795. https://doi.org/10.1016/S0040-1625(02)00357-8
41. Shpakovsky N (2006) Evolution trees. Analysis of technical information and generation of new ideas, TRIZ Profi, Moscow
42. Cascini G, Rotini F, Russo D (2009) Functional modeling for TRIZ-based evolutionary analyses. In: Proceedings of the International Conference on Engineering Design, pp 371–384
43. Gadd K (2011) TRIZ for engineers: enabling inventive problem solving. Wiley, West Sussex
44. San YT, Jin YT, Li SC (2009) TRIZ schematic innovation in manufacturing. Firstfruits Sdn. Bhd, Selangor
45. Li T (2010) Applying TRIZ and AHP to develop innovative design for automated assembly systems. Int J Adv Manuf Technol 46(1–4):301–313. https://doi.org/10.1007/s00170-009-2061-4
46. Hsieh HN, Chen JF, Do Q (2015) Applying TRIZ and Fuzzy AHP based on lean production to develop an innovative design of a new shape for machine tools. Information 6:89–110. https://doi.org/10.3390/info6010089
47. Russo D, Montecchi T, Ying L (2012) Knowledge based approach for identifying TRIZ contradictions. In: Design Engineering Workshop 2012, pp 134–140
48. Cameron G (2010) TRIZICS. CreateSpace, North Charleston, USA

49. Rosli MU, Ariffin MKA, Sapuan SM, Sulaiman S (2013) Integrated AHP-TRIZ innovation method for automotive door panel design. Int J Eng Technol 5(3):3158–3167
50. Tan R (2011) Contradiction-oriented problem solving for innovations: five opportunities for China's companies. J Innov Entrep 4(3):1–19. https://doi.org/10.1186/s13731-015-0017-5
51. Mesbah NF, Yusof SM (2015) Systematic way for problem identification of car braking system by using TRIZ. In: International Proceedings 2013 of Malaysia-Japan Academic Scholar Conference, pp 147–153
52. Khalili SMR, Daghigh V, Farsani RE (2011) Mechanical behavior of basalt fiber-reinforced and basalt fiber metal laminate composites under tensile and bending loads. J Reinf Plast Compos 30(8):647–659. https://doi.org/10.1177/0731684411398535
53. Kuan HTN, Cantwell WJ, Hazizan MA, Santulli C (2011) The fracture properties of environmental-friendly fiber metal laminates. J Reinf Plast Compos 30(6):499–508. https://doi.org/10.1177/0731684411398536
54. Yousif BF, Ku H (2012) Suitability of using coir fiber/polymeric composite for the design of liquid storage tanks. Mater Des 36:847–853. https://doi.org/10.1016/j.matdes.2011.01.063
55. Dhakal HN, Zhang ZY, Richardson MOW (2007) Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. Compos Sci Technol 67(7–8):1674–1683. https://doi.org/10.1016/j.compscitech.2006.06.019
56. Kamarudin KM, Ridgway K, Hassan MR (2016) Modelling constraints in the conceptual design process with TRIZ and F3. Proc CIRP 39:3–8. https://doi.org/10.1016/j.procir.2016.01.034
57. Kurata YB, Marie R, Bano LP, Navales MR, Cedron DB, Pinga DJM (2016) Renewal process streamlining of a government service facility through simulation: a TRIZ approach in facilities system design. In: Asia Pacific Industrial Engineering & Management Systems Conference, pp 1–8
58. Ong MC, Abdul Rahman MN (2016) Microelectronics thermal dissipation characterization using triz. J Adv Manuf Technol 10(1):83–94
59. Domb E, Miller J, MacGran E, Slocum M (1998) The 39 features of Altshuller's contradiction matrix. https://triz-journal.com/39-features-altshullers-contradiction-matrix/. Accessed 27 Sep 2016
60. El-shekeil YA, Sapuan SM, Jawaid M, Al-shuja'a OM (2014) Influence of fiber content on mechanical, morphological and thermal properties of kenaf fibers reinforced poly (vinyl chloride)/thermoplastic polyurethane poly-blend composites. J Mater 58:130–135. https://doi.org/10.1016/j.matdes.2014.01.047
61. Karim R, Rahman MF, Hasan M, Islam MS, Hassan A (2013) Effect of fiber loading and alkali treatment on physical and mechanical properties of bagasse fiber reinforced polypropylene composites. J Polym Mater 30(4):423–433
62. Vaisanen T, Das O, Tomppo L (2017) A review on new bio-based constituents for natural fiber-polymer composites. J Clean Prod 149:582–596. https://doi.org/10.1016/j.jclepro.2017.02.132
63. Holbery J, Houston D (2006) Natural-fibre-reinforced polymer composites in automotive applications. J Miner Met Mater Soc 58(11):80–86. https://doi.org/10.1007/s11837-006-0234-2