A Review on Status of Research in Metal Additive Manufacturing

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Abstract Additive manufacturing is the essential technology in present near net shape manufacturing scenario in the field of aerospace, automobiles, electronics, medical implants, robotics, biomedical, etc., where near net shape manufacturing plays a prominent role in dimensional accuracy. Additive manufacturing has undergone drastic changes from plastics, polymers to metals. Additive manufacturing plays a key role in manufacturing of required components in short span of time without any defect. In this paper, the different research aspects of additive manufacturing are discussed on basis of two broad areas like design for manufacturing and process parameter control. The field of additive manufacturing has brought the manufacturing to next level were it made production and product development easier. An analysis is made on the published research articles and the research gaps were found and finally the future scope in the field of metal additive manufacturing is provided.

Keywords Additive manufacturing · Process parameter control · Design for manufacturing

1 Introduction

Fabrication of near net shape metallic components is the attractive manufacturing route for recent aeronautical, aerospace and automotive industries. The additive manufacturing technology through additive manufacturing, 3D models can be printed or fabricated directly using a laser source or electron beam source. The metal additive manufacturing follows the principle of layer by layer printing of 3D

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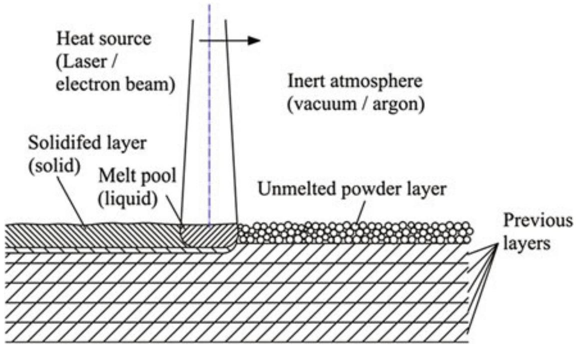


Fig. 1 Schematic representation of additive manufacturing process

objects. Additive manufacturing avoids tooling and minimizes the wastages. The working principle of selective laser melting and electron beam melting is shown in Fig. 1. The heating source of either laser or electron beam melts the successive layers of metal powder bed and fused with each other to form a 3D finished component. In this paper, the status of research in metal additive manufacturing field has been discussed. The recent trend in metal additive manufacturing has been focusing on two broad categories. Design for additive manufacturing and material properties monitoring through manipulating the process parameters of selective laser melting and electron beam melting processes are those broad categories.

2 Research on Design for Additive Manufacturing

The interesting feature of additive manufacturing is facilitating the design freedom. However, to ensure the quality and reliability of additive manufactured products, few design rules should be incorporated at the design stage itself. Ponche et al. [1] have proposed a new numerical chain based on a new design for additive manufacturing methodology. This new numerical chain has been proposed for Additive Laser Manufacturing of thin walled metal parts. The main objective of this work is to minimize the gap between a CAD model and the corresponding manufactured part. This new method involves part orientation, functional optimization, and manufacturing path optimization as important steps. The part orientation step involves the determination of design area. The functional optimization step involves determining the optimal part geometry which is going to be the initial part geometry. The final step in this methodology is to determine the optimized manufacturing paths. Through these manufacturing paths, the manufacturing program is generated along with the final part CAD model.

Guido et al. [2] explained about the extended design freedoms of technical parts which provides them a new potential with the new project “Direct Manufacturing Design Rules”. This research made the design benefits accessible to different user groups. Hence a specific method was defined then design rules were developed for

Fusion Deposition modeling, Laser sintering, and Laser Melting. The results for suitable design for additive manufacturing were summarized in a design rule catalog.

Klhan et al. [3] discussed about the geometrical freedom in design which is utilized to largely improve the functionality of series products by substituting conventional parts with additive manufacturing. Four criteria identified for redesign are integrated design, individualization, lightweight design, and efficiency and it is observed that a product, to be successful, needs to be improved in both a technological and economic direction. On the economic side, the investment in the change of design and process has to pay off either by lower manufacturing costs or by benefits during the lifetime of the product by fully utilizing the geometric freedom in the redesign, impressive increases in performance can be realized. This opens new perspectives in product development.

Cooper et al. [4] exploit the benefits of Additive Layer Manufacturing (ALM) in the weight reduction of internal combustion engines inlet or exhaust valves. CT scan technology was used as a reverse engineering tool. The hybrid manufacturing route was preferred to reduce the manufacturing cost of the vales though ALM. Further investigations are needed to join conventionally manufactured hollow stem to the valve head manufactured by ALM by friction welding route.

3 Research on Effect of Process Parameters of Additive Manufacturing Routes in Metallic Components Manufacturing

Guijun et al. [5] implemented micro-LAAM (Laser Assisted Additive Manufacturing) in layer by layer manufacturing of nickel-based super alloys IN100 which has poor weldability that results in cracking and porosity, the defects were eliminated by optimization and crack free deposition is achieved with minimal heat input, post heated sample was observed with EBSD (Electron Back Scatter Diffraction) and found three size of γ precipitates 0.5–1 µm, 0.1–0.3 µm, 10 µm and the volume fraction of c to γ phase were 60–40 %. After grain refinement the tensile and yield strength were found to be improved than the aerospace requirement specification 5397 for IN100 material.

