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Influence of the process parameters of FDM on the performance factors of ABS, PLA and PETG materials: A Review

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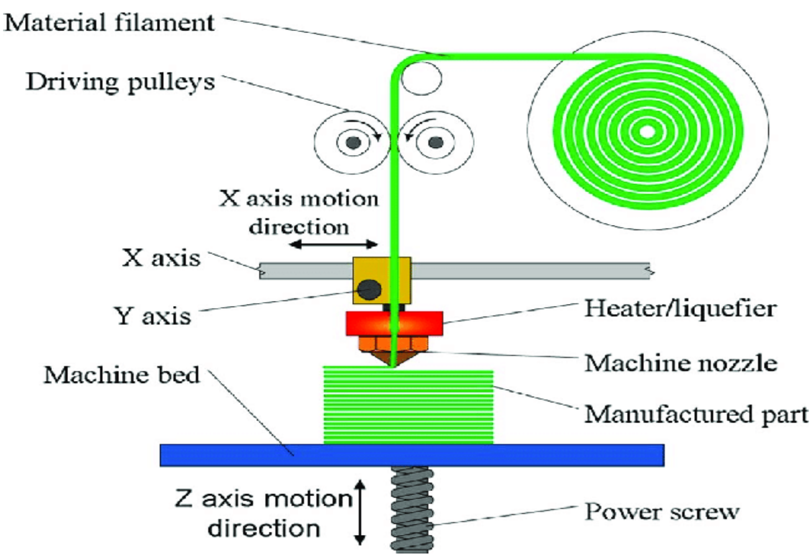
ABSTRACT: *Fused deposition modelling (FDM) is one of the most advanced rapid 3D printing technique which is highly capable to manufacture variety of products having simple to sophisticated intricate geometries. This technology is fast, flexible and easy to use. This technique creates 3D parts using the principle of Additive manufacturing in which any part is created by piling up the layers of the material over each other to give the desired shape and size to the final product. Quality and performance of the 3D printed part depends on the different building parameters of the FDM. Thus, the study to understand the effect of various process parameters of FDM on the mechanical properties of different materials becomes more significant. Objective of this paper is to summarize the various research works done by the other researchers in this field on ABS, PLA and PETG materials.*

