An Experimental on the Influence of Process Parameters on the Tensile Properties of Carbon Fiber Reinforced PLA FDM Parts

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Article Info
Volume 81
Page Number: 4606 - 4611
Publication Issue:
November-December 2019

Article History
Article Received: *5 March 2019*
Revised: *18 May 2019*
Accepted: *24 September 2019*
Publication: *23 December 2019*

Abstract:

In recent years, one digital manufacturing technique gaining more excitement among researchers from academia and industry, which is used to build three-dimensional components by melting, extruding and depositing successive layers of semi-molten materials, is fused deposition modeling (FDM). FDM is a well-known additive manufacturing methods, a rapid prototyping method that is used widely for fabricating components from plastic materials directly from a digital file. However, it is a challenging task for FDM technique to build functional end user parts due to lack of basic knowledge about the effect of various FDM process parameters such as layer thickness, raster angle, infill pattern, air gap, build orientation and more. The quality and functionality of the FDM fabricated parts were influenced by the above mentioned processing parameters. The main focus of this paper is to experimentally investigate the independent influence of different FDM process parameters on the tensile properties. The study is carried out on 20% carbon fiber reinforced PLA material to analyze the individual effect of layer thickness, printing speed and infill pattern on the tensile property. Test specimen were printed by varying the above mentioned process parameters. The results indicated that the layer thickness and the printing speed significantly affected the tensile strength of the material. It has been observed that the individual process parameters have a considerable influence on the tensile strength of the 20% carbon fiber reinforced PLA FDM fabricated parts which help the design engineer to decide the proper process parameters so that fabricated FDM parts can have good tensile strength.

Keywords:*FDM, 20% carbon fibre reinforced PLA, layer thickness, printing speed, infill pattern, tensile strength.*

I. INTRODUCTION

Additive manufacturing (AM) is a collective term for technologies that fabricate parts layer by layer by adding material. One of these technologies is Fused deposition modeling (FDM) also known as 3D printing. It is a basic process that is used for prototypes building, but it laid its roots and entered into approximately every industry and has at the present become one of the most extensively accepted manufacturing techniques due to its benefits such as lower production cost, ease of handling etc. Rapid prototyping is a valuable, full-scale application which has not expanded much attention because of its congeniality of presently existing materials with rapid prototyping technology[1]. To prevail over this restraint, the advancement of new materials having exceptional characteristics than traditional materials and its compatibility with technology is needed. Another method is by changing the process parameters suitably during manufacturing stage which may

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improve mechanical properties[2]. G and M codes are directly created from 3D models developed which intern controls the material addition. The heated thermoplastic filament in semi-liquid state is extruded all the way from a minute nozzle as per 3D CAD model in STL format. The filament is generally available with different circular cross-sections and with different diameters. Most commonly used diameters range from 1.75mm to 3.0mm. FDM provides us a platform to produce complex shapes without using dies and molds. It also has the capacity to create internal features which is not possible in conventional manufacturing methods. In this process the consolidated complex parts are produced by reducing the number of assemblies[3]. During fabrication, FDM faces challenges such as staircase effect at curves, coarse surface finish, anisotropic mechanical properties, and need for supports at overhanging parts. In order to overcome this many researchers used chemical treatment[4-6], machining, heat treatment and optimization parameters.

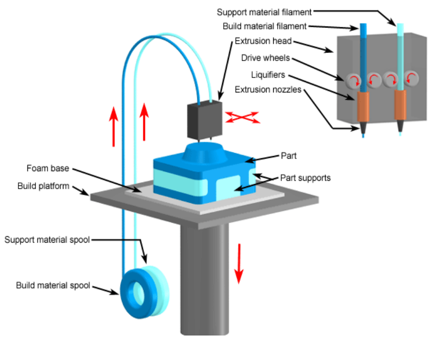

Figure 1: Basic diagram of FDM machine

Fused deposition modeling prints parts of whichever geometry by sequential deposition of material in the form of a layer. The layers deposited subsequently make a bond with the previous layer during solidification. The supports are generated along with the main component through a secondary nozzle. These supports can be broken during post-processing. The influence of a range of process parameters of FDM were investigated by many researchers. The effect of part orientation and different raster angles inABS printed parts were studied by Durgan and Ertan [7]. They observed that horizontal orientation with a zero degree raster angle had the best tensile properties. The effect of bead to bead air gap, different raster angle, build direction and perimeter to bead air gap on tensile strength were studied by Bagsik et al [8]. The effect on ABS printed parts due to a range of part orientation and raster angle on tensile strength were studied by Garg et al [9] and they found that part building orientation drastically affected tensile strength. Parts that were built on short edge showed lowest tensile strength whereas parts built on longer edge showed the highest tensile strength. Various processing parameters such as infill patterns, print speed, infill percentage, layer thickness, extrusion temperature, infill density, were studied by Quattawi et al[10] on various mechanical properties. The compressive and tensile strength of PLA parts were examined by Song et al [11].

