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Optimization of Process Parameters in FDM Process Using Design of Experiments

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ABSTRACT : Design of experiments (DOE) is a methodology based on statistics and other disciplines for arriving at an efficient and effective planning of experiments with a view to obtain valid conclusions from the analysis of experimental data. Design of Experiments determines the pattern of observations to be made with a minimum of experimental efforts.

DOE process is implemented to FDM process to optimize the processing time. In this study three process parameters at three levels are selected. Using full factorial design totally 27 experiments are required. Using design of experiments and orthogonal array the total number of experiments are reduced to 9. Therefore the optimum processing time will be obtained in these 9 experiments. Thus 9 experiments are conducted and the experimental data obtained from the experimental trails are analyzed using S/N ratio and ANOVA analysis.

Keywords : Design of Experiments, FDM, S/N ratio, ANOVA.

I. INTRODUCTION

Design of experiments and analysis of results are engaging the attention of the Research Scholars and also practicing engineers. Many statistical tools are being used in the recent past. Present day competition in the industry is pushing for more and more emphasis on quality. Improved quality and enhancement in the market share can be achieved through preventive action rather than inspection and process control techniques. Design of experiments is one such quality improvement process which builds quality into products and process as that eliminates expensive controls and inspection. It is a valuable tool to optimize product and process design, to accelerate development cycle and to reduce development cost. This will also improve easy transition of products from R & D stage to manufacture.

DOE technique is applied to part of a manufacturing system; Rapid Prototyping (RP) should be integrated with other manufacturing technologies. In RP process different technologies exist, viz: Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), 3-D printing (3DP) etc. FDM is an important RP technique that can fabricate the prototypes out of ABS plastics. So the present work investigates effect of process parameters on FDM process using design of experiments. Finally the processing time for FDM process is optimized.

II. SELECTION OF PROCESS PARAMETERS IN FDM PROCESS

When preparing to build FDM parts, many fabrication parameters are needed in the software. To achieve optimum quality, these parameters are set differently according to requirements of applications. Therefore, the first step in the experiment was to identify the process control parameters that are likely to affect the quality of FDM parts. Three process parameters are selected at three different levels as shown in table (1).

Table 1: Selection of process parameters and their levels.

Parameter	*Notation*	*Level 1*	*Level 2*	*Level 3*
Layer thickness in mm	A	0.1778	0.254	0.330
Air gap in mm	B	–0.020	0.00	+0.020
Raster angle in degree	C	0 30	45	

III. ORTHOGONAL ARRAYS (OA)

An experiment in which all possible combination of factor levels are used is called 'full factorial experiments'. If an experiment consists of 'n' number of factors and each factor at 'X' levels. Number of trials possible (treatment combinations) = X^n

As the number of factors considered at multi levels increases, it becomes increasingly difficult to conduct the experiment with all treatment combinations. In this situation, orthogonal arrays are at our rescue (which are highly fractionalized factorial layouts), becomes useful in reducing the number of trials.

A. Selection of Orthogonal Array

The first step in selecting the correct standard OA involves counting the total degrees of freedom (dof) in the study. This count fixes the minimum number of experiments that must be run to study the factors involved.

In counting the total dof, the investigator commits 1 dof to the overall mean of the response under study. This begins the dof count as 1.

The number of dof associated with each factor under study equals one less than the number of treatment levels available for that factor. Following this the investigator considers the 2-factor interactions of interest.

One determines the total dof in the study as follows: if n_A and n_B represent the number of treatments available for two factors A and B respectively, (n_A & n_B) would equal the total combinations of treatments. Then

1 = dof to be used by the overall mean

$n_A - 1$ = dof for A

$n_B - 1$ = dof for B

$(n_A - 1) \times (n_B - 1)$ = dof required to study the A × B –factor interaction

An example will illustrate this procedure. If a design study involves three 3-level factors (A,B and C), then the dof would be as follows:

Source of dof	***Required dof***
Overall mean	1
A,B, C	3(3 – 1) = 6

Hence,

Total dof = 1 + 6 = 7

Therefore, in this example, one must conduct at least 7 experiments to be able to estimate the desired three main effects. The corresponding OA must therefore have at least 7 rows. Therefore L9 orthogonal array is selected for experimentation and shown in table (2).

Table 2: L9 Orthogonal Array for Experimental-Setup

Experiment	*Layer thickness*	*Air gap*	*Raster angle*	*Dummy level*
1	1	1	1	0
2	1	2	2	0
3	1	3	3	0
4	2	1	2	0
5	2	2	3	0
6	2	3	1	0
7	3	1	3	0
8	3	2	1	0
9	3	3	2	0

IV. EXPERIMENTATION

A trial run was performed in which a series of samples were built on the FDM Prodigy Plus machine. Totally 9 samples were produced by FDM according to the L9 array.

A. Results

The study involved 9 sample components produced by FDM Prodigy Plus machine. Experimental results for processing time were shown in figure (1). From graphs it was found that the layer thickness, air gap increases as processing time decreases and raster angle effects moderately. The DOE showed that there is interaction between layer thickness and raster angle, the interaction between air gap and raster angle is negligible.

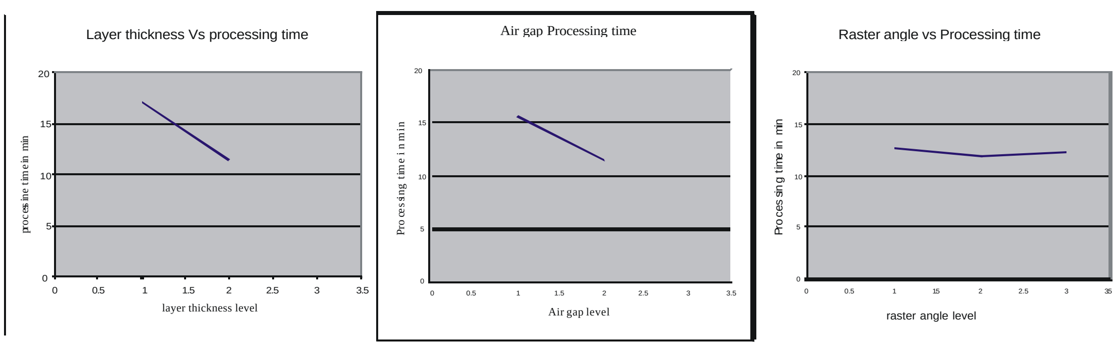

Fig. 1. Variation Processing Time with different Process Parameters.

V. ANALYSIS

A. Signal to noise (S/N) ratio

The signal to noise ratio measures the sensitivity of the quality characteristic being investigated to those uncontrollable external factors. To minimize the problem, the governing relationships for the S/N ratio in terms of the experimentally measured values of Ra, i.e.,

$$S/N \text{ ratio} = -10 \log_{10} MSD$$

Where MSD = $\Sigma(y_i - \bar{y})^2 / n$, y the target value that is to be achieved, the number of samples. The S/N ratio values obtained for the trials are listed in Table (3).

Table 3: S/N ratio for optimization of Processing Time.

Factor	*Level 1*	*Level 2*	*Level 3*	*L2 - L1*
Layer thickness	–24.57	–20.83	–18.40	3.74
Air gap	–23.59	–20.75	–19.46	2.84
Raster angle	–21.52	–20.05	–21.24	1.47

B. Anova analysis

ANOVA analysis provides significance rating of the various factors analyzed in this study. Based on the above rating, factors, which influence the objective function significantly, could be identified and proper control measures adopted. In a similar way, those factors with minimum influence could be suitably modified to suit economic considerations. The ANOVA computations are carried out based on procedure out lined in ref (5) and listed table in (4) and (5). A variable possessing the maximum value of variance is said to have the most significant effect on the process under consideration.

When the contribution of any factor is small, then the sum of squares, (SS) for that factor is combined with the error (SS_e). This process of disregarding the contribution of a selected factor and subsequently adjusting the contributions of the other factors is known as pooling. In this work the effect of raster angle and the interaction between layer thickness and raster angle, air gap and raster angle were found to be negligible effect. Hence these were pooled and the contributions of other factors were significantly changed.

Table 4: ANOVA analysis for Processing Time (with out pooling).

Factor	*Sum of SS Squares*	*dof*	*Variance, V % of contribution*	*F -test*
Layer thickness	234.33	2	117.16	66.57 55.52
Air gap	108.33	2	54.166	30.77 25.67
Raster angle	3.00	2	1.50	0.85 —
Error	6.328	3	2.11	1.79
	352	9		

Table 5: ANOVA analysis for Processing Time (with pooling).

Factor	*Sum of SS Squares*	*dof*	*Variance, V % of contribution*	*F -test*
Layer thickness	234.33	2	117.16	66.57
Air gap	108.33	2	54.166	30.77
Error	9.328	13	0.92	1.04
	352	17		

VI. CONCLUSIONS

Using Design of Experiments (DOE), the number of experiments required is greatly reduced. According to DOE only 9 experiments are sufficient to analyze the results and it was found that layer thickness and air gap effect the processing time greatly. The effect of raster angle, the interaction between layer thickness and raster angle, air gap and raster angle were found to be negligible. From ANOVA analysis it was found that the layer thickness contributes 66.57% on processing time at 99% significant level and Air gap contributes 30.77% on processing time at 95% significance. According to S/N ratio the optimum processing time obtained at level 3 of layer thickness, at level 3 of air gap and at level 2 of raster angle. Thus the trial number 9 gives the minimum processing time.

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