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Optimization of Fused Deposition Modeling (FDM) Process parameters for improving dimensional accuracy using Grey Taguchi Method

B.D. Parmar[1], N.G.Parmar[2]

[1]*Mechanical Engg Deptt. Govt.Ployechnic,Junagadh*
[2] *Mechanical Engg Deptt. Govt.Ployechnic, Kheda*

Abstract- *Rapid Prototyping(RP) technology meets the current needs in the industry. Fused Deposition modeling (FDM) is one of the key technology of RP. Dimensional accuracy of FDM produced part is major constraint. This paper presents experimental investigations on influence of important process parameters viz. Layer thickness, part orientation and air gap on dimensional accuracy of Fused Deposition Modeling (FDM) processed PC (Poly Carbonate) part. Optimum parameters setting to minimize percentage change in length, width and thickness of standard test specimen have been found out using Taguchi's parameter design. To this end, percentage change in length, width and thickness of standard test specimen of produced component are considered as a multiple responses and simultaneous optimization has been carried out with help of grey taguchi method.*

Keywords*- RP, FDM, layer thickness, raster width, air gap, Taguchi Method.*

I.INTRODUCTION

Fused deposition modeling is one of rapid prototyping system that produces prototypes from plastic materials such as PC (Polycarbonate),ABS (Acrylonitrile butadiene styrene)etc, by laying the tracks of semi-molten plastic filament onto a platform in a layer-wise manner from bottom to top.

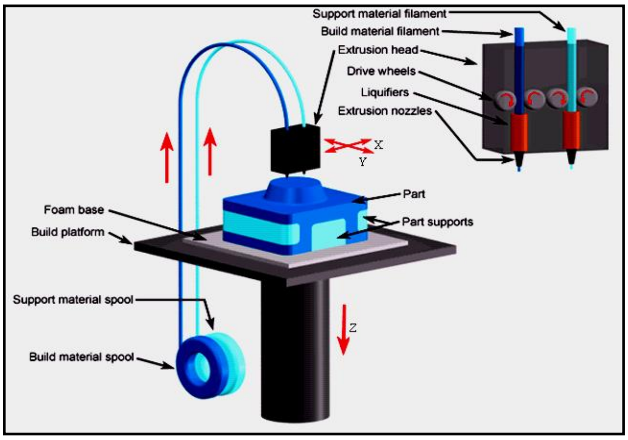

Figure1.Fused deposition modeling process

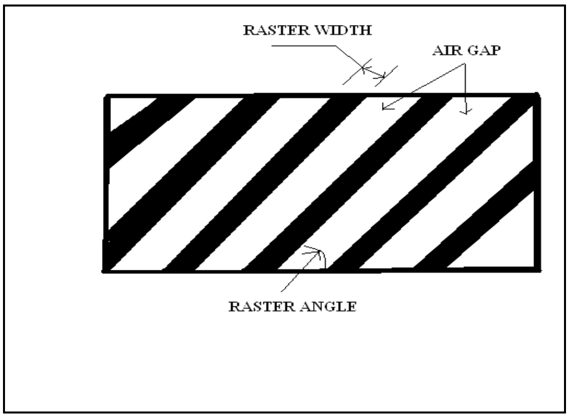

Figure2.Showing raster width, raster angle, air gap

Main process parameters of Fused deposition modeling process are as follows
1.. Layer thickness: It is a thickness of layer deposited by nozzle and depends upon the type of nozzle used.
2. Orientation: Part builds orientation or orientation referrers to the inclination of part in a build platform with respect to X, Y, Z axis. Where X and Y-axis are considered parallel to build platform and Z-axis is along the direction of part build.
3. Part raster width (raster width)**:** Width of raster pattern used to fill interior regions of part curves.
4. Raster to raster gap (air gap): It is the gap between two adjacent rasters.
The present work attempts experimental investigations to study influence of important process parameters viz., layer thickness, part orientation, air gap and raster width on dimensional accuracy of Fused Deposition Modeling (FDM) processed part.

