Studies on Effect of Fused Deposition Modelling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon

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Abstract: This paper discusses the process parameters for fused deposition modelling (FDM). Layer thickness, Orientation angle and shell thickness are the process variables considered for studies. Ultimate tensile strength, dimensional accuracy and manufacturing time are the response parameters. For number of experimental runs the taguchi’s L9 orthogonal array is used. Taguchis S/N ratio was used to identify a set of process parameters which give good results for respective response characteristics. Effectiveness of each parameter is investigated by using analysis of variance. The material used for the studies of process parameter is Nylon.

Key words: Fused deposition modelling; Nylon;

1. Introduction
Fused deposition modelling (FDM) is a popular RP technology largely utilise in industries to build complex geometrical efficient parts in short time. The quality and performances of parts manufactured by FDM mainly depends on several process parameters. Thus, it is essential to study process parameters to attain 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. Various organization techniques are available for study of process parameters. Among all the techniques available, Taguchi method is still so popular best outstanding to its reduced number of experimental trials and simplification. By literature survey, the process parameter shell thickness is not used in previous work and lack of work on Nylon material is found therefore the aim of the paper is to study the effect of process parameters like shell thickness, orientation angle and layer thickness by using FDM (Pramaan Mini) on Nylon 618.

Gorski et al [1] have studied influence of process parameters on dimensional accuracy of parts manufactured using fused deposition modelling process, they have reported that orientation angle directly influences on repeatability and strength of FDM parts is not related to accuracy. T. Nancharaiah et al [2] have described an experimental design technique for determining the optimum surface finish and dimensional accuracy of a part built by the Fused Deposition Modeling (FDM) process. The design investigates 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 levels for each factor. The results are statistically analyzed to determine the effective parameters. They have found 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 investigated 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 obtained the main process parameters that affect the performance of the prototype were found. Experiments were carried out to confirm the effectiveness of this approach. The Taguchi method, a powerful tool to design optimization for quality was used to find the optimal process.
parameters for fused deposition modeling (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. Process parameters have been shown to affect the Ra. They have concluded that in particular the slice height and the raster width are important parameters while the tip diameter has little importance for surfaces running either parallel or perpendicular to the build direction. A chemical post-processing treatment had been analyzed and yielded a significant improvement of the Ra of the treated specimens. The proposed chemical treatment was economic, fast and easy to use. Instead, the existing state of the art commercial systems are still operator-dependent, last several hours and have high costs. Samir Kumar Panda et al[5] have optimized 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 on three responses viz., tensile, flexural, and impact strength of test specimen and they have used Central Composite Design (CCD) and have validated the models using ANOVA and bacterial foraging technique was used to suggest combination of parameter settings to achieve good strength simultaneously for all responses. The objective of the work is to achieve maximum ultimate tensile strength, optimum dimensional accuracy, and manufacturing time using Taguchi’s L9 orthogonal array.

2. Experimental details

2.1 The Taguchi approach
The Taguchi system is a generally recognized technique that suggests a systematic and effective practice for design optimization. This is exclusively vital for rapid prototyping where production cost of prototypes is still elevated. The L9 orthogonal array is used to find number of experimental runs.

2.2 Design of Experiment (DOE) and Experimentation Setup
In this study, three important process parameters such as layer thickness, part orientation angle, and shell thickness are taken to study their effects on response characteristics such as tensile strength, dimensional accuracy and manufacturing time. Nylon was the material used for all the experiments. The layer thickness which is defined as the thickness of vertical deposited layer from the FDM nozzle as shown in Figure 1. The layer thickness process parameter is used to examine the stimulus of building thicker or thinner layers on the superiority of products.

| #Run | Parameters/Levels |
|------|-------------------|
|      | A  | B  | C  |
| 1    | 1  | 1  | 1  |
| 2    | 1  | 2  | 1  |
| 3    | 1  | 3  | 3  |
| 4    | 2  | 1  | 2  |
| 5    | 2  | 2  | 3  |
| 6    | 2  | 3  | 1  |
| 7    | 3  | 1  | 3  |
| 8    | 3  | 2  | 1  |
| 9    | 3  | 3  | 2  |
The orientation angle of part is defined as how the part should be positioned when produced as shown in Figure 2. Shell thickness is the thickness of the outside shell in the horizontal direction. This gives outer bonding strength to part shown in figure 3.

