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Parametric Optimization on FDM Machine for Percentage Change in Length Width and Thickness

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Abstract— The Rapid prototyping (RP) refers to a class of technology that can automatically construct the physical models from computer aided design (CAD) data. The biggest advantage of RP processes is that an entire 3-D (three-dimensional) consolidated assembly can be fabricated in a single setup without any tooling and fixture use. These processes are based on additive principle for part fabrication. The part fabrication methodology is independent of the complexity of the part geometry. Fused deposition modelling is one of the RP process that produced prototype from plastic material by layering track of semi molten plastic filament on to a platform in a layer wise manner from bottom to top. The quality of FDM made parts are highly depends upon various process parameters of FDM machine, hence optimization of FDM process parameters is necessary in order to improve the quality of parts like dimensional accuracy. The different experiments on FDM machine at different levels with the help of Taguchi method and other various optimization methods then we will conclude the best parameter set for dimensional accuracy for ABS material. After experiments with the help of Analysis of variance we conclude that the Layer thickness factor is highly inf.luence to Dimensional accuracy rather than Orientation angle and Raster width. We use regression technique and we conclude that this model is conforming at 95% confidence level. After optimization technique of grey relational analysis we conclude that the best combination set of Layer thickness, Orientation angle and Raster width is 0.254mm, 0degree, and 0.5064mm for Dimensional accuracy.

Key words: Rapid Prototyping, FDM Machine, ABS Material, Dimensional Accuracy, Taguchi Method, Analysis Of Variance, S/N Ratio, Regression Analysis, Grey Relational Analysis

I. INTRODUCTION

Rapid prototyping works on the basis of adding layers of material to form the desired shape. The majority of commercial rapid prototyping system build object by adding one layer after another. For simplicity, it can be visualized as stacking slices of bread until complete three-dimensional bread loaf is achieved. Rapid prototyping is a highly automated layer manufacturing process. The object is designed in any solid modeling software (CAD) and the data is converted into a standard format widely known as standard triangulation language (STL) which is understandable by the rapid prototyping machine. Rapid Prototyping machine then manufactures the object using layer manufacturing method. Upon completion of a three-dimensional model, it is subjected to post processing treatment for removing support material that was used to support overhang features during fabrication. [1]

The basic five-step of Rapid Prototyping process:

1) Create a CAD model of the design.
2) Convert the CAD model to STL format.
3) Slice the STL file into thin cross-sectional layers.
4) Construct the model one layer atop another.
5) Clean and finish the model. [2]

FDM mainly involves a feeder role or coil which into an extrusion head or nozzle. Before the material reaches the nozzle, it is heated to soften the material to a molten state when it can be deposited onto the platform. This is done with the heating elements in nozzle which melts the material. This nozzle is controlled by a computer availed manufacturing package which can be move the nozzle in horizontal, vertical directions. As the molten material ejects out of the nozzle, it is then spread onto the platform in the desired shape as a layer. The deposition platform is then lowered to a height to one layer height of the component and the deposition process is reiterated over the deposited layer. This process is reiterated layer by layer starting from the base and worked its way to the top to consummate the whole model. The deposition head of the machine mainly consists of the drive, the tip and the heating compartment. The raw material is fed into the machine with the drive which contains wheels mounted on back of head. These drive blocks are responsible for loading and unloading of the raw materials from the rolls and can be computer controlled for precision. A heating element is utilized as bubbles wrap for the heating compartment and withal blends in an L shape angle. This is done to divert the horizontal flow of the filament to a vertical direction which can be then utilized as an area to melt the material. External threading is done on the tips so that they can be screwed in with the internal screws on the heating compartment. [4]

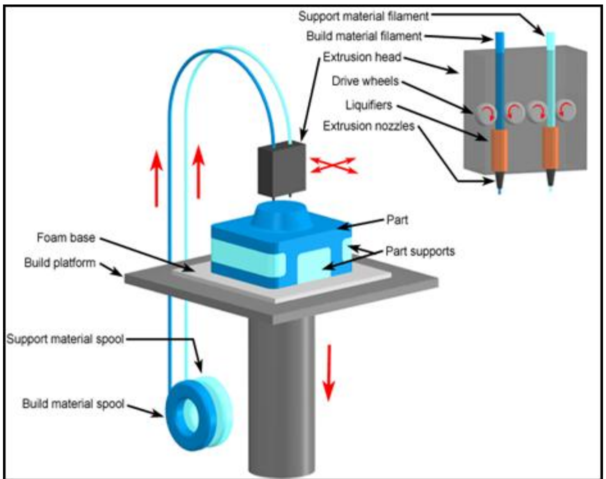

Fig. 1: Fused Deposition Modeling (FDM) [4]