The part produced from FDM machine does not match with dimension of CAD model due to presence of shrinkage. It is essential to study the effect of each parameter on responses such as percentage change in length, width, and thickness of specimen. A design of experiment (DOE) is used to study the effect of process parameters on responses.[1] Optimum parameters setting to minimize percentage change in length, width and thickness of standard test specimen have been found out using Taguchi's parameter design. Experimental results indicate that optimal factor settings for each performance characteristic are different.[2] Hence simultaneous optimization has been carried out with help of Grey Taguchi method

II. EXPERIMENTAL SETUP

Three factors viz., layer thickness (A), part build orientation (B) and raster to raster gap (air gap) (C) varied each at three level, as shown in Table 2, are considered. Others factors are kept at fixed level as shown in Table 1, 3D solid model of test part is modeled in PROE software and exported as STL file. [3]STL file is imported to FDM software (Insight). Test specimen as shown in figure 4 are fabricated using FDM 360 mc.[4] The material use for part fabrication is Polycarbonate[PC]. Three readings of length, width and thickness are taken per sample. Dimensions are measured using Mitutoyo vernier caliper having least count of 0.01 mm.

Figure3. Stratasys FDM 360mc Machine setup

Figure 4. Manufactured sample test specimens

Measured values show that there is shrinkage in length (L) and width (W) but thickness (T) is always more than the CAD model value. Percentage change in dimension is calculated using equation (1).

$$\%DX= ((X-X_{CAD})/ X_{CAD})*100 \quad \ldots\ldots(1)$$

Where X is the measured value of length or width or thickness, X_{CAD} represent the respective CAD model value and % DX stands for percentage change in X.

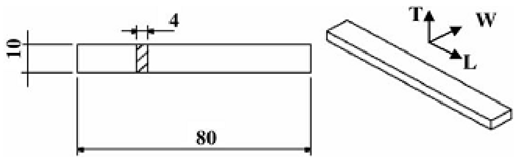

Figure 5. Showing the Dimensions of test specimen in mm

Table 1, Process parameters at fixed level

Factors	Value	Unit
Part fill style	Perimeter/ raster	-
Contour width	0.3556	mm
XY &Z shrink factor	1.007	-
Perimeter to raster gap	0.0000	mm
Raster width	0.568	mm

Table 2Process parameters to be controlled

Factors	Symbol	Level			Unit
		1	2	3	
Layer thickness	A	0.1778	0.2540	0.3302	mm

Orientation	B	0	45	90	degree
Air Gap	C	-0.004	0	0.004	mm

III. METHODOLOGY

3.1 SN Ratio

It is used to determine the influence and variation caused by each factor and interaction relative to the total variation observed in the result. S/N ratio uses a single measure, mean square deviation (MSD), which incorporates the effect of changes in mean as well as the variation (standard deviation)[5].Results behave linearly when expressed in terms of S/N ratios. Aim of experimental plan is to reduce the percentage change in length (%DL), width (%DW) and thickness (%DT), respectively. Hence, smaller the better quality characteristic is considered. S/N ratio (η) is determined

η = -10log10 (MSD) ……………….....................(2) , MSD = $\sum$ (Yavg – Yo) ^2 /n ………….....................(3)

Where, Yavg is average value of n data points and Yo is target value (Zero in our case)

3.2 Normalization

Experiment conducted provide data in SN ratio (smaller is the better) but this data should be normalized using the formula as shown below in equation (4). The normalization is carried out to give values in range of 0.1 to 0.9 for all responses to avoid chance of local maxima or minima.[6]

$$Z_{ij} = 0.8\left[\frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})}\right] + 0.1$$

, i=1,2,3,……,n , ………….. ……………………………... (4)

3.3 Grey Relational Analysis

Through the grey relational analysis, a grey relational grade is obtained to evaluate the multiple performance characteristics.[7] As a result, optimization of the complicated multiple performance characteristics can be converted into the optimization of a single grey relational grade.