Keywords: *FDM, Additive Manufacturing, Process Parameters, ABS, PLA, PETG*

1. Introduction

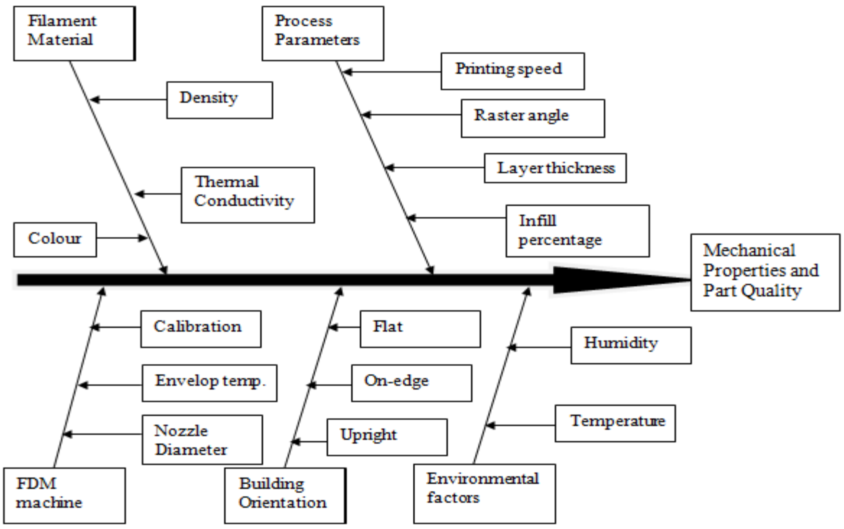
Fused Deposition Modelling (FDM), also commonly called as Fused Filament Fabrication (FFF) is one of the most used rapid prototyping technique which can create wide range of prototypes and 3D functional parts in short time and with less material wastage. This technology is user friendly, requires no additional tools or fixtures and can create customized parts as per the desired requirements. Some of the major application fields of FDM are automotive industry, textile industry, medical field, tissue engineering, industrial field, food and packaging industry etc. Fused deposition modelling works on the principle of Additive manufacturing in which thermoplastic filament material is first heated in the in-built heater till it changes into the molten form and then this molten material is extruded through the orifice of the nozzle in the form of layers which gets deposited over each other till the desired shape and the size of the final product is achieved. Printing temperature and bed temperature plays important role in bonding of layers so that they can strongly adhere to each other. FDM is compatible with various different polymers, low melting point metals and composites. The most used polymers are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic acid). ABS is famous for the high strength, high temperature resistance and durability it offers while PLA is mostly used because it posses the properties like biodegradability, flexibility and is easy to print. Compared to ABS and PLA, PETG (Polyethylene Terephthalate Glycol) is relatively new material and it has advantage over ABS and PLA in terms of strength, durability and temperature resistance. PETG is suitable for keeping edible items and has less warping and shrinkage compared to ABS. Also, due to the presence of Glycol, PETG becomes less brittle compared to the PLA material. Some other filament materials which are also found compatible with FDM technology are TPU (Thermoplastic Elastomers), Wood, TPU (Thermoplastic Polyurethane), Polycarbonate (PC), Nylon, HIPS (High Impact Polystyrene), Polyvinyl alcohol (PVA) etc[1].

Figure 1: Working Principle of FDM [2]



Performance and quality of any 3D printed part is significantly governed by the different process parameters. To further improve the properties of 3D printed part, selection of process parameters needs to be done carefully as they can influence the response parameters of the final product. Some of the most important process parameters of FDM are – Building orientation, raster angle, layer thickness, printing speed, infill pattern, nozzle geometry, infill percentage, bed temperature, printing temperature, number of contours, air gap etc. As FDM has started gaining popularity, extensive research work has been done across the world by various researchers to understand and study the individual as well as combined effect of these process parameters on the mechanical properties and tribological properties of different FDM filament materials. Performance of the 3D printed part is measured in terms of different response parameters like tensile strength, compressive strength, dimensional accuracy, surface roughness, manufacturing cost, printing time, flexure strength, endurance strength, storage modulus etc. To achieve the best results, optimization of the magnitude of process parameters is done for which appropriate design of experiment is selected for carrying out the experiments and then later for doing the analysis to find out the most significant parameter or parameters. Some of the available design of experiment techniques is Taguchi Method, Artificial Neural Network, Response Surface Method, Fuzzy Logic, Genetic Algorithm, Fractional factorial, ANOVA, Regression Analysis etc.

Figure 2: Fishbone diagram of FDM [3]



2. Literature Review

A brief review has been done to summarize the research and experimental work done by the various researchers to study and investigate the effect of various process parameters of FDM on the performance factors of ABS, PLA and PETG printed 3D parts.

Chacón J. M et al. [5] This paper investigated the effect of various process parameters on the output factors like tensile strength, flexure strength and printing time using response surface technology. Process parameters selected for conducting the experiment are layer orientation, layer thickness and feed rate. Testing is done on the PLA specimens. From the result obtained, following conclusion can be drawn: -1) On-edge samples showed the optimal mechanical performance in terms of strength. In upright samples, tensile strength increases as layer thickness increases. 2) If minimum printing time is required: high layer thickness & feed rates are recommended.

Liu z et al. [6] This paper presents the comparision between PLA material and PLA with additives. Additives added in PLA are wood, ceramic, copper, aluminum and carbon fibers. Effect of raster angle and building orientation is studied on the tensile strength and flexure strength. In case of PLA and its composites, the best tensile and flexural properties is obtained when external loading direction is parallel to the build orientations and raster angles of printed filaments are oriented longitudinally. By adding ceramic, copper and aluminium powders into PLA, the value of tensile strength and flexure modulus is obtained high compared to the virgin PLA under different printing orientations and raster angles.