The literature survey suggest that property and feature of FDM parts can be enhanced by optimizing main process parameters. As a result, detection of critical and ideal process parameters are necessary for improving the excellence for manufacturing parts using FDM process. The literature proposes that comparatively less significant efforts have been made to check the influence of the process parameters such as infill density, infill pattern at various layer thickness on tensile properties of 20% carbon reinforced PLA materialspecimen manufactured through FDM process.

II. EXPERIMENT DETAILS

In this part, the details such as material used for FDM process, process parameter, specimen fabrication were discussed.

III. MATERIAL

In this study, commercial 20% carbon fibre PLA wire filament is used for fabricating the tensile specimen.Carbon fiber PLA is a bio degradable thermoplastic polymer manufactured from sugarcane, starch and carbon. It is best material for FDM process due to its light weight, higher strength, excellent layer adhesion and low warpage. This material is stronger than ABS and ordinary PLA filament. Carbon-reinforced PLA has high tensile strength, high chemical resistance, high stiffness, low weight, low thermal expansionand high-temperature tolerance.

IV. PROCESS PARAMETERS

In this work, effect of process parameters such as infill pattern, infill density and layer thickness were considered at three levels. Levels and values of the process parameters level and values were shown in the Table 1.

Parameter	Level 1	Level 2	Level 3
Layer thickness	0.075	0.1	0.125
Infill pattern	Triangle	Line	Grid
Infill density	60	70	80

Table 1. Selected levels of process parameters

Infill density indicates the volume or percentage of liquefied material filled to make a product. Zero

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percent of infill is known as shell whereas a hundred percent of infill is known as solid. Less infill takes less time to build a specimen but produce decreased mechanical properties. High infill density takes more time to build a specimen and produces best mechanical properties. Three different infill densities 60,70 and 80% were selected in this work.

Infill pattern determines the way in which nozzle fills and raster crossways the infill layers. Examples of some infill patterns are honeycomb, cat fill, grid, rectilinear, diamond, and triangular. Three different infill patterns such as grid, rectilinear and triangular patterns shown in the fig. 2 were used in this work. Printing time and amount of material used depends on the complexity of infill pattern.

Layer thickness in 3D printing is a measure of the height of the layer of each consecutive addition of material in which layers are stacked. Lesser layer thickness produces improved mechanical properties whereas increased layer thickness produces decreased mechanical properties. Three layer thickness were selected for this work and they are 0.075mm, 0.1mm, 0.125mm

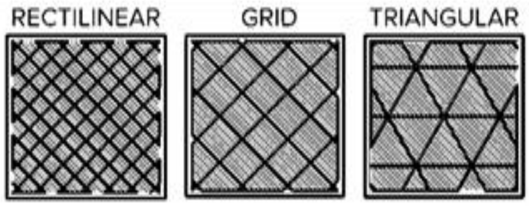
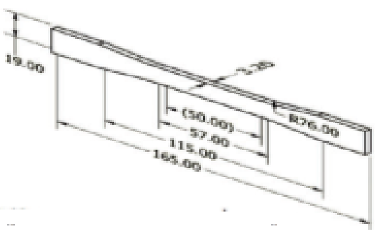


Figure 2: Different infill patterns

V. SPECIMEN PREPARATION

In this work, 27 test specimens were printed with permutation of three different process parameters. The models were according to the American Society for Testing and Materials (ASTM) ASTM type IV standards D638 as shown in the fig. 3 for plastic to figure out mechanical properties, dimensional accuracy and repeatability. CAD model was prepared using Solidworks designing software. The model was sliced and converted to .STL format using Ultimaker CURA software. A total of 27 components were printed using 20% carbon fiber reinforced PLA material filament.A Creality Ender 3 3D printer used in this work is shown in the fig. 4. Sample specimens were shown in the fig. 5.



