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Research Scopes in Laser Based AM for Metals- An Ample Assessment

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Abstract:
Additive manufacturing (AM) contributing to increase of National Grass Product (NGP) and National Net Products (NNP) by buy-to-fly ratio, that is saving energy and time, low wastage, eco-friendly, encourages JIT production system and AM is a revolutionary approach in manufacturing industry, as it is a promising method in manufacturing the metal parts so as to overcome the common problems which are associated with conventional techniques. These methods mainly focus on the manufacturing of the multifaceted profiled or contoured parts (e.g., permeable gallows, freeform surfaces, and yawningniche). This concept deals with, adding up material in manufacturing a part than the concept of removal like conventional machining practices. This study focuses the laser AM of metals. The objective of this study to conduct the survey and highlight the research scope by identifying the application areas, methods involved, influencing parameters, possible new research objectives, possibilities of Hybrid manufacturing etc. for further research.

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I. INTRODUCTION

AM is opposed to rapid prototyping, bypasses the Subtractive Manufacturing (SM), material handling in between operations, helps to produce product from new CAD (computer-aided design) model or a reengineered CAD model. First, The designer know how to create the (CAD) file or scan file of the preferred parts which is be desires to be designed or created. Then such files are rehabilitated to layers with specific thickness, usually ranging from 20 to 100 µm, using supporting software such as Autofab (Materialize, Louvain, Belgium). Finally, In AM the part is fabricated the part by machine often referred as 3D printer, layer by layer. The source of energy (electron beam/laser/ultrasonic) is to be considered for manufacturing the cross section of each layer. One can enhance the properties of the product with complex and innovative features in design without worrying about the manufacturability and with focus of improve performance like cooling, less S/W ratio etc. [1]. ASTM International categorizes the AM processes into seven main categories, according to the adhesion and bonding method. These categories are: (i) powder bed fusion, (ii) VAT photo polymerization, (iii) direct energy deposition, (iv) material extrusion, (v)material jetting, (vi) binder jetting and (vii) sheet lamination. The technique of material jetting is well known as VAT polymerization which could be used in liquid AM processes, while material extrusion could be used in filament processes. Powder AM processes could use powder fusion, binder jetting, or direct energy deposition for binding the powder particles. The

Fig.1 depicts bonding techniques based classification of AM. Since then various processes have been introduced. Fig. 2 depicts the feedstock based classification of AM.

II.APPLICATIONS OF METAL AM

A. Aerospace Industries

AM is preferred in the aerospace industries, because they constantly produce low volume of complicated geometrical, light weight, and high quality and mechanically sound products. In such industries the AM methods like EBM (Electron Beam Melting), FDM (Fusion Deposition Modeling), DED (Direct Energy Deposition), and SLM (Selective Laser Melting) are widely employed for manufacture in minimum quantity of spares and parts like kind of on demand, replacement, wings, lightweight structures etc.[2]. highly developed materials like nickel super-alloys, aluminum alloys, Ti - alloys and special steels have been manufactured at aerospace industry using AM technologies [3]. AM technologies open the door for developing new materials and designs for aerospace diligence. The most important challenges reported in the literature include mechanical anisotropy, micro-structural in homogeneity, residual stresses, dimensional accuracy, and surface finish [4-8].

B. Automotive Industries

Metal AM has significant implications on part design as well as supply chains and inventory systems, which is particularly relevant for the automotive industry. Like aerospace, automobile industries also produce low volume of complicated geometrical, light weight, and high quality and mechanically sound products. The high strength and possibilities of AM is the high strength to volume ratio parts in particularly light weight parts even though if it has very complex geometry can produce with minimal wastage and time. Examples of automotive parts produced by AM include structural composite components, engine valves, and turbocharger turbines [9]. A significant advantage is in-house and on demand production, which reduces inventory needs,
Shippingcosts and material procurement costs [10]. Notwithstanding the capabilities of the AM processes in the automotive industry, the parts produced should comply with
The standards which is to perform a certain level of performance.

The main challenges in the AM of automotive components are:

(i) The thermal stresses induced in the AM parts which affect the repeatability and performance of these parts,

(ii) The surface finish and dimensional accuracies, and

(iii) The size of the parts produced [11] in addition to this; processing speed is critical due to typical production volumes.