Grey Relational Co-efficient

$$\gamma(y_o(k), y_i(k)) = \frac{\Delta\min + \xi\Delta\max}{\Delta_{oj}(k) + \xi\Delta\max}$$

……………………………………………………….. (5)

and Grey relational Grade $\bar{\gamma}_j = \frac{1}{k}\sum_{i=1}^{m}\gamma_{ij}$ …………………. ……………. ……………………..(6)

Table 3, L9 Orthogonal array with S/N ratio Data for Experimental plan

Factors/Levels				%DX			**SN Ratio**		
Exp No	**A**	**B**	**C**	**% DL**	**% DW**	**% DT**	**% DL**	**% DW**	**% DT**
1	1	1	1	0.95	0.31	0.63	27.8586	6.006	-10.8813
2	1	2	2	1.03	0.56	0.63	28.5808	8.7547	-10.8813
3	1	3	3	0.12	0.81	0.76	16.4669	11.5034	-9.5424
4	2	1	2	0.85	0.08	0.15	26.5882	2.5387	-15.9176
5	2	2	3	0.05	1.06	0.69	14.8739	13.6354	-10.2376
6	2	3	1	0.54	0.21	1.03	22.3259	4.8807	-7.0436
7	3	1	3	0.03	0.49	0.09	15.3233	7.99	-17.5012

8	3	2	1	0.28	0.12	0.42	18.6802	3.874	-13.0642
9	3	3	2	0.64	0.38	0.52	23.6836	2.9634	-12.0411

Table 4, Grey relational co-efficient and grey relational grade

Exp.No.	Normalization of S/N ratio			Grey relational co-efficient			GRG
	% DL	% DW	% DT	% DL	% DW	% DT	
1	0.1422	0.6500	0.3936	0.4205	0.6875	0.5206	0.5429
2	0.1000	0.4519	0.3936	0.4074	0.5510	0.5206	0.4930
3	0.8070	0.2537	0.2912	0.8554	0.4598	0.4746	0.5966
4	0.2163	0.9000	0.7789	0.4458	1.0000	0.8195	0.7551
5	0.9000	0.1000	0.3443	1.0000	0.4074	0.4974	0.6349
6	0.4651	0.7312	0.1000	0.5584	0.7651	0.4074	0.5770
7	0.8738	0.5070	0.9000	0.9545	0.5832	1.0000	0.8459
8	0.6778	0.8037	0.5606	0.7123	0.8510	0.6184	0.7272
9	0.3858	0.8694	0.4823	0.5168	0.9473	0.5684	0.6775

IV ANALYSIS OF RESULTS

In order to find optimal factor setting that maximizes response (GRG), response plot of main factors is studied. Three categories of performance characteristics are usually used in the analysis of the S/N ratio, i.e., the lower-the-better, the higher-the-better, and the nominal-the-best. In this analysis, the higher GRG is the indication of better performance. [8]The analysis was made using the software MINITAB 15, specifically used for design of experiment applications.

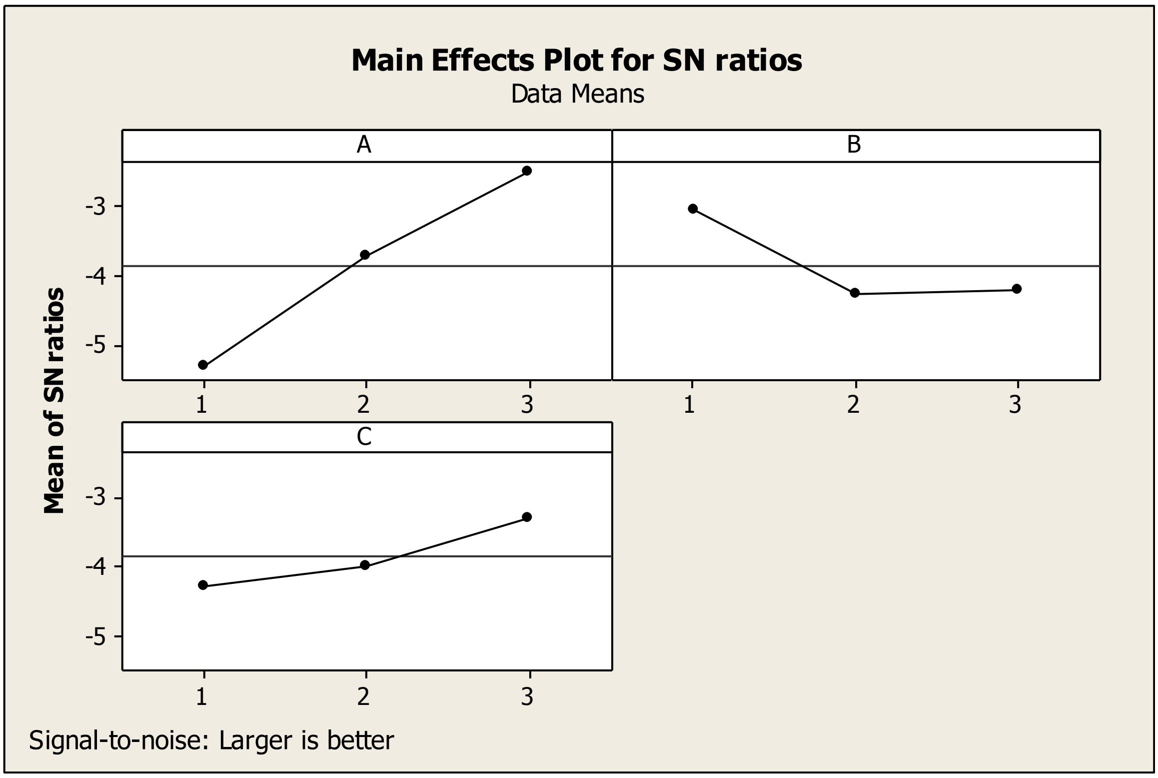

Figure 6.S/N ratio plot of all factors for GRG

Analysis of variance (ANOVA) of GRG is carried out at 95% of confidence level to check the significance of model and various terms in it as shown in Table 5. Probability of F value greater than calculated F value due to noise is indicated by P value. If P value is less , significance of corresponding term is established. The coefficient of determination (R^2) which indicates the percentage of total variation in the response explained by the terms in the model is 91.14%. Since all the factors A, B and C are having less P value, they are considered as significant process parameters. For simultaneous optimization of all characteristics,it is clear from the S/N ratio plot of all factor for GRG (Figure. 6), the factor levels should be maintained at $A_3B_1D_3$

Table 5. Analysis of variance for GRG

Source	DF	Seq SS	Adj SS	Seq MS	F	P
A	2	0.063824	0.063824	0.031912	7.11	0.123
B	2	0.018792	0.018792	0.09396	2.11	0.322
C	2	0.009141	0.009141	0.004570	1.03	0.494
Error	2	0.008915	0.008915	0.004458		
Total	8	0.100673				
S = 0.0667662 R-Sq = 91.14%						

V.CONCLUSION

In the present work, effect of three factors viz., layer thickness, part build orientation and air gap each at three levels together with all the other factors is studied on the dimensional accuracy of FDM build part. Taguchi's design of experiment is used to find the optimum factor levels and significant factors. It is found that shrinkage is dominant along the length and width of test part where as thickness is always more than the desired value. Study on the observed results show that there are large numbers of conflicting factors independently or in interaction with others may influence the dimensional accuracy. Few of them have more percentage influence as compared to others. Therefore, instead of considering only significant factors and interactions, it is proposed that fabrication process must be based on optimum factor level setting. But fabrication of part is to be done in a manner so that all the three dimensions show minimum deviation from actual value simultaneously, at the common factor level setting. Grey Taguchi method has the ability to combine all the objectives that is minimizing the percentage change in length, width and thickness into single objective known as grey relation grade. Maximization of grey relation grade shows that layer thickness of 0.3302mm, part orientation of 0°and air gap of 0.004 mm will produce overall improvement in part dimension.

VI. ACKNOWLEDGEMENT

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