Optimization of Parameters by using of Grey-Taguchi Approach in the Context of Fused Deposition Modeling

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***Abstract-* Rapid Prototyping (RP) is a technology, which enables fabrication of physical objects directly from CAD data sources. Out of all commercially available RP processes, Fused Deposition Modeling (FDM) uses heated thermoplastic filament which are extruded from the tip of nozzle in a prescribed manner in a temperature controlled environment for building the part through a layer by layer deposition method. Simplicity of operation together with the ability to fabricate parts with locally controlled properties resulted in its wide spread application not only for prototyping but also for making functional parts. However, FDM process has its own demerits related with accuracy, surface finish, strength etc. Hence, it is absolutely necessary to understand the shortcomings of the process and identify the controllable factors for improvement of part quality. For improving dimensional accuracy of the part, Taguchi's experimental design is adopted and it is found that measured dimension is oversized along the thickness direction and undersized along the length, width and diameter of the hole. It is observed that different factors and interactions control the part dimensions along different directions. The Grey-Taguchi approach has used for recommending optimal factors setting for predicting and improving overall dimension of the considered part.**

***Keywords*-Dimensional Accuracy, Rapid Prototyping, Fused Deposition Modeling, Taguchi's Design, Grey Relation Analysis**.

I. Introduction and Literature Survey

FDM (Fused Deposition Modeling) possesses the historic importance in order to eliminate on expensive tooling, flexibility, and possibility of producing so complex parts and shapes [22]. FDM has found for reducing time and cost over conventional technologies [26]. One of the current defies faced by FDM users are the quality of parts produced, which is allied with the accurate application of the specified performance [18, 21]. It is imperative in order to make out seminal performance of FDM process in respect to the variation of input process parameters, in order that, the FDM process can be carried out under the economic circumstances.

An author conducted the prevalent literature survey in the context of FDM machining process. The literature survey has been depicted [1-10], [13-15], [18, 24], [26-29]. The literature survey concluded that so few of published manuscript merely dealt with FDM process for finding the optimum setting amongst input parameters, in addition to this, to find the significant input parameter amongst considered parameters.

Therefore, author carried forward their research work in purpose to compensate research gaps.

In present report, an author exposed an ABS material and statistical methods, which are used for testing the FDM processed for a part. It presents the details of the part fabrication methodology and various tests that the samples are subjected. Dimensional accuracy, surface roughness, part mechanical strength, and wear characteristics are considered for measuring the overall quality of part in accordance with industrial desirability index. Entries tests are carried out at the temperature 23±2ºC and relative humidity 50±5% as per ISO R291:1977 (Plastics – Standard Atmospheres for Conditioning and Testing). The methodology pertains to the design of experiment technique based on Taguchi approach and then, the response surface analyses are also presented.

II. Problem Formulation:

The design freedom, elimination of tooling and the subsequent removal of many design for manufacture (DFM) related constraints helps the designers to adjust their design intent to facilitate the component or assembly to be manufactured using the capability of RP. Manufacturing of different components simultaneously and sequentially, especially for low volume production, is possible. It is a fast and flexible manufacturing with reconfigurable capability. Consequently, its gains have benefited diverse fields like medical, aerospace, automobile, construction, tooling and die making. In spite of these advantages, a number of key barriers still exist across many RP processes. For example, a new foundation for CAD systems is needed that overcomes the limitations of solid modeling in representing very complex geometries and multiple materials. Most machines are designed in such a way that they have inherent trade-offs among part size, accuracy, strength, surface smoothness and speed. There are significant variations in geometry and property among identical parts built on different machines. There is a need for industrial standards for data transfer between dissimilar CAD-RP systems, testing and characterization of part properties. Availability to be processed materials is also limited. Since most of the RP processes are patented, many of the best improvements to a particular process or machine is available to one manufacturer.

Goal based design tools are needed to integrate general design for RP rules with process specific capabilities to rapidly produce CAD geometry that meet specific design requirements. These tools should enable designers to better utilize preassembled and complex-geometry benefits of RP. There is a need to develop screening methodologies for RP materials or development of new materials or altering existing materials as per the process requirement. A much better understanding is needed for the basic physics and chemistry of RP processes to capture the complexity of the process and effect of various parameters in an interacting environment on responses.

Technical and operation related advances are needed to ensure that RP processes are as reliable and predictable as conventional manufacturing processes. Control algorithms based on predictive models of system response to process changes are needed to maximize the performance of RP machines. Developments of formalized standards for the RP industry will help to achieve continued growth and further advancements of RP technologies.

III. Specimen Fabrication:

Specimens are fabricated using FDM Vantage SE machine for respective characteristic measurement. This machine is developed and marketed by Stratasys Inc., 14950 Martin Drive, Eden Prairie, MN 55344-2020 U.S.A. As compared to other vantage series machines like vantage I, vantage X, and vantage S, vantage SE series machine has large build chamber volume (406x355x406mm). It incorporate multiple materials like ABS, ABSi (high impact grade of ABS), PC (polycarbonate), PC-ABS and PC-ISO and uses Water Works layer thicknesses that are 0.127mm, 0.178mm and 0.254mm. It has two auto load model material and two auto load support material canisters with 1510 cubic cm modeling material per canister.

IV. Statistical Approach:

FDM has significant advantages in terms of the elimination of expensive tooling, the flexibility, and the possibility of producing very complex parts and shapes [22-25]. Existing examples tend to prove that this process offer time and cost advantages over conventional technologies [26, 33, 46]. One of the current challenges faced by FDM users is the quality of parts produced, which is allied with the accurate application of the specified performance [18, 21]. This makes it essential to understand the performance of FDM process parts with the variation of process parameters so make them reliable for industrial applications. To achieve this, the present chapter describes the materials and methods used for the testing of FDM processed part under investigation. It presents the details of the part fabrication methodology and various tests that the samples are subjected. Dimensional accuracy, surface roughness, part mechanical strength, and wear characteristics are considered as measure of part quality in accordance to industrial requirements. All tests are carried out at the temperature 23±2ºC and relative humidity 50±5% as per ISO R291:1977 (Plastics-Standard Atmospheres for Conditioning and Testing). The methodology related to the design of experiment technique based on Taguchi method and the response surface analyses are also presented.