2.3 Experimental Procedure

Parts to be manufactured were modelled using Catia V5 modelling software and transferred as STL file. The STL file is introduced to FDM ultimaker software. Parts were fabricated using Pramaan mini printer invented by global 3D lab works having nozzle diameter of 0.4 microns. The material used for part fabrication was Nylon618. The tensile test was performed using Universal Testing System (UTS) with capacity of 20 tons on rectangular bar specimen as per ASTM as shown in Figure 4. Dimensional accuracy test was carried out using digital calliper by measuring specimen dimensions in the directions of X, Y and Z axes on a Cube specimen as shown in Figure 5. Manufacturing time is the time taken by the 3D printer to create the parts using FDM technology. The tests specimens after being manufactured using FDM process are shown in figure 6 and figure 7. Figure 8 shows the layout of input parameters acting upon response characteristics.
**Figure 6:** Specimens for ultimate tensile strength.

**Figure 7:** Specimens for dimensional accuracy test.

**Figure 8:** Experimental Process layout
2.4 Design of Experiment (DOE).
In this work, factors as shown Table 2 are set as per testing plan (Table 3) using design of experiment (DOE) methodology. The engineering material used for test specimen fabrication is Nylon618. The specimens are fabricated using FDM technique in a pramaan mini printer machine for respective tests. The key FDM variable parameters are reflected in this study in Table 1 to calculate the link between these parameters and the recommended response features.

Table 2: Parameters and Their Levels

| Parameter          | Symbol | Unit | Level 1 | Level 2 | Level 3 |
|--------------------|--------|------|---------|---------|---------|
| Layer thickness    | A      | mm   | 0.1     | 0.2     | 0.3     |
| Orientation angle  | B      | degree | 0     | 15      | 30      |
| Shell thickness    | C      | mm   | 0.4     | 0.8     | 1.2     |

Table 3: Input parameters that affect output parameters

| #Run | Layer thickness (mm) | Orientation angle (degree) | Shell thickness (mm) | Ultimate tensile strength (MPa) | Dimensional accuracy (mm³) | Mfg. time (min) |
|------|----------------------|-----------------------------|----------------------|--------------------------------|---------------------------|----------------|
| 1    | 0.1                  | 0                           | 0.4                  | 19.05                          | 1018.66                   | 60             |
| 2    | 0.1                  | 15                          | 0.8                  | 19.18                          | 1002.56                   | 79             |
| 3    | 0.1                  | 30                          | 1.2                  | 25.48                          | 1041.85                   | 101            |
| 4    | 0.2                  | 0                           | 0.4                  | 9.51                           | 1089.52                   | 34             |
| 5    | 0.2                  | 15                          | 0.8                  | 15.68                          | 1080.74                   | 42             |
| 6    | 0.2                  | 30                          | 1.2                  | 7.71                           | 1073.04                   | 48             |
| 7    | 0.3                  | 0                           | 0.4                  | 8.35                           | 1053.34                   | 25             |
| 8    | 0.3                  | 15                          | 1.2                  | 8.83                           | 1167.63                   | 26             |
| 9    | 0.3                  | 30                          | 0.8                  | 11.82                          | 1051.79                   | 34             |

The rationale for considering the three variable process parameters for experimentation is given here. The layer thickness is known to affect the end-product because the smaller the layer thickness the stronger the finished part will be when subjected to axial load. Part orientation angle is important because when the part is built inclined, it will have the tendency to withstand greater loading in x-direction and y-direction. Shell thickness will have the tendency to affect the internal structure of the finished product.

Using DOE approach the 9 full factorial conditions were generated as shown in Table 3 for the experimental runs. For every run, the tests were agreed out and each run in the design contains of permutation of FDM parameters levels and each run result will contain response of tensile strength (UTS), dimensional accuracy, and manufacturing time.
2.5 Cura Ultimaker:

Cura Ultimaker of version 14.09 is open source software which refers that any individual can use the software. It was used to print 3D parts using FDM process and Cura leads to change various process parameters before the parts are built and let’s to place the model where to be built within the build volume area, visualize the features of a part and also the manner in which the particular part is built.