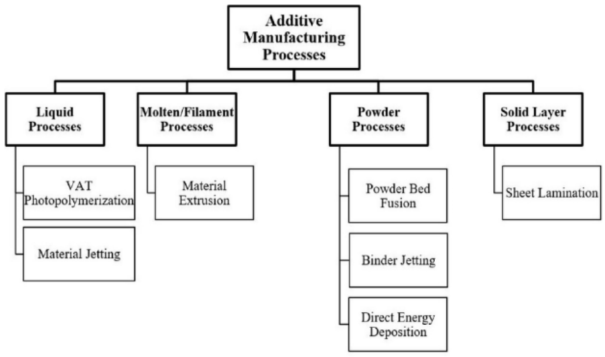

Fig. 1. Adhesion and bonding methods in additive manufacturing

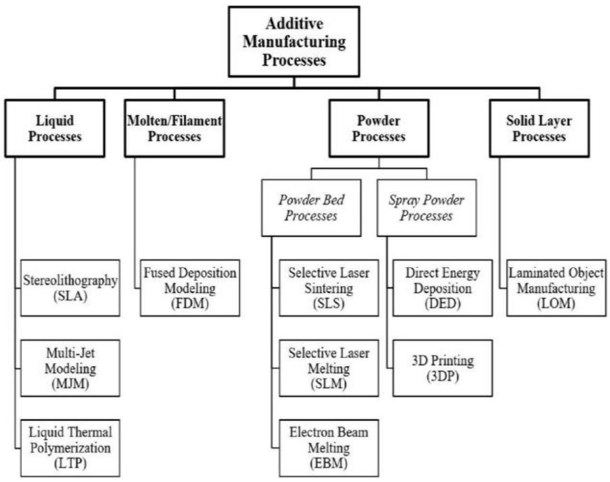

Fig. 2 Various Techniques in Additive Manufacturing

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C. Tooling Industries

For the tooling industry, AM can offer cost and time saving through by passing of the steps of subtractive manufacturing. In addition, the AM technology offers the ability to manufacture the specially designed and optimized channels for cooling and fabrication of highly customized molds. AM can impart unique properties to parts and reduce production cycle time. AM molds made with integrated conformal cooling also prolong their service life as it provides the designer with the ability to reduce the thermal stress loading that the die experiences [12]. The mechanical behavior of the tools fabricated by AM affects the performance and service life of these tools. In general, performance tests are highly recommended for the tools fabricated by AM to fully assess their cost and performance benefit for an application [13].

D. Healthcare Industry

The use of metal AM processes in the healthcare industry is briefly reviewed. In the dental industry, AM processes are used for creating precise dental crowns, bridges, and implants. The capability of the SLM process to manufacture custom, complex, accurate, and fully dense objects makes it suitable for dental applications. The process of creating crowns and bridges consists of dental impression which scanned from teeth of patient, digital modeling of the part, and then SLM production [12]. This process provides a competitive market for AM of dental implants that rivals traditional casting and milling production methods. Additionally, a similar process is used for the manufacturing of personalized prosthesis and supports for artificial teeth made of titanium or cobalt-chromium [13]. The technology is very useful for fabricating custom-made medical implants as well as surgical tools and fixtures for use in operation rooms. Fabricating the custom implants with high degree of accuracy than SM is an attractive feature of AM for medical application. [14]. The foremost advantage of 3D printing the Healthcare components manufacturingsectors is its capability to manufacture very complicated geometry on components with low production cost as well as customized components [15].

E. Nano-Manufacturing

Recently, AM technologies have been integrated with nanotechnology to fabricate parts from new nano-composites. The main benefit of using nano-materials in 3D printing processes is enhancing the material properties of the fabricated parts [16]. Parts with better optical, thermal, electrochemical, and mechanical properties have been obtained. Recently the AM developed to use wide range of nano-metrials including, quantum dots, Nano-wires, CNT, nano-graphene and Nano powders to eliminate the defects like nano meter sized pores and voids in products [17].

III. LASER METAL AM

The proven record of adopt products with high flexibility, reduced by half of 'time-to-market', reduced product weight by 64%, high quality, scrap reduced to 10% etc., the AM is now globally eminent in manufacturing. The technologies laser metal AM are broadly classified as 'powder-fed, and 'powder-bed'. Laser is a tool in the Laser metal AM for both technologies. The lasers like flash lamp (general), CO_2(for processing polymer powder processing), neodymium-doped diode-pumped yttrium aluminum (General), and blue diode lasers (to process photo polymers) are preferred in metal AM. The efficiency can be improved by using shorter wavelength lasers either disk or diode or fiber, because they yield high metal absorptivity. The longer wavelength lasers preferred for nonmetals powders like polymer and ceramics. The roughness is proportional to the reflectivity so half of the reflectivity is recommended for decrease roughness [18].