Specimens shown in Figure 4.4 are fabricated in FDM vantage SE machine as per Taguchi experimental plan as discussed in previous section. Three readings of length (L), width (W), thickness (T) and diameter (d) of circular through hole are taken per sample and mean is taken as representative value for each of these dimensions. Relative change in dimensions is calculated as per equation 4.1.

$$\Delta X = \left| \frac{X - X_{CAD}}{X_{CAD}} \right| \quad (4.1)$$

Where, X represents measured value of dimension, X_{CAD} represents the respective CAD model value, ΔX represents relative change in X.

Signal to noise (S/N) ratio is used to determine the influence and variation caused by each factor and interaction relative to the total variation observed in the result. The advantage of using S/N ratio lies in the fact that it takes into account both the effect of change in mean and variation (variance) with equal priority using a single measure known as mean square deviation (MSD). Analysis using the S/N ratio provides guidelines to select the optimum factor level based on least variation around the target and also on the average value closest to the target [199]. Objective of experiment plan is to reduce the relative change in length (ΔL), width (ΔW), thickness (ΔT) and diameter (Δd) as small as possible. Therefore "smaller the better" quality characteristic is considered. For "smaller the better" quality characteristic, S/N ratio (η) is expressed by equation 4.2.

$$\eta = 10\log_{10}(\text{MSD})$$
$$\text{MSD} = \sigma^2 + (\text{Y}_{\text{avg}} - \text{Y}_{\text{o}})^2 \quad (4.2)$$

Where, σ^2 is called variance, Y_{avg} is average value for data points and Y_{o} is a target value (zero in this case).

Experiment analysis is made using Minitab R14 software. Main effect plot for S/N ratio is used to predict the optimum factor level. Relative influence of each factor and interaction is determined by ANOVA. Calculations needed for ANOVA are shown in equation 4.3-4.6.

$$S_T = \sum_{i=1}^{N} (\eta_i - \bar{\eta})^2 \quad (4.3)$$

Where, S_T is a total sum of square, N is total number of observation and $\bar{\eta}$ is the overall mean of S/N ratio.

$$SS_j = \sum_{i=1}^{l} (\eta_{ji} - \bar{\eta})^2 \quad (4.4)$$

where SS_j is sum of square deviation of j^{th} factor, i is level of j^{th} factor.

$$V_j = \frac{SS_j}{f_j} \quad (4.5)$$

V_j and f_j is variance and degree of freedom respectively of j^{th} parameter.

$$F_j = \frac{V_j}{V_e} \quad (4.6)$$

F_j is F-statistic of j^{th} factor and V_e is variance of error.

If error degree of freedom becomes zero then it is not possible to calculate F-value and analysis of variance (ANOVA) cannot be carried out. In such cases, factors and interactions having small sum of squares are pooled together to represent error sum of squares. Significance of factor and interaction is determined by comparing calculated F-value with standard F-value at a particular confidence level (95% in present study). Once the significant factors and interactions are identified, the final step is to predict and verify improvements in observed values through the use of factor level combination (equation 4.7).

$$\begin{aligned}\eta_{pre} &= \bar{\eta} + (\bar{A}_i - \bar{\eta}) + (\bar{B}_j - \bar{\eta}) + (\bar{C}_k - \bar{\eta}) + (\bar{D}_m - \bar{\eta}) + (\bar{E}_n - \bar{\eta}) \\ &+ [(\overline{A_i B_j} - \bar{\eta}) - (\bar{A}_i - \bar{\eta}) - (\bar{B}_j - \bar{\eta})] \\ &+ [(\overline{B_j C_k} - \bar{\eta}) - (\bar{B}_j \quad \bar{\eta}) - (\bar{C}_k \quad \bar{\eta})] \\ &+ [(\overline{B_j D_m} - \bar{\eta}) - (\bar{B}_j - \bar{\eta}) - (\bar{D}_m - \bar{\eta})] \\ &+ [(\overline{B_j E_m} - \bar{\eta}) - (\bar{B}_j \quad \bar{\eta}) - (\bar{E}_m \quad \bar{\eta})] \qquad (4.7)\end{aligned}$$

η_{pre} is predicted S/N ratio value of response, $\bar{\eta}$ is overall experimental average, $\bar{A}_i, \bar{B}_j, \bar{C}_k, \bar{D}_m, \bar{E}_n$ are average response for factor A, B, C, D, E at respective level i, j, k, m, n (i, j, k, m, n = 1, 2, 3) respectively. Factors and interactions which are insignificant are usually omitted from equation 4.7.

Four performance measures such as relative change in length, width, thickness and diameter of hole are considered with an aim to minimize all responses simultaneously at the single factor level setting. However, the Taguchi method is best suited for optimization of a single performance characteristic whereas grey based Taguchi (Grey Taguchi) combines all performance characteristics (objectives) considered in the study into a single value that can be used as the single characteristic in optimization problems. Grey Taguchi method is based on grey system theory proposed by Professor Deng Ju-long from China in the year 1980 and provides approaches for analysis and abstract modeling of systems for which the information is limited, incomplete and characterized by random uncertainty. Grey relational analysis (GRA) is an impacting measurement method in grey theory that analyses uncertain relations among factors and interactions in a given system. It is actually a measurement of the absolute value of the data difference between sequences and it could be used to measure the approximate correlation between sequences. The steps involved in GRA.

