November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

A Research on Effect of Infill Pattern, Infill Density and Layer Thickness for Fused Deposition Modelling to Enhance the Tensile strength of ABS Parts

R. Srinivasan
Professor, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: vlbsrini@gmail.com)

T. Pridhar
Associate Professor, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: preeth_t@rediffmail.com)

P. Prathap
Professor & Head, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: lprathap.p@skct.edu.in)

L. S. Ramprasath
UG Student, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: lsramprasath@gmail.com)

S. Rahul
UG Student, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: srahulomp@gmail.com)

N. Sree Chara
UG Student, Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India.
(Email: nanthagopalsree@gmail.com)

Article Info
Volume 81
Page Number: 4708 - 4715
Publication Issue:
November-December 2019

Abstract:
In additive manufacturing, Fused Deposition Modelling (FDM) is the most common method among the different types which involves melting, extrusion and deposition of thermoplastic filament. It is the most extensively used additive manufacturing method for the reason of its capability to create components having complex shape. On the other hand, end-consumer functional component with fused deposition modelling confirmed to be a demanding assignment due to the influence of quality on wide variety of processing parameters of the build parts and their functionality. Further, the final part’s building time, mechanical properties requires a more intrinsic understanding to detail on the impact of the FDM processing parameters. This paper presents an experimental investigation on Acrylonitrile butadiene styrene (ABS) thermoplastic filament to assess the effects of process parameters such as infill density, infill pattern, layer thickness on the tensile strength. A set of test specimen specimens were printed using varying processing parameters for the

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

experimentation of the tensile strength of each fabricated sample. From the findings of the experiments, suitable processing parameters for an assuring tensile strength were analyzed and studied to develop better end-user functional parts.

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

Keywords: *Fused deposition modelling (FDM), Acrylonitrile butadiene styrene (ABS), Additive Manufacturing (AM), infill pattern, infill density, layer thickness, tensile strength.*

I. INTRODUCTION

Additive Manufacturing (AM) is recognized as 3D printing that refers to a method by which digital 3D design data is used to manufacture a component in layers by depositing material. The layers are fabricated by addition of material as a substitute of removing it as contrasted to subtractive manufacturing such as machining. The strengths of AM lies in those areas wherever conventional manufacturing attains its limitations. At present, the manufacturing industry is a area extremely globalized with a continuous requirement for production expansion and improvement. In this outlook, AM is consider as one of the newest manufacturing revolutions and a upcoming innovative technology for the reason of its simplicity of use and capability to fabricate complex parts [1].

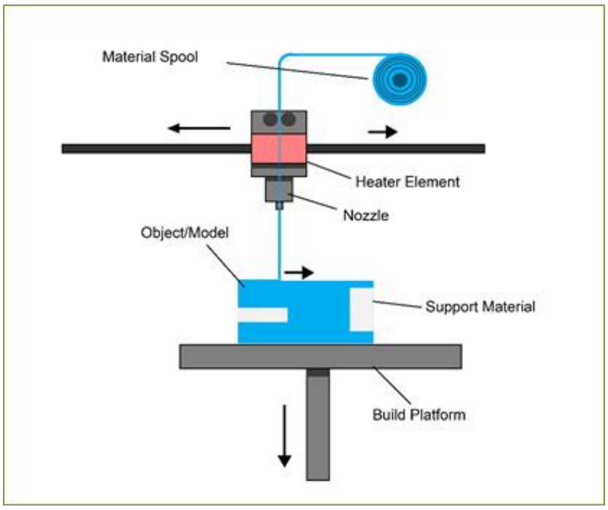

Fig. 1.FDM machine schematic view.

Depending upon the plethora of applications used in various type of industries, different AM processes are used based on the output required for example Selective Laser Sintering/Melting (SLS/SLM), Stereolithography (SLA), Fused Deposition Modelling (FDM) andLaminated Object Manufacturing (LOM) systems are existing commercially for production of layered components. The most favourable and robust AM technique to be capable of producing complicated and entangled 3D models in intact and realistic time requirement is fused deposition modelling (FDM) [2].

In FDM, additive manufacturing technologies, parts are built by layers. In this process a thermoplastic filament is heated to a semi liquid state and extruded through a small nozzle per 3D CAD models generally STL files. Layers deposited create a bond with the preceding layers and solidify. Whenever needed it also generates support material and the support structures are removed from the part after the part is being completed. Even though FDM methods have important industrial significance for developing intricate components, there is a demand to carry out suitable research paying attention on important aspects such as flexural strength, tensile strength and hardness. The tensile strength of the manufactured parts depends on the various process parameters, such as layer thickness, infill pattern, infill density, etc., and also the type of material used. Some common materials include Poly lactic acid (PLA), Acrylonitrile butadiene styrene (ABS), Wood fibre (cellulose + PLA), Polyethylene terephthalate (PET), etc., among these Acrylonitrile butadiene styrene (ABS) a thermoplastic, heated with no trouble moulded and if cooled evenly

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

hardened [3]. ABS filament used in customary manufacturing in a diversity of industries. Convenient properties of ABS filament's such as flexibility, machinability, temperature resistance and strength put together a favorite choice for engineers and others.

II. LITERATURE SURVEY

Numerous researchers have deliberated the impact of a wide variety of FDM process parameters resting on as layer thickness, impact strength and flexural strength. Christian et al. [4] examined the process parameters and suggested that the mechanical properties of a material can be improved by lowering the printing speed and lowering the layer thickness. Ziemian et al. [5] has concluded that the mechanical properties of the ABS parts manufactured by FDM mostly depend on raster angle and illustrates the anisotropic performance by means of the orientation of raster and directionality of polymeric molecules. Bakar et al· [6] analyzed the roughness and accuracy using surface tester and coordinate measuring machine respectively. These analyses were carried out over the performance of the FDM parts. In this they have analyzed the FDM process parameters with the help of six test model that were developed with varying parameters like internal raster, counter width, which also included the features like slots, cube, ring, and cylinder. Sood et al· [7] analyzed the influence of significant process parameters like orientation, layer thickness, raster angle, air gap and raster width on the mechanical properties of the products produced by FDM process.. Mercedes Perez et al· [8]has studied the process parameters that include layer height, printing path, printing speed, wall thickness and temperature. They have also investigated the surface roughness in additive manufacturing process and reported that wall thickness and layer height are the two important process parameter that affect the surface quality. Dawoud et al. [9] examined the influence of air gap and raster angle on flexural, tensile and impact properties of ABS part manufactured from FDM process and in addition made a assessment with the injection moulded ABS part. They have noted that parts are capable of reaching 91% of the tensile strength during negative air gap and flexural strength of 86% to injection moulded products. Uddin also investigated the printing parameters of layer thickness, print orientation and print plane on mechanical properties and failure mechanisms of ABS material. A lot of researchers have also examined further parameters of FDM process apart from the above mentioned one which includes infill percentage, layer thickness, feed rate and orientation on tensile strength of samples.

From this literature review, it is observed that attempts are being made to enhance one or more main process parameters to get better tensile properties as well as the excellent quality of the manufactured FDM parts. It is also noted that various process parameters influences the quality of FDM printed parts. Hence, for the enhancement of the superior quality of the parts developed by FDM, the detection of significant and optimal process parameters is very vital. The literature recommends that comparatively slighter efforts have been accounted to study the combined influence of the process parameter such as infill density, infill pattern and layer thickness on the tensile properties of the 3D printed parts. In this regard, an experimental examination was planned to study the effect of infill pattern and infill density at a range of layer thickness on the tensile properties of FDM-printed samples. In the present research work, ABS material is used to manufacture the specimen. The subsequent section explains the process of manufacturing and testing of samples; the outcomes were discussed in the following section.

III. EXPERIMENTAL DETAILS

Material and Process parameters

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

In this investigation, commercial polymer material Acrylonitrile butadiene styrene (ABS) is used for printing specimens. ABS is an opaque thermoplastic polymer comprised of three monomers, acrylonitrile, butadiene and styrene. The acrylonitrile in ABS offers thermal and chemical stability, while the butadiene adds strength and toughness. Glossy nice finish is given by styrene to the finished polymer. ABS has a low melting point, which allows its easy use in 3D printing. High tensile strength and resistance to chemical corrosion and physical impacts allows the finished plastic to resist heavy use and undesirable environmental conditions. This engineering plastic has a extensive range of applications in industries such as automobile, electronic products and construction materials [12].

Three process parameters namely infill pattern, infill density and layer thickness of three levels were considered. The values of parameters at each level are shown in Table **(1).**

Parameters	Level 1	Level 2	Level 3
Infill pattern	Triangular	Grid	Cubic
Infill density	60%	70%	80%
Layer thickness	0.1	0.15	0.2

Table 1.Process parameters at various levels.

Infill density.The quantity of plastic used on the within of the print is defined as infill density. A higher infill density means that there is additional plastic on the inside of the print, most important to a stronger object. Higher infill density takes more time to print and lesser infill density takes less time to print.

Infill pattern.In 3D printing, the term “infill pattern” refers to the structure that is printed inside an object. It is extruded in a designated percentage and pattern, which is set in the slicing software. A lot of geometrical patterns are existing such as rectilinear, triangular, diamond, honeycomb, etc., More complex the infill pattern, more time and material will be required. Different infill patterns used in this work is shown in the fig. 2.

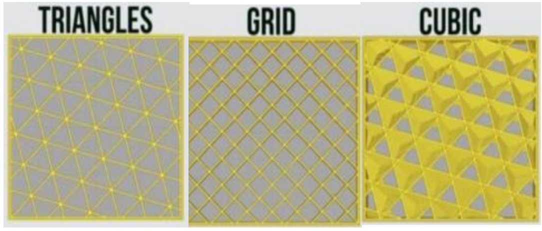

Fig. 2. Various infill pattern used

Layer thickness. It is among the most trivial of 3D printer process parameters, and it often plays a huge role in the entire 3D printing process. Layer thickness in 3D printing process is the layer height of every consecutive addition of material stacked.

Experimental design procedure and testing

In this experimental investigation, 3D model of the sample is designed as per the ASTM D638 type IV standard using Solidworks CAD modelling software and converted into .STL file. As per the ASTM standard dimensions of the investigation specimen is shown in the figure 3, the test specimen of CAD model is shown in the figure 4 and the tensile specimen printed using the 3D printer is shown in the figure 5. For slicing, the .STL file is introduced to software used for slicing, called CURA. An FDM machine Creality Ender 3 shown in the figure 6 is used for this experimental investigation. 27 specimens having process parameters of different combination is selected for printing. The printed specimens were undergone tensile properties test using Universal Testing Machine (TUE-C-1000) shown in the figure 7.

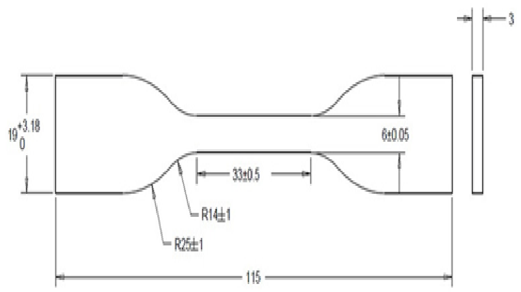

Fig. 3. Dimension of tensile test specimen as per ASTM standard

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

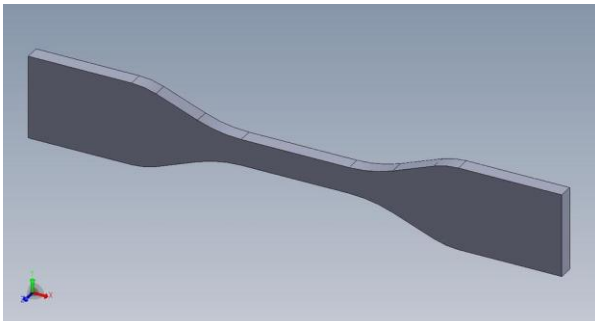

Fig. 4. CAD model of the tensile specimen

Fig. 5. Tensile test specimen as per ASTM standard

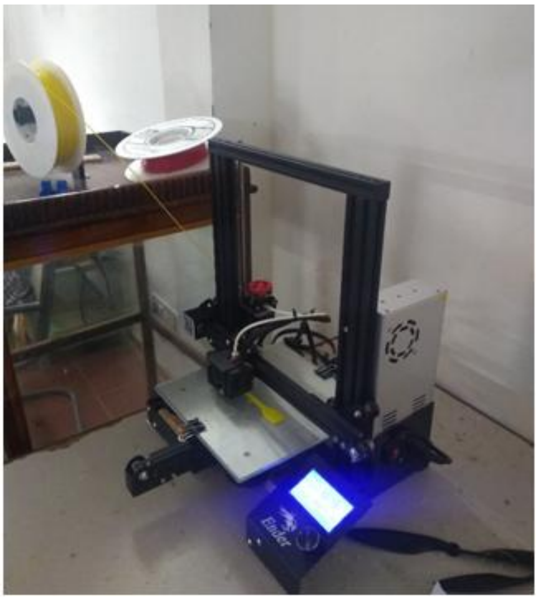

Fig. 6. 3D Printing machine

Fig. 7. Universal testing machine

IV. RESULTS AND DISCUSSION

Table (2) exhibits the tensile test data of the ABS specimen processed through different levels of process parameters for infill density, infill pattern and layer thickness. The test specimen printed from a 0.4 mm diameter nozzle of Creality Ender3 FDM machine is tested using Ultimate tensile strength (UTS) testing machine. The load is increased on the test specimen until the breakage happens to calculate the ultimate tensile strength..

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

Table 2 Tensile test results

S. No.	Infill pattern	Layer Thickness (mm)	Infill density (%)	UTS Test (MPa)
1	Triangular	0.1	60	27.9
2	Triangular	0.1	70	28.1
3	Triangular	0.1	80	33.1
4	Triangular	0.15	60	26.2
5	Triangular	0.15	70	28.1
6	Triangular	0.15	80	31.4
7	Triangular	0.2	60	24.3
8	Triangular	0.2	70	26.1
9	Triangular	0.2	80	28.3
10	Grid	0.1	60	26.1
11	Grid	0.1	70	28.9
12	Grid	0.1	80	31.6
13	Grid	0.15	60	24.9
14	Grid	0.15	70	27.1
15	Grid	0.15	80	29.9
16	Grid	0.2	60	22.1
17	Grid	0.2	70	25.4
18	Grid	0.2	80	26.8
19	Cubic	0.1	60	24.9
20	Cubic	0.1	70	26.3
21	Cubic	0.1	80	29.9
22	Cubic	0.15	60	23.6
23	Cubic	0.15	70	25.8
24	Cubic	0.15	80	28.9
25	Cubic	0.2	60	20.8
26	Cubic	0.2	70	23.9
27	Cubic	0.2	80	25.4

Influence of infill pattern on the tensile strength

Figure 8(a,b,c) shows the results of tensile strength for different infill density, infill pattern and layer thickness. The graph shows that the triangular infill pattern yields higher tensile strength. The specimen manufactured at 80% infill density of triangular pattern at 0.1mm layer thickness exhibits superior tensile strength (fig. 8c) when compared to the samples printed at other infill patterns. The higher tensile strength in triangular pattern is due to the presence of huge number of segments of short lines. When the sample is printed with other infill pattern for 80% infill density shows lower tensile strength than that of triangular infill pattern. Cubic pattern shows lower tensile strength due to the presence of discontinuous beads and air gaps.

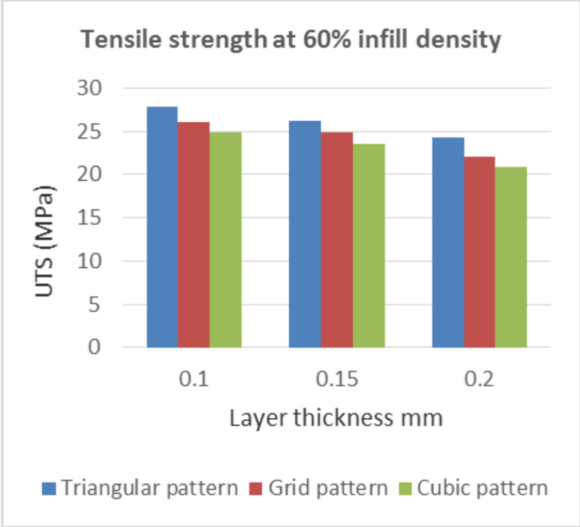

Fig 8a

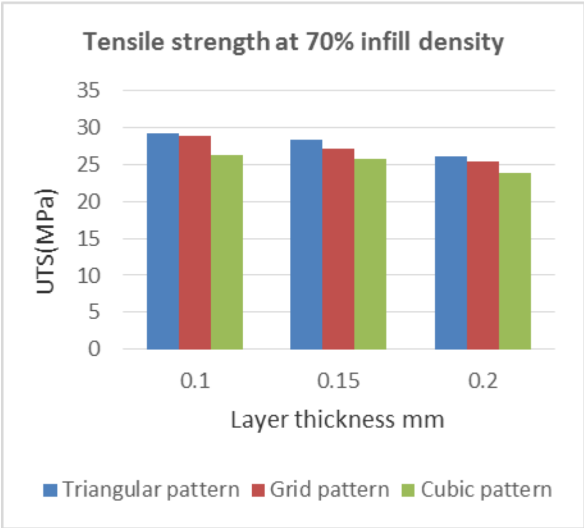

Fig 8b

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

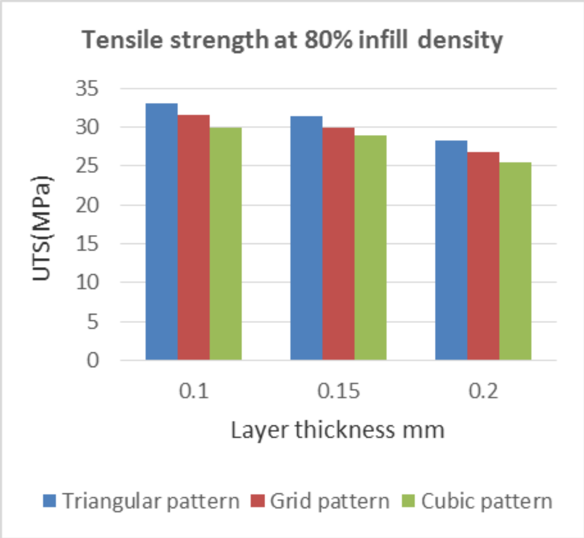

Fig 8c

Fig. 8. UTS at 60%, 70% and 80% of infill density for different layer thickness and infill pattern

Influence of infill density on the tensile strength

The process parameters that creates a greater impact on tensile strength is infill density. From figure 8c, it is found that the result of the tensile strength on the samples printed at infill density of 80% shows better results when compared to infill density of 60% (fig. 8a.) and 70% (fig. 8b). The sample printed with 80% infill density for triangular infill pattern at 0.1mm layer thickness shows the best result on the ultimate tensile strength. This is owing to the presence of minor air gaps and higher deposition of materials.

Influence of layer thickness on the tensile strength

Another crucial influencing process parameter is layer thickness or layer height that creates impact on tensile strength. From all the graph of fig 8 (a,b,c) it is observed that the better results are shown on the ultimate tensile strength for the FDM printed parts with 0.1mm layer thickness. The best result is shown on the printed parts with 80% infill density, triangular infill pattern, 0.1mm layer thickness. For all the other levels of process parameters with layer thickness 0.1mm gives the better result on the tensile strength. This is due to the presence of dense material on each layer deposition.

V. CONCLUSION

Based on the various build parameters Acrylonitrile butadiene styrene (ABS) material was successfully fabricated by using creality Ender 3 desktop 3D printer and was tested by using Universal testing machine TUE-C-1000. The subsequent conclusions were drawn from the present research work:

1. Varying the two process parameters such as layer thickness and infill density and created a greater impact on the value of ultimate tensile strength.
2. Higher values of tensile strength was observed in triangular infill pattern at 80% infill density, whereas the lower tensile strength was observed in grid and cubic pattern. Lower tensile strength was due to the presence of discontinuous beads. 80% infill density can be preferred by consumers over 100% infill density because 80% infill density reduces the amount of material used, thus ultimately reducing the product cost with very little difference in tensile strengths.
3. Specimens fabricated with layer thickness of 0.1 mm showed higher tensile strength when compared to other layer thickness of 0.15mm and 0.2 mm respectively. This is due to the decrease in air gap and layer thickness.
4. Higher tensile strength was observed in specimen printed with triangular infill pattern, whereas lower strength was observed for grid and cubic pattern. This was due to the presence of discontinuous beads.

REFERENCES

1. Hopkinson N, Hague R, Dickens P. Rapid Manufacturing: An Industrial Revolution for the Digital Age; John Wiley & Sons: Hoboken, NJ, USA, 2006; ISBN 9780470032862.
2. Yan X, Gu P. A review of rapid prototyping technologies and systems. Comput. Aided Des. Appl. 1996, 28, 307–318.
3. https://www.3dalt.com/common-materials

November-December 2019
ISSN: 0193-4120 Page No. 4708 - 4715

4. .Christiyan K.J, Chandrasekhar U, Venkateswarlu K. A Study on the influence of process parameters on the mechanical properties of 3D printed ABS composite. In IOP Conference Series: Mater Sci Engineering,2016 114(1) 1-8.
5. .Ziemian C, Sharma M, Ziemian S. Anisotropic mechanical properties of ABS parts fabricated by fused deposition modelling. In: Gokcek M, editor. Mechanical engineering, In Tech 2012 159-180.
6. Baker N.S.A, Alkahari M.R, Boejang H, 2010.Analysis of Fused Deposition Modelling. Journal of Zhejiang University-Science A (Applied physics and science) 11(12),1972-1977.
7. Sood A.K, Chaturvedi V, Datta S, Mahapatra S.S, 2011.Multiobjective optimization of process parameter in fused deposition modelling using weighted principle complex analysis. Journals of advance manufacturing system 10(2),241-250.
8. Mercedes Perez, Gustavo Medina-Sanchez, Alberto Garcia-Collado, Munish Gupta, Diego Carou. Surface quality enhancement of fused deposition modelling (FDM) printed samples based on the selection of critical printing parameter.
9. Dawoud M, Taha I and Ebeid SJ. Mechanical behaviour of ABS: an experimental study using FDM and injection moulding techniques. J Manuf Processes 2016; 21: 39–45.
10. .https://www.adrecoplastics.co.uk/abs-plastic-properties-and-application/