Influence of FDM Process Parameters on Build Time Using Taguchi and ANOVA Approach

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Abstract: ***Rapid prototyping refers to the technique of building objects layer by layer from the digital CAD data. FDM is an RP technique which deposits semi-molten thermoplastic polymer on to the bed to build up the objects directly from the designed CAD data. However this technique may not be effective in terms of build time when compared to other RP technique such as SLA, DLP, which limits its application in lead time product development. 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 also optimization of these parameters to obtain FDM part in lower lead time using Taguchi and ANOVA approach***

Keywords: Fused Deposition Modeling (FDM), Optimization, Taguchi Approach, Analysis Of Variance (ANOVA).

1. Introduction

FDM process is an RP technique which produces part by depositing layer by layer of molten thermoplastic on the bed .At the initial stage the digital CAD model is designed and saved as stereo lithographic file (STL) [1]. Once the STL file is generated the file contains 3D part is sliced to the required thickness. Each sliced section represents the 2D cross section of the designed model, the sliced image produces the G-code which intern control the FDM system [2].

This unique technology of producing any physical object consisting of complex geometry has invoked many designers and product developers to overcome problems of extensively producing prototype using conventional manufacturing process.

FDM consists print head consisting of heated nozzle which extrudes thermoplastic material as it travels over the bed depositing the material [3][4]. Print head travel is guided by the computer controlling the FDM machine whose travel is specified by the 2D sliced image of the model. After the first layer the head moves by the required slicing height and performs the similar operation and the cycle is repeated until the final part is manufactured. Main disadvantage that governs the FDM technique is the ineffectiveness of the system to produce part quickly as that of other RP technology. In this paper the main intension of experimentation was to conduct test to observe how the process parameters effect the build time of the FDM machine, so as to decrease the lead time of manufacturing. While preparing for building some of the process parameters are likely to affect the build time [5][6].

i. Print Speed: The speed at which the print head travels over the bed depositing materials. However more speed causes backlash effect which can induce quality defects on the finished part.

ii. Layer Thickness: It is the height of the individual sliced 3D model Figure 1. It specifies the quality output requirement of the RP part, hence the layer height is inversely proportional to the quality.

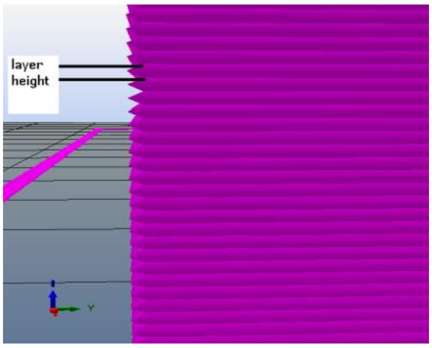

Figure 1: sliced view of the model using virtual RP simulation software.

iii. Fill density: It is the amount of material deposited within the FDM part. In this case as the infill density decreases the toughness of the part produced also decreases. Infill density is usually expressed in terms of percentage Figure 2.

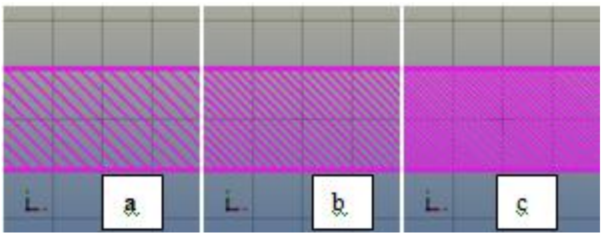

Figure 2:a Infill density when 20%, b- when 30%, c-50% for the given model

2. Experimental Detail

Figure 3: Experimental ABS based FDM sample

The following experiment samples were produced on desktop based FDM machine Figure 3. The CAD model was designed using CATIA v5 and subjected to slicing using CURA engine for the respective designed parameters as per the Table 2, 3. The parameters such as Print speed, Layer thickness, Infill density were varied in the control panel .For this experiment Acrylonitrile butadiene styrene (ABS) material having 1.75mm diameter was considered. Analytical software Minitab 15 was used for the analysis.

There have been various methods to optimize the process parameters to obtain the best results. Two approaches considered in this paper are as follows.

2.1 Taguchi Method

Most of the time conducting numerous experimentation to obtain a significant results may be very tedious job and prove costly, hence Taguchi came up with an analytical approach of studying the process parameters space by conducting lesser number of experimentation by the use of orthogonal array[8][9].

Since the paper was on minimizing the build time of FDM part so as to improve the lead time, the objective function smaller the better was considered. Experiment consists of 3 governing process parameters with 3 levels, and hence suitable orthogonal array of L9 was considered Table 2.

Table 1: Considered FDM Parameters And Its Level

Factors	Levels		
Print speed	40	55	70
Layer height	0.4	0.2	0.1
Infill density	50	30	20

Table 2: Orthogonal Array (OA) L9

Experiment no	Control factors		
	A	B	C
1	1	1	1
2	1	2	2
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

Table 3: OA with Control Factors

Experiment no	Control factors			
	Print speed	Layer height	Infill density	Build time sec
1	40	0.4	50	1876
2	40	0.2	30	2639
3	40	0.1	20	4146
4	55	0.4	30	1383
5	55	0.2	20	1941
6	55	0.1	50	5542
7	70	0.4	20	1173
8	70	0.2	50	2622
9	70	0.1	30	3722

2.2 Analysis of S/N Ratio

Due to some uncontrollable parameters in the FDM machine which may result in delay in lead time of the part ,it was of great importance of studying the response variation using signal to noise ratio[10][11]. For this experiment the objective function „smaller the better" S/N ratios were considered [1].

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad -[1]$$

Where n= sample size, and y =Build time in seconds.

Table 4: Obtained S/N Ratio values

Experiment no	S/N Ratio
1	-65.4647
2	-68.4288
3	-72.3526
4	-62.8164
5	-65.7605
6	-74.8733
7	-61.3860
8	-68.3727
9	-71.4155

The build time for different samples were calculated as per in the Table 3.

The analysis of the S/N ratio shows the optimal performance parameters was obtained at 70mm/s print speed, 0.4 mm layer thickness and 20 % infill density .Fig 4. Graph shows the effect of the process parameters on the build time.

Table 5: S/N ratio values for build time by factor level

level	Control factors		
	Print speed	Layer height	Infill density
1	-68.75	-72.88	-66.50
2	-67.82	-67.82	-67.55
3	-67.06	-63.22	-69.57
Delta	1.63	9.66	3.07
Rank	3	1	2

Table 6: Analysis of S/N ratio for build time

Sources	DF	Seq SS	Adj MS	F	C %
A	2	4.302	2.151	6.13	2.68
B	2	140..48	70.2	200.1	87.7
C	2	14.606	7.30	20.81	9.12
E	2	0.702	0.351		0.43
Total	8	160.093			100

Results shows that build time increases drastically with decrease in layer height Table 6, and factors like infill density and print speed shows significant effect on the build time. However increasing the layer height reduces the print quality.

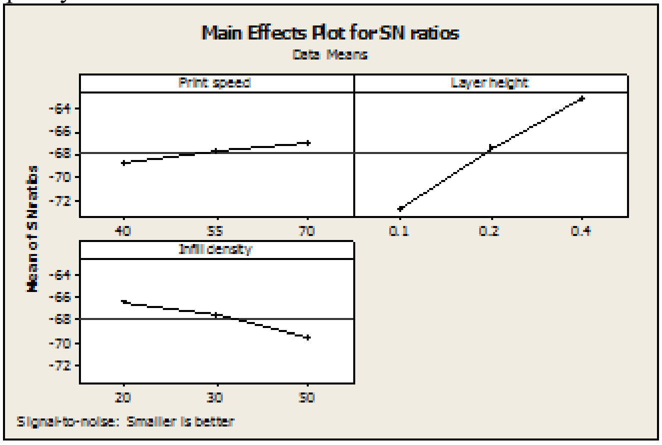

Figure 4: S/N Effects of process parameters on build time

2.3 Analysis Of Variance (ANOVA)

In order to study the effects of process parameters on the build time in FDM process [12]. From total mean S/N ratio total sum of squared deviation was calculated using [2].

$$SS_T = \sum_{i=1}^{n} (n_i - n_m)^2 \quad - [2]$$

Where n corresponds to number of trail runs in OA, n_i is the mean S/N ratio for the ith experiment. Contribution P for the build time response by the process parameters were calculate as [3]

$$p = \frac{SS_d}{SS_T} \quad - [3]$$

Where SS_d. refers to sum of squared deviation

Fisher test was considered to study which parameters have significant effect on the build time response. F ratio is termed as ratio of the mean square error to the residual error [13].

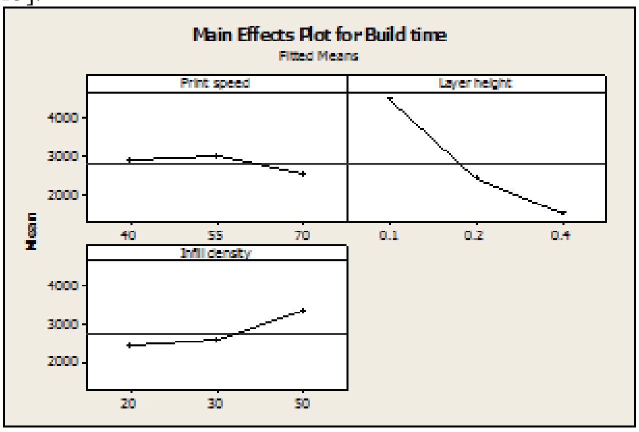

Figure 5: ANOVA Effect plots of process parameters on build time

It can be observed from Table 7 that the applied print speed (A), layer height (B) and infill density (C) affect the build time by 2.13%, 85.49%and 8.92% in the FDM, Fig 5. Hence a compromise should be done with quality of the product where lead time promotes more importance than the quality of the product at the preprocessing level.

Table 7: ANOVA results for effects of process parameters on build time

Source	DF	Seq SS	F	C
A	2	352285	0.62	2.13
B	2	14090739	24.79	85.49
C	2	1470475	2.89	8.92
E	2	568442		3.44
Total	2	16481940		
S= 533.124		R-Sq= 96.55%		

3. Conclusions

In this paper the build time for FDM samples built up with the FDM process were analyzed depending on the print speed, layer height and infill density. Therefore the samples were generated with different parameters for the tool path generation and the time taken for the build was noted down for each trial .The results show that the build time depend on the layer thickness and infill density.

The build time for a given print can be reduced by positively decreasing the layer thickness and negatively reducing the infill density. But the results also indicate that compromise between the output quality should be made in order to reduce the build time. Hence this result is best suited where quality of the product is not prior importance at the preprocessed condition.

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