From Table.3, it is observed that shrinkage is predominant in length, width, and diameter of hole but dimension increases from its desired value in thickness direction. Shrinkage may be attributed to contraction of deposited fibre. Contraction will take place in two stages. First is related with the contraction of depositing fibre when cooling from extrusion temperature to glass transition temperature. At this stage depositing fibre is free to contract. In second stage, contraction will take place in deposited fibre when cooling from glass transition temperature to build chamber temperature. During this stage deposited fibre will bound with already deposited fibre by local re-melting of previously solidified material and diffusion. As a result of constraint offer by bounded surface it is not free to contract or expand. This may lead to distortion and dimensional inaccuracy within the part.

For the case of thickness, it seems that increase is mainly due to prevention of shape error and irregular layer surface generated at the time of deposition.

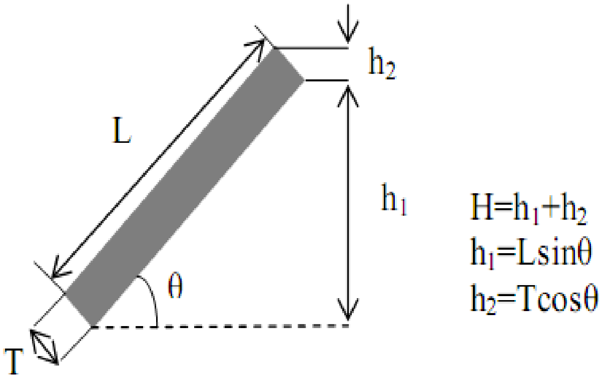

FIGURE .1 ORIENTATION OF PART WITH RESPECT TO THE BASE (H IS HEIGHT OF PART)

The material extruded out of circular cross section nozzle tip will spread sideward and forward while the layer is being deposited. This cause there cross section to change from circular to approximately elliptical and as a result surface of generated layer will not be flat as can be seen in Figure.7. Deposition of next layer on this not so flat layer will results in its irregular deposition and may increase the dimension along the thickness. Diffusion of material between neighbouring raster's also produces the bump Figure.8, because of overfilling at contact area which results in uneven layer. As a result, the next layer which will be deposited on this layer will not get the even planer surface and may result in increase in dimension along the part build direction. Further if the rasters are deposited with positive air gap as shown in Figure.9, the material from bottom layer will extrude upward.

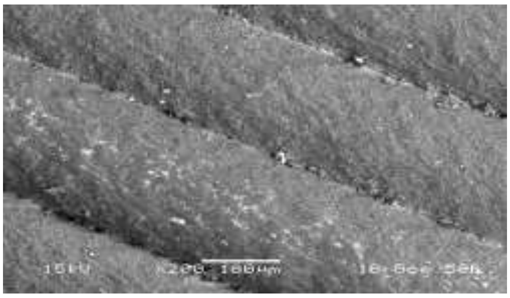

Figure .2 SEM image of part showing not so flat layer surface. (The surfaces of the test part were examined by scanning electron microscope (SEM) JEOL JSM-6480LV in the LV mode)

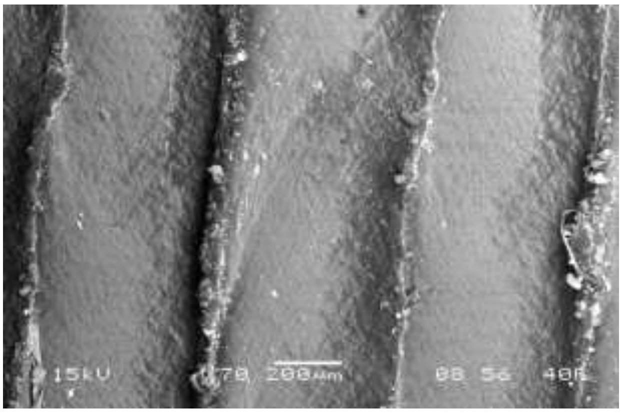

Figure .3SEM image of part showing overfilling at the contact of two raster. (The surfaces of the test part were examined by scanning electron microscope (SEM) JEOL JSM-6480LV in the LV mode)

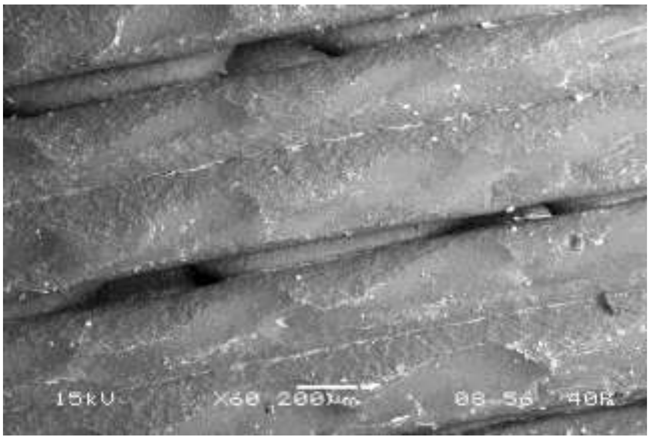

Figure .4 SEM image showing air gap (The surfaces of the test part were examined by scanning electron microscope (SEM) JEOL JSM-6480LV in the LV mode)

5. MEASUREMENTS:

5.1 Dimensional Accuracy:

Test specimen employed for measuring dimensional accuracy is shown in Figure.5. Dimensions are measured using Mitutoyoverniercalliper having least count of 0.01mm.Vernier caliper is a precision instrument that can be used to measure internal and external distances accurately. For measurement purpose it has two jaws, external and internal jaws. External jaws are used to measure external dimensions like length, width and thickness. Internal jaws are used for measuring internal dimensions of holes and cavities. Other then these two jaws there is depth measuring bar used for measuring the heights or depth. For measuring length (L), width (W) and thickness (T), the specimen to be measured is placed between external jaws and they are carefully brought together. For measuring hole diameter (d) internal jaws are adjusted carefully until they touch the internal surface of hole.

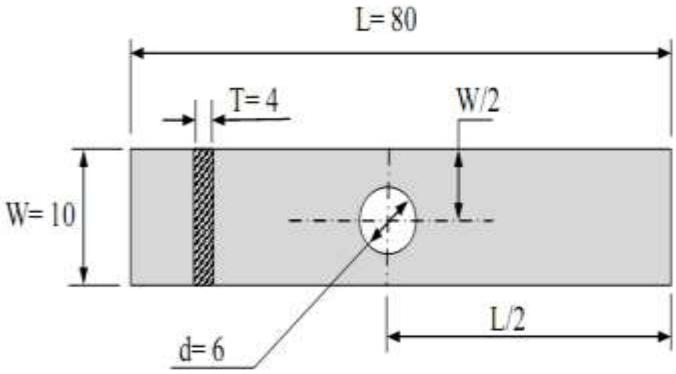

Figure .5 Test sample for dimensional analysis (all dimensions are in mm)

5.2 Design of Experiment using Taguchi design:

5.2.1. Analysis of Variance (ANOVA)

ANOVA is a fundamental step in the DOE, which is a dominant statistical tool aimed at statistically quantifying interactions between independent variables through their methodical modifications to determine their impact on the predicted variables.

The ANOVA pre requires the following assumptions:

- The treatment data must be normally distributed,
- The variance must be the same for all treatments,
- All samples are randomly selected.

Each of the sources of variation is measured using its' sum of squares'. The sum total of all the 'sums of squares' equals the total sum of squares for all the variation. The purpose is to find out how much of the variation can be explained by each factor. Thus it is possible to say that X% of the variation is due to factor A, Y% to factor B, Z% to common cause variation and so on. The total of the percentages from all sources of variation will sum to 100A hypothesis test is then carried out to see if the amount of variation from each source is statistically significant. The test works by comparing the variation due to each factor to the 'common cause variation'. Sum of Squares (SS) The sum of squared distances. SS Total is the total variation in the data. SS Re-gression is the portion of the variation explained by the model, while SS Error is the portion not explained by the model and is attributed to error. The calculations are:

$$SS\ Regression = \sum(\hat{y} - y)^2$$
$$SS\ Error = \sum(y - \hat{y})^2$$

SS Total = SS Regression + SS Error

Where y = observed response, ˆy = fitted response, and y = mean response. Minitab displays the adjusted sum of squares and sequential sum of squares. The adjusted sums of squares do not depend on the order the factors are entered into the model. It is the unique portion of SS Regression explained by a factor, given all other factors in the model, regardless of the order they were entered into the model. The sequential sums of squares depend on the order the terms are entered into the model. It is the unique portion of the sum of squares explained by a term, given any previously entered terms.

5.2.2. Degree of Freedom:

Indicates the number of independent pieces of information involving the response data needed to calculate the sum of squares. The degrees of freedom for each component of the model are:

$$DF\ Regression = p - 1$$
$$DF\ Error = n - p$$
$$Total = n - 1$$

Where, n = number of observations and p = number of terms in the model.

5.2.3. Mean Square:

In an ANOVA, the term Mean Square refers to an estimate of the population variance based on the variability among a given set of measures. The calculation for the mean square for the model terms is:

$$MST\ erm = \frac{Adj\ SSTerm}{DFTerm}$$

5.2.4. F-value

F-value is the measurement of distance between individual distributions. As the F- value goes up, the P-value goes down. F is a test to determine whether the interaction and main effects are significant. The formula for the model terms is:

$$F = \frac{MST\ erm}{MS\ (Error)}$$

The degrees of freedom for the test are:
Numerator = degrees of freedom for term
Denominator = degrees of freedom for error
Larger values of F support rejecting the null hypothesis that there is not a significant effect

5.2.5. P-value:

P-value is used in hypothesis tests to help you decide whether to reject or fail to reject a null hypothesis. The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value, if the null hypothesis is true. A commonly used cut-off value for the p-value is 0.05. For example, if the calculated p-value of a test statistic is less than 0.05, you reject the null hypothesis.

5.2.6. Model Adequacy Check:

Before the conclusions from the analysis of variance are adopted, the adequacy of the underlying model should be checked it is always necessary to

• Examine the fitted model to ensure that it provides an adequate approximation to the true system;
• Verify that none of the least squares regression assumptions are violated. Now we consider several techniques for checking model adequacy. Before the full model ANOVA, several R^2 are presented. The ordinary R^2 is

$$R^2 = \frac{SS_{regression}}{SS_{total}}$$

5.2.7. *R2(R-sq):*

Coefficient of determination; indicates how much variation in the response is explained by the model. The higher the R2, the better the model fits your data. The formula is:

$$R^2 = 1 - \frac{SS\ Error}{SS\ Total}$$

Another presentation of the formula is:

$$R^2 = \frac{SS_{regression}}{SS_{total}}$$

R^2can also be calculated as the Correlation (Y, ˆy)^2
Adjusted R^2(R-sqadj): Adjusted R^2accounts for the number of factors in your model. The formula is:

$$R^2 = 1 - \frac{MS\ (Error)}{SS\ Total/DF\ Total}$$

V. Machining Parameters:

This chapter presents experimental investigations on the influence of important process parameters such as layer thickness (A), part orientation (B), raster angle (C), air gap (D) and raster width (E) along with their interactions on dimensional accuracy of Fused Deposition Modelling (FDM) processed ABSP400 (acrylonitrile-butadiene-styrene) part. Machining parameters and their levels are presented in Table 1.and fixed levels of the parameters are shown in Table 2.

Table .1 MACHINING PARAMETERS AND THEIR LEVELS

Factor	Symbol	Levels			Unit
Layer thickness	A	0.125	0.170	0.250	mm
Orientation	B	0	15	30	degree
Raster angle	C	0	30	60	degree
Raster width	D	0.40	0.45	0.50	mm
Air gap	E	0	0.004	0.008	mm

TABLE .2 FIXED MACHINING PARAMETERS

Factor	Value	Unit
Part fill style	Perimeter Raster	-
Contour width	0.4064	mm
Part interior style	Solid normal	-
Visible surface	Normal raster	-

6.1 Influence of change in width

Measured values show that there is shrinkage in width always more than the computer aided design (CAD) model value. Change in dimension is width is showing the Figure 1. According to the this graph the layer thickness is inversely proportional to the change in width, and orientation is first decreasing up to the 15 mm then they are increasing the value of change in width. The Raset angle and Raster width in slightly change with increasing and decreasing trends. According to the Analysis of variance table the Air gap is not significant factors that are shown in Table .4.

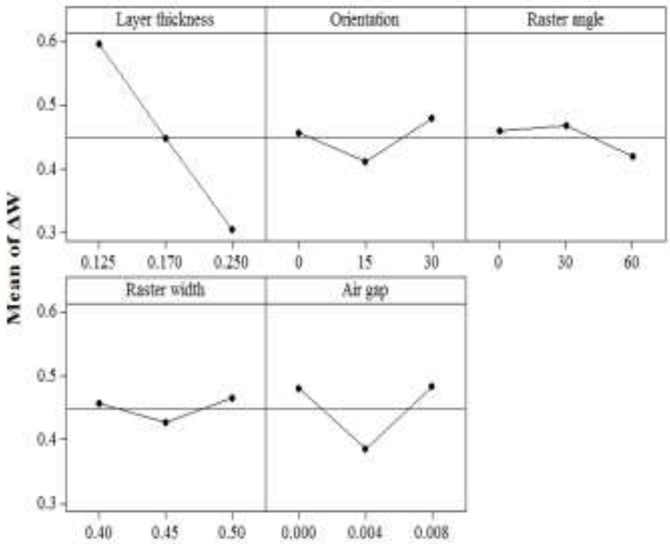

FIGURE .1 MAIN EFFECT PLOT FOR ΔW

The residual plot of change in width (ΔW)i. This residual plot in the graph and the interpretation of each residual plot indicate below.

a) Normal probability plot indicate outlines don't exist in the data, because standardized residues are between -2 and 2.
b) Residuals versus fitted values indicate the variation is constant.
c) Histogram shows the data are not skewed and not outline exist.
d) Residual versus order of the data indicate that systematic effects in the data due to time of data collection order.

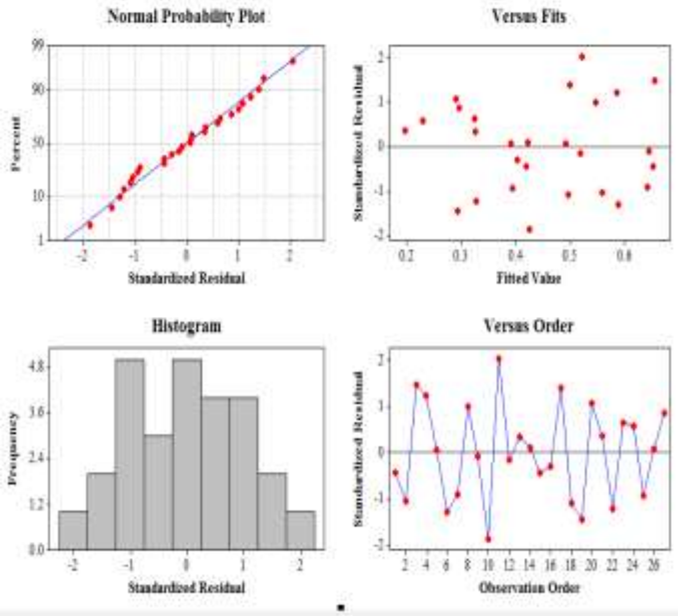

FIGURE 2 RESIDUAL PLOTS FOR ΔW

TABLE .4. ANALYSIS OF VARIANCE FOR CHANGE IN WIDTH

Source	DF	Seq SS	Adj MS	F	P
Layer thickness	2	0.383328	0.191664	7.90	0.004
Orientation	2	0.020741	0.010370	0.43	0.660
Raster angle	2	0.012099	0.006049	0.25	0.782
Raster width	2	0.006914	0.003457	0.14	0.868
Air gap	2	0.054825	0.027412	1.13	0.348
Residual Error	16	0.388346	0.024272		
Total	26	0.866252			

TABLE 5. RESPONSE TABLE FOR MEANS

Level	Layer thickness	Orientation	Raster angle	Raster width	Air gap
1	0.5963	0.4570	0.4607	0.4570	0.4800
2	0.4481	0.4126	0.4681	0.4274	0.3859
3	0.3044	0.4793	0.4200	0.4644	0.4830
Delta	0.2919	0.0667	0.0481	0.0370	0.0970
Rank	1	3	4	5	2

6.2 Influence of change in Thickness:

Measured values show that there is shrinkage in width always more than the computer aided design (CAD) model value. Change in dimension is width is showing the Figure 3. According to the this graph the layer thickness is directly proportional to the change in thickness, and orientation is first increasing the up to the 15 mm then they are decreasing the value of change in thickness. The Raster angle and Raster width in slightly change with increasing and decreasing trends. According to the Analysis of variance table the air gap is not significant factors that are shown in Table 7.

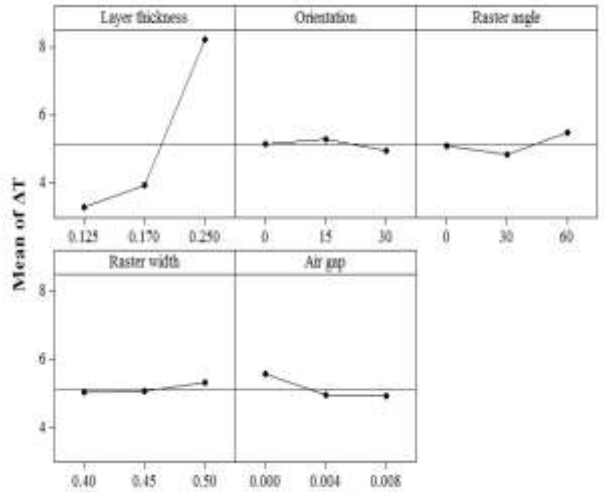

Figure.3 Main effect Plot for ΔT

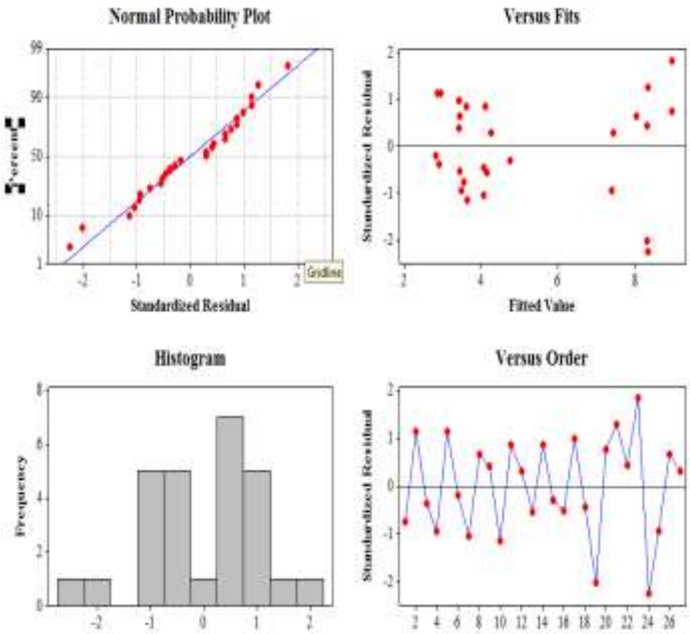

FIGURE .4 RESIDUAL PLOTS FOR ΔT

TABLE .6 ANALYSIS OF VARIANCE FOR CHANGE IN THICKNESS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	2	129.775	129.775	64.8874	53.33	0.000
Orientation	2	0.534	0.534	0.2672	0.22	0.805
Raster angle	2	2.025	2.025	1.0126	0.83	0.453
Raster width	2	0.488	0.488	0.2441	0.20	0.820
Air gap	2	2.385	2.385	1.1924	0.98	0.397
Residual Error	16	19.467	19.467	1.2167		
Total	26	154.674				
S = 1.103 R-Sq = 87.4% R-Sq(adj) = 79.5%						

TABLE .7.RESPONSE TABLE FOR MEANS

Level	Layer thickness	Orientation	Raster angle	Raster width
1	3.278	5.167	5.102	5.028
2	3.935	5.306	4.833	5.074
3	8.222	4.963	5.500	5.333
Delta	4.944	0.343	0.667	0.306
Rank	1	2	4	5

6.3. Influence of change in Length:

Measured values show that there is shrinkage in width always more than the computer aided design (CAD) model value. Change in dimension is Length is showing the Figure 5.5. According to the this graph the layer thickness is directly proportional to the change in thickness, and orientation is first decreasing the up to the 15 mm then they are decreasing the value of change in length. The Raster angle and Raster width in slightly change with increasing and decreasing trends. According to the Analysis of variance table the Air gap is not significant factors that are shown in Table .9.

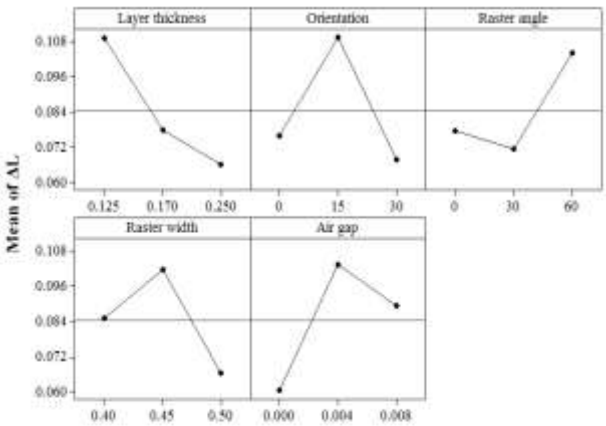

FIGURE. 5 MAIN EFFECT PLOT FOR ΔL

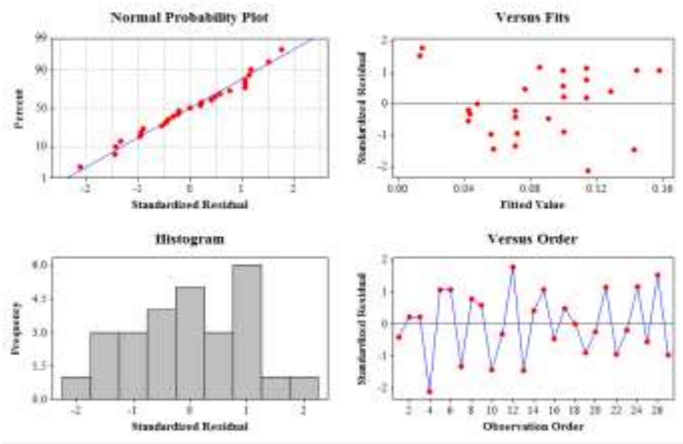

FIGURE . 6 RESIDUAL PLOTS FOR ΔL

TABLE.8 ANALYSIS OF VARIANCE FOR CHANGE IN LENGTH

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	2	0.0089	0.008956	0.004478	2.72	0.096
Orientation	2	0.0087	0.008764	0.004382	2.66	0.101
Raster angle	2	0.0054	0.005436	0.002718	1.65	0.223
Raster width	2	0.0055	0.005577	0.002789	1.69	0.215
Air gap	2	0.0086	0.008612	0.004306	2.61	0.104
Residual Error	16	0.0089	0.026352	0.001647		
Total	26	0.0636				
S = 0.04058 R-Sq = 58.6% R-Sq(adj) = 32.8%						

TABLE .9.RESPONSE TABLE FOR CHANGE IN LENGTH

Level	Layer thickness	Orientation	Raster angle	Raster width	Air gap
1	0.10926	0.07602	0.07759	0.08509	0.06046
2	0.07787	0.10944	0.07148	0.10167	0.10333
3	0.06611	0.06778	0.10417	0.06648	0.08944
Delta	0.04315	0.04167	0.03269	0.03519	0.04287
Rank	1	4	2	5	3

6.4. Influence of change in Diameters:

Measured values show that there is shrinkage in width always more than the computer aided design (CAD) model value. Change in dimension is diameter is showing the Figure .7. According to the this graph the layer thickness is directly proportional to the change in diameter, and orientation is first decreasing the up to the 15 mm then they are decreasing the value of change in diameter. The Raster angle and Raster width in slightly change with increasing and decreasing trends. According to the Analysis of variance table the Air gap is not significant factors that are shown in Table .10

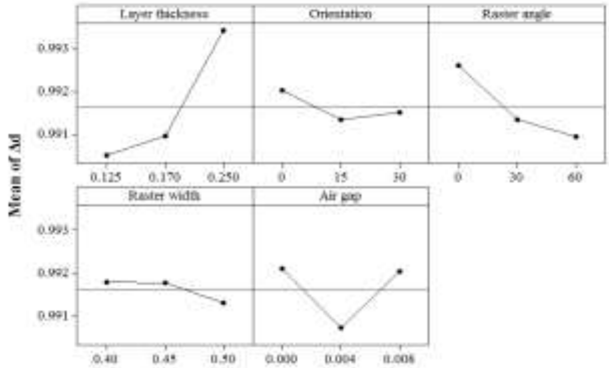

FIGURE .7 MAIN EFFECT PLOT FOR ΔD

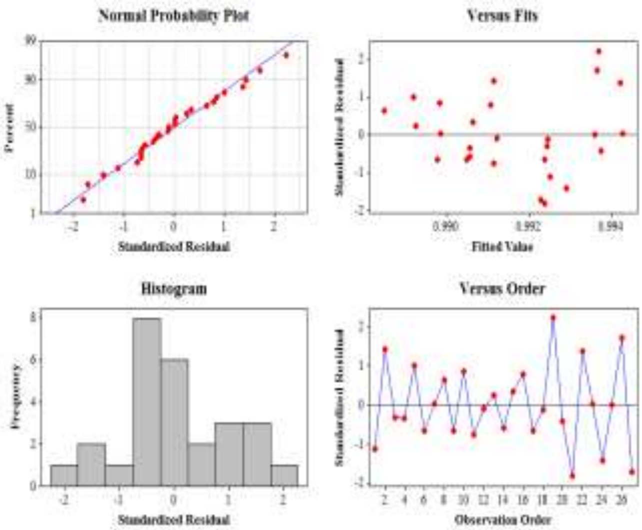

FIGURE .8 RESIDUAL PLOTS FOR ΔD

TABLE.10 ANALYSIS OF VARIANCE FOR CHANGE IN DIAMETER

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	2	0.000044	0.000044	0.000022	3.57	0.052
Orientation	2	0.000002	0.000002	0.000001	0.18	0.840
Raster angle	2	0.000014	0.000014	0.000007	1.10	0.357
Raster width	2	0.000001	0.000001	0.000001	0.11	0.896
Air gap	2	0.000011	0.000011	0.000005	0.87	0.436
Residual Error	16	0.000099	0.000099	0.000006		
Total	26	0.000171				
S = 0.002489 R-Sq = 42.1% R-Sq(adj) = 6.0%						

TABLE.11RESPONSE TABLE FOR CHANGE IN DIAMETER

Level	Layer thickness	Orientation	Raster angle	Raster width	Air gap

1	0.9905	0.9920	0.9926	0.9918	0.9921
2	0.9910	0.9913	0.9913	0.9918	0.9907
3	0.9934	0.9915	0.9909	0.9913	0.9920
Delta	0.0029	0.0007	0.0017	0.0005	0.0014
Rank	1	4	2	5	3

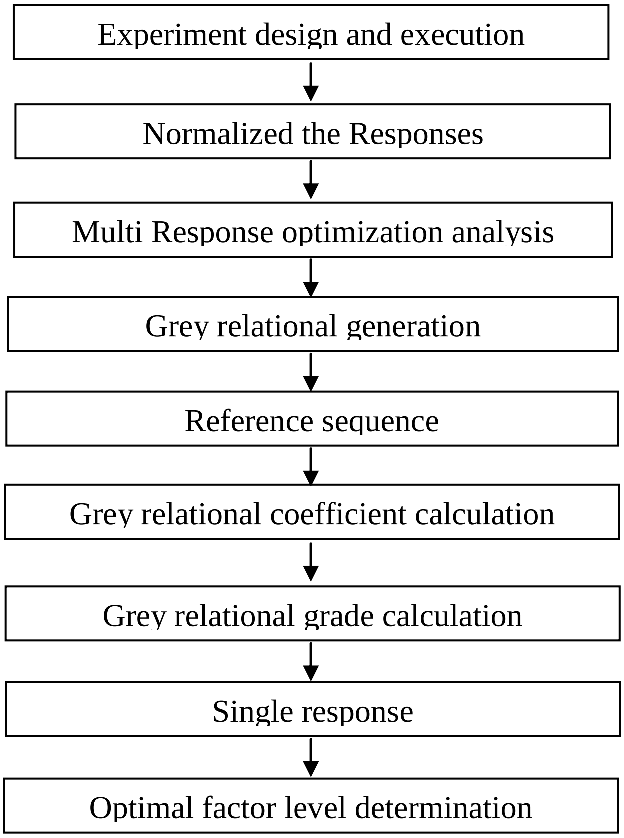

FIGURE .9 PROCEDURE FOR GREY BASED TAGUCHI METHOD

6.5. Multi- Response optimization using GRA Methods:

The multiple performance measures considered in this work are relative change in length (ΔL), width (ΔW), thickness (ΔT) and diameter of hole (Δd). All of these dimensions can be combined together into a single representative unit that is volume and change in volume can be minimized. The main disadvantage of this approach is that it may be possible that some dimensions show large deviation and some may show small deviation from the desired values. The combined effect may decrease change in volume. But actual fabrication of part should be made in such a manner that all dimensions show minimum deviation from desired value simultaneously at a common factor level setting.

Gray Relational Analysis is an impacting measurement method in Gray system theory that analyses uncertain and insufficient information between one main factor and all the other factors in a given system . In this section, the use of orthogonal array with the Gray relational analysis and methodology for multi-response optimisation is discussed (Singh et al., 2004). The optimisation of the process was performed in the following steps:

6.5.1. Calculation of GRG

The indication of the better performances in Change in width , length, diameters and thikness is ``smaller the better'' where as it. In the analysis of Gray relation for ``higher is better'' response normalising was done by Equation 3 and when the response is ``lower is better'', normalising was done by Equation 4.

$$x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (3)$$

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (4)$$

Where $x_i^*(k)$ and $x_i(k)$ the normalised data and observed data, respectively, for i^{th} experiment using k^{th} response. The smallest and largest value of $x_i(k)$ for the the k^{th} response are $\min x_i(k)$ and $\max x_i(k)$, respectively. After pre-processing the data, the Gray relation coefficient $\zeta_i(k)$ for the k^{th} response characteristics in the i^{th} experiment can be expressed as following:

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_i(k) + \zeta \Delta_{max}} \quad (5)$$

Where $\Delta_i(k)$ is the k^{th} value in Δ_i different data series. Δ_{max} and Δ_{min} are the global maximum and global minimum values in the different data series, respectively. The distinguishing coefficient ζ lies between 0 and 1, which is to expand or compress the range of GRC. It is selected by decision makers by his own judgment, and its different values usually provide different results in GRG. The mean of the range of ζ = 0.5, is chosen without any prejudice of the decision makers' own judgment. After calculating the GRCs, for n number of responses, the GRG (γ) can be calculated using Equation 6.

$$\gamma = \frac{1}{n} \sum_{i=1}^{n} \zeta_i(k) \quad (6)$$

The magnitude of γ reflects the overall degree of standardised deviation of the i^{th} original data series from the reference data series. In general, a scale item with a high value of γ indicates that the respondents, as a whole, have a high degree of favourable consensus on the particular item.

VII. CONCLUSIONS:

In the present work, effect of five factors that is, layer thickness, part build orientation, raster angle, air gap and raster width each at three levels together with the interaction of part build orientation 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 and interactions. It is found that shrinkage is dominant along the length, width and diameter of hole of test part where as thickness is always more than the desired value. To improve the dimensional accuracy, four performance characteristics such as change in length, change in width, change in thickness and change in hole diameter of test part are considered with the aim to minimize each one of them.

It is found that factor optimal settings are different for performance characteristics. To determine the optimum factor level setting which will satisfy all the four performance characteristics simultaneously, grey Taguchi method is adopted. The result of grey Taguchi method shows that layer run number 23 is the give the best results that is (thickness of 0.250 mm, part orientation of 15°, raster angle of 0° and raster width of 0.50 mm) for optimal factor settings for improving all performance characteristics simultaneously.

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TABLE 3 OBSERVATION TABLE

S.N.	Layer thickness	Orientation	Raster angle	Raster width	Air gap	ΔL	ΔW	ΔT	Δd
1	0.125	0	0	0.40	0.000	0.057500	0.600000	2.9167	0.990370
2	0.125	0	0	0.40	0.004	0.120000	0.433333	3.9167	0.993889
3	0.125	0	0	0.40	0.008	0.106667	0.833333	2.5833	0.991852
4	0.125	15	30	0.45	0.000	0.048333	0.733333	2.6667	0.989907
5	0.125	15	30	0.45	0.004	0.190833	0.500000	3.8333	0.991111
6	0.125	15	30	0.45	0.008	0.176667	0.433333	2.6667	0.989259
7	0.125	30	60	0.50	0.000	0.028333	0.533333	3.1667	0.989907
8	0.125	30	60	0.50	0.004	0.137500	0.666667	4.0000	0.989722
9	0.125	30	60	0.50	0.008	0.117500	0.633333	3.7500	0.988519
10	0.170	0	30	0.50	0.004	0.012500	0.200000	2.6667	0.991481
11	0.170	0	30	0.50	0.008	0.033333	0.766667	4.3333	0.989722
12	0.170	0	30	0.50	0.000	0.070000	0.500000	4.5000	0.991019
13	0.170	15	60	0.40	0.004	0.096667	0.366667	3.6667	0.989722
14	0.170	15	60	0.40	0.008	0.140833	0.433333	4.8333	0.989444
15	0.170	15	60	0.40	0.000	0.132500	0.366667	4.5000	0.991296
16	0.170	30	0	0.45	0.004	0.075833	0.366667	3.0000	0.992593
17	0.170	30	0	0.45	0.008	0.091667	0.666667	4.2500	0.991111
18	0.170	30	0	0.45	0.000	0.047500	0.366667	3.6667	0.992222
19	0.250	0	60	0.45	0.008	0.071667	0.120000	6.5833	0.997963
20	0.250	0	60	0.45	0.000	0.063333	0.420000	9.5833	0.992963
21	0.250	0	60	0.45	0.004	0.149167	0.240000	9.4167	0.988889
22	0.250	15	0	0.50	0.008	0.041667	0.180000	8.6667	0.996852
23	0.250	15	0	0.50	0.000	0.035833	0.400000	10.5000	0.994352
24	0.250	15	0	0.50	0.004	0.121667	0.300000	6.4167	0.990185
25	0.250	30	30	0.40	0.008	0.025000	0.280000	6.5833	0.993611
26	0.250	30	30	0.40	0.000	0.060833	0.400000	8.5833	0.996944
27	0.250	30	30	0.40	0.004	0.025833	0.400000	7.6667	0.988981