Siadat A. et al [7] In this paper, parametric optimization is done on the FDM parameters using Taguchi design of experiment. Impact of process parameters like layer thickness, shells, infill pattern and infill percentage are studied on the compressive strength of the PLA and PET-G material drilling grid. Objective of this paper is to maximize the compressive strength of the drilling grid. Two DOEs are performed for both the materials (PLA and PET-G) on two different machines, keeping the control factor and optimization method constant. From the result, it can be concluded that compression force is affected most by infill percentage for both PLA- and PETG based drilling grids as the two materials are almost similar. It is followed by number of shells, layer thickness, and infill pattern for PLA drilling grid and by infill pattern, number of shells and layer thickness for PETG drilling grid. PET-G has good adhesion of the layers.

H. Saruhan et al. [8] This paper studied the effect of occupancy rate or infill percentage on the tensile strength and surface roughness of specimen. Specimen is made using PETG material. Occupancy rate selected for conducting experiments are 20 %, 50% and 80%. While carrying out experiment, printing speed is kept constant and rectilinear structure is selected. After observing the results, it can be concluded that as the occupancy rate increases, average value of tensile strength also increases. This trend is obtained due to decrease in the hollow space inside the structure. While in the case of surface roughness, average values are close to each other for all occupancy rates. However, there is little decreasing trend obtained while occupancy rate increasing.

Durgashyam, K. et al. [9] In this paper, study is done on PETG material and effect of process parameters like infill density, feed rate and layer thickness are studied on the tensile strength of PETG. ANOVA process is done to find the best parameter. In the result, the tensile strength shows decreasing trend as the layer thickness increases, it is due to the increasing vacuum space in between the adjacent layers as layer thickness increases which leads to weak tensile strength. Tensile strength decreases as feed rate increases. It is because of the insufficient time available for proper orientation of layer. But after a critical value, tensile strength increases along with feed rate that is because of the material directionality property. Infill density tells about the filled volume in any structure. As infill density increases, material becomes less hollow and thus, tensile strength increases. It can be conclude that for attaining highest tensile strength in case of PET-G material, layer thickness and feed rate should be minimum but infill density should be maximum. At minimum layer thickness, moderate feed rate and minimum infill density, material exhibit high flexure strength. Out of all process parameters, layer thickness is the most significant parameter.

Sood AK et al. [10] In this paper, the effect of five process parameters such as part orientation, road width, layer thickness, air gap and raster angle are studied on the dimensional accuracy of FDM fabricated ABSP400 part using gray Taguchi method. Central Composite Design was used to build empirical model for tensile strength, flexure strength and impact strength. From obtained experimental values, it was noted that tensile strength first decreases and then increases as layer thickness increases. The weak interlayer bonding is responsible for dip in tensile strength, as the thickness increases, less number of layers are required. Hence, less chance of distortion which results in increase in strength. Strength is also found to be increased with respect to raster angle in the experiment.

Nancharaiah T et al. [11] In this paper, the effect of the process parameters such as layer thickness, road width, raster angle and air gap are studied on the performance parameters like surface finish and dimensional accuracy. Experiments were conducted using Taguchi's design of experiments with three levels for each factor. ABS is selected as the base material. After conducting the experiment, following trend is observed – Small layer thickness can be used to increase both surface quality and dimensional accuracy, Large bead width increases surface quality and moderate bead width increases dimensional accuracy. Large air gap can degrade surface quality and dimensional tolerances.

Juan Claver et al. [12] This paper has done a comparative analysis of the mechanical properties of the parts produced by two most popular polymers ABS and PLA using FDM technology. Process parameters selected are - layer height, infill density and layer orientation. Performance factors selected for study are tensile yield stress, tensile strength, nominal strain at break and modulus of elasticity. Result shows that infill percentage plays significant role in deciding the tensile strength of the material. Also, PLA is found to be more rigid than ABS.

K.G. Jaya Christiyan et al. [13] This paper investigated the effect of layer thickness and printing speed on the tensile and flexure strength of ABS composite part printed using FDM technique. ASTM D638 and ASTM D760 standards were followed to conduct tensile and bending testings respectively. In the result, it is found that low printing speed and low layer thickness gives highest tensile strength and flexure strength.

Silva et al. [14] This paper has done a comparative study in between adapters made for lower limb prosthesis using two different materials - PLA and PETG. Objective of this research is to evaluate the maximum deformation through compression tests and stress analysis simulation to find out the best material suitable in the role of adapter for lower limb prosthesis. Design matrix was created using Taguchi orthogonal array. In the result, it is found that PETG shows the maximum deformation of 0.597 mm while PLA showed 0.3 mm. Also, in PETG sample no crack and fracture was found. Thus, it is considered to be the most reliable material for manufacturing of adapters or connectors for limb prosthesis.

Szykiedans K et al. [15] In this paper, research is done on the two materials, PETG (Z-PETG) and PETG with glass (Z-glass). Process parameters selected to study are Raster angle, Building orientation and Layer thickness. From this study, it is evident that layer orientation, additives and printing direction have significant effect on the elastic modulus of the material. Maximum tensile modulus is obtained for Z-Glass material. The differences between Young's modulus values are because of presence of air gaps in the print structure and stress concentration along filaments beads. These two phenomena can cause crack surface area. Conducted tests have proved that 3D prints are anisotropic in nature.

Samykano M. et al. [16] In this research paper, three major process parameters such as layer height, raster angle, and infill density have been considered to study their effects on tensile properties and toughness of ABS material. Response Surface

Methodology is used for the prediction of the test result. The tensile properties that were deduced from raw data after the tensile test are ultimate tensile strength, elastic modulus and yield strength. From the result, it can be concluded that as the infill percentage and layer thickness increases, tensile properties also increases.

Peterson et al. [17] This paper reviews existing literature available on Fused Filament Fabrication while focusing on the mechanical performance of ABS structures. It also reviews another polymer PLA, processing considerations of ABS and PLA and filament fabrication. Polymer weld theory and its applications are also discussed in this paper. As FDM is thermally driven process, thus thermal analysis techniques and thermo gravimetric analysis was reviewed under the sub-section Filament characterization method.

3. Conclusion & Future Scope

This paper reviews the available literatures to understand the effect of process parameters of FDM on the various different response factors. Study is narrowed down only to three materials ABS, PLA and PETG so that their behaviour can be better comprehended as they are the mostly used 3D printing filaments. It is found that tensile strength is the most studied performance factor by researchers while layer thickness, building orientation, infill percentage and raster angle are most studied process parameters. Some of the common trends which can be observed in different studies are –

1. As the infill percentage increases, tensile strength of the part also increases. It is due to the unavailability of hollow space and strong bonding inside the part.
2. The base material with additives are found to be more strong and have better performance compared to their virgin state.
3. Low strength of any 3D printed part are mainly because of the following reasons- volumetric shrinkage, interlayer porosity, interlayer bonding and anisotropy.
4. Layer thickness and Tensile strength have no clear relationship. It is due to the involvement of multiple factors like interlayer bonding, void between adjacent layers and temperature gradient.

There is still huge scope to further improve this technique. Some of the ways for improvement in this technology are –

1. By developing new material matrix to improve the performance of the available filament materials.
2. Taking the process parameters like humidity and environmental temperature into consideration and studying their effect on the various available response factors.
3. Doing creep analysis of the 3D printed materials.
4. Improving the working of machine parts so that materials having high melting point can also be used for fabrication.

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