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Effect of Layer Height on Tenile Strength of Fused Deposited Modeling Printed Carbon Poly-Lactic Acid Part

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Abstract

Fused deposition modelling (FDM) is an additive manufacturing process that creates objects by depositing successive layers of material. FDM is the most widely used additive manufacturing process because of its ability to create complex geometries. Various FDM process parameter affects the mechanical property of FDM objects. The main objective of this paper to stud the layer height of specimens, one of the important process parameter, build using Carbon poly-lactic acid part(C-PLA) with FDM process. For that Dogbone specimens as per ASTM D638-14 standard prepared using FDM process with three different layer height(h) of 0.12 mm, 0.23 mm and 0.35 mm. Three different sets of specimens with 0^0 ,45^0, 90^0 raster orientation (θ) were printed using FDM process. Then specimens were tested on UTM machine to evaluate ultimate tensile strength for all specimens. Results show that high tensile strength found for lower layer height specimens compare to higher layer height specimens.

Keywords: Fused deposition modeling, Tensile strength, Elastic modulus,PLA

1. Introduction: The development of rapid prototyping (RP) technology, which uses Fused deposition modelling, has made the object development process faster. RP is a technique that can be used to create 3D objects from computer-aided design (CAD) data using additive manufacturing (AM)[1]. There are many types of RP technologies, such as selective laser sintering, fused deposition modelling, laminated object manufacturing, stereolithography, etc. FDM is one of most popular AM techniques due to its improved accuracy, shorter manufacturing time, its ability to create complex geometries and simplified procedures. Several researchers have investigated the various different material for FDM process like acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyether-ether-ketone PEEK) , ABS plus-P430 polymer , hyper-elastic porous metamaterials , combination of FDM material with synthetic fabrics , Ultem 9085 and polyethylene terephthalate glycol (PETG)[2-6]. PLA is widely used in manufacturing and production processes due to its wide range of applications. It is biocompatible, biodegradable, thermally stable, and solvent-resistant, making it a suitable material for FDM printing.[7] PLA has good stability during printing and a low melting point, which makes it a stable component during the FDM process.[8] To build an object using FDM, a CAD model must be converted to STL format and imported into an FDM software program like Slic3r. In this G-code building software, all printing parameters, such as orientation angle, layer height, building pattern, printing speed, nozzle temperature, wall perimeters, bed temperature, feed rate, and infill density, must be specified and a G-code file must be created. The G-code file is then sent to the FDM printer to build the component. Due to this process Complex geometry object can be created using the FDM process.

Many researchers have investigated the effect of printing parameter on mechanical properties of FDM printed object. Arghavan Farzadi et al. investigated on effect of layer printing delay to characterize mechanical properties, concluded that medium print delay gives better result [9] . The effect of various parameters such as raster angle, raster width, build orientation, etc had directly effect on mechanical properties of FDM printed object[10,13,14,15,17]. Color of filament had no effect on mechanical property of FDM printed component. rated in effects of tool path parameters on mechanical properties of components made of FDM process. FDM printed parts are highly affected by the core infill density and also the wall perimeter [11]. J. Maszybrocka suggests that the mechanical properties of a 3D-printed part are highly affected by the core filling (infill) density and the outer layer (wall perimeter) [11]. Various infill patterns like rectilinear, triangular, honeycomb, grid, wiggle etc. can be used for manufacturing FDM object. Mechanical property of FDM object has significant effect of this infill pattern [12]. Nozzle extrusion temperature has also effect on mechanical properties of FDM printed parts.[15]. Dawoud et al. [16] investigated the effect of air gap on tensile, flexural and impact properties of FDM-printed ABS part and made a comparison with the injection moulded ABS part. In FDM process, layer height is the thickness of each layer of material deposited by the printer. It is also known as printing resolution, and the lower the layer height, the higher the printing resolution [18]. For example, six layers of 0.2 mm each will result in a print thickness of 1.2 mm. Different layer heights will result in different printing times and printing quality.

In present work Carbon PLA filament is used to prepare FDM dogbone parts as per ASTM D638 using different layer height. Then Specimens were tested on UTM machine to investigate its mechanical property like Modulus of Elasticity and tensile strength.

2. Materials and Methods: In Present work Carbon PLA(CPLA) filament were used to prepare FDM specimens. In present work CPLA filament consist of 20% Carbon powder and 80% PLA material. IN FDM Process, CPLA filament deposit in liquid form through heated extruder nozzle on horizontal axis platform. Specimens were prepared by Layer-by-layer deposition material while nozzle and heated bed moved in horizontal and vertical direction as information given in G code file. Figure 1 shows the schematic working of FDM process.

Table 1. Fused deposition modelling printer Parameter

Parameter	Setting
Nozzle diameter	0.4 mm
In fill density	100%
Deposition speed	12 mm/s
Nozzle temperature	220 °C
Bed Temperature	60 °C
No. of perimeter	2
Infill Pattern	Rectilinear

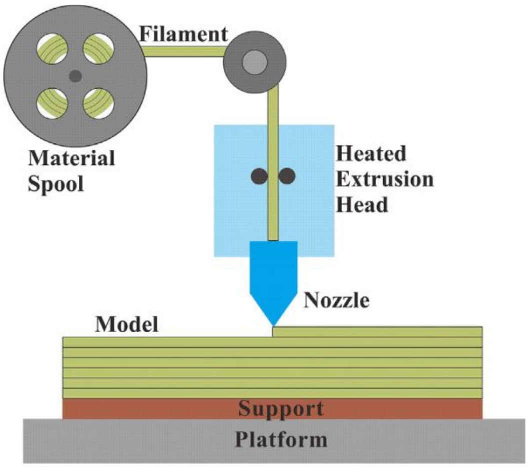


Figure 1. FDM Process Schematic

Specimens as per ASTM standard D638 type 1 (see Figure 2.) were prepared with a layer different layer thickness(h) of 0.12 mm, 0.23 mm and 0.35 mm. Total thickness of specimens were kept as 1.4 mm for all specimens. For example, four layers of 0.35 mm layer height each will result in a total print thickness of 1.4 mm. Different layer heights will result in different number of layers and printing time and printing quality. Other printing parameters were kept as given in table 1. For each set five different specimens were prepared.

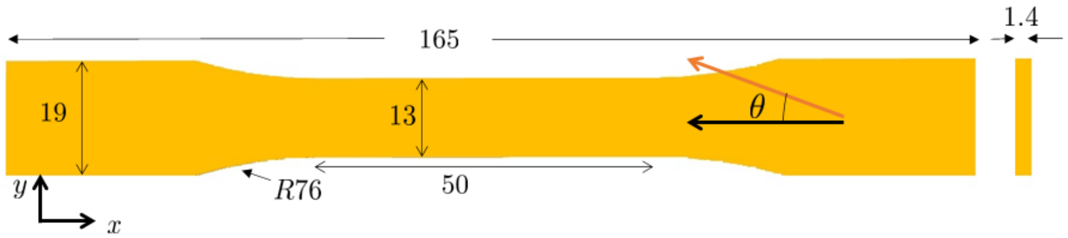


Figure 2. ASTM D638 type-I tensile specimen All dimensions are in mm)

Figure 3 shows FDM-printed specimens with different raster orientations of 0°, 45°, and 90°. For each raster orientation, three different layer heights (h) of 0.35 mm, 0.23 mm, and 0.12 mm were also prepared. Figures 4, 5, and 6 show FDM-printed specimens with a raster orientation of 0° and different layer heights. The same procedure was used to print specimens with raster orientations of 45° and 90° and different layer heights. Five specimens were prepared for each set. Before performing the experiment on the UTM machine, the dimensions of each specimen were measured to ensure an accurate cross-sectional area. Tensile tests were performed on each specimen using the UTM machine to determine the mechanical properties. The specimens were experimentally tested using a computerized universal testing machine at a loading speed of 2 mm/min. The test was continued until the specimen broke into two pieces.

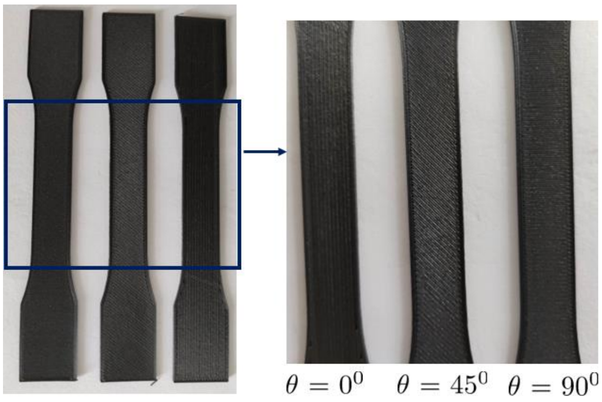


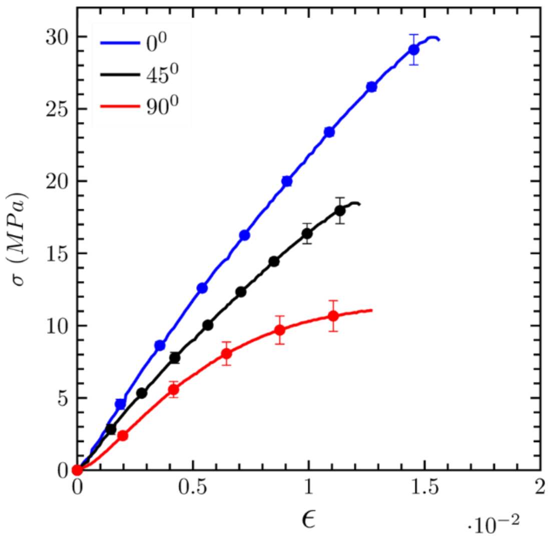
Figure 3. Specimen with 0^0 ,45^0, 90^0 raster orientation

Figure 4. Specimen with $\theta = 0^0$ and h =0.35 mm

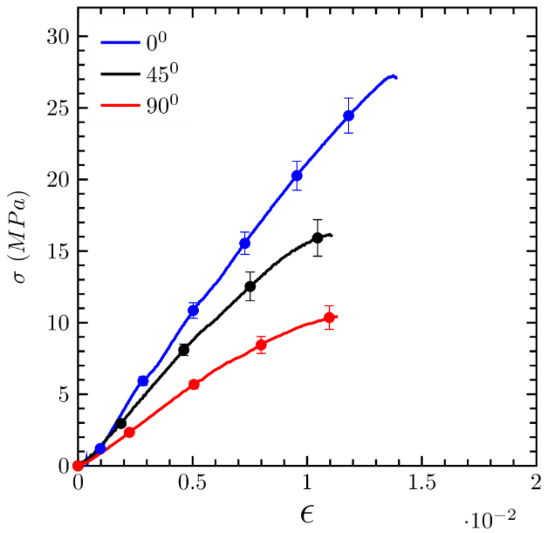
Figure 5. Specimen with $\theta = 0^0$ and h =0.23 mm

Figure 6. Specimen with $\theta = 0^0$ and h =0.35 mm

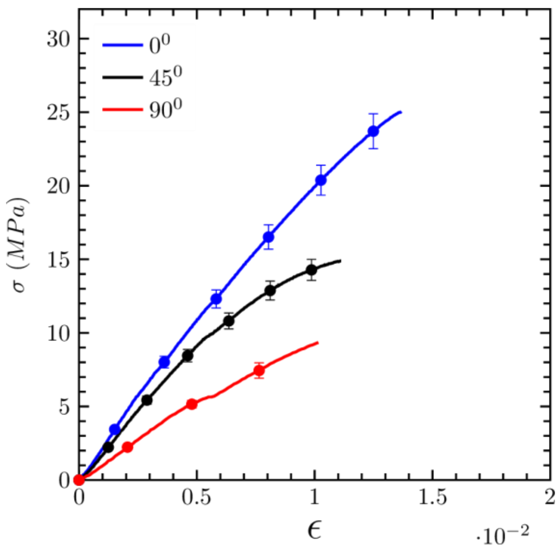
3. Results and Discussion: As shown in Figure 7 shows the resultant stress (σ in MPa) – strain(ε) curve for all specimens. In Figure 7.a shows the stress-strain curve for specimens of layer height (h=0.12 mm) with different raster orientation (θ) of 0^0 ,45^0, 90^0. For each set of specimen curve shows with error bar at specified interval for display clarity as five different specimens for each set were tested. Similar curve. For Tensile strength measurement, Highest stress value all specimen stress-strain curve measured, and average value is shown in Table 2. Table 2 shows the comparison between various test data that tensile strength increases with decrease in layer height for all raster angle specimens. The results of this study show that the printing layer thickness, an important and controllable FDM parameter, has a significant effect on the mechanical properties of FDM specimens. Reason for this it could be as shown in Figure 3-6 for building similar thickness specimen lower layer thickness require more number of layers compare to higher layer thickness so this create less gaps between beads of printing and created great bonding between beads. So, Decreasing the layer thickness can significantly increase the printing time, so this factor should be considered when selecting a layer thickness.



(a) h= 0.12 mm



(b) h= 0.23 mm



(b) h= 0.35 mm

Figure 7

The differences in tensile strength for different orientations can be explained by considering two main fail-ure modes: inter-raster failure and trans-raster failure Inter-raster failure occurs when two individual beads separate, while trans-raster failure is the failure of each individual bead. From Figure 8(a) and (b), the beads in the flat and on long edge orientation are deposited along the length of the specimen and are aligned in the direction parallel to the applied load during the tensile test. Therefore, beads are pulled parallel to the loading direction which results into the trans-raster failure. Here, individual beads withstood. most of the applied load. So, the acting load yields higher resistance to tensile failure and gave maximum tensile strength. On the other case, the beads in on short edge orientation are perpendicular to the applied load. Here, inter-raster failure occurs because the force is applied perpendicular to bead axis. In this case, layer adhesion considerably affects the tensile strength, since most of the applied load is withstood by the inter-raster fusion bonds between adjacent beads. This is the reason for low values of tensile strength for parts built with on short edge orientation.

Table 2 Tensile strength test data for Dog bone specimen

	Tensile strength (MPa) $\theta = 0^0$	Tensile strength (MPa) $\theta = 45^0$	Tensile strength (MPa) $\theta = 90^0$
h=0.12 mm	29.9	18	11.05
h=0.23 mm	27.2	16	10.41
h=0.35 mm	25.1	14.89	9.40

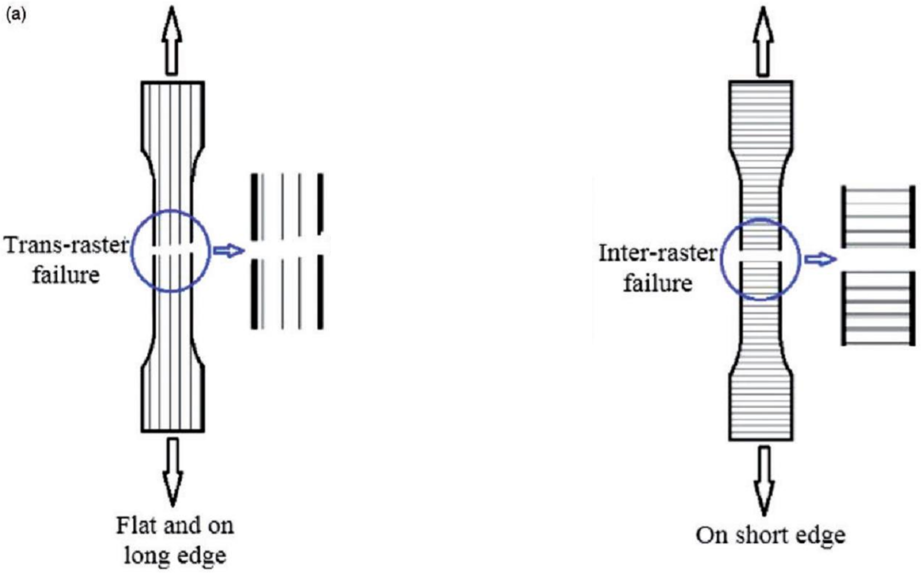


Figure 8. Temsile loading direction (a) Flat anf on long edge (b) on short edge

Conclusion: The study was carried out to fabricate specimen with different layer height dog bone specimen and testing in UTM to evaluate tensile strength. Layer height plays a crucial parameter in FDM process for manufacturing inject. This parameter plays important role in total component building time and tensile strength of component. Test data shows that tensile strength increases with decrease in layer height for all raster angle specimens. So Lower the layer height higher the tensile strength was observed.

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