Yanyan et al. [6] used the hybrid fabrication technique for fabricating TC11 titanium sample alloy for examining the microstructure, micro-hardness, and tensile strength and found that the sample fabricated consist of three typical zone without any defect in metallurgy the zones are called to be the laser additive manufactured zone (LAMZ), the wrought substrate zone (WSZ), and the bonding zone and also found LAMZ has superfine basket-wave microstructure which results in superior tensile properties and HAZ caused by rapid cooling but no recrystallization or grain growth found in HAZ due to the heat effect in $\alpha + \beta$ region micro transition zone has coarse for k-like primary α and fine β microstructure and the TC11 sample fabricated has tensile strength of 1,033,713 MPa and elongation 6.8 ± 0.2 % and the fracture occurs in substrate which shows mechanical properties of bonding zone is better than the substrate. Micro-hardness in the transition zone was found to be increased noticeably from the WS Z to the LAMZ

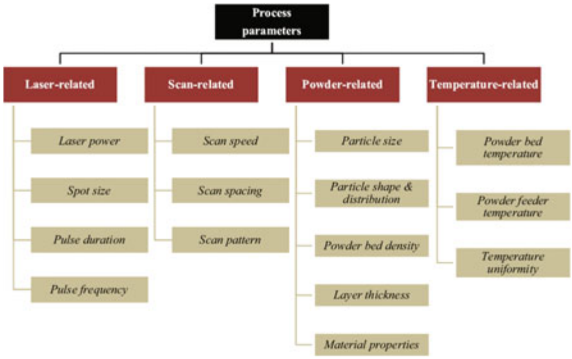
Ting et al. [7] fabricated TA2/TA15 graded structural material (GSM) using additive manufacturing (LAM) process and examined the chemical composition, microstructure and micro-hardness of the as-deposited GSM and found that near-equiaxed grains was Widmanstätten α-laths microstructure where β phase volume fraction increase and α phase volume fraction decreases. The part containing large columnar grains was divided into four deposited layers with 3000 μm in width was fine basket-weave microstructure, the graded zone micro-hardness increases from the TA2 part to the TA15 part from 173 to 400 due to the solid solution strengthening and grain boundary strengthening.

Yali et al. [8] simulated the temperature fields in additive manufacturing of AlSi10 Mg by Selective laser melting (SLM) using FEM and investigated the effect of laser power and scan speed on SLM and found cooling rate elevated slightly from 2.13×10^6 to 2.97×10^6 °C/S when laser power increased from 150 to 300 W but when the scan speed increased from 100 to 400 mm/sit enhanced significantly from 1.25×10^6 to 6.17×10^6 °C/s after repeating various combination it is found that a sound metallurgical bonding between the neighboring fully dense layers was achieved at laser power of 250 W and scan speed of 200 mm/s, due to the larger molten pool depth (67.5 lm) as relative to the layer thickness (50 lm).

Konrad et al. [9] attempted to create light weight material for industrial application, and the work focuses on low power fiber laser, feasibility of high strength aluminum alloys, and custom developed powder system with different particle sizes in Al and Cu/Zn particles and found that their size did not change during mixing process. With this customized Al–Cu/Al–Zn composition able to create aluminum alloy composition during laser melting No brittle hard oxidation upper layer was noticed on melted lines, which is very promising for further development of multi additive layer manufacturing process of reactive materials The manufactured additive layers, characterized by a fine microstructure with homogeneously dissolved intermetallic phases in the metal matrix, has a big potential for usability properties of the final manufactured product.

Processing of aluminum and it alloys through Selective Laser Melting is still challenging. Aluminum alloy powders have poor flow ability, high reflectivity, and high thermal conductivity compared to steels and titanium materials [10]. Moreover, difficulties in elimination of oxide layers, porosities, and cracks are major challenges in SLM of aluminum alloy powders [9]. Most of the researches are now focusing on SLM of AlSi10 Mg and AlSi12 Mg alloys (6000 series alloys). The main process parameters are depicted in the following Fig. 2 [10]. Therefore, challenging in processing of aluminum alloy powders through additive manufacturing still persists.

Fig. 2 Process parameters for SLM process



4 Conclusion

With the statistical analysis on research articles, the challenges faced in metal additive manufacturing in design and process parameter control were brought out in this paper. The results of research were analyzed and the research gaps were identified and conclusions are presented.

- New design rules for metal additive manufacturing are derived for repeatability and reliability of parts manufactured by additive manufacturing routes.
- Research on design for metal additive manufacturing is in nascent stage and some of the research works are discussed. Specifically design rule for electron beam additive manufacturing needs to be focused.
- Various research works on metallic components manufacturing through additive manufacturing with various metals are briefly discussed
- Most of the research works are based on Laser additive manufacturing rather than Electron Beam Melting. The wide gap in this area should be bridged with appropriate research works.
- Metal additive manufacturing of aluminum alloys is still challenging and further research works are needed in this area.

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