A Review on Additive Manufacturing Trends Challenges And Applications

Mr. A Daniel Praneeth[1], Mr. Ayub Ashwak[2], Mr. B Harish Raj[3]
[1, 2, 3]Assistant Professor, Dept of Mech. Engineering
[1, 2, 3] Holy Mary Institute of Technology & Science, Hyderabad, India

Abstract*- Additive manufacturing is a new pattern underway cycles inferable from its numerous advantages. It tends to be characterized as the way toward delivering parts through the affidavit of material in a layer-by-layer design. It has been a subject of extraordinary investigation furthermore, survey by numerous analysts. In this work, an extensive audit relating to added substance fabricating has been achieved. The advancement of added substance producing as an unmistakable innovation and its different stages are talked about. The significance of part direction, assemble time assessment, and cost calculation has additionally been investigated. The momentous part of this work is the ID of issues related with various added substance producing strategies. In view of the defects in added substance producing, its hybridization with different strategies, like subtractive assembling, has been underlined. This review will help readers understand the different aspects of additive manufacturing and explore new avenues for future research*

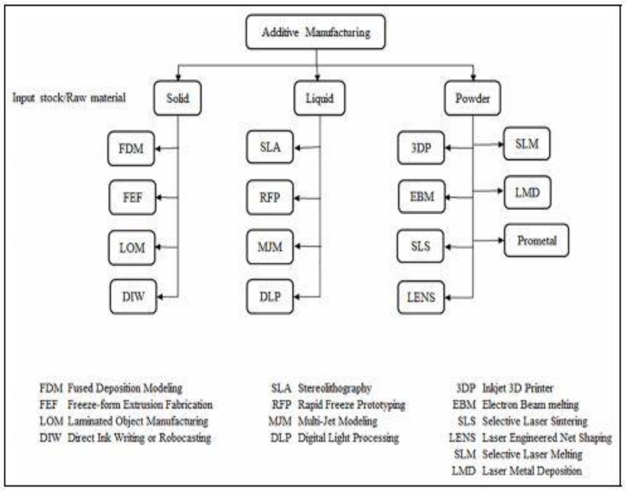
Keywords- Additive manufacturing, subtractive manufacturing, hybrid manufacturing, part orientation, cost models

I. INTRODUCTION

Additive manufacturing (AM) can be described as a technique of blending materials by either fusion, binding, or solidifying materials such as liquid resin and powders. It builds part in a layer-by-layer fashion using 3D CAD modeling. The terminologies such as 3D printing (3DP), rapid prototyping (RP), direct digital manufacturing (DDM), rapid manufacturing (RM), and solid freeform fabrication (SFF) can be used to describe AM processes. AM processes fabricate components using 3D computer data or Standard Tessellation Language (STL) files, which contain information regarding the geometry of the object. AM is very useful when low production volumes, high design complexity, and frequent design changes are required. It offers the possibility to produce complex parts by overcoming the design constraints of traditional manufacturing methods. Although, AM has many benefits, its applications are still limited because of its low accuracy and long build times compared to CNC machines. It does not have the same constraints as CNC machining because it segregates the part in cross sections with a resolution equal to that of the process.2 Nevertheless, the accuracy and build time can be improved by employing suitable part orientation. Optimized part orientation can enhance the accuracy and diminish the building time and support volume, which in turn minimizes the part production cost. Moreover, AM in contrast to conventional production processes consists of additional controllable process parameters and higher active interaction between the material properties and process parameters. There are different kinds of AM processes depending on the material preparation, layer generation technique, phase change phenomenon, material type, and application requirements.