Steps involved in Cura ultimaker:

- Part loading
- Setting of process parameters
- Slicing of layers
- Conversion of layers into G-Codes
- Fabrication

3. Results and discussions:

3.1 S/N ratio and Analysis of Variance (ANOVA)

The main effect plot for ultimate tensile strength (UTS), Dimensional accuracy (DA), and manufacturing time are as shown in the figure9. The response variables are stated in the table 3. The analysis of variance was used to found statistically significant parameters and proportion of contribution of these factors on ultimate tensile strength (UTS), Dimensional accuracy (DA), and manufacturing time. In Taguchi’s technique a loss function is used to work out the deviation between the experimental value and the desired value. This function further renovated into signal to noise ratio. Taguchi’s philosophy includes three general ways to evaluate the relationship between quality and variability. They are: Nominal is better approach, Smaller is better approach, Larger is better approach. In this present work, the maximum strength, optimum dimensional accuracy and minimum manufacturing time are the indications of improved performances.

3.2 Ultimate Tensile Strength:

Figure9 displays the key effects plot for Ultimate Tensile Strength (UTS). Based on the values of S/N ratios better values for tensile strength is obtained by larger values of S/N ratio. On the basis of analysis of S/N ratio the boosted process parameters for succeeding larger tensile strength are 0.1mm layer thickness, 30° orientation angle and 1.2mm shell thickness.

Table 4: Analysis of Variance for ultimate tensile strength

| Source               | DF | Adj SS | Adj MS | F    | P   |
|----------------------|----|--------|--------|------|-----|
| Layer thickness      | 1  | 200.80 | 200.80 | 15.20| 0.011|
| Orientation angle    | 1  | 10.94  | 10.94  | 0.83 | 0.405|
| Shell thickness      | 1  | 32.29  | 32.29  | 2.45 | 0.179|
| Error                | 5  | 66.03  | 13.21  |      |     |
| Total                | 8  | 310.06 |        |      |     |
3.3 Dimensional Accuracy:
Figure 11 shows the main effects plot for dimensional accuracy. Based on the values of S/N ratios, the optimum values for dimensional accuracy is obtained by smaller values of S/N ratio. On the root of analysis of S/N ratio the optimized process parameters for succeeding optimum dimensional accuracy are 0.1mm layer thickness, 30 degree orientation angle and 0.8 shell thickness.
Table 6: Analysis of Variance for Dimensional accuracy

| Source             | DF | Adj SS | Adj MS | F    | P    |
|--------------------|----|--------|--------|------|------|
| Layer thickness    | 1  | 7328.3 | 7328.3 | 3.72 | 0.112|
| Orientation angle  | 1  | 4.4    | 4.4    | 0.01 | 0.964|
| Shell thickness    | 1  | 1159.3 | 1159.3 | 0.59 | 0.478|
| Error              | 5  | 9843.2 | 1968.65|      |      |
| Total              | 8  | 18335.2|        |      |      |

Figure 11: S/N ratio values for Dimensional accuracy.
3.4 Manufacturing time
Figure 16 shows the main effects plot for manufacturing time. Based on the values of S/N ratios minimum time for Manufacturing is obtained by smaller values of S/N ratio. By observing analysis of S/N ratio the optimized process parameters for succeeding minimum manufacturing time are 0.3mm layer thickness, 0 degree orientation angle and 0.4mm shell thickness.

| Source            | DF | Adj SS  | Adj MS  | F     | P    |
|-------------------|----|---------|---------|-------|------|
| Layer thickness   | 1  | 4004.4  | 4004.4  | 45.15 | 0.004|
| Orientation angle | 1  | 682.7   | 682.7   | 7.70  | 0.039|
| Shell thickness   | 1  | 192.7   | 192.7   | 2.17  | 0.200|
| Error             | 5  | 443.4   | 88.65   |       |      |
| Total             | 8  | 5332.9  |         |       |      |
Process parameters were optimized for FDM process using Taguchi’s L9 orthogonal array. Significant process parameters were identified using ANOVA. The set of process parameters which give optimum results are,

For ultimate tensile strength 0.1mm layer thickness, 30° orientation angle and 1.2mm shell thickness.
For dimensional accuracy 0.1 mm layer thickness, 30° orientation angle and 0.8mm shell thickness.
For manufacturing time 0.3mm layer thickness, 0 degree orientation angle and 0.4mm shell thickness.

The percentage contribution shows the effect of process parameter on response characteristics. By noticing the all three figures10, 12, 14 we became to know that the layer thickness is the most affected process parameter on the response characteristics. Because the thinner layer thickness gives better bonding strength and gives good axial loading capability. When the orientation angle changes the bonding strength between layers is varied with layer thickness.

**Figure 13:** S/N ratio values for manufacturing time

**Figure 14:** Percentage contribution of each process parameter for Manufacturing Time
5. Reference

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