IV. THE SLM PROCESS

This powder-bed fusion with aid of Laser methodology adopted for this process, which is usually preferred for producing performs, flat surfaces in the rate of 2–40 cm^3/h. The permissible

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minimum thickness is 0.03 mm. The finish of 10 to 50µm roughness can be achieved. The product complexity nearly unlimited but product dimensions are limited. As it is selective focus type, called Selective Laser Sintering. Basically it is complex process in which many parameters like are involved length of singe track (spacing of hatch), layer thickness, average size of the particles of the powder, capacity of laser, speed and strategy of the scan, distribution of powder particles, are influencing in manufacture the parts with appreciable metallurgical as well as neglected internal stress. SLM is most popular by its power output, because its powder absorptivity was found in the rage of 0.65 to 0.55 g/s for metal powders like aluminum, stainless steel 316 and alpha beta titanium alloy (TC4) which is 90% higher than powder fed system [19]. The name implies that the bed is lowered after completion of each layer deposition [20]. The influencing process parameters are related to Operating Temperature, Powder Laser and the Scan related. Bed Temperature, Powder temperature, and its uniformity are temperature related parameters. Powder related parameters are material of the powder, Bed density, particle shape, its size and its distribution and layer thickness. The pattern of scanning, scan spacing and scan speeds are scan related parameters. Laser's wave length, power of laser, size of the spot, pulse frequency and its duration are Laser related parameters. The researchers can focus the parameter optimization for the specific applications.

V. LASER METAL DEPOSITION (LMD)

The LMD belongs to powder-fed type which is preferred for any existing parts or any 3D surface of same minimum thickness to the finish of 60–500 µm. There is limitations in dimensions of parts and its complexity are limited this method. The production rate is 10–80 cm^3/hr. the powder feedings either of continuous coaxial or off-axis or discontinuous coaxial [21].

VI. LASER-BASED DMD FOR METALS AND ALLOYS PARTS

It is one of the laser-cladding-based solid free-form fabrications (SFF) with the advantage of feedback system are integrated within. Its accuracy is 0.01inch and maintains a uniform thickness of deposition which reduces time of after machining. It is one of the multilayer laser-cladding methods but additionally possess the feedback control which often referred as 'CAD to part' and one step fabrication. DMD facilitate to produce components with 100% dense and also with multiple materials. It converts the adapted image from X-ray tomography or CAD Model or from a magnetic tape into product. Some practical cases are: gas turbine blades are fabricated with iron, nickel and titanium aluminates as X_3Al fr dual protection from chemical and thermal effects [20]. AM produced Cr_2O_3 Components are corrosive proof and strongly can withstand up to 800^oC [12].

VII. LASER BASED HYBRID MANUFACTURING

Some of the applications the readily available setup may not support in that situation the hybrid manufacturing are preferred to achieve the desired results. Sometimes the process instability experienced for some materials due to difficulty to weld of the included materials which results defects like lack of fusion, crack due to cold or hot, structural issues at micro level etc. Hence hybrid is invited in laser based AM of metals. The multiple laser beams with various focuses are increased the absorptance and surface temperature and thereby the built-up rate increased [13]. The hybrid of LMD and PTA helps hastily of build up, in which PTA employed for preheating [11]. The other possibilities of laser based hybrid manufacturing are: (i) Multi laser beams with different wavelengths based on the requirements of part of job or material differences of the specific part of the job. (ii) Additional thermal support like flame shall be employed in the melt pool. (iii) Plasma may adopt to support in the process zone (iv) Introducing mechanical impacts like laser aided shock peening, concurrent hammering etc.

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VIII. MACHINING CHARACTERISTICS

From the survey of AM processes, FDM, EBM, SLM and DED are generally employed processes in the AM for metal fabrication. The operating parameters are usually decide the machining characteristics which made impact on minute and major level influence of mechanical andphysical expectations in manufacturing the product. Based on the ingredient of work material their influence is discussed below.

A. Titanium Alloys

Many researches are focusing on studying the characteristics of titanium TiAl6V4 (UNS R56400) produced by different AM processes to meet aerospace standards. A study showed that the mechanical and fatigue behaviors of the SLM, significantly exaggerated components which made up of TiAl6V4 by the residual stresses and internal voids. The pores size is highly affects the fatigue and tensile strengths of the components. The residual stresses encourages the crack growth [9,10]. [11] reported that the mechanical properties TiAl6V4 components can be altered by SLM.. The surface qualities are extremely influenced by operating parameters of SLM like scanning strategies, laser melting parameters and scanning parameters [16], voids characteristics [17], microstructure [12], and mechanical properties [19,20] of TiAl6V4 parts.

Moreover, few studies were performed to find the optimum SLM process parameters for fabricating TiAl6V4 parts suitable for the aerospace industry [12]. Similar studies performed using other AM processes such as DED [33,34] and EBM achieved similar results. In EBM production of TiAl6V4, a function is developed to control the beam speed and energy throughout the fabrication method for enhancing the thermal properties of the Products. [13,14].

