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Applications of Additive Manufacturing - A Review

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***Abstract*— Traditional techniques of manufacturing have several backlogs that include high operational costs, lower productivity and problems associated with environmental issues. Additive manufacturing is a novel method that has overcome these issues to a greater extent, wherein deposition of substrate on solid interface is done in a schematic layer by layer method. This method can be used to manufacture products with higher precision rate. The aim of current work is to provide an overview of these modern methods of manufacturing and show their applicability over a wide range of industries.**

Keywords—Component; formatting; style; styling; insert (key words)

I. INTRODUCTION

The technique of Additive manufacturing (AM) involves manufacturing of parts using design data directly from raw products. Unlike other conventional methods, it requires no expensive die or tools. There are several techniques that including Stereo lithography, Fusion deposition, Laser melting, laser sintering, electron beam melting, powder deposition etc. [1, 2].

Pinkerton showed use of lasers in additive manufacturing methods [3]. Steuben et al incorporated thermal models for a broader range of AM processes [4]. Mihret et al. [5] demonstrated use of CFD in additive manufacturing [5]. Elahinia et al. [6] investigated manufacturing of Nickel Titanium using AM techniques [6]. Eric et al. [7] showed that increasing the speed of coating leads to an increase in surface roughness of substrate-part interface. Zanardini et al. [8] introduced Product Service Systems (PSS) concept in AM as depicted in figure no 1.

		LEVERAGE	
		Environmental	Economical
DRIVER	Design process	Case d. US POSTAL SERVICE	Case c. DALLARA AUTOMOBILI
	Infrastructure & Rapidness	Case a. US NAVY	Case b. MAERSK

Figure no1: Study Cases

Yoo et al. [9] developed a 3-step model of technology development towards additive manufacturing of function- integrated mechatronic systems. Wirth et al. [10] pushing AM beyond the conventional boundaries by creating PIAM as platform for all unconventional and re-created aspects of material science, manufacturing, tooling, design, simulation and standardization. Maija et al. [11] proposed various processes of AM that enable repair, replacement, refurbishment of metallic products. Zhang et al. [12] developed a new Composite AM, using a KUKA KR6 R700 robot as shown in Figure 2.

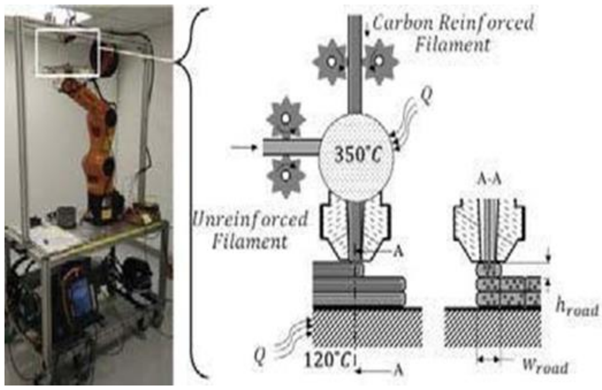

Figure no 2: Experimental setup [12]

A 3D nozzle was developed to print reinforced carbons. This allows reinforcement in all planes as continuous fibres can jump from one layer to the next without cutting. Spalleka et al. [13] provided a Specific adaptation located within a fixed solution space without product features. This needed a detailed product structure planning in order to define scope of product structure limits shown in figure no 3. During the conception and design phases of the product development, the constraints of individualization were assessed as see in figure no 3[13].

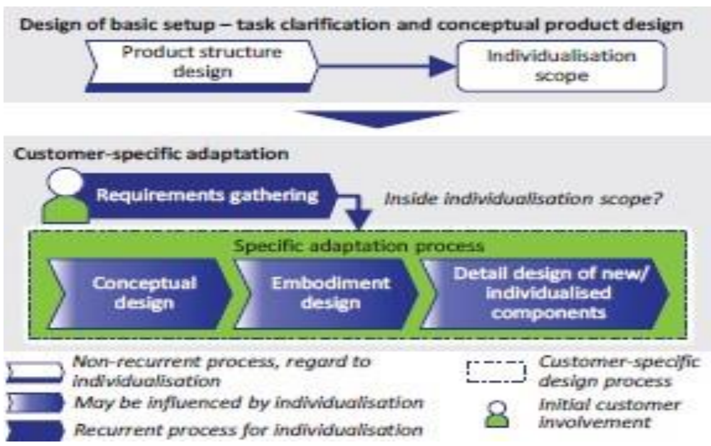

Figure no 3: Design process of specific adaptation [13]

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II. LITERATURE REVIEW

AM is having an increasing role in many industries, and AM capabilities now cover a wide ranges of applications as summarized by figure 4 [14].

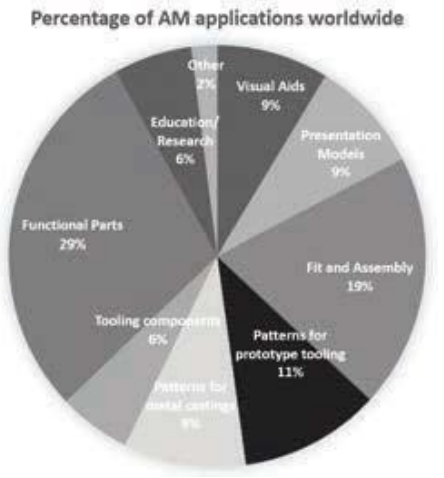

Figure no 4: Applications of AM methods [14]

Figure no 5 compares various economic and technological aspects of AM processes. Moroni proposed a method to orient a part considering all components as a functional assembly taking a case study of universal U-joint shown in figure no 14 [15]. This procedure defined significantly affects the final fabricated part/product. Williams et al. [16] introduced an intelligent application of materials with site-specific properties allowing more efficient components and use of resources. Schroder et al. [17] developed a business model which evaluated the process costs of additive manufacturing technologies.

AM technology's opportunities and limitations from a technological perspective.

Technological characteristics of AM	
Opportunities	**Limitations**
+ Direct digital manufacturing of 3D product designs without the need for tools or molds	– Solution space limited to 'printable' materials (e.g., no combined materials) and by size of build space
+ Change of product designs without cost penalty in manufacturing	– Quality issues of produced parts: limited reproducibility of parts, missing resistance to environmental influences
+ Increase of design complexity (e.g., lightweight designs or integrated cooling chambers) without cost penalty in manufacturing	– Significant efforts are still needed for surface finishing
+ High manufacturing flexibility: objects can be produced in any random order without cost penalty	– Lacking design tools and guidelines to fully exploit possibilities of AM
+ Production of functionally integrated designs in one-step	– Low production throughput speed
+ Less scrap and fewer raw materials required	– Skilled labor and strong experience needed

AM technology's opportunities and limitations from an economic perspective.

Economic characteristics of AM	
Opportunities	**Limitations**
+ Acceleration and simplification of product innovation: iterations are not costly and end products are rapidly available	– High marginal cost of production (raw material costs and energy intensity)
+ Price premiums can be achieved through customization or functional improvement (e.g., lightweight) of products	– No economies of scale
+ Customer co-design of products without incurring cost penalty in manufacturing	– Missing quality standards
+ Resolving "scale-scope dilemma": no cost penalties in manufacturing for higher product variety	– Product offering limited to technological feasibility (solution space, reproducibility, quality, speed)
+ Inventories can become obsolete when supported by make-to-order processes	– Intellectual property rights and warranty related limitations
+ Reduction of assembly work with one-step production of functional products	– Training efforts required
+ Lowering barriers to market entry	– Skilled labor and strong experience needed
+ Local production enabled	
+ Cost advantages of low-wage countries might diminish in the long run	

Figure no 5: Economic and technological comparisons of AM methods [16]

III. APPLICATIONS

Commercially, Titanium based alloys are widely used as a raw material in medical implants [18]. Parka et al. [19] compared the morphological changes and concentration of light elements (O and N) in products from unused Ti powder that was recycled 50 times. Ahna et al. [20] investigated the mechanical and micro-structural characteristics of commercial purity (CP) titanium implants with various porosities. Zhou et al. [21] developed a three-dimensional model of the arc to simulate molten pool dynamics. Figure no 6 shows simulated results for temperature distribution and electromagnetic forces.

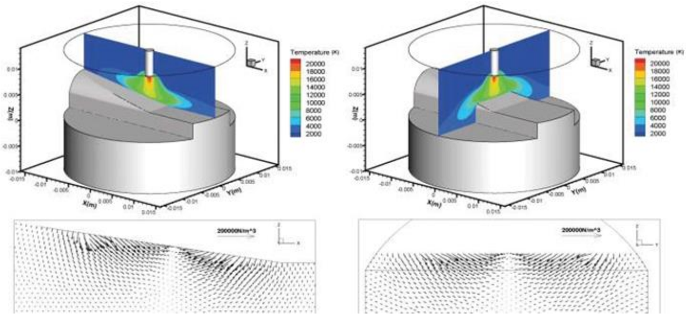

Figure no 6: Temperature distribution and electromagnetic forces [21]

Sun et al. [22] developed a novel method to fabricate Ti-6Al-4V powder for injection molding process. They were able to predict a linear variation of the oxygen content with the specific surface area of a milled hydride. Abha et al. [23] presented a Lattice Boltzmann based algorithm for layer generation, energy absorption, evaporation, and wetting. Bao et al. [24] studied smooth particle hydrodynamic (SPH) technique by Autodyn software. Dunbara et al. [25] conducted study on temperature distributions and distortions during laser bed fusion method (LBFM) using a setup. Zinoviev et al. [26] simulated the grain structure developed during laser additive manufacturing and discussed effects of heat source on grain size. Wang et al. [27] predicted the distributions of residual stresses in Inconel 625 walls fabricated by using direct energy deposition as shown in figure no 7. Heat treatment method may be used to relieve these stresses, but it also changes the micro-structure of material.

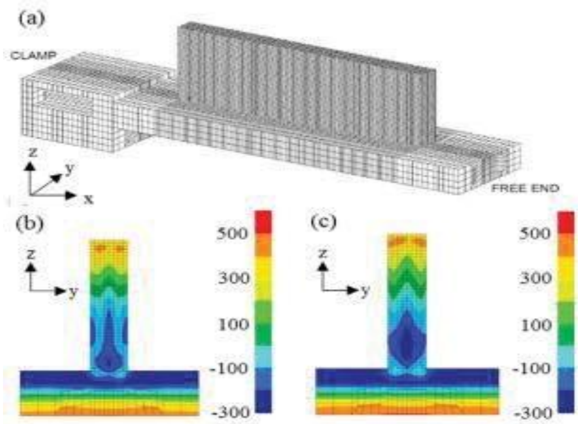

Figure no 7: Residual stress contours

Kanninen et al. [28] fabricated fuel cells using laser additive manufacturing. Hence, they demonstrated use AM for proto typing purpose. Habib et al. [29] optimized the deposition direction taking into complexity of contour which minimizes deposition time. Hodge et al. [30] have predicted residual stress concentration in Selective laser melting

(SLM)method using various models of heat transfer and solid mechanics. Dialami el al. [31] have proposed a new finite element based method for predication of residual stresses and distortion of parts produced by additive manufacturing. Zhang et al. [32] have used neuron fuzzy interface systems (NFIS) for prediction of residual stresses in Aluminum components used for aircraft industry. Yang et al. [33] have predicted residual stresses on a 6Al-4V Titanium based work piece using finite element analysis. Meyghani et al. [34] made comparative study of results obtained from ABAQUS, ANSYS and FLUENT based simulations for Friction stir welding process. Kortabarri et al. [35] made a comparative study of stress concentration on a Inconel 718 based work piece. Wong et al. [36] found that stresses can be controlled by decreasing thickness of substrate material layer during AM. Chua el al. [37] proposed a model for predication of residual stresses in orthogonal cutting processes. Hoque et al. [38] studied residual stresses produced during laser bed fusion processes. Korner et al. [39] have used Lattice Boltzmann structure to model powdered beds. Peng et al. [40] showed effects of entrapment of gas bubbles in nickel super alloy. An ABAQUS based algorithm presented by Liu et al. [41] to simulate the residual stresses developed. Vastola et al. [42] have analyzed the residual stress in a work piece of Ti6Al4V based alloy made by electron beam melting process.

Mukherjee et al. [43] investigated effects of residual stresses in an Inconel 817 substrate manufactured using laser beam technology. These computed results can be useful to study the delaminating, layer separation and warping processes occurring during AM. Li et al. [44] developed concept of virtual heat source to study stresses developed during laser melting process.

IV. TECHNOLOGY

A typical flow chart for manufacturing products by this method is shown in figure no 8. The process of AM can be divided into two phases: Virtual visualization and physical manufacturing.

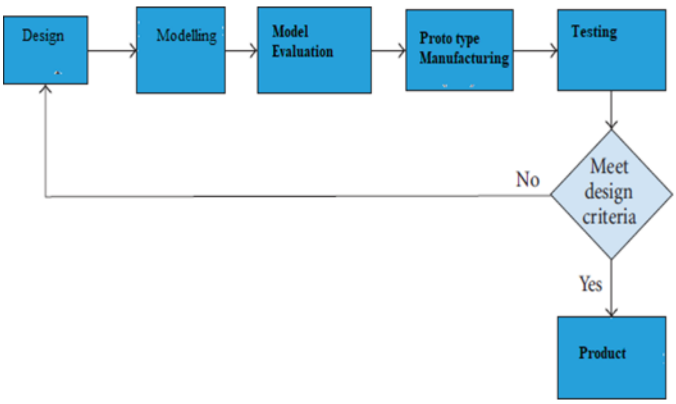

Figure no 8: Flow chart for AM [45]

In Electron beam melting the machine distributes a layer of metal powder onto a build platform, which is melted by the electron beam. The build platform is then lowered so that metal powder will be coated on top [46]. Scherillo et al. [47] studied microstructure of sheets of TI6Al4V alloy made using EBM and Linear Friction Welding (LFW). The comparison of simulation and analytical findings was done by measuring the spacing evolution under the solidification condition [48]. Poly Jet printing process consists of use of ultraviolet bulbs and photopolymer materials. In this process, each sprayed polymer layer is cured by UV light to produce fully cured solid parts. Two different photopolymer materials may be used for building, one for the fabrication of actual model and another gel like material for supporting features [49]. Stereo lithography (SL) process starts with a model in a CAD software that is then translated to a STL file in which the pieces are "cut in slices" having information for each layer. A novel version of this process has been developed with a higher resolution in which layer thickness of less than 10 µm can be achieved [50, 51]. Laminated manufacturing (LOM) [52] process is based on the principle of lamination. This technology fabricates parts followed by a subtractive step which cuts the outline with a CO_2 laser cutter. After each outline has been cut, the roll of paper is advanced, and then a new layer is glued onto the stack. The process is repeated until the whole part is fabricated which is followed by trimming, hand finishing and curing are required.

V. CONCLUSIONS

This section discusses various industrial application of AM processes. These methods have been used in wide range of purposes that include aerospace, automotive, manufacturing, tooling and medicinal applications. Aerospace sector has shown interest in these technologies because of its ability to fabricate direct metal parts such as from titanium, and the ability to fabricate complex and higher performance products easily without any tooling [53]. SL is being used to manufacture anatomical implants, tailor- made biomedical devices such as hearing aids and has proven to facilitate and speed up the intensive planning of surgical procedures [53]. Some of challenges studied through the literature of AM technology are as follows:

A) The misunderstanding consideration for using rapid prototyping technique for fabrication of prototypes only as it can be used in producing finished products.

B) Adequate strength and accuracy are required for metallic parts.

C) Higher costs and lower quality of produced products that are hard to recycle.

D) Layer thickness optimization effects the processing time and needs larger data files.

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