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Review on Process Parameters of FDM and Their Impact on Tensile Strength and Wear Resistance of Additive Manufacturing Specimen

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Abstract. Additive Manufacturing (AM) is an advanced manufacturing process which reduces the physical involvement of human beings for producing products. All we required is to make a three-dimensional CAD module and feed it to a three-dimensional printer. During its beginning it was just used to make a prototype, as more research has been taking place to improve its ability to make a good product due to which now it is able to produce the final product. Whenever we think about producing a product using additive manufacturing it is necessary to wisely choose the right material, right AM technique and their process parameters which fulfill the requirements. In this paper we are reviewing the process parameters of the most popularly used AM technique that is Fused Deposition Modeling (FDM) and their effect on tensile and wear strength of the printed specimen. For our study we are majorly focused on PLA and Carbon PLA as PLA is mostly use and environment friendly.

Keywords. Fuses Deposition Modeling, process parameter, tensile strength, wear resistant, carbon PLA

1. Introduction

Additive Manufacturing (AM) is an advanced manufacturing technique in which a complex product is formed with less wastage because it makes a product from a 3D CAD model to a 3D physical model by adding layer upon layer. This manufacturing technique is developed hand to hand with the advancement of computers. In its early phase it is used for rapid prototyping but now it is used to make direct products and now efforts are continuously made to manufacture full body organs in future [1].

First experiment to create a 3D model is take place in 1960 using photopolymers after that any attempts had been take place and many different type of additive manufacturing techniques has been evolve such as Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), Selective laser sintering (SLS), Material Jetting, Direct Light Processing (DLP) and many more. Evolution of all these technologies and their advantages makes the industries use additive manufacturing [2].

AM technology can be broadly classified into two categories according to the physical form of the material used which is solid and liquid. Solid is also further classified into three different forms in which material is used that is powder, wires, and sheet form. Selective Laser Sintering (SLS) is one of the AM Technologies which use powder as a raw material. This powder is preheated, and a CO2 laser is used to form a product in which thin layer powder is spread on the platform and a laser is applied according to the design which melts the powder from a specific position in this way layer is added on upon another. Fused Deposition Modeling (FDM) uses material in wire form or filament which is melted in the heating element of the FDM and extruded the material layer upon layer to form the product. In Laminated Object Manufacturing (LOM) sheet of material is added layer upon layer using adhesive and cut in desired shape by using laser.

Second type of method which uses liquid material are Stereolithography (SL), Direct Light Processing (DLP) and Material jetting. All three of them use radiation curable resins or photopolymers as material but the way of disposing of layers is different. Stereolithography (SL) moves laser on resins thin layer in a guided way to layer for forming product whereas in Direct Light Processing (DLP) the entire layer is projected in on go. In the Material Jetting process material is deposited layer upon layer in the form of very small droplets which solidify, it works on the principle of Drop On Demand (DOD) [1].

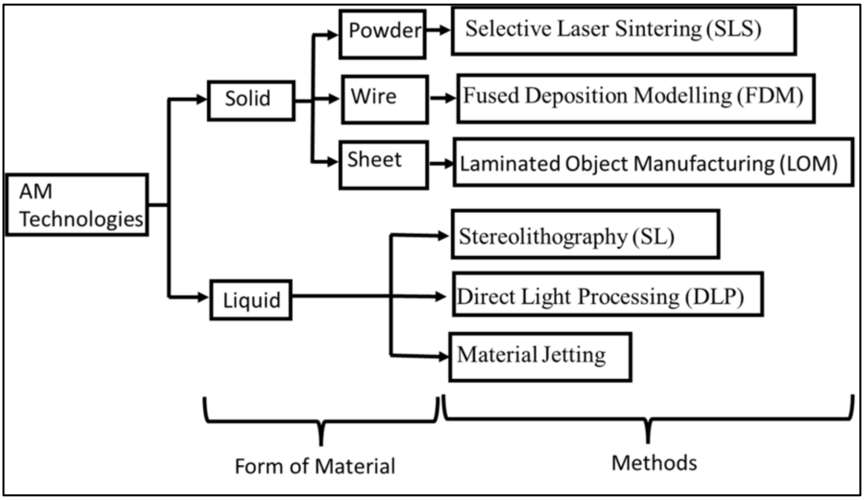

Figure 1. Classification of AM Technologies.

2. About FDM

Fused Deposition Modeling (FDM) is one of the most common additive manufacturing techniques in which material in the form of wire is feed by the feeder mechanism, then it melted and came out from the nozzle through the extruder. In this way material is added to make a complete product layer upon layer. FDM consists of various components i.e., Extruder Nozzle, Feeder Mechanism, heating element and Platform as shown in Fig. 2. Commercialization of FDM was take place in 1991 in US [2].

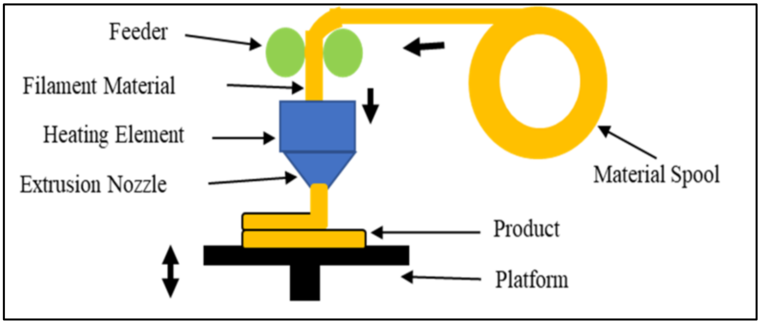

Figure 2. Elements of FDM.

2.1. Steps followed in FDM

For creating a 3D model using FDM we must follow some set of steps (as shown in Fig.2) which combine to make a physical model. Mainly what we require is a .gx file which is accepted by the FDM printer. To make this .gx file we have first make the 3D model of the product then save this CAD file in .stl format. The reason behind making a .stl file is that the software used for slicing (which is our next step) accepts a .stl file. After loading the .stl file in FlashPrint (a slicing software) we give scaling process parameters such as layer thickness, extrusion temperature, platform temperature and many more. After slicing we finally get the .gx file and this file is fed in the 3D printer. To start the printing, we must do some setting up of the machine and after that we give the start command. Product is formed layer by layer according to the given process parameters.

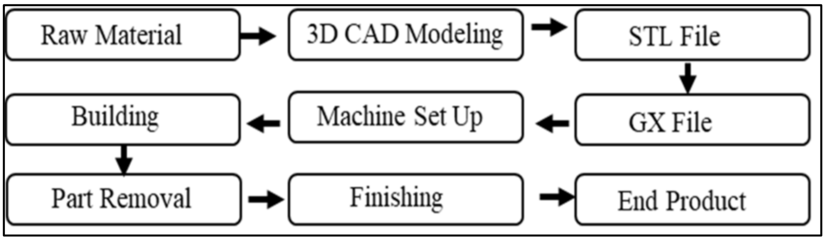

Figure 3. Steps to build 3D object using FDM.

2.2. FDM process parameters

There are various parameters in the FDM 3D printing technique such as Layer Thickness (LT), Extrusion Temperature (ET), Print Speed (PS), Infill Density (ID), Infill Pattern (IP), Raster Angle (RA), Part Orientation (PO), Air Gap (AG), Raster Width (RW), Platform Temperature (PT), Shell number (SN), etc. Combination of these process parameters helps us to make the desired product have required mechanical properties [3].

2.3. Materials

There are a wide variety of materials present in the market for FDM. In this study we have taken PLA, Carbon Fiber PLA (CF-PLA), ABS, PETG and Nylon, majorly focused on PLA and Carbon fiber PLA.

2.4. Mechanical Properties

There are various mechanical properties which are required in the additive manufactured product for their proper functioning. These mechanical properties are Tensile Strength, Surface Waviness, Flexural Strength, Compressive Strength, Wear Strength, Impact Strength and many more [4]. All these mechanical properties can be increased or decreased by doing slight changes in their printing process parameters and we can get the desired property according to its nature of application.

2.5. Recent Research

In this review paper we have focused on the tensile strength and wear resistance of the additive manufactured specimen. ASTM specified standard for plastics is ASTM D638 for tensile testing and ASTM G99 for wear testing [5] [6]. Table 1 shows the various research which are taken place to improve the tensile strength and reduce the wear rate of 3D printed specimen by doing changes in the value of the selected process parameters.

Table 1. Summary of various research which show impact of process parameters on tensile strength and wear rate and their findings

Ref.	Process Parameters	Material	Findings
[7]	LT, PO, RA, RW and AG	PLA	Wear Strength decreases with an increase in LT and RW, and increase in AG
[8]	PO, RA, RW and AG	PLA	Tensile Strength is maximum at 0° PO, small RW and negative AG
[9]	RA, LT and RW	PLA	Tensile Strength is maximum at 0° RA, lower LT and higher RW
[10]	PO and LT	PLA	Tensile Strength increasing with PO or decrease of LT
[11]	LT, ET, PS and PT	PLA	Tensile Strength is maximum at 50°C PT, 230°C ET, 30mm/s PS, and 0.2 mm LT
[12]	IP and ID	CF- PLA	Inclusion of carbon decreases the Ultimate tensile strength for 27% in PLA
[13]	ID, PS and ET	PLA	Tensile Strength found maximum on 100% ID, 210° C ET and 124.778 mm/s PS
[14]	PS, ID, and LT	PETG	Tensile Strength found maximum at 60 mm/s PS, 80% ID and 0.2 mm LT
[15]	ID, LT, and PS	Nylon	Maximum Tensile Strength is observed at 0.1 mm LT, 100% ID and 70 mm/s PS
[16]	ID, IP, and LT	ABS	Found that ID and LT are most significant parameters
[17]	LT, IP, and ID	CF-PLA, PLA, & ABS	Minimum wear rate found at 0.075 mm LT, Grid IP and 80% ID. Carbon fiber PLA shows minimal wear rate.
[18]	LT, ID, and IP	Carbon PLA	Combination of Hexagonal IP, 60% ID and 0.64 mm LT

			shows maximum tensile strength
[19]	LT, PO, and ET	PLA	Wear Rate found minimum at 0.3 mm LT, 90° PO and 220°C ET. PO shows major influence.
[20]	PO, RA, ND, ET, ID, SN and ES	PLA	Optimum parameters found are On-edge PO, (30°/-60°) RA, 0.5 mm ND, 220°C ET, 100% ID, 3SN, 20mm/s ES. With maximum influence of PO
[21]	ET, LT, and PS	PLA	Lower LT and higher ET can give high tensile strength
[22]	LT and PO	PLA and Carbon PLA	Tensile Strength is maximum between 1to 1.8 mm LT and minimum at Z-direction of Carbon Fiber PLA. Carbon Fiber PLA has higher strength then PLA in X and Y direction
[23]	LT, ID, and PS	PLA	On increasing ID tensile strength increase and increase significantly. Samples behaves more brittle on increasing ID very high or reducing LT. ID of 40% is more suitable in terms of cost, material, and time savings

Table 1 shows that process parameters such as layer thickness, extrusion temperature and infill density are frequently taken by the researchers for their research. It shows that these process parameters have significant impact on tensile strength and wear resistance. So, these process parameters must be considered to get good results. Numerous works have been done to find optimal parameter to find mechanical properties. The range of values for above-mentioned three parameters in which mechanical properties are found to be good is Layer Thickness between 100 and 300 microns, Extrusion Temperature between 190°C and 220°C and Infill density between 80% and 100%.

Carbon fiber PLA improves the mechanical properties mainly tensile and wear strength. This is very similar to the behavior absorbed by adding carbon elements in ferrous material. It has been found that on decreasing the layer thickness, tensile strength increases and wear rate decreases this is because on increasing the layer thickness it is found that fusibility of layer decreases and layer is not able to adhere to each other properly.

The various research show effect of different process parameters on tensile and wear resistance separately but none of them give the range of process parameters in which both tensile strength and wear resistance is optimum.

3. Conclusion

Additive manufacturing has potential to remove traditional manufacturing process due to its ability to build product with less wastage of raw material and less overall production time. Commonly used material in FDM process is PLA and my research has proved that addition of carbon material improves the mechanical properties of specimen.

The abilities to build complex 3D models attracts the researcher to do reach of additive manufacturing process so that it becomes more efficient. We can produce the product of desired mechanical properties, and this can be possible only by choosing right printing process parameters and their optimum values. It is found that variation in values of some process parameters such as Layer Thickness, Extrusion Temperature and Infill density have more significant effect on the mechanical strength of the specimen.

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