All dimensions are in mm
Figure 3: ASTM standard for tensile specimen

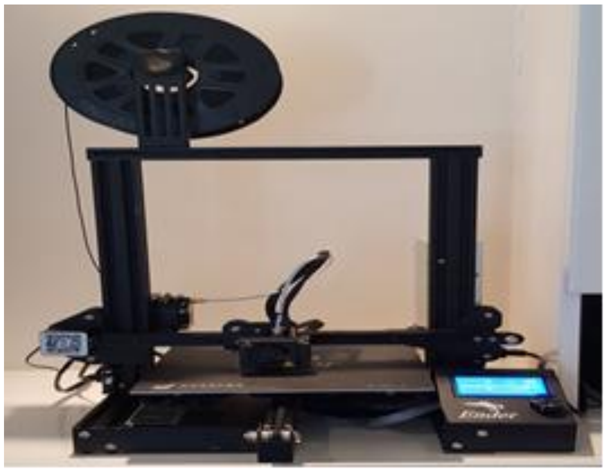


Figure 4: 3D Printing machine

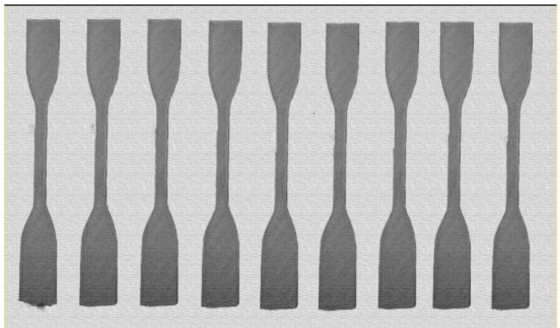


Figure 5: Tensile specimen as per ASTM standard

VI. TENSILE TESTING

The mechanical properties of the products were tested according to ASTM standard D638 on Universal testing machine TUE-C-1000. The tensile testing machine used in this work is shown in the fig. 6

Figure. 6 Universal Testing Machine

VII. RESULTS AND DISCUSSION

Table 2 shows the ultimate tensile strength (UTS) observed for different process parameters in the present investigation.

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Effect of layer thickness on tensile strength

Figure 7 exhibits the effect of layer thickness on UTS at various infill density and infill pattern. The results of the experiment suggests that specimen built with 0.075 mm thickness result in maximum tensile strength invariably for different infill pattern as shown in fig.7c. The tensile strength of the carbon fibre PLAis approximately 30% more than that of the ordinary PLA filament. The higher tensile strength is because of the presence of minimum air gap between the beads for lower layer thickness. The specimen built using 0.125 mm thickness was faster to build than the other two layer thickness but resulted in lower tensile strength is shown in fig. 7a was due to presence of more air gaps. The specimen generated using 0.1 thickness resulted in moderate tensile strength. Therefore when time matters consumer can prefer 0.1mm thickness whereas if strength matters, 0.075 can be preferred.

Influence of infill pattern on tensile strength

Fig.7 exhibits the influence of infill pattern on ultimate tensile strength at a variety of infill density and layer thickness. The results from experiment suggest that in the

majority of the cases, specimens built with triangular pattern results in higher tensile strength which is evident from the fig 7a, 7b and 7c. From the fig. 7c it is evident that the specimen built with triangular pattern and80% infill density showed higher tensile strength compared to the grid and rectilinear pattern for same process parameters. Rectilinear pattern takes.

S.No	**Layer thickness Mm**	**Infill pattern**	**Infill density %**	**Ultimate tensile strength (MPa)**
1	0.075	Triangular	60	36.3
2	0.075	Triangular	70	39.8
3	0.075	Triangular	80	43.7
4	0.1	Triangular	60	35.2
5	0.1	Triangular	70	38.1
6	0.1	Triangular	80	41.3
7	0.125	Triangular	60	32.1
8	0.125	Triangular	70	35.7
9	0.125	Triangular	80	39.3
10	0.075	Rectilinear	60	33.3
11	0.075	Rectilinear	70	36.4
12	0.075	Rectilinear	80	40.1
13	0.1	Rectilinear	60	32.1
14	0.1	Rectilinear	70	35.3
15	0.1	Rectilinear	80	38.1
16	0.125	Rectilinear	60	31.2
17	0.125	Rectilinear	70	33.2
18	0.125	Rectilinear	80	36.3
19	0.075	Grid	60	35.1
20	0.075	Grid	70	38.2
21	0.075	Grid	80	42.3
22	0.1	Grid	60	34.1
23	0.1	Grid	70	36.9

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24	0.1	Grid	80	39.9
25	0.125	Grid	60	31.8
26	0.125	Grid	70	33.2
27	0.125	Grid	80	37.8

Table 2. Tensile test results

less time to print and widely used pattern, but showed less tensile strength. The reason for lower tensile strength of rectilinear pattern is that it has larger number of air gaps and discontinuous beads when compared to other two infill patterns. Time taken for constructing samples of triangular pattern is longer than other two patterns. This is because of the huge number of segments of short lines which is also a reason for the higher tensile strength.

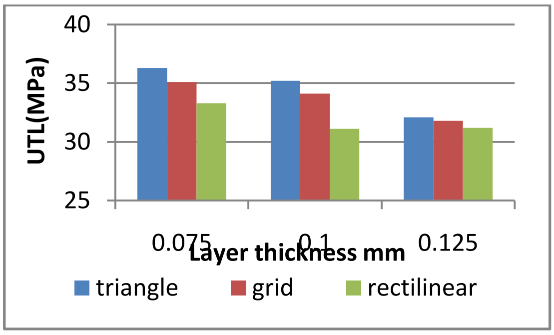

Fig. 7a

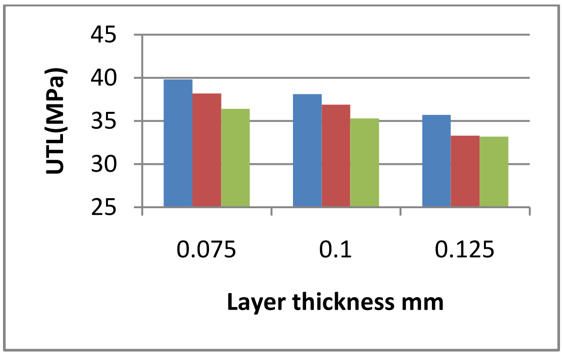

Fig. 7b

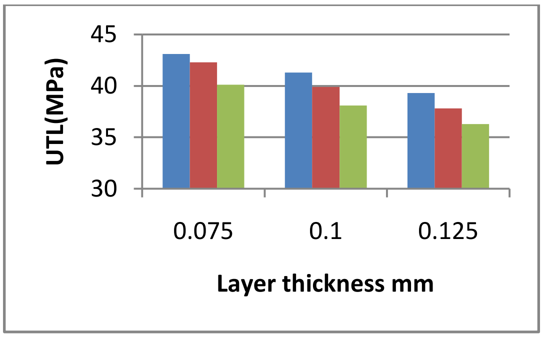

Figure. 7 Graph plotted between layer thickness and ultimate tensile strength for 60% (Fig. 7a) 70% (Fig. 7b)and 80% (Fig. 7c) infill density respectively.

Effect of infill density on tensile strength

The UTS at various layer thickness and infill pattern for different infill density is shown in the fig. 7.The experimental results suggest that in all the cases, specimen built with 80% infill density results in maximum tensile strength, is evident from the fig. 7c. The specimen built with 70% infill density (fig. 7b) showed relatively less tensile strength compared to 80% infill density and 60% (fig. 7a) had very less values of tensile strength. This is due to that the 80% infill density structure is dense with minor air gaps present between each bead.Lesser tensile strength in 60% infill density is due to the formation of more air gaps between each bead. In most of the cases the tensile strength is increased with the increased in the infill percentage. More material will be provided at higher infill percentage which in turn increases the tensile strength. Thus consumers can prefer 80% infill density over 100% infill density because 80% infill density reduces the amount of material used, thus ultimately reducing the cost of the product with very little difference in tensile strengths.

VIII. CONCLUSION

- Tensile strength of 20% carbon fibre PLA filament is approximately 30% more than that of the tensile strength of the ordinary PLA filament.
- The specimens fabricated with layer thickness of 0.075mm when compared to layer thickness of 0.125mm invariably of the infill pattern achieved higher tensile strength. This increase in tensile strength was due to that the decrease in layer thickness and decrease in the air gap.
- Triangular infill pattern showed superior values of tensile strength for 80% infill density, whereas the grid and rectilinear pattern showed lower tensile strength. Lower tensile strength in other two infill pattern was due to the presence of discontinuous beads.
- Increase in the infill density increases the tensile strength and displays maximum tensile strength for specimen built with 80% infill density. The specimens built with 60% and 70% infill density has lower tensile strength when compared to 80%, this is due to the presence of air gap between each bead.

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