B. Aluminum Alloys

Although AM has gained considerable popularity in aerospace and automotive applications, it still faces many challenges with processing aluminum alloys [12]. Many investigations were performed to find the process parameters required to produce high dense aluminum AlSi10Mg (UNS A03600) parts by SLM [14]. Few studies focused on investigating the quality of the aluminum parts produced by AM processes [15]. It was noticed that these studies showed that the work materials aluminum alloys like AlSi12 and AlSi10Mg are affected significantly in macro level in mechanical properties like fatigue and elongation behaviors and micro level in deficiencycreated by process and post processing dealings of SLM. [10]. AlSi10Mg still manifests fatigue strength lower than that of a corresponding wrought material. Internal voids and/or large internal precipitated particles serve as fatigue crack initiation sites. However this material also does show a very fine microstructure and anisotropic mechanical properties along the building direction [16].

C. Iron- and Nickel- Based Alloy

UNS S31603 is a code of Stainless steel 316L, and the same is most often employed material in powder-based 3D printing. The wire size, power particle’s grain size are directly influencing in the density of product there by describes its mechanical fitness for the purpose and others aspects.[17]. The Selective Laser Melting of UNS S31603 the process parameters like scan speed, building position, its direction, exposure time, thickness of layer defined are greatly effecting the surface quality of the product and they are to be optimized for obtaining the desired surface quality [18]. AM technology opens the door for fabricating special alloys such as nickel-based alloys. Some studies showed that AM produced Inconel 718 (UNS N07718) parts contained small cracks that may influencerequired properties in all orders especially in the building direction [19]. These cracks can be attributed to the phase transition and the formation of columnar dendrites during the melting process [18]. On the other hand, few studies illustrated the way of making best choice of the process parameters for SLM of dense Components from UNS K93600 (Invar 36) [20].

IX. SURFACE FINISH ON LASER BASED AM METALS

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The scope on surface finish optimization is highlighted in the heading. It is highly recommended that surface finishes to be quantified based on purpose and relevance. The literatures address the surface finish can be optimized by optimizing the position of the component [10-12], optimizing the surface finish by varying the position incessantly [13,14] and the others attempts in the literatures are process variable optimization for specific tasks. Based on the literatures some of the objectives are highlighted here for future research. Based on the experimental observations a design data shall be provided for the most applicable material for the specific process for the specific job. This will gives support for the user who adopts the process as per requirements. Suppose new materials are employed for a specific application in a particular AM process, the comprehensive array of data shall be provided like full factorial Taguchi design of Experiments with resultant surface roughness at each combination of parameter settings. Generally researchers focus the average values of roughness. As the roughness and material addition rate is indirectly proportionate, the objectives may be set to indentify the peak roughness. This will helps to avoiding such peak roughness based on the purpose. The roughness for the components in AM are globally defined as tolerance requirements including for irrelevant surfaces like the surfaces which has no functional requirements, hidden surfaces etc. so it is suggested that pointing out the irrelevant surfaces. The position of the surfaces is directly proportionate and influencing more on surface roughness. The position in the space is infinite. So the position versus surface roughness plot will helps to adopt the roughness by predefined position.

X. CONCLUSION

The above survey showed that additive parts differ from wrought but defects like voids, lack of adhesion between subsequent printed layers, and substandard mechanical/fatigue properties. Developments in metal additive manufacturing offer significant possibilities for the creation of new types of products. A summary of the main research issues includes: Newly emerging metal additive manufacturing processes have many limitations and challenges compared to extensively studied, subtractive manufacturing processes. Process repeatability, complex thermal stresses, and material micro structural implications of the process are the largest challenges to industrial relevance of AM, especially for aerospace diligence. The challenges of factors which affect the dens of the products of AM and consequently all the mechanical properties and material characteristics are can be addressed in two ways. They are: the first, and most common solution is to refine the quality of additive components through carefully controlled post processing techniques [18] and the second, and less established solution for optimizing and controlling the influencing process parameters to manufacture high quality products through parts [21,22].

Some of the hot scopes are listed below.

- Optimizing the process parameters to achieve the desired properties on AM products collectively are individual requirements of part by either numerical or experimental examinations.
- Developing new materials for enrich qualities of based AM products/ process
- Establishing rules and protocols for customizing design manufacture in AM.
- Adopt Real-time process control for AM.
- Exploring the hybrid manufacturing and multi-materials additive manufacturing
- Improving the productivity of the additive manufacturing systems by short out irrelevant surfaces, hybrid different wave length lasers etc.

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