Additive manufacturing with composites of poly lactic acid (PLA)

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Abstract. Additive manufacturing [AM] is a technology wherein the product is manufactured in a sequence of layer. AM has found a wide range of applications in today’s world as the need for a process of rapid prototyping is increasing. AM has its own place in the world of research and has been subjected to constant upgrades in process, machine setups and various other parameters. This study elaborately reviews about various methodologies in AM, its applications and its drawbacks. This work is concentrated to understand different methodologies adapted in additive manufacturing process and its process is been discussed.

Keywords: FDM, Filament Orientation, Natural Fibers

1. Introduction
Additive manufacturing as said is a process where in a material is manufactured in a layer wise fashion. AM was originally developed from stereolithographic process \cite{1} by Mr. Charles Hull in 1986. Initially, the object or the component that is to be manufactured is designed in using various computer aided tools (CAD), which is then processed through other secondary manufacturing aiding software to convert the object into a very large finite number of layers. These layers on piling up on above the other makes the product. From the time of development, AM is a key place for research and development and has undergone various upgrades in its processes. Some of the processes of AM include powdered bed fusion technology, fused deposition modelling, contour crafting, and 3D printing. The scope for research and application of additive manufacturing is increasing as the need for rapid prototyping in the manufacturing industries is increasing. Additive manufacturing has also found a wide of applications that include construction sectors, organ development, biotechnological applications, automotive sectors and much more. AM techniques has the ability to manufacture a complex and multipoint geometry based components with ease by using a wide range of raw materials like polymer based plastics, wood, metals, composites, concretes.

The process which was initially used by the architects to make a prototypes of the construction has now been developed to construct the houses itself as number of houses were 3d printed by Win Sun in China \cite{3}. AM holds a numerous advantages over the conventional manufacturing process that includes flexibility in design, reduction in wastage of materials unlike subtractive manufacturing, production of complex shapes within the tolerance and customization in every product. On the other hand, the drawbacks of the additive manufacturing cannot be avoided as it is difficult to design various machining parameters in the designing phase like the control of surface roughness, the resolution to which a material can be printed, the bonding between the layers, the directional dependent property of the 3d printed objects which may lead to a weakness in mechanical properties \cite{4}. Various research methodologies has to be taken to study for the compatibility of this technique with different materials. This paper aims to summarize a detailed review of additive manufacturing techniques, filaments
limitations of our study to polymer based plastics), developments in the properties of filaments and various applications of AM process.

2. Additive manufacturing process and methodologies
As said earlier, the process starts with modeling of the component in a 3D file by a drawing tool or by digital scans. The complex geometries of the components are wrapped up using various software tools. The codes generated from the design moves the nozzle or the heating source in the required direction. The powdered or the wired feed stock is then converted into the product. AM is classified into seven types based on the standards set by the American Society for Testing and Materials (ASTM). The seven types include binder jetting, directed energy deposition, material jetting, material extrusion, vat photo polymerization, sheet lamination and powder bed fusion [5]. These methodologies are discussed briefly in the upcoming parts. The general additive manufacturing machine setup has the following parts – a platform on which the component is built, a heating source, control mechanism for the movement of nozzle (generally a stepper motor), and a feed stock supplier to supply the filaments, wire and sheets as required in the processes.
3. Material extrusion

Material extrusion is the process in which the solid filament is melted and extruded which is then deposited in the required position with the help of codes that is generated from the design. FDM is the most commonly used material extrusion process. In this method, the filament of the thermoplastic is fed continuously into the nozzle or through the orifice, where the plastic is fused together and then it is made to pile up in a layer wise manner. The feed rate of the filament is controlled by the stepper motor and the nozzle is heated to the required temperature of melting. The process and methodology is quite simple and could be done in a quicker manner. This process is mainly suitable for the thermoplastics such as Poly lactic acid [PLA], Acrylonitrile butadiene styrene [ABS], nylon etc. After being fused to the required shape in the room temperature, it is allowed to cool down and solidify to get the final part. The major drawback of this process is the surface roughness and appearance. These printed materials may also have a lower mechanical properties due to improper layer formation and bonding. Another drawback that is to be noted is that the availability of less number of thermoplastics that could be used here. This widens the scope for the development of new thermoplastic composites, which is also reviewed in this study. In the recent days light weight materials widely used in various industrial applications [4-16].

![Material Extrusion Process](image)

**Figure 3.** Material Extrusion Process

4. Powder bed fusion

The principle behind this process is the thermal heating and fusion by a laser source. The required raw material which is in its powdered form is made to a levelled bed on the additive manufacturing equipment. The laser source is used to heat and fuse these powders. Generally the powders get fused up during focused heating by the laser source. The position of the laser for heating is controlled by the additive manufacturing machine with help of the codes that is generated from the design of the component. This method could be employed for both plastics as well as the metals. The component produced by this techniques are light in weight, heat and corrosion resistant and hence this process is widely preferred. PBF can be subdivided into various processes depending upon the type and quality of fusion as selective laser sintering [SLS], selective laser melting [SLM], electron beam melting [EBM], multi jet fusion etc. The main difference between the sintering and melting process is the quality of fusion. Sintering deals with partial fusion or fusion in solid phase whereas the melting process is a complete phase change process. Another main criteria of division is the method of fusing that includes thermal, laser, electron beam, fusing with agents. The complete analysis of the SLS and SLM process are given in the reference [6].

5. Directed energy deposition

In this process the high energy heat source, basically a laser source is focused on the area of feed stock that is to be melted. The feed stock is a powder or a wire like we use win welding apparatuses. The main difference between the DED and PBF is that the former doesn’t need a feedstock in terms of bed.
Generally, DED technique is used with metals and hence it could be interchangeably called as directed metal deposition or metal deposition technique. This process is also called as laser engineered net shaping [LENS], laser solid forming [LSF], directed light fabrication [DLF] etc. This process is mainly used generally with metals or when size of the component is very large. Recent researches are done to use this technique in heavy structural applications to avoid the secondary manufacturing process and the losses associated with that.

6. Jetting additive manufacturing:
Jetting is a process in which the manufacturing takes place with the help of the liquid agent like in normal printers. In binder jetting process, the liquid binding agent is forced out on the powder of the feedstock with controlled movement of nozzle according to the design.

![Figure 4. Jetting Process](image)

The liquid binding agent binds the powder particles together to give a final product. This method is just joining of particles with an aid of an agent. In material jetting process, the raw material is added in a dropwise manner to give the final product just like the ink-jet technology.

7. Vat-photo polymerisation
This process is also called as stereo lithography and was developed by Mr. Charles Hull in 1984. This method works on the principle of binding between the particles by the usage of a light source like a LASER. This method uses an ultraviolet laser to polymerize the monomers. This chain polymerization leads to the bonding between the layers. STL process mainly involves the usage of resins and chemical reactions for bonding. This process is limited to photopolymers only.

8. Sheet lamination technique
This process uses stacks of sheets of raw materials to perform additive manufacturing process. The laser source is used to cut and laminate the sheets. The sheets are piled up on the building platform, where the laser light source is used to cut the sheets. The laser is moved according the codes generated by the software to the given design. The process is further subdivide into laminated object manufacturing [LOM] and ultrasonic additive manufacturing.
The binding of layers may take place with help of an adhesives or by the method of welding depending on the type of material used. The main advantage of this process is that there is no inertial tension and fragility of the parts [7]. The manufactured material also has high surface finish, low material and process costs [8].

9. Polylactic acid

PLA is abbreviated as Poly lactic acid or Polylactide is a thermoplastic polyester. PLA material plays a vital role in industries because it is economically produced from renewable resources. PLA is a versatile and commercially biodegradable thermoplastic based on lactic acid. The chemical formula for PLA is \((C_3H_4O_2)_n\). The melting point of PLA is 150 to 160 °C (302 to 320 °F; 423 to 433 K). Density of poly lactic acid is 1.210–1.430 g·cm\(^{-3}\).

In addition, it is easier and more convenient to use for 3D printing. When you use PLA, your final product tends to be shinier and smoother. It is generally more pleasing aesthetically.

![Chemical formula for Polylactic acid](image)

**Figure 5.** Chemical formula for Polylactic acid

10. Conclusion

In this paper the different methods adapted in additive manufacturing and its process has been discussed and in understanding the various methodology its observed FDM process is widely adapted due to is cost efficiency and elegance in prototyping. There is found to be a huge scope in adaptation of additive manufacturing in prototyping considering its efficiency in design adaptation and modification elegance.

References

[1] Hull C. US Patent 4,575,330, March 1986.
[2] Wu P, Wang J, Wang X. A critical review of the use of 3-D printing in the construction
[3] Vaezi M, Seitz H, Yang S. 2013;67(5):1721–54.
[4] Yap CY, Chua CK, Dong ZL, Liu ZH, Zhang DQ, Loh LE, Sing SL. ApplPhys Rev 2015;2(4):041101.
[5] Mueller B, Kochan D. ComputInd 1999;39(1):47–53.
[6] Melchels FPW, Feijen J, Grijpma DW. 2010;31(24):6121–30.
[7] Eckel ZC, Zhou C, Martin JH, Jacobsen AJ, Carter WB, Schaeder TA ceramics. Science 2016;351(6268):58–62.
[8] M. Vinayagam, K.S.Ashraff Ali, S.Prasath T.Sathish, M. Ravichandran, Journal of Materials Research and Technology, 9 (2020) 14662-14672.
[9] V. Mohanavel, K. Rajan, M. Ravichandran, Journal of Materials Research, 31 (2016) 3824-3831.
[10] V. Mohanavel, M. Ravichandran, Materials Research Express, 6 (2019) 106557.
[11] Manapat JZ, Chen Q, Ye P, Advincula RC Macromol Mater Eng 2017;302(9). 1600553-n/a.
[12] Gibson I, Rosen D, Stucker B. New York, NY: Springer New York; 2015. 56 p. 245–68.
[13] Williams CB, Mistree F, Rosen DW. J Mech Des 2011;133(12):121002.
[14] Vinayagam Mohanavel, S. Suresh Kumar, J. Vairamuthu, P. Ganeshan, B. NagarajaGanesh, 2020, Journal of Natural Fibers, 2021, DOI : 10.1080/15440478.2021.1875368
[15] Vinayagam Mohanavel, Thandavamoorthy Raja, Anshul Yadav, Manickam Ravichandran, Jerzy Winczek, Journal of Natural Fibers, 2021, DOI : 10.1080/15440478.2021.1958432
[16] M. Vinayagam, KS Ashraff Ali, K Ranganathan, J Allen Jeffrey, MM Ravikumar, S Rajkumar, Materials Today: Proceedings, (2021), DOI : 10.1016/j.matpr.2021.04.596