II. CLASSIFICATION

AM processes or machines can be classified based on machine dimension, nozzle dimension, speed of the nozzle, and workspace dimensions. AM can be categorized in numerous ways based on the functional framework of the material. Although the methods of classification can also include the patterning energy, the technique of generating primitive geometry, the nature of used materials, and the support procedure.5,6 However, in broad sense, AM processes can be summarized and classified according to the type of material used. Figure 4 summarizes the existing methods for AM based on the type of material. Solid-based AM. The AM technologies in which input raw material is in solid state have been discussed in this sub-section. Among so many existing solid-based AM technologies, FDM, freeze-form extrusion fabrication (FEF), laminated object manufacturing (LOM), and direct ink writing (DIW) are the most popular. FDM. The working of FDM as shown in Figure 5 is based on the principle of layered manufacturing technology.9 In this technology, the plastic raw materials (filaments) are extruded through the nozzle, which is heated to melt the material. The nozzle head moves according to the tool path, which is generated for each layer. FEF. This process was developed at the University of Missouri–Rolla, Rolla, Missouri,11 and it worked by extrusion of an aqueous ceramic paste. In this technology, the paste was extruded layer-by-layer into a build



Classification of AM processes depending on the state of raw material.

Part orientation in AM Suitable orientation of the part is crucial in AM for improving the Geometrical and Dimensional Tolerance (G&DT), reducing build times and minimizing support volume and part production costs. The part orientation affects surface accuracy, builds height, and supports volume. This criterion, along with the production cost, has been the main research area for many years.57–59 The work of Cheng et al.60 offered a classification based on different types of surfaces using a weighted value to acquire high surface accuracy. Two different objective functions were presented for selecting the optimal part orientations. The objective function of accuracy was formulated by the multiplication of each surface area type with the given weight and the maximum value of the objective function that provided the optimal orientation. If different orientations resulted in the same value for the accuracy, then the secondary objective function, which was minimum build time, was considered.

Cost estimation in AM

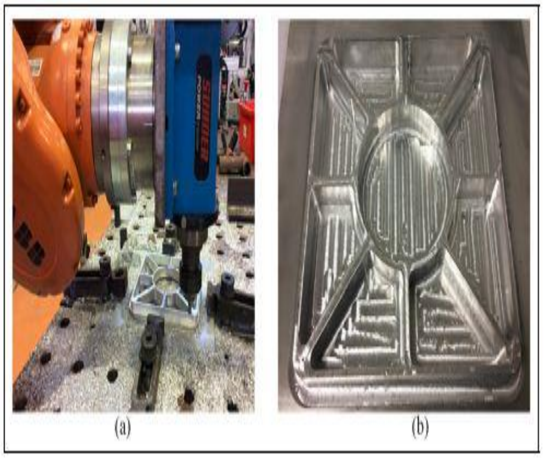
here are two categories motivating the examination of AM costs. The first category involves comparison of AM with other conventional processes, namely, machining and injection molding (IM). The objective is identification of scenarios and circumstances in which AM is cost effective. The other category includes determining the resources that are used at different steps in AM. This category determines information about the resources being used and their overall utilization. Recently, cost models have been developed for various AM technologies. This section has discussed leading cost models in order to understand their applications.

Trends in AM

AM was first demonstrated in the 1980s by Kodama, who published an article titled ‘‘Three-Dimensional Data Display by Automatic Preparation of a Three Dimensional Model.’’2 The emergence of AM took place in 1987 with STL by Chuck Hull (courtesy: 3D Systems), a technique which solidifies thin layers of ultraviolet (UV) light-sensitive liquid polymer using a laser. It can successfully manufacture complex and customized products with fewer skilled workers, shorter delivery times, and shorter product life cycles. The chart in Figure 3 describes an increase in the number of patents associated with AM from 1982 until 2012.4 The technology based on selective laser sintering (SLS) was first patented in 1988 by Carl Deckard at the University of Texas, followed by fused deposition modeling (FDM) in 1989 by Scott Crump, co-founder of Strasays Inc. It can be asserted that the academic project in 2005 by Dr Adrian Bowyler at the University of Bath, England was one of the major breakthroughs in the area of 3DP. They developed a self-replicating fabricating system, known as Rep Rap, capable of manufacturing its own components. Since then, a number of ventures, such as Makerbot (2009), Form Labs (2011), and HP Fusion Jet 3D printer (2016), have come up. It can be observed that the emergence of AM technology commenced in the 1980s for generating 3D

III. IMPACT ON MANUFACTURING

There are many AM applications including lightweight products for the aerospace, automotive, medical, architectural modeling, and energy industries. These include applications where low volume production, high design complexity, and the ability to change designs frequently are needed. However, AM still needs significant development with regard to design, material, novel techniques, and machines.