II. LITERATURE SURVEY

Anoop kumar sood et al. they have investigate the effect of five important FDM parameters like Layer thickness, Part build orientation, Raster angle, Raster to raster gap (Air gap) and Raster width. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypesimprove Dimensional accuracy of Length, Width and Thickness. Methodology use Taguchi method for design of experiment, (ANN) artificial neural network and signal-to-noise (S/N) ratio was used to find out which parameter is significant over output response. After the experimental work they have conclude Layer thickness of 0.178 mm, part orientation of 0 º, road width of 0.4564 mm and air gap of 0.008 mm will produced overall improvement in part dimensions. They have dimensions are measured using Mitutoyo vernier caliper having least count of 0.01 mm. Measured values show that there is shrinkage in length (L) and width (W) but thickness (T) is always more than the CAD model value.[5]

L.M. Galantucci et al. they have investigate the effect of three important FDM parameters like Tip size, Raster width and Slice height to improve surface finish and roughness of parts use ABS material. We have measurements 18mm* 18mm* 8mm square base prisms have been manufactured using FDM machine and different levels of the input variables. The Tip values were 0.254mm (low) and 0.305mm (high), the raster width was 0.305mm (low) and 0.709mm (high), the slice height was 0.178 mm (low) and 0.254mm (high). The response variable is surface roughness Ra.After the experimental work they have conclude 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.[6]

B.H.Lee et al. they have investigate the effect of four important FDM parameters like Layer thickness, Raster angle, Air gap and Raster width. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes improve Quality achieve. Taguchi method was employed for design of experiments. Analysis of variance and signal-to-noise (S/N) ratio was used to find out which parameter is significant over output response. After the experimental work they have conclude FDM parameters i.e. layer thickness, raster angle and air gap significantly affect the elastic performance of the compliant ABS prototype.[7]

Anoop Kumar et al. they have studied the influence of important process parameter viz. layer thickness, part orientation, raster angle, and air gap and raster width along with their interaction on dimensional accuracy of fused deposition modeling (FDM) process ABS parts. They have observed that the shrinkage is dominant along with the length and width direction of built parts. But the positive deviation from the required value is observed in the thickness direction. Optimum parameter settings to minimize percentage change in length, width and thickness of standard test specimen have been found out using Taguchi's parameter design. They were used artificial neural network (ANN) for prediction purpose. Finally they conclude that for minimizing percentage change in length higher layer thickness (0.254 mm), 0 orientation, maximum raster angle (60º), medium raster width and 0.004 air gap will give desire results. On the other hand lower value of layer thickness (0.127mm), orientation (0), raster angle (0) and higher value of raster width and minimum value of air gap (0.004mm) will minimize percentage change in thickness of test specimen. They adopted grey Taguchi method to fabricate the part in such a manner that all the three dimensional shows minimum deviation from actual value. Finally maximization of grey relational grade shows that layer thickness of 0.178 mm, part orientation of 0 º, raster angle of 0 º, road width of 0.4564 mm and air gap of 0.008 mm will produced overall improvement in part dimensions.[8]

Anoop Kumar. Sood et al. they have investigate the effect of five important FDM parameters like layer thickness, part build orientation, raster angle, raster width and air gap. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes mechanical strength of test specimens. They have methodology the central composite design (CCD) for design of experiments and Optimal parameters setting for each response is determined using ANOVA was used to find out which parameter is significant over output response. After the experimental works they have conclude if the layer thickness increases, less number of the layer will be required and distortion effect will minimized, hence strength is increase. They also find out that the strength of prototype will decrease with increase in orientation because of the number of layer also increase with it. The optimal parameter setting is listed as layer thickness (A) = 0.127mm, part build orientation (B) = 29.97°, raster angle (C) = 0.045°, raster width (D) = 0.407mm and air gap (E) = 0.0000004 mm resulting in MPI (Multi-response performance inde) value of 0.9456. [9]

L. Novakova-Marcincinova et al. they have investigate Fused Deposition Modeling (FDM) rapid prototyping technology are mainly used as basic materials ABS (Acrylonitrile Butadiene Styrene), polyamide, polycarbonate, polyethylene and polypropylene.. we have investigation of ABSplus thermoplastic (Acrylonitrile Butadiene Styrene): Environmentally stable - no appreciable warpage, shrinkage or moisture absorption, 40 percent stronger than standard ABS material. or use ABS-M30 thermoplastic: 25-70 percent stronger than standard ABS material, greater tensile, impact, and flexural strength, layer bonding is significantly stronger for durable part, versatile Material: Good for form, fit and moderate functional applications.or use ABS-M30i thermoplastic: biocompatible (ISO 10993 certified) material, ideal material for medical, pharmaceutical and food packaging industries, sterilizable using gamma radiation or ethylene oxide (EtO) sterilization methods. or use ABSi thermoplastic: translucent material, ideal for automotive tail lens applications, good blend of mechanical and aesthetic properties, available in translucent natural, red and amber colours.or use PC-ABS thermoplastic (Polycarbonate ABS): most desirable properties of both PC and ABS materials, superior mechanical properties and heat resistance of PC, excellent feature definition and surface appeal of ABS, highest impact strength. They have conclude Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into design engineering, analysis and planning and tooling and manufacturing. A wide range of industries can benefit from RP and these include automotive, aerospace, biomedical, consumer, electrical and electronic products. [10] Dario Croccolo et al.they have investigate the effect of three important FDM parameters like Part Building Direction, Bead width, Raster Angle, Air gap, Layer thickness and Number of contours on along with their interaction on static strength and stiffness of fused deposition modeling (FDM) process ABS parts and Experimental tensile tests have been performed according to the ASTM D638-10 Standard. After the experimental work they have conclude that The high disagreement between the analytical and experimental results indicates that the mechanical properties must depend on the inclined rasters that have to be taken into account as well as the longitudinal beads. [11]

Pavan Kumar Gurrala et al. they have investigate Volumetric change and effect of "curl" type geometric inaccuracy on the parts made of Acrylonitrile Butadiene Styrene (ABS) specimens has been studied. The inherent inaccuracy developed during the manufacturing process has been compensated and the change in volume of the given part has been estimated. DOE was used in arriving at minimum number of experiments to be conducted and ANOVA is in analyzing and arriving at the parametric equation and they have conclued It has been found that the horizontal and vertical directions are more predominate in affecting the shrinkage and curl when compared to the model interior. [12]

Jaimin Patel at al. they have investigate the effect of three important FDM parameters like layer thickness, orientation angle and raster width on tensile strength and flexural strength of FDM fabricate test specimens. Taguchi method was employed for design of experiments. Analysis of variance and signal to noise ratio were used to find out which parameter is significant over output response. After the experimental work and ANOVA analysis they have conclude that the layer thickness and orientation angle is highly significant to response characteristics whereas raster width have a little effect. [13]

S.Dinesh kumar at al. they have investigate the effect of five important FDM parameters like Layer thickness, Air gap, Raster width, Contour width and raster orientation. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes Surface roughness. Taguchi method was employed for design of experiments. Analysis of variance and Regression analysis were used to find out which parameter is significant over output response. After the experimental work they have conclude that Negative air gap at (-0.01mm) and layer thickness at (0.254mm) raster width at (0.508mm) can be used to reduce surface roughness. Use small layer thickness to increase surface quality. Reduce support material to reduce building time and improve the surface finish.[14]

Rajendra darbar at al. they have investigate the effect of four important FDM parameters like Air gap,Raster angle, Raster width and Layer thickness. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes improve the quality. Taguchi method was employed for design of experiments. Taguchi method, (ANN) artificial neural network, signal-to-noise (S/N) ratio, analysis of variance was used to find out which parameter is significant over output response. After the review they have conclude the optimization of FDM parameter is necessary to achieve high quality parts. Taguchi method s best approach for experimental design. Orthogonal array, S/N ratio and ANOVA analysis is helpful to determine most signification factor which affect performance characteristic. ANN is use tool in order to predict the experimental result.[15]

T. Nancharaiah et al. they have investigate the effect of four important FDM parameters like layer thickness, road width, raster angle and air gap. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes improve surface finish and dimensional accuracy. Taguchi method was employed for design of experiments. Signal-to-noise (S/N) ratio, ANOVA analysis and Correlation analysis was used to find out which parameter is significant over output response. After the experimental work they have conclude Use small layer thickness to increase both surface quality and dimensional accuracy. Large bead width increases surface quality and moderate bead width increases dimensional accuracy. Consider the effect of raster angel on part accuracy and surface quality. A negative air gap can degrade surface quality and damnation tolerances. [16]

Imtiyaz Khan et al. they have investigate the effect of five important FDM parameters like layer thickness, part build orientation, raster angle, raster width and air gap. In this paper the authors study the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototypes improve Dimensional accuracy. After the Review of FDM Based Parts they have conclude Increasing slicing thickness, stair stepping errors increase number of layers in a part depends upon the layer thickness and part orientation. If number of layers is more (due to decrease in layer thickness or increase in orientation) high temperature gradient towards the bottom of part is resulted. This will increase the diffusion between adjacent rasters increase the bonding of rasters and improve the strength.[17]

Mayank Zelawat at al. In this research paper, five FDM parameters layer thickness, air gap, raster width, contour width and raster orientation. The optimum parameters settings that affect the output characteristic responses as proposed in this study such as surface roughness (Ra), dimensional accuracy (DA) and tensile strength (UTS). Air gap parameter has been proved statistically to influence the surface finish of FDM built parts, combined with layer thickness at (0.254 mm) and raster width at (0.508 mm). Negative air gap at (-0.01), the beads of ABS M-30 overlapped. This resulted in a smooth surface construction and a lower Ra value compared with other built parts with default settings. Hence, it has been found that the voids between the deposited layers caused a roughed surface. Building parts with thinner layers or narrower roads may reduce the surface roughness. it has been concluded that negative air gap was sufficient to increase the tensile strength of the building parts where by filling the porosity or voids the beads has increased significantly the bonding between the deposited.[18]

Tejendrasinh S. Raol at al. They have investigate the effect of three important FDM parameters like layer thickness, part built orientation and raster angle. In this paper the authors study the influence of FDM machining parameters on polycarbonate (PC) prototypes surface roughness. They have methodology Response surface methodology (RSM) was used to find out which parameter is significant over output response. After the experimental work they have conclude response surface methodology (central composite design matrix) and mathematical model have been developed. The response plots are analyzed to assess influence of each factor and their interaction on surface roughness. Experimental result analysis and surface plots concluded that part build orientation has the most significant effect on surface roughness followed by layer thickness. However raster angle has least significant influence on surface roughness.[19]

III. MATERIAL

From above literature survey it was found that there are very few researches done on dimensional accuracy of FDM fabricated ABS material parts so we want to do research on this material. ABS (Acrylonitrile Butadiene Styrene) is a thermoplastic resin commonly used for injection molding applications. ABS Plastic is a copolymer of Acrylonitrile, Butadiene, and Styrene, and generally possesses medium strength and performance at medium cost. It is tough, hard and rigid and has good chemical resistance and dimensional stability. Acrylonitrile is a synthetic monomer produced from propylene and ammonia butadiene is a petroleum hydrocarbon obtained from butane styrene monomers, derived from coal, is commercially obtained from benzene and ethylene from coal.

Molecular formula ($C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$ is a common thermoplastic polymer.[3]

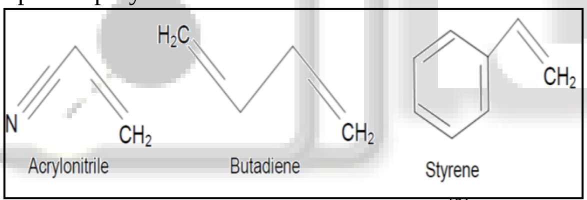

Fig. 2: Monomers In ABS Polymer [3]

IV. SPECIMEN PREPARATION

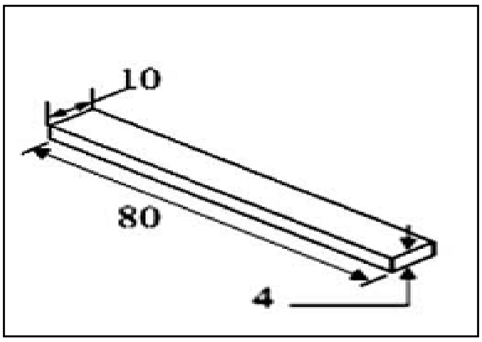

Fig. 3: Specimen Design for Dimensional Accuracy

3D solid models of prototype will model using creo parametric 2.0 software solid modelers. Then the model is converted into .STL file format.

As per Taguchi's L9 orthogonal array total nine specimens for percentage change in Length, Width and Thickness as per ASTM standard. The part will fabricate using FDM 360mc machine with ABS material. ASTM standard there is no any fix design for test specimen of dimensional accuracy. So here we are selected simple geometrical specimen design for dimensional accuracy shown in Figure 3. [5]

V. DESIGN OF EXPERIMENT

The purpose of Design of experiment is to plan, design and analyze the experiment so that the valid and objective conclusions can be drawn effectively and efficiently. The design of experiment based on

1) Factorial design
2) Taguchi method
3) Response surface method

A. *Taguchi Approach*:

The objective of Taguchi's effort is process and product design improvement through the identification of easily controllable factor and their settings, which minimize the variation in product response while keeping the mean response on target. By setting those factors at their optimal levels, the product can be made robust to changes in operating and environmental conditions. Thus more stable and higher quality products can be obtained and this is achieved during Taguchi parameter design stage by removing the bed effect of the cause rather than the cause of the bed effect. Furthermore, since the method is applied in a systematic way at a pre-production stage (off line), it can greatly reduce the number of time consuming tests needed to determine cost effective process conditions, thus saving in costs and wasted products.

Orthogonal array for L_9				
Sr. No.	Control factor	Level		
		1	2	3
1	Layer thickness (mm)	0.127	0.178	0.254
2	Orientation angle (degree)	0	15	30
3	Raster width (mm)	0.4064	0.4564	0.5064

Table 1: Selected FDM Process Parameters and Levels

Sr. No.	Layer thickness (mm)	Orientation angle (degree)	Raster width (mm)
1	0.127	0	0.4064
2	0.127	15	0.4564
3	0.127	30	0.5064
4	0.178	0	0.4564
5	0.178	15	0.5064
6	0.178	30	0.4064
7	0.254	0	0.5064
8	0.254	15	0.4064
9	0.254	30	0.4564

Table 2: Experimental Plan As Per L_9 Orthogonal Array

Percentage Change In Length, Width And Thickness Is Calculated Using This Eq.

$$\%\Delta X = \frac{|X - Xmesure|}{Xmesure} \times 100$$

VI. ANALYSIS OF VARIATION

Source	DF	Seq SS	contribution	Adj SS	Adj MS	F-Value
Layer thickness	2	0.01169	63.71%	0.00177	0.000584	8.80
Orientation angle	2	0.00039	21.11%	0.00039	0.000194	2.91
Raster width	2	0.00015	7.95%	0.00015	0.000073	1.10
Error	2	0.00013	7.24%	0.00013	0.000066	
Total	8	0.00183	100%			

Table 3: Summary of ANOVA Calculation for Percentage Change In Length

Above analysis shows the percentage contribution of individual parameters onchange in Length. The percentage contribution of Layer thickness is 63.707 %, Orientation angle 21.106 % and Raster width 7.9667 % and the error is 7.24 %.

Source	DF	Seq SS	contribution	Adj SS	Adj MS	F-Value
Layer thickness	2	0.119054	89.50%	0.119054	0.059527	15.06
Orientation angle	2	0.005550	3.89%	0.005550	0.002775	0.70
Raster width	2	0.010069	7.06%	0.010069	0.005034	1.27
Error	2	0.007906	5.54%	0.007906	0.003953	
Total	8	0.142578	100%			

Table 4: Summary of ANOVA Calculation for Percentage Change In Length

Above analysis shows the percentage contribution of individual parameters onchange in Width. The percentage contribution of Layer thickness is 83.501 %, Orientation angle 3.893 % and Raster width 7.06175 % and the error is 5.5544684 %.

Source	DF	Seq SS	contribution	Adj SS	Adj MS	F-Value
Layer thickness	2	0.46087	91.76%	0.46087	0.230438	15.14
Orientation angle	2	0.00428	0.85%	0.00428	0.002144	0.14
Raster width	2	0.00665	1.33%	0.00665	0.003329	0.22
Error	2	0.03044	6.06%	0.03044	0.015221	
Total	8	0.50226	100%			

Table 5: Summary of ANOVA Calculation for Percentage Change In Length

Above analysis shows the percentage contribution of individual parameters onchange in thickness. The percentage contribution of Layer thickness is 91.759 %, Orientation angle 0.854 % and Raster width 1.326 % and the error is 6.061 %.

The (Anova) analysis of variation for Percentage change in Length, Width and thickness with the help of Minitab 17 statistical software.

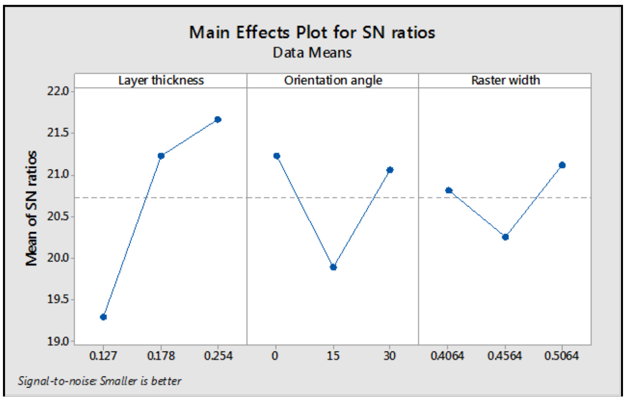

Fig. 4: Main Effect Plot (A) Percentage Change In Length, For S/N Ratio (Smaller Is Better)

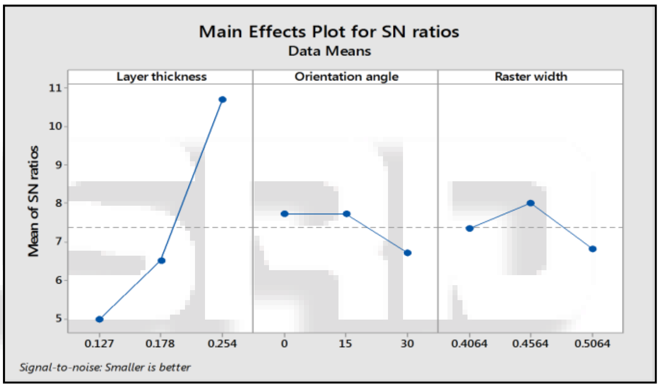

Fig. 5: Main Effect Plot (B) Percentage Change In Width For S/N Ratio (Smaller Is Better)

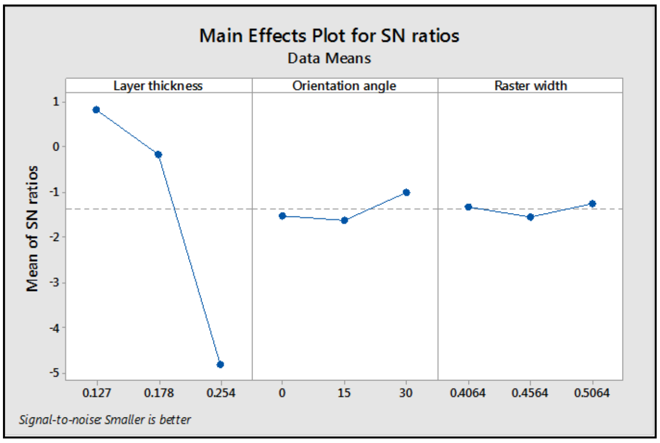

Fig. 6: Main Effect Plot (C) Percentage Change In Thickness For S/N Ratio (Smaller Is Better)

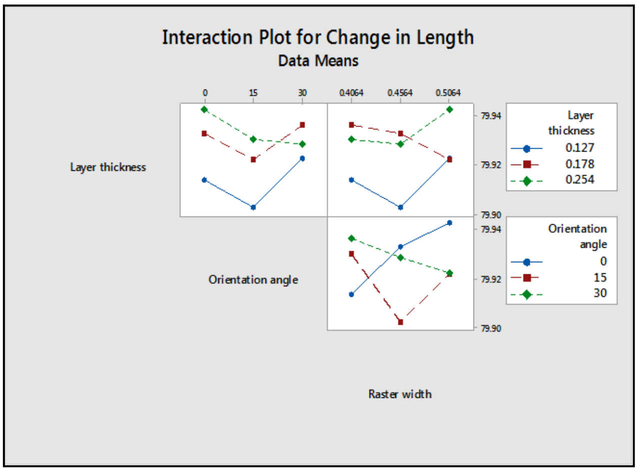

Fig. 7: Interaction Plot of Every Parameter with Each Other For Percentage Change in Length

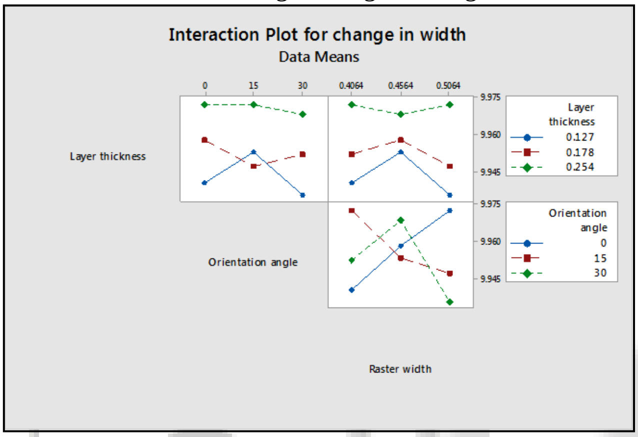

Fig. 8: Interaction Plot Of Every Parameter With Each Other For Percentage Change In Width

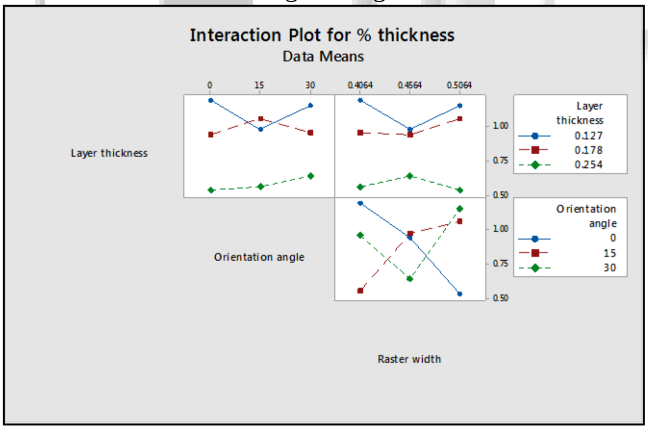

Fig. 9: Interaction Plot of Every Parameter with Each Other For Percentage Change in Thickness

VII. Regression Analysis

A. *Multiple Linear Regression Analysis:*

The multiple regression analysis expresses a linear relationship between a response variable and two or more independent or predictor variables. The multiple linear regression analysis is the extended model of simple linear regression analysis. Let us consider the variable 'Y' is the dependent variable and the variable 'Xi' is the independent or the predictor variable. So the general form of the multiple linear regression equation can be written as.

$$Y^* = a + b_1x_1 + b_2x_2 + \ldots\ldots\ldots\ldots\ldots + b_nx_n$$

Where;

Y^* = Dependent variable predicted by regression model

a = Constant of linear regression model or Y-intercept

b_i = Regression coefficients

X_i = Independent variables or predictor variables

Here, (i = 1, 2, 3, 4 …….. n)

n = Number of independent variable or predictor variable

A multiple linear regression models are developed in order to predict the values of percentage change in Length, Width and Thickness of test specimen. The developed models are reasonably accurate and can be used for prediction within limits. The regression equation for the percentage change in length, Width and Thickness are generated with the help of Minitab17 statistical software is as follow.

Error (%) = ((Experimental value - predicted value) / Experimental value) x 100

Regression analysis of percentage change in Length

Percentage change in length = 0.1426 - 0.1931 Layer Thickness + 0.000026 Orientation angle – 0.031 Raster width

Ex no	Layer thickness	Orientation angle	Raster width	% Change in length	Regression Value	Predict Error
1	0.127	0	0.4064	0.108062	0.1054748	2.391312
2	0.127	15	0.4564	0.121875	0.104318	14.40582
3	0.127	30	0.5064	0.096875	0.103158	-6.48557
4	0.178	0	0.4564	0.083938	0.09408	-12.0825
5	0.178	15	0.5064	0.0975	0.09292	4.697641
6	0.178	30	0.4064	0.08	0.09641	-20.5123
7	0.254	0	0.5064	0.071938	0.077854	-8.22403
8	0.254	15	0.4064	0.087438	0.081344	6.969281
9	0.254	30	0.4564	0.089438	0.080184	10.34661

Table 6: Comparison of Experimental Value and Regression Value

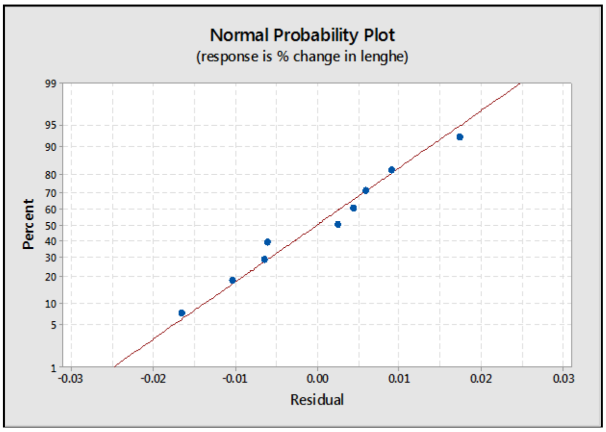

Fig. 10: Normal Probability Plots For Percentage Change In Length

Regression analysis of percentage change in Width

% width = 0.678 - 2.199 Layer thickness + 0.00167 Orientation angle + 0.335 Raster width

Ex no	Layer Thickness	Orientation angle	Raster Width	% Change in Width	Regression Value	Predict Error
1	0.127	0	0.4064	0.5945	0.534871	10.03011
2	0.127	15	0.4564	0.4690	0.576671	-22.9575
3	0.127	30	0.5064	0.6450	0.618471	4.113023
4	0.178	0	0.4564	0.4195	0.439472	-4.76091
5	0.178	15	0.5064	0.5290	0.481272	9.022306
6	0.178	30	0.4064	0.4780	0.472822	1.083264
7	0.254	0	0.5064	0.2785	0.289098	-3.80539
8	0.254	15	0.4064	0.2795	0.280648	-0.41073
9	0.254	30	0.4564	0.3195	0.322448	-0.92629

Table 7: Comparison of Experimental Value and Regression Value

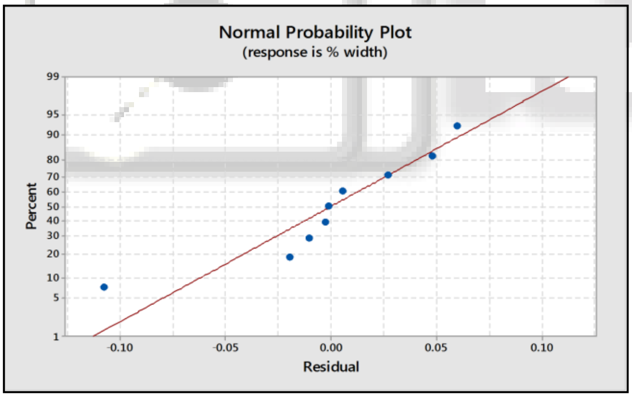

Fig. 11: Normal Probability Plots For Percentage Change In Width

Regression analysis of percentage change in Thickness

% thickness = 1.604 - 4.259 Layer thickness + 0.00100 Orientation angle + 0.138 Raster width

Ex no	Layer thickness	Orientation angle	Raster Width	Percentage change in length	Regression Value	Predict Error
1	0.127	0	0.4064	1.18875	1.11919	5.851508
2	0.127	15	0.4564	0.97375	1.14109	-17.1851
3	0.127	30	0.5064	1.1525	1.16299	-0.91021
4	0.178	0	0.4564	0.9375	0.90888	3.052672
5	0.178	15	0.5064	1.0575	0.93078	11.98257
6	0.178	30	0.4064	0.955	0.93198	2.410346
7	0.254	0	0.5064	0.53125	0.59209	-11.4536
8	0.254	15	0.4064	0.55625	0.59329	-6.66017
9	0.254	30	0.4564	0.64	0.61519	3.875438

Table 8: Comparison of Experimental Value and Regression Value

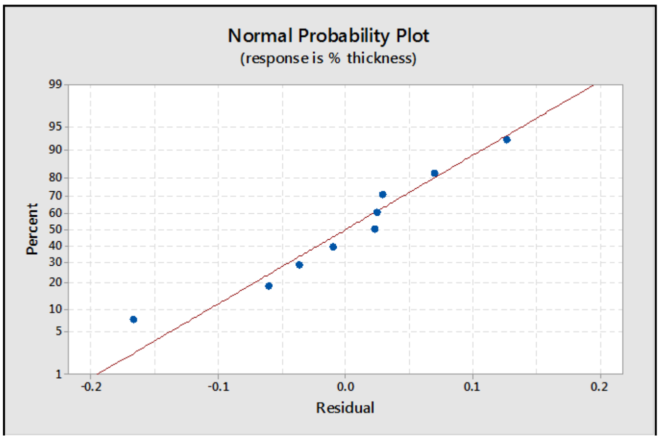

Fig. 12: Normal Probability Plots for Percentage Change in Thickness

VIII. GREY RELATIONAL ANALYSIS

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$Xik = \frac{maxyik - yi(k)}{maxyik - minyi(k)}$$

The Grey relational coefficient ξik is defined as follows

$$\xi ik = \frac{\min\Delta + \zeta\max\Delta}{\Delta i\,k + \zeta\max\Delta}\ ;\ 0 \le \xi ik \le 1$$

The grey relational grade γi can be computed as:

$$yi = \frac{1}{n}\sum_{k=1}^{n} \xi i\ (k)$$

Run order	Normalize value of percentage change in Length	Normalize value of percentage change in Width	Normalize value of percentage change in Thickness
1	0.276609	0.13779	0
2	0	0.480218	0.327619
3	0.500631	0	0.055238
4	0.759697	0.61528	0.382857
5	0.488115	0.316508	0.2
6	0.838557	0.455662	0.35619
7	1	1	1.001905
8	0.689609	0.997271	0.96381
9	0.649558	0.888131	0.83619

Table 9: Normalization Value of Percentage change in Length, Width and Thickness

Run order	Δij of percentage change in Length	Δij of percentage change in Width	Δij of percentage change in Thickness
Ideal sequence	1	1	1
1	0.723391	0.86221	1
2	1	0.519782	0.672381
3	0.499369	1	0.944762
4	0.240303	0.38472	0.617143
5	0.511885	0.683492	0.8
6	0.161443	0.544338	0.64381
7	0	0	0.001905
8	0.310391	0.002729	0.03619

Table 10: VALUE TABLE FOR Δij:- Using Δij=|x0j – Xij| X0j=1

A. Grey Relational Co-Efficient For Experimental Results:

Run order	Co efficient value of percentage change in Length	Co efficient value of percentage change in Width	Co efficient value of percentage change in Thickness
1	0.4087	0.367051	0.334603
2	0.333333	0.490301	0.428107
3	0.500316	0.333333	0.347396
4	0.675399	0.56515	0.449276
5	0.494127	0.422478	0.386081
6	0.755923	0.478772	0.438801
7	1	1	1
8	0.616986	0.994573	0.936057
9	0.58793	0.817168	0.756098

Table 11: Co Efficient Value of Percentage Change in Length, Width And Thickness

B. Grey Relational Grade for Percentage Change in Length, Width and Thickness:

Run order	Co efficient value of percentage change in Length	Co efficient value of percentage change in Width	Co efficient value of percentage change in Thickness	Grey relational grade	Grade No
1	0.4087	0.367051	0.334603	0.370118	9
2	0.333333	0.490301	0.428107	0.417247	7
3	0.500316	0.333333	0.347396	0.393682	8
4	0.675399	0.56515	0.449276	0.563275	4
5	0.494127	0.422478	0.386081	0.434229	6
6	0.755923	0.478772	0.438801	0.557832	5
7	1	1	1	1	1
8	0.616986	0.994573	0.936057	0.849205	2
9	0.58793	0.817168	0.756098	0.720399	3

Table 12: Calculation of GRC and GRG

In grey relational analysis higher the grey relational grade of experiment says that the corresponding experimental combination is optimum condition for multi-objective optimization and gives better product quality. Also from the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

From Table 12 it is found that experiment no.7 has the best multiple performance characteristic among 9 experiments, because it has the highest grey relational grade of 1.

C. Main Effect Plot of SN Ratio For Grey Relational Grade:

