Experimental Investigation of FDM Process for Testing of Tensile Strength

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Abstract— In this paper experimental investigation is carried out by changing various input process parameters such as layer thickness, orientation angle and filler density. Specimens are produced as per the ASTM standards by using fused deposition modelling (FDM). Tensile test is conducted for all specimens with use of tensometer and better combinations of input parameters are determined. Mathematical models are developed by using experimental data. Developed simulation models are solved by MS-EXCEL software. T, and F- tests are conducted and statistically analyzed.

Keywords— ***ABS plastic, fused deposition modelling and tensile test.***

1. INTRODUCTION

Fused deposition modelling (FDM) is a popular rapid prototyping largely used in industries to build complex geometrical efficient parts in less time. The quality and performances of parts manufactured by FDM mainly depends on different process parameters. Thus, it is essential to study process parameters to achieve desired quality characteristics in the parts developed by FDM process. Study of effect of each process parameter on response characteristics of the FDM parts helps to adjust level of process variable leading to improvement in quality of parts.

1.1 References

Gorski et al [1] have studied influence of process parameters on dimensional accuracy of parts manufactured using fused deposition modelling process, they have described that orientation angle directly effects on repeatability and strength of FDM parts is not correlated to accuracy. T. Nancharaiah et al [2] have described an experimental design technique for defining the optimum surface finish and dimensional accuracy of a part built by the fused deposition modelling (FDM) process. The design considers the effect of the process parameters layer thickness, road width, raster angle and air gap on the surface finish and dimensional accuracy. Experiments were conducted using Taguchi’s design of experiments with three level of each factor. The results are statistically analysed to determine the effective parameters. They have initiate that the layer thickness and road width affect the surface quality and part accuracy greatly. Raster angle has little effect. But air gap has more effect on dimensional accuracy and little effect on surface quality. B.H. Lee et al [3] have studied the process parameters in order to achieve optimum elastic performance of a compliant ABS prototype so as to get maximum throwing distance from the prototype. Through this they have to obtained the main process parameters that affect the performance of the prototype were found. Experiments were conducted to confirm the effectiveness of this approach. The Taguchi method, a powerful tool to design optimization for quality was used to find the optimum process parameters for fused deposition modelling (FDM) rapid prototyping machine that was used to produce acrylonitrile butadiene styrene (ABS) compliant prototype. An orthogonal array, main effect, the signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) were employed. L.M. Galantucci et al [4] have studied the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) of prototypes and analyzed the roughness of FDM prototypes. They have determine that in particular the slice height and the raster width are important parameters however the tip diameter has little importance for surface running either parallel or perpendicular to the build direction. Samir Kumar Panda et al [5] have enhanced the FDM process parameters using Bacterial Foraging technique, they have studied the effects of five important process parameters such as layer thickness, orientation angle, raster angle, raster width and air gap o three responses viz., tensile, flexural and impact strength of test specimen and they require used Central Composite Design (CCD) and have authorized the models using

ANOVA and bacterial foraging technique was used to propose combination of parameter settings to attain good strength simultaneously for all responses. H. Bikas et al [6] studied the map available additive manufacturing methods based on their process mechanisms, review modelling approaches based on modelling methods and identify research gaps. J. Martinez et al [7] contribute to development, making numerical simulations of two different composite structures with a ply-level approach, and analyze obtained results. Anoop K. Sood et al [8] focuses on extensive study to understand the effect of five important parameters such as layer thickness, part build orientation, raster angle, raster width and air gap on the compressive stress of test specimen. O.S. Carneiro et al [9] This strategy enables a true comparison between parts printed with parts manufactured by compression molding, using the same grade of raw material. Printed samples were mechanically characterized and the influence of filament orientation, layer thickness, infill degree and material was assessed. Regarding the latter, two grades of PP were evaluated: a glass-fiber reinforced and a neat, non-reinforced, one. Sung-Hoon Ahn et al [10] has described characterizes the properties of ABS parts fabricated by the FDM 1650. Using a Design of Experiment (DOE) approach, the process parameters of FDM, such as raster orientation, air gap, bead width, color, and model temperature were examined. Tensile strengths and compressive strengths of directionally fabricated specimens were measured and compared with injection molded FDM ABS P400 material. From literature review, the process parameter filler density is not used in previous work and aim of the paper is to study the effect of process parameters like layer thickness, orientation angle and filler density by using FDM on ABS plastic material.

2. EXPERIMENTAL PROCEDURE

Parts to be manufactured were modelled using NX modelling software and transferred as STL file. Parts were fabricated using Dimension 1200es 3D printer. The material used for part fabrication was acrylonitrile butadiene styrene (ABS). The tensile test was performed using Tensometer with capacity of 20 tons on rectangular bar specimen as per ASTM as shown in Figure 1. Manufacturing time is taken by the 3D printer to create the parts using FDM technology. The test specimens after being manufactured using FDM process are shown in Figure 2. Figure 3 shows the layout of input parameters acting upon response characteristics.

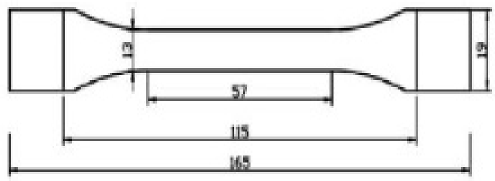

Figure1: Dimensions of tensile test specimen.

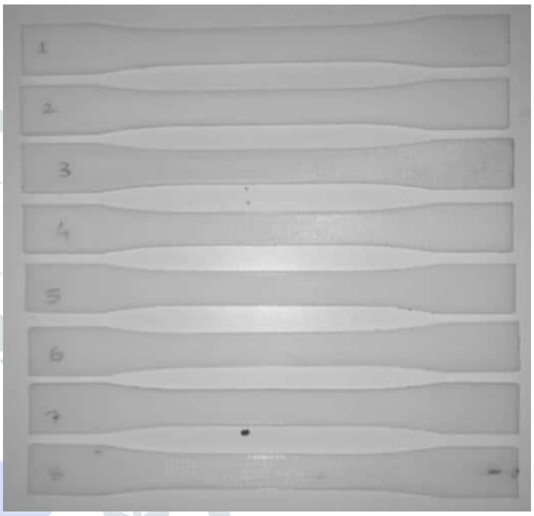

Figure 2: Specimens for ultimate tensile strength.

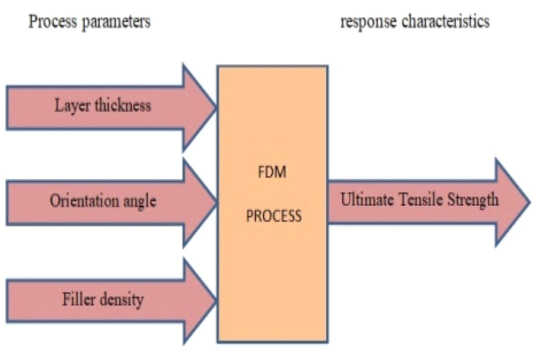

Figure 3: Experimental process layout.

2.1 Experimental details

In this experimental process, process variables are set as per testing plan as shown in Table 1. The material used for test specimen fabrication is ABS plastic. The specimens are fabricated using FDM technique in Dimension 1200es 3D printing machine for tensile test.

Table 1 Parameters and their levels

S. No	Parameter	Unit	Level 1	Level 2
1	Layer thickness	mm	0.254	0.3302
2	Orientation angle	degree	0	30
3	Filler density	percentage	75	100

Table 2 represents the input parameters effect on output parameter. Tensile test is conducted for all specimens and results are tabulated. Based on the results optimum value is obtained at a specimen with layer thickness of 0.254mm having orientation angle 0^0 and filler density 100% got highest ultimate tensile strength 33.86 N/mm^2.

Table 2: Input parameters effect on output parameters

Parameters				Results
S. No	Layer thickness (mm)	Orientation angle (degree)	Filler density (percentage)	Ultimate tensile strength (N/mm^2)
1	0.254	0	100	33.86
2	0.254	0	75	27.66
3	0.254	30	100	31.46
4	0.254	30	75	30.66
5	0.3302	0	100	31.46
6	0.3302	0	75	26.93
7	0.3302	30	100	29.66
8	0.3302	30	75	27.33

Figure 4 shows the output. It is obtained by using input parameters "layer thickness, orientation angle and filler density" respectively and ultimate tensile strength is output parameter.

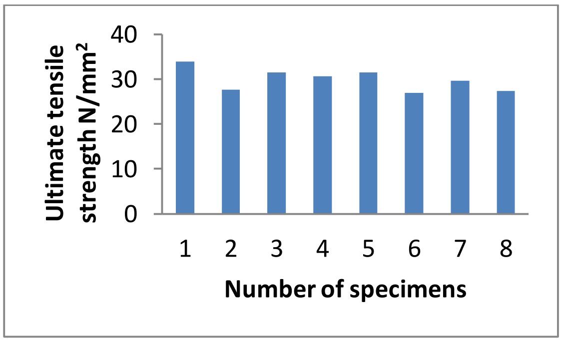

Figure 4: Experimental results.

Above graph shows the output. It is obtained by using input parameters "layer thickness, orientation angle and filler density" respectively and ultimate tensile strength is output parameter.

3. RESULTS AND DISCUSSIONS

3.1 Regression analysis

The regression analysis is carried out to find statistically significance parameters and proportion of contribution of these factors on ultimate tensile strength (UTS). Mathematical equations are developed between independent variables (layer thickness, orientation angle and filler density) and dependent variable (tensile strength) and these mathematical equations are solved by using MS-EXCEL software and determine the analysis of R (Regression), F, and T-tests.

3.2 Consideration of variables in regression analysis

Three process variables are layer thickness, orientation angle and filler density respectively and considered as independent variables and tensile strength as dependent variable for the regression analysis. '1' is assigned for change of process parameter otherwise '0'. The variable definitions are given in Table 3.

Table 3: Regression table

S. NO	Y (Ultimate tensile strength)	X1 (Layer thickness)	X2 (orientation angle)	X3 (Filler density)
1	33.86	1	1	1
2	27.66	0	0	1
3	31.46	0	1	1
4	30.66	0	0	1
5	31.46	1	1	1
6	26.93	0	0	1
7	29.66	0	1	1
8	27.33	0	0	1

3.3 Regression equation for ultimate tensile strength

The results of regression analysis for ultimate tensile strength are shown below:

$$Y_1 = 28.145+2.1X_1+2.41X_2+0X_3$$

The F-observed value for tensile strength in the regression analysis is 6.2412 which is substantially greater than the F- critical (statistical table) value of 4.74 (at 95% confidence level and 2. 7 d. f.). Hence, the regression equation is suitable in explaining the performance of tensile strength. The t- value for constant term in the regression equation (t) is 41.59, which is greater than 2.365 (table value at 95% confidence level and 2. 7 d. f.). Each of the independent parameters is tested for statistical significance in a similar manner.

CONCLUSION

In this present experimental analysis specimens are prepared as per ASTM standards. Tensile testing is carried out and experimental results are tabulated. Determined best combination of process parameters for tensile strength.

Mathematical models are developed and solved by MS-EXCEL software and determined F-test, T-test and R (regression) values and statistically analysed.

- There is a strong co-relation between input variables and output variables.
- Process variables are significant effect on output parameters.

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