(a) Process of post-machining. (b) Final finished part with the desired dimensional accuracy

IV. AM CHALLENGES

Certainly, there are numerous benefits, such as design flexibility, ability to print complex structures, ease of use, and product customization, that can be associated with AM. However, AM technology has still not matured enough so that it can be employed in real world applications. There have been drawbacks and challenges that need investigation as well as advanced technological development. The limit on the part size, anisotropic mechanical properties, building of overhang surfaces, high costs, low manufacturing efficiency, poor accuracy, warping, pillowing, stringing, gaps in the top layers, under-extrusion, layer misalignment, over-extrusion, elephant foot, mass production and limitation in the use materials are the challenges that need further analysis and exploration.147,148 Some of the limitations and challenges related to AM are described as follows.

Void formation

The void formation between subsequent layers of AM parts is one of the major drawbacks. This kind of problem occurs due to reduced bonding between layers, thus causing inferior mechanical performance.147,148 For example, extrusion-based AM technologies such as FDM results in void formation between the fabricated layers, thus inducing anisotropic mechanical properties148,149 and delamination.150 Indeed, the amount of the porosity induced by void formation typically depends on the type of AM process and the material used. Hence, to minimize the effect of void formationbetween subsequent layers, Paul et al.151 evaluated the effect of nozzle geometry on the void formation between subsequent layers. The results of their study showed that the performance of rectangular nozzles was better than cylindrical nozzles.

Stair-stepping

One of the biggest challenges in AM process is the appearance of staircase effect or layering error in the fabricated parts. This kind of error is insignificant for internal fabricated surfaces; however, it substantially affects the quality of external surfaces. Although, many methods (post-processing) like sand sintering can be employed to minimize or get rid of this defect152 but they also increases the time and cost of the overall process.

Anisotropic in mechanical properties and microstructure

Another challenge that can be observed with AM is the existence of anisotropy in microstructure and mechanical properties. AM technologies produce parts in a layer-by-layer fashion by curing the photo resin, melting the filament or melting the powder bed, resulting in the generation of thermal gradient. The AM parts often results in different microstructure and mechanical properties along build direction and the other directions.153,154 For example, the plates manufactured by FDM technology possess better strength in x, y direction as compared to the strength in z-direction (build direction).

Small build volume

The user of AM technologies is also dealing with the challenge of small build volume. It is considered as one of the main disadvantages of AM technology. Generally, the large parts are scaled down or cut to subparts, which adds time and effort. Moreover, the scaling down of the model in most cases is not feasible and effective. The assembly of subparts after scaling down possesses lesser strength if adhesives are used or become bulky in case mechanical fasteners are employed.155 Until now, AM has not been successful for large-scale industrial applications.

Fabrication of weapons or drugs for crime purposes

As a result of its capability to fabricate complex structures, AM can also be employed to produce weapons that can be used for crime purposes. This aspect of AM has also limited its spread in some countries.

V. COMPLIANCE WITH FOOD & DRUG ADMINISTRATION SAFETY STANDARDS

The medical devices and implants as well as the food that are fabricated and produced by AM must comply with the regulations outlined by local Food & Drug Administration (FDA). Since the AM technologies are relatively new to the medical industry, FDA is still working on the design of distinct rules and regulations. Moreover, the existing regulations are complex and difficult to implement; as a result, companies are hesitant to use AM in healthcare sector.

VI. CONCLUSION

Advancements in manufacturing industry depend on leading edge research associated with manufacturing processes, materials, and product design. As product complexity increases, there is a need for new and innovative manufacturing processes. AM is a recent trend in production processes because of the many benefits it provides as well as the challenges it has to overcome. It has been subjected to intensive investigation and indepth review by the research community. In this work, an exhaustive review related to AM has been carried out. The importance of part orientation, build time estimation, and cost computation have been reviewed in detail. The most important feature of this work is the identification of the problems associated with different AM methods. Among the primary AM challenges, part size limitation, anisotropic mechanical properties, building of overhang surfaces, high costs, poor accuracy, warping, layer misalignment, mass production, and limitation in the use materials need further research and investigation. Based on this review, the various aspects of AM technology can be summarized as follows. It can be asserted that the selection of suitable part orientation is crucial in AM. It helps to improve geometrical and dimensional error, reduce build time, and minimize support volume and part production costs. The staircase effect has been identified as the most important factor affecting the part accuracy. Indeed, the staircase effect is directly proportional to the layer thickness. It has also been observed that build time, which possess greater significance in improving productivity, depends on machine speed, part size, layer thickness, and build orientation. It has been noticed that there is a need for the development of an effective and ubiquitous cost model for the AM. Meanwhile, the costs of AM can be categorized in terms of material, machine, manufacturing, and labor costs. The summation of these costs represents the overall unit cost. It is important to incorporate the following requirements in the future.

REFERENCES

[1] Zhu Z, Dhokia V, Nassehi A, et al. A review of hybrid manufacturing processes—state of the art and future perspectives. Int J ComputInteg M 2013; 26: 596–615.
[2] Gibson I, Rosen DW and Stucker B. Additive manufacturing technologies: rapid prototyping to direct digital manufacturing. Berlin: Springer, 2009.
[3] Zeltmann SE, Gupta N, Tsoutsos NG, et al. Manufacturing and security challenges in 3D printing. JOM 68: 1872–1881.
[4] Wohlers T and Gornet T. History of additive manufacturing. Wohlers report, 2014, http://www.wohlersassociates.com/history2014.pdf
[5] Williams CB, Mistree F and Rosen DW. A functional classification framework for the conceptual design of additive manufacturing technologies. J Mech Des 2011; 133: 121002.
[6] Manogharan G. Hybrid manufacturing: analysis of integrating additive and subtractive methods. Raleigh, NC: North Carolina State University, 2014.
[7] Huang SH, Liu P, Mokasdar A, et al. Additive manufacturing and its societal impact: a literature review. Int J Adv Manuf Tech 2013; 67: 1191–1203.
[8] Bikas H, Stavropoulos P and Chryssolouris G. Additive manufacturing methods and modelling approaches: a critical review. Int J Adv Manuf Tech 2016; 83: 389–405.
[9] Ahmad A, Darmoul S, Ameen W, et al. Rapid prototyping for assembly training and validation. IFAC Papersonline 2015; 48: 412–417.

[10] Yagnik PD. Fused deposition modeling—a rapid prototyping technique for product cycle time reduction cost effectively in aerospace applications. IOSR J Mech Civ Eng 2014: 62–68.
[11] Huang V. Fabrication of ceramic components using freeze– form extrusion fabrication. PhD Dissertation, Department of Materials Science and Engineering, University of Missouri-Rolla, Rolla, MO, 2007.
[12] Mathur R. 3D printing in architecture. Int J Innovat Sci 2016; 3: 583–591.
[13] Mueller B and Kochan D. Laminated object manufacturing for rapid tooling and pattern making in foundry industry. Comput Ind 1999; 39: 47–53.
[14] Cesarano J. Robocasting: direct fabrication of ceramics from colloidal suspensions. In: Proceedings of solid freeform fabrication symposium, Austin, TX, 11–13 August 1997, pp.25–36.
[15] Cesarano J, King BH and Denham HB. Recent developments in robocasting of ceramics and multimaterial deposition. In: Proceedings of solid freeform fabrication symposium, Austin, TX, 11–13 August 1998.
[16] Li Q and Lewis JA. Nanoparticle inks for directed assembly of three-dimensional periodic structures. Adv Mater 2003; 15: 1639–1643.
[17] Chua CK, Leong KF and Lim CS. Rapid prototyping: principles and applications. 2nd ed. Singapore: World Scientific Publishing Company, 2003.
[18] Hoffmann J. ThermoJet und medizinische Modelle—Ein Erfahrungsbericht. RAPROMED, 2000, https://tu-dresden. de/ing/maschinenwesen/if/ff/ressourcen/dateien/pazat/forschung/for_ber_pdf_html/lit00_html/hoff-001.pdf?lang=en
[19] Zhang W, Leu MC, Ji Z, et al. Rapid freezing prototyping with water. Mater Des 1999; 20: 139–145.
[20] Zhang W, Leu MC, Ji Z, et al. Method and apparatus for making three-dimensional objects by rapid freezing. Patent US6253116B1, USA, 1997.
[21] Zocchi G. New developments in 3D printing of composites: photocurable resins for UV- assisted processes, 2016, https://www.politesi.polimi.it/handle/10589/124844
[22] 3D and Printing Industry, http://3dprintingindustry.com (accessed 20 August 2016).

[23] Ameen W, Al-Ahmari A, Mohammed MK, et al. Manufacturability of overhanging holes using electron beam melting. Metals 2018; 8: 397.

[24] Murr L, Quinones SA, Gaytan SM, et al. Microstructure and mechanical behavior of Ti–6Al–4V produced by rapid-layer manufacturing, for biomedical applications. J Mech Behav Biomed Mater 2009; 2: 20–32.

[25] Murr LE, Gaytan SM, Ceylan A, et al. Characterization of titanium aluminide alloy components fabricated by additive manufacturing using electron beam melting. Acta Mater 2010; 58: 1887–1894.

[26] Koike M, Martinez K, Guo L, et al. Evaluation of titanium alloy fabricated using electron beam melting system for dental applications. J Mater Process Tech 2011; 211: 1400–1408.

[27] Karlsson J. Optimization of electron beam melting for production of small components in biocompatible titanium grades. Acta Universitatis Upsaliensis, Uppsala, 2015.

[28] Ameen W, Ghaleb AM, Alatefi M, et al. An overview of selective laser sintering and melting research using bibliometric indicators. Virt Phys Prototyp 2018; 13: 282–291.

[29] Casavola C, Campanelli SL and Pappalettere C. Preliminary investigation on distribution of residual stress generated by the selective laser melting process. J Strain Anal Eng Des 2009; 44: 93–104.

[30] Vandenbroucke B and Kruth JP. Selective laser melting of biocompatible metals for rapid manufacturing of medical parts. Rapid Prototyping J 2007; 13: 196–203.

[31] Yasa E and Kruth J. Application of laser re-melting on selective laser melting parts. Adv Prod Eng Manag 2011; 6: 259–270.

[32] Paul R. Modeling and optimization of powder based additive manufacturing (AM) processes. PhD Thesis, University of Cincinnati, Cincinnati, OH, 2013.

[33] Klingbeil NW, Beuth JL, Chin RK, et al. Measurement and modeling of residual stress-induced warping in direct metal deposition processes. In: SFF symposium, 1998, pp.367–374, http://sffsymposium.engr.utexas.edu/Manuscripts/1998/1998-40-Klingbeil.pdf

[34] Zaeh MF and Branner G. Investigations on residual stresses and deformations in selective laser melting. Prod Eng 2010; 4: 35–45.

[35] Clijsters S, Craeghs T and Kruth JP. A priori process parameter adjustment for SLM process optimization. In: Proceedings of the 5th international conference on advanced research and rapid prototyping: innovative developments in virtual and physical prototyping, 28 September–1 October 2011, pp.553–560. USA: CRC Press.

[36] Knol MF. Thermal modelling of selective laser melting: a semi-analytical approach, 2016, https://repository.tudelft.nl/islandora/object/uuid%3Ae6b406fe-0b13-4f1c8e13-da961b3f3718

[37] Boddu MR, Landers RG and Liou FW. Control of laser cladding processes for rapid prototyping: a review. In: Proceedings of the 12th annual solid freeform fabrication symposium, Austin, TX, 6–8 August 2001, pp.460–467.

[38] Griffith ML, Ensz MT, Puska JD, et al. Understanding the microstructure and properties of components fabricated by laser engineered net shaping (LENS). In: