A Design, Development and Mechanical Characterization of FDM Machine

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Abstract

Additive manufacturing is a technology rapidly expanding on a number of industrial sectors. AM processes make three-dimensional parts directly from CAD models by adding materials layer by layer, offering the beneficial ability to build parts with geometric and material complexities that could not be produced by subtractive manufacturing processes. Through intensive research over the past two decades, significant progress has been made in the development and commercialization of new and innovative AM processes, as well as numerous practical applications in aerospace, automotive, biomedical, energy and other fields. In fused deposition modeling (FDM) additive manufacturing process, it is often difficult to determine the actual levels of process parameters in order to achieve the best dynamic mechanical properties of FDM manufactured a part. This is mainly due to a large number of FDM parameters and a high degree of interaction between the parameters affecting such properties. This requires a large number of experiments to be determined.

This paper presents a Design, Development, Analysis, Prototype model and testing of 3D printed components mechanical strength characterization. A study on the influence of FDM process parameters such like as fill density, layer thickness and build orientation on the dynamic mechanical properties of the FDM manufactured parts using the Taguchi L-9 three Levels design. The most influential parameters were statistically obtained through the analysis of variance (ANOVA) technique, and the results indicate that the Fill Density, the Layer Thickness and build orientation largest impact on mechanical properties of Part manufactured by PLA Material.

Keywords: Design, Analysis, Prototype and Mechanical Properties testing

1. INTRODUCTION

Additive manufacturing (AM) is one of the fasted growing industrial sectors in the USA and has been considered the next industrial revolution [1] In 2014, there was an estimated $1.065 billion spent on the AM of production grade parts and the industry has grown at an average rate of 76 % over the last 14 years [2]. The ability to rapidly design and build models with minimal lead times has been readily adopted by companies producing smaller batches of parts may be customized by batch. With a low cost to create an individual part or for small lot size production, AM processes are able to significantly reduce tooling costs. As decreasing costs of production continues, the feasibility of AM replacing traditional processes like injection molding is becoming increasingly probable. Fused deposition modeling (FDM) is the most commonly used 3D printing technology for plastic parts in the modern manufacturing world due to its ability of producing complex geometrical shapes without tooling safely in an office-friendly environment. This process produces three-dimensional parts layer-by-layer directly from computer aided design (CAD) model [3]. The process usually begins with taking the feedstock material in the form of a filament and heating it to the semi-molten state. The semi-molten filament is then extruded through the nozzle, which moves over the build table in three axes motion creating a cross section of three-dimensional object onto the platform [4]. The deposited material cools, hardens, and bonds to the layer beneath it. This process is repeated. up to the last layer [5] In the literature, various studies have been published to improve the mechanical properties under static loading conditions through appropriate adjustments in the process parameters, but the progress has been slow because of the complex nature of the FDM process and conflicting influence of these process parameters. Onwubolu and Rayegani [6] analyzed the effect of build orientation, raster angle, raster width, and air gap on tensile strength of the processed parts. Results indicated that the parts strength improved with decreasing air gap and build orientation and increasing raster angle. Masood et al. [7] conducted an experimental work to identify the critical FDM operating conditions to produce parts with highest mechanical performance. Durgun and Ertan [8] described how the parts built by FDM with different part orientations and raster angles influence the surface roughness, tensile strength and flexural strength. This study demonstrated that the part orientation has a strong effect on the surface roughness and mechanical performance than the raster angle. Gorski et al. [9] developed a method to compute deformation and stresses in the built parts by FDM by considering critical processing variables. Zhang nd Chou [10] developed a finite element model to analyze the distortions and stress distribution at different processing conditions through central composite design (CCD) and analysis of variance ANOVA technique. It was concluded that layer thickness was the main factor affecting the residual stress and distortion in FDM manufactured parts.

In the present literature, there has been no systematic study done for new 3D printer development and mechanical properties testing of FDM manufactured part by the PLA Material. This study investigates the influence of three FDM process parameters (layer thickness, fill density and build orientation) on the dynamic mechanical properties of FDM processed PLA part. In this study, empirical relationships between the process parameters were studied using Taguchi L-9

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Three levels design and analysis of variance (ANOVA) technique. Figure 1 shows the working methodology.

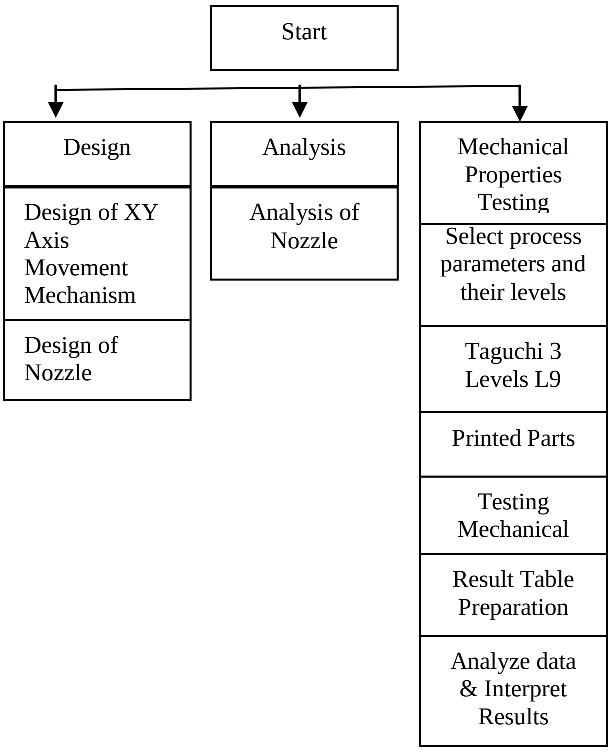


Fig. 1. Working Methodology

2. DESIGN OF 3D PRINTER

In this section, we are presenting the 3D printer aims, mechanism of Printer design.

2.1 Aims of Design

A figure 2 shows the three axis of movement: X, Y, and Z in which bed and extruder move in different ways. The Z-axis consists of the Table that will move forwards and backward (front to back). The X-axis will move the Extruder left and right. The Y-axis will allow the Extruder to move up and down.

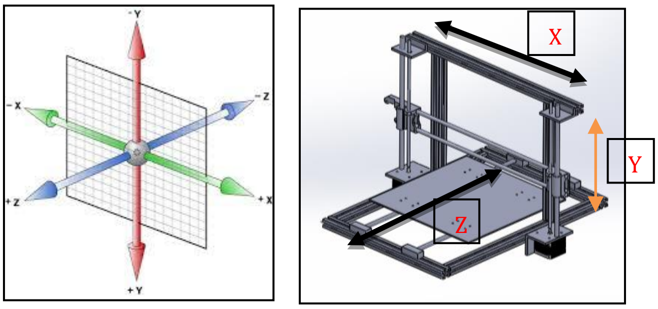


Fig. 2. CAD Model of 3D Printer with X, Y and Z Movement

2.2 Mechanism of 3D Printer

A 3D Printer CAD mechanism shows in figure 3 a first thing which is very essential is a frame at which all movements are to be taken out in X, Y and Z direction. The Slider hot end moves left to right in X-direction with the help of timing belt and pulley mechanism. The slider moves front to back in Y-direction along with X -direction by timing belt and pulley. The build platform moves up and down by the application of lead Screw and Nut.

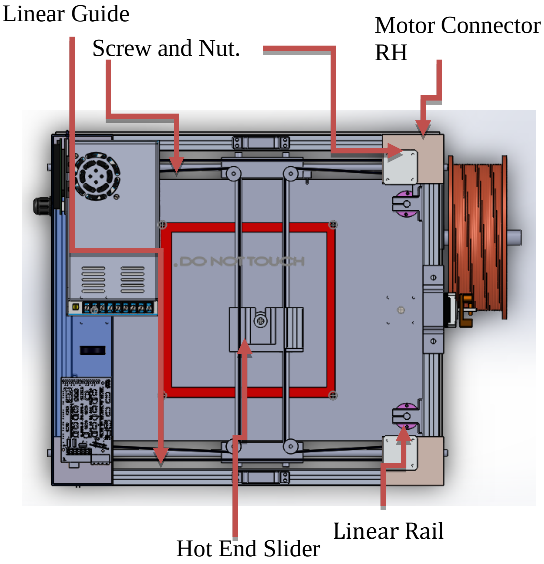
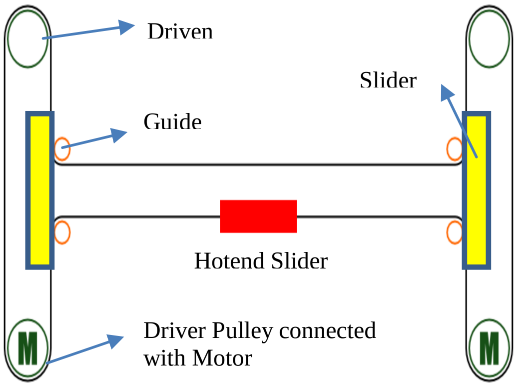
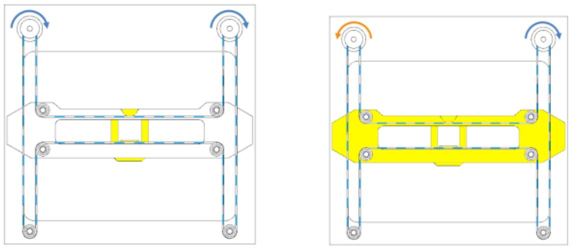


Fig. 3. CAD Model of 3D Printer Mechanism

Belt drives are used for X and Y stage for transmitting power from one place to another because the need to travel longer. The typical belt drive set-up has at least two wheels and a belt connecting them together. H- belt mechanism is used for travelling in X and Y direction with the help of motors, pulleys and belts. The green circles marked M are the two motors. These are mounted in a fixed position, they can't move. The other two green circles are freely rotating pulleys which can't move either. The orange circles are guide pulley which can move between the motors and the pulleys. A timing belt (in black) is tensioned in the shape of an H between all these. A carriage (in red) is connected to the timing belt in the center between two of the Guide Pulleys because the backside of the timing belt is smooth.

A figure 4 shows H belt working mecahnism. When the two motors move in the same direction, one motor pulls on the "carriage side" of the belt, while the other "pushes" it (i.e. pulls in the resulting slack). Due to this, the carriage will move left/right between guide pulleys. The motors move in opposite directions, It is pull both the timing belt in the same direction. Therefore, the carriage can't move sideways, it has to move up/down. For the implementation of H belt in actual design motor connectors and pulley connectors are used where motors and driver pulley mounted between pulley connectors and motors connectors SS rods are used where sliders are sliding which having the guide pulley.





X- Direction

Y- Direction

Fig. 4. XY Axis Mechanism

2.3 Design of Nozzle

The nozzle diameter is a one of the main parameter. Long nozzle is more convenient for cleaning and they let more cooling air flow around shorter nozzle reduces heat loss a bit and they probably give a better control and reading of the temp. (Sensor on the heating block) therefore input nozzle diameter is d1=1.75mm because of the filament diameter is 1.75 mm. The output diameter of the nozzle is 0.4 mm, which is universally available and used. The printer speed is 50 mm/ sec.

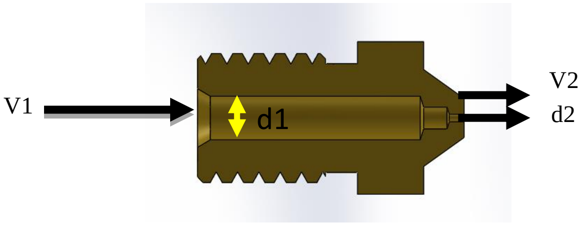


Fig. 5. Design of Nozzle

It should have sufficient temperature range from 0-300°C for both ABS (110°C) and PLA (160°C) Printing. It should have a small size and a nozzle which should have diameter 0.4 mm. It should have heater cartridge for obtaining the temperature range and thermistor which sense the temperature range from 0 to 300°C. It should have provision for isolating hot end and cold end by a barrier and have a heat sink with the fan to maintain cold end temperature. Therefore, E3D hot end which is used to maintain the temperature.

A Figure 6 shows the Full CAD Model of FDM printer with 150 x 150 x 150 mm work table dimension.

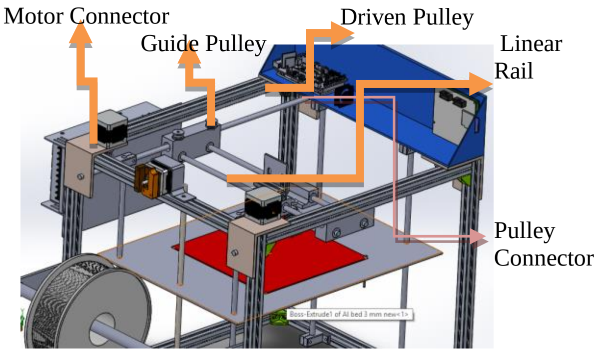


Fig. 6. CAD Model of 3D Printer

3 ANALYSES

3.1 Analysis of Nozzle

A nozzle is flowing the heated material therefore Computation fluid dynamics analysis is required to measure the Fluid Flow at a velocity of 70 mm/sec at inlet and figure 7 (b) shows the steady state thermal analysis of nozzle. The maximum Temperature Prediction at 250°C to Block by steady state analysis and maximum steady state thermal temperature is 227.94 C.

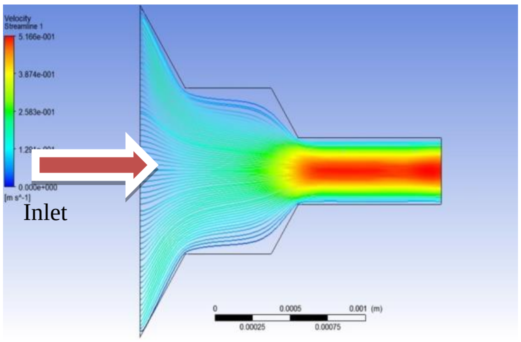


Fig.7 (a). CFD Analysis of Nozzle

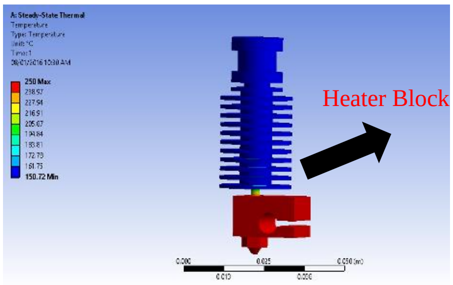


Fig. 7 (b). Steady State Thermal Analysis of Nozzle

4. TESTING

This section represents the testing setup of FDM component and experimental strategy. Table 1 shows the Design of Experiment (DOE) Taguchi three levels L9 Method.

Table 1 Experimental Parameters and their Levels

Sr. no	Layer Thickness	Fill Density	Printing Speed	Build Orientation
1	0.1	30	50	0
2	0.2	40	100	90
3	0.3	50	150	--

4.1 Tensile Test

A tensile strength tested by the universal testing machine of PSI Sales Pvt Ltd. A Tensile testing by the ASTM D638 Specimen and dimensions in figure 8. A Figure 2 shows the dimensions of the tensile test component.

Fig. 8. Tensile Testing Setup

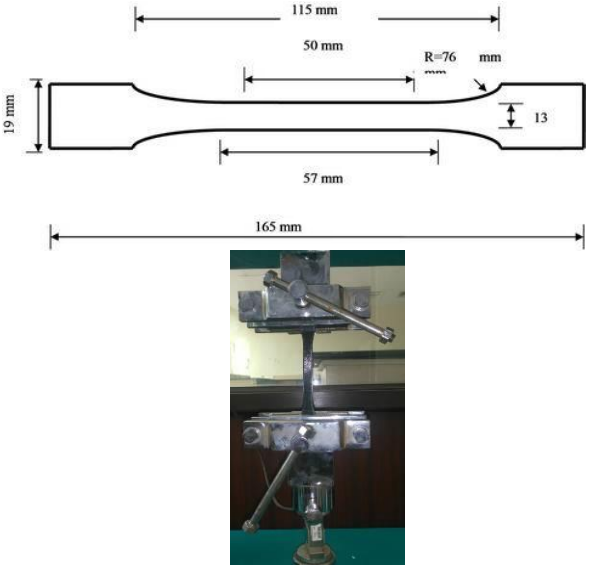


Fig. 9. ASTM D638 specimen for Tensile Test

4.2 Compressive Rockwell Hardness Test

A Figure 10 shows the Rockwell hardness of PSI Sales Pvt Ltd. (THR 150). The Rockwell hardness of plastic ASTM D785-08 is used and size of the specimen is 25 x 25 x 6 mm in thickness.

Fig. 10. Rockwell Hardness Tester

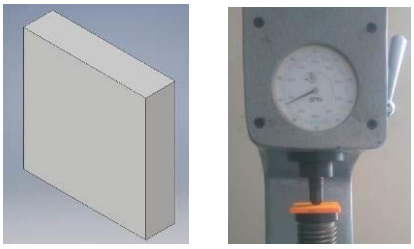


Figure 11 ASTM D785-08 specimen for Hardness Test

5. RESULT AND DISCUSSION

The table 2 shows, the experimental results of 3D printed components tensile strength, compressive strength and flexure strength. A figure 12 (a) and 12 (b) shows the results of the tensile and Rockwell test.

Fig. 12 (a). ASTM D638 tested specimen for Tensile Test

Fig. 12 (b). Tested specimen of Rockwell Hardness

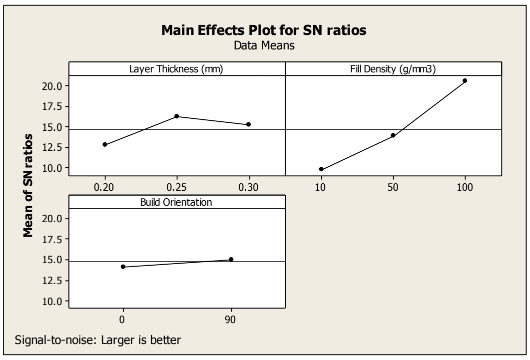


Fig. 13 (a). Main effective plot of Tensile strength

Table 2 Experimental Result of FDM component fabricated by PLA Material

Sr. No	Layer Thickness (mm)	Fill Density	Build orientation	Tensile Strength (N/mm^2)	Compressive Strength (R Scale)
1	0.2	10	0	2.02	14.66
2	0.2	50	90	4.85	66.33
3	0.2	100	90	8.43	49.00
4	0.25	10	90	3.99	93.66
5	0.25	50	90	5.12	30.66
6	0.25	100	0	13.26	45.33
7	0.3	10	90	3.60	76.33
8	0.3	50	0	4.91	73.83
9	0.3	100	90	10.85	21.33

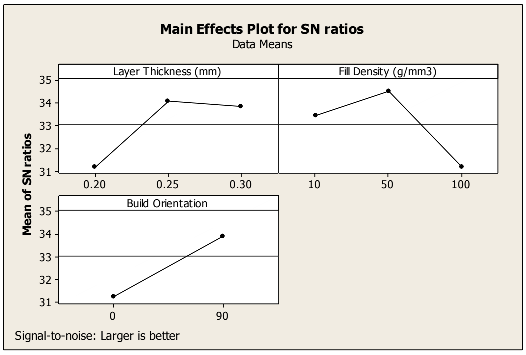


Fig13 (b). Main effective plot of Rockwell

A figure 13 (a) shows the layer thickness is increased the tensile strength is increased up to mid-range and it is slightly decreasing. The fill density is the most important factor, to increase the tensile strength. The build orientation is not much effect on the tensile strength. In figure 13 (b), compression strength is up to mid-range and then it is slightly decreased. A fill density is increased the compressive strength is decreased and build orientation also plays a vital role in compressive strength.

6. CONCLUSION

- A new Fusion Deposition methodology based machine has been designed, analyzed and developed successfully with an aim to characterize the Printed Product Properties with the design parameters of the fusion deposition machine.
- The machine design and realization parameters which influence the Printed Product Properties (PPP) are identified based on the experimental study conducted on the test & analysis of the properties and are documented in the paper.
- It has been found from the data that the thickness of the Printed Product effects the compressive strength to a larger extent, whereas the tensile strength is effected to a minor extent only.
- Tensile strength of the printed product is increased when the fill density is being increased. The effect is vice versa in the compressive strength of the same product.
- It has also found that the build orientation is also playing a major role in the PPP. While the effect of build orientation is minor it largely changes the compressive strength of Printed Product.
- The study can be conducted on a variety of printable material; however this data is limited to the study conducted on PLA materials.

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