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Effect of FDM Process Parameters on Tensile Strength of PLA

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Abstract: In rapid prototyping (RP), 3D printing is growing fast due to its ability to build different complex geometrical shapes and structures in the least possible time. In this manufacturing process, a computer-aided design (CAD) model is used to fabricate a physical model. The prototype is made by deposition of material in layer by layer. The major advantage of this manufacturing process is that it can fabricate complex parts quickly with minimum loss of material. There are many rapid prototyping techniques available commercially. Fused deposition modeling (FDM) is one of the most widely used methods. The mechanical behavior of 3D printed fabricated PLA parts depends on the interaction of different process parameters and the raw material properties. In this work, the effect of process parameters, namely layer thickness, Volume Infill, and print speed, has been studied on mechanical properties like tensile strength. It was observed that tensile strength increased with an increase of volume infill, minimizing print speed and layer thickness. The experimental results are compared with the simulated results from ANSYS.

***Index Terms* – PLA, FDM, Tensile Strength, ASTM D638-14, FEA.**

I. INTRODUCTION

Additive manufacturing (more commonly known as 3D printing) is the process of additively building up a part one layer at a time. There is a range of 3D printing technologies with each having its benefits and limitations and each being able to print parts from different materials. Parts can be produced in almost any geometry, which is one of the core strengths of 3D printing.

1.1 The 3D printing process

While there are many different 3D printing technologies in the general process from design to the final part. Although each method of 3D printing produces parts differently, these 5 core steps are constant across all technologies.

1. Producing a 3D file

Producing a digital model is the first step in the 3D printing process. The most common method for producing a digital model is Computer Aided Design (CAD). Reverse engineering can also be used to generate a digital model via 3D scanning.

2. STL creation and file manipulation

To print a 3D part, a CAD model must be converted into a format that a 3D printer can interpret. This begins by converting the CAD model into a STereoLithography (STL) file, also referred to as the Standard Triangle Language file. STL uses triangles (polygons) to describe the surfaces of an object, essentially simplifying the often complex CAD model. Most CAD programs are capable of exporting a model as an STL file. Once a STL file has been generated, the file is imported into a slicer program, which slices the design into the layers that will be used to build up the part. The slicer program takes the STL file and converts it into G-code. G-code is a numerical control programming language used in CAM to control automated machines like CNC machines and 3D printers. The slicer program also allows the 3D printer operator to define the 3D printer build parameters by specifying support location, layer height, and part orientation.

3. Printing

The selection of 3d printing method and material depends on the specific application. These are mainly classified into liquid based, Solid based, and powdered based technologies.

4. Post processing

Post processing procedures vary by printer technology. Some technologies require a component to cure under UV before handling while others allow parts to be handled right away. For technologies that utilize support, this is also removed at the post processing stage.

1.2 Process Parameters

1.2.1 Layer height (mm)

As this additive manufacturing method uses layer by layer printing, the Layer Height Parameter plays an important role in variation in mechanical as well as physical properties. Layer Height varies from 0.06 to 0.1mm for a 0.4mm diameter nozzle.

1.2.2 Shell thickness (mm)

The shell thickness is the thickness of the outer shell of the part. This is used in combination with the fill density which is selected for printing to increase the mechanical as well as physical properties.

1.2.3 Infill density (%)

It is the density of the part which is to be printed. For a solid part use 100% and for an empty part use 0% fill density. A value of around 20 is usually enough. This won't affect the outside of the print and adjusts how strong the part becomes.

1.2.4 Printing speed (mm/s)

Printing speed is the speed at which printing happens by the movement of the printing head. A well-adjusted printer can reach 150mm/s, but for good quality prints, it needs to print slower.

II. LITERATURE REVIEW

R. Anitha, et.,al.[1] The objective of this paper is to study the influence of process parameters like Print speed (A), Layer thickness(B), Infill density(C) on the build time and optimization of these parameters to get the Fused Deposition Modeling part in lower lead time using Taguchi and ANOVA approaches. The results have shown that the build time depends on infill density and layer thickness.

M. Tharunkumar, et.,al.[2] In this paper, tensile strength, impact strength, and flexural strength are considered as three evaluation indexes to characterize the mechanical properties of an FDM part. The orthogonal test of five factors and three levels was designed. The Taguchi method is used to optimize and study the influence of various process parameters on the three performance indexes.

ChandraSekharUdayagiri, et.,al. [3] In this paper, the improvement of Impact Strength is achieved by Optimizing the FDM Process Parameters using Polycarbonate material. This study includes four important process parameters like layer thickness; build orientation, raster angle, and raster width whose influence on Impact Strength is studied.

M Alhubail1,,et.,al.[4] In this paper, the effect of FDM parameters on Impact Strength is experimentally investigated. Experiments were conducted according to DOE with three different process parameters such as direction of rotation, build orientation angle and model interior. The process parameters were optimized by using Taguchi method, S/N ratio is evaluated and the effect of the process parameters on Impact strength was estimated by the analysis of variance.

P. Chennakesava, et.,al. [5] In this paper, it is studied the effect of various process parameters, i.e. layer thickness, road width and speed of deposition of fused deposition modeling parts. The FDM parts which are fabricated are depend upon the process parameters. Taguchi approach was used for the design of experiments. L18 orthogonal array was selected for experiments. In addition, it is concluded that the layer thickness is the most crucial factor for Minimum Surface Roughness of FDM parts.

Masood,Jahar L, et.,al. [6] This paper presents the results of the experimental work on the effect of the Fused Deposition Modelling (FDM) process, variable parameters such as layer thickness, air gap, raster width, contour width and raster orientation on the quality characteristics such as surface roughness (SR) and tensile strength (TS). Taguchi design (L32) was used to obtain the experimentation runs. The results showed that higher tensile strength could be obtained by changing layer thickness and raster width at a low level and the air gap at -0.01 mm.

AshayKohad,et.,al, [7] This study includes the identification of various process parameters involved in FDM, which affects the quality of Parts fabricated. This study aims to find effects of process parameters on different performance parameters based on previous research done. This study also aims to compare different techniques for optimization of process parameters in Fused Deposition Modeling.

III. MATERIALS AND METHODS

3.1 Design of Specimen

For specimen preparation, the CAD files of a dog-bone tensile specimen by Type I of ASTM D638 standard40 were modeled in CATIA software and exported as STL format. The imported file then was converted to the G-code to be able to be readable by the FDM machine. The process parameters such as layer thickness, volume infill, and print speed were considered for different combinations. All other process parameters such as shell thickness, print temperature, diameter of filament and nozzle size were kept constant for all samples which their values were listed in Table1. These parameters were selected from the recommendations of 3D printer manufacturer and our experiences about the quality of different 3D printed specimens with good mechanical strength. The specimens were printed and selected for further analysis.

Figure 1(a): Dimension specifications of the specimen as per ASTM standards (b) CAD model of Specimen

3.2 Sample preparation process

The strength of PLA parts depends on a large number of parameters. In this study, three controllable variables have been considered, namely, layer thickness, infill density, and print speed to carry out experimental work. The experiments were conducted keeping these process parameters at various levels. The parts were fabricated on a Global 3D pramaan 3D printer. The combinations for each of the process parameters were selected as layer thickness 0.1 mm and 0.2 mm, infill density of 10% and 50%, and the print speed of 20mm/sec and 40 mm/sec. The combination of process parameters has been given in Table 1.

Table 1: Design of Experiments

S. No	Sample No	Infill density (%)	Print speed (mm/sec)	Layer Thickness (mm)
1	Sample 1	10	20	0.1
2	Sample 2	10	20	0.2
3	Sample 3	10	40	0.1
4	Sample 4	10	40	0.2
5	Sample 5	50	20	0.1
6	Sample 6	50	20	0.2
7	Sample 7	50	40	0.1
8	Sample 8	50	40	0.2

3.3 Manufacturing of specimens using FDM

FDM is one of the techniques used in additive manufacturing used for producing 3D models of polymers. The basic construction of the machine is as shown in figure 2. In FDM machine, a plastic filament of a standard Diameter of 1.75mm is used. This filament is heated in nozzle, the extruder deposits these melted Filaments into layer by layer form as per the program given to system. Additive Manufacturing (AM) technologies meet the requirements by creating products with complex, customized, and even assembled geometries, in a much faster and more economical way. The printing process is driven by the controlled planar translation of a print head in stacked layers that determines the spatial accumulation of material. Depending on the process, the print head typically either deposits material by fused deposition modeling. Poly Lactic Acid (PLA) is the most common 3D printing filament used in FDM machines.

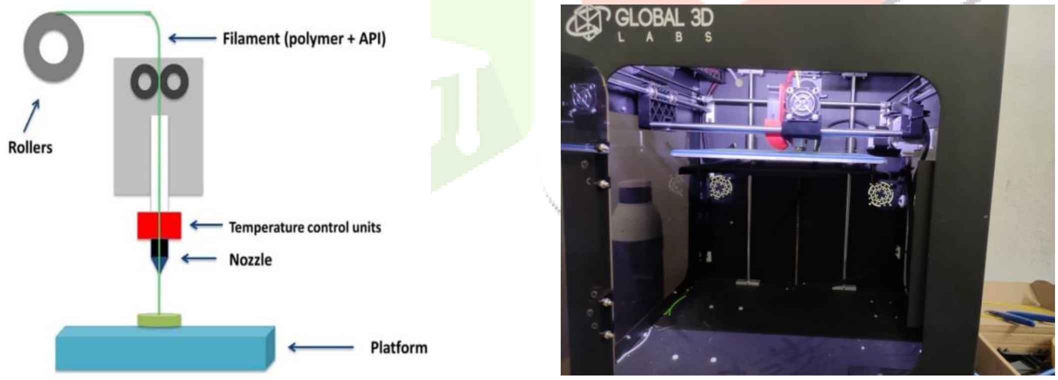

Figure 2: FDM 3D Printer

3.4 Experimental Procedure

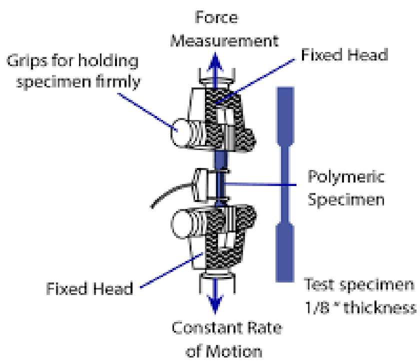

Figure 3: Tensile testing

After fabricating the samples, these specimens were tested. A universal testing machine (UTM) is used to test the tensile strength and compressive strength of materials. Tensile strength is one of the most analyzed mechanical properties. The parts for the tensile test were produced according to the American Standard for Testing and Materials (ASTM) D638 standard. This standard is used for testing the tensile properties of thermoplastics. The test specimens were dumbbell-shaped.

3.5 Analyzing by Finite Element Analysis

Accompanying the experiments, simulations have been utilized for understanding the structural effect on the test results. The finite element method (FEM) was employed by solving this condition. The material is considered as isotropic and homogeneous by using the same engineering constants such as Young's modulus and Poisson's ratio which is taken from tensile test results. The discretization, was implemented linear form functions and tetrahedron elements with a suitable mesh acquired by an h-convergence analysis. All preprocessing steps, that is, CAD generation, boundary conditions marking, and triangulation, have been accomplished in ANSYS. Standard uniaxial testing simulation was performed for different loadings. On one end the specimen is clamped and on the other end, the specimen is pulled by a given force per area.

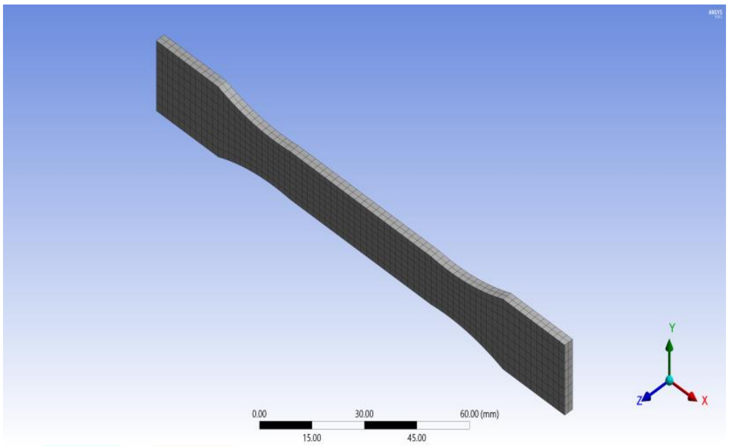

Figure 4: Mesh model of the specimen

4. RESULTS AND DISCUSSIONS

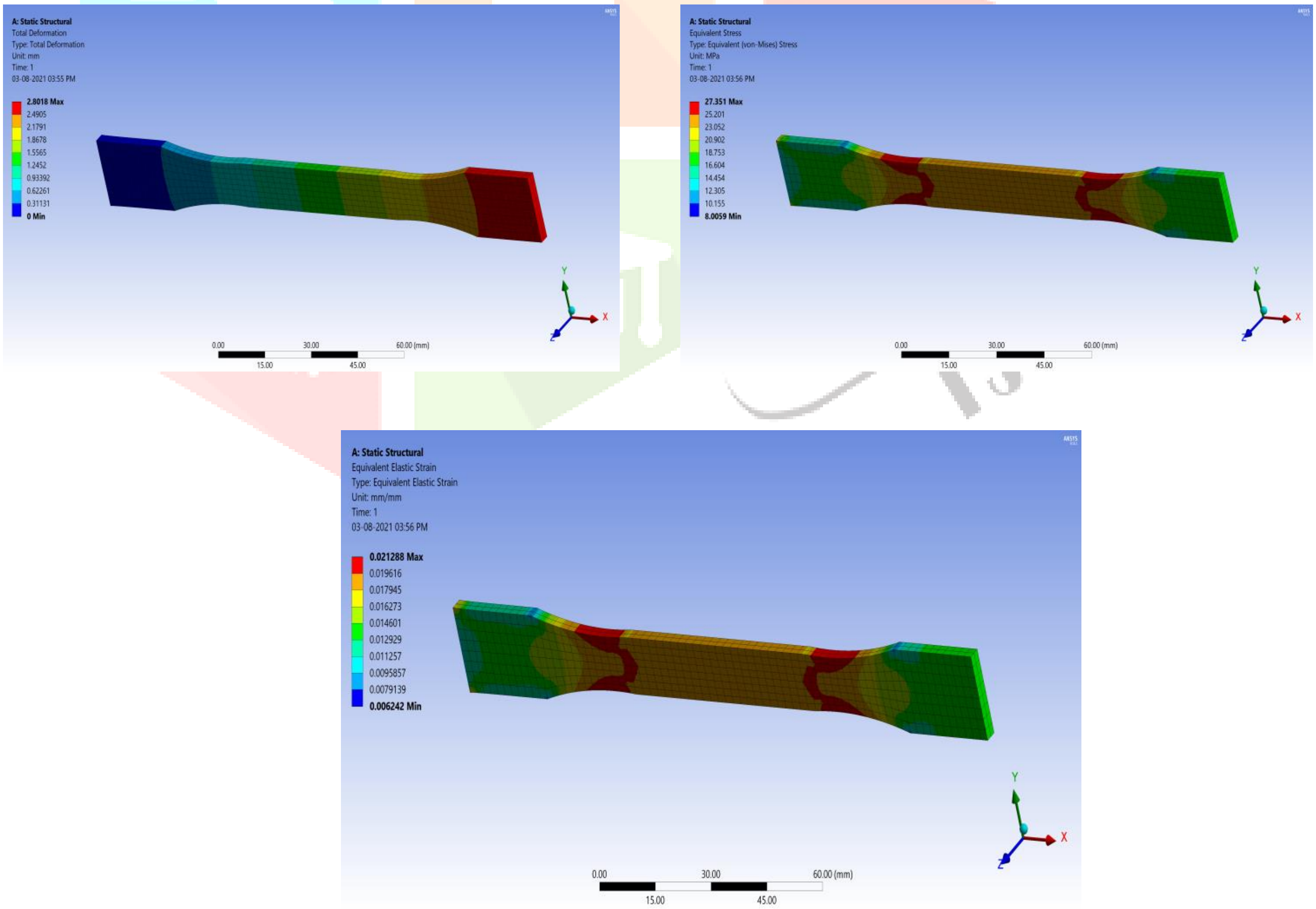

Figure 5: (a) maximum deformation (b) Maximum Stress (c) Maximum strain

Table 2: Tensile testing results

S.No	Sample Name	Elongation (mm)	Tensile Strength MPa	Youngs Modulus MPa	Peak Load N
1	Spec- 1	1.651	15.153	1044.61	623.6
2	Spec- 2	2.372	16.965	928.27	692.5
3	Spec- 3	2.346	20.601	1065.25	849.1
4	Spec- 4	2.812	17.932	950.43	726.8
5	Spec- 5	2.896	25.732	1284.78	1026.1
6	Spec- 6	2.090	20.232	1020.5	790.8
7	Spec- 7	2.587	23.025	1238.46	921.8
8	Spec- 8	3.624	23.227	1173.92	893.8

Table 3: Simulated results from Ansys

Sample	Deformation mm	Equ Stress MPa	Max Principal Stress MPa	Min Principal Stress MPa	Equ Elastic Strain
1	2.0942	16.622	20.281	4.3368	0.01591
2	2.6171	18.459	22.452	4.816	0.01988
3	2.7963	22.633	27.529	5.9051	0.02124
4	2.6827	19.373	23.564	5.0545	0.02038
5	2.8018	27.351	33.267	7.136	0.02128
6	2.7185	21.079	25.639	5.499	0.02065
7	2.6111	24.571	29.886	6.4106	0.01984
8	2.6111	24.571	29.886	6.4106	0.01984

5. CONCLUSION

The Effect of FDM process parameters of layer thickness, volume infill and print speed of PLA material was first systematically investigated in this study and also tensile test was performed. The results indicated that the optimal combination of tensile strength is layer thickness of 0.2 mm, volume infill of 50%, and print speed of 20mm/sec. From this set of combinations the optimum tensile strength is obtained as 25 MPa. Then further we compared the results with simulated results using ANSYS. These results are closely matched with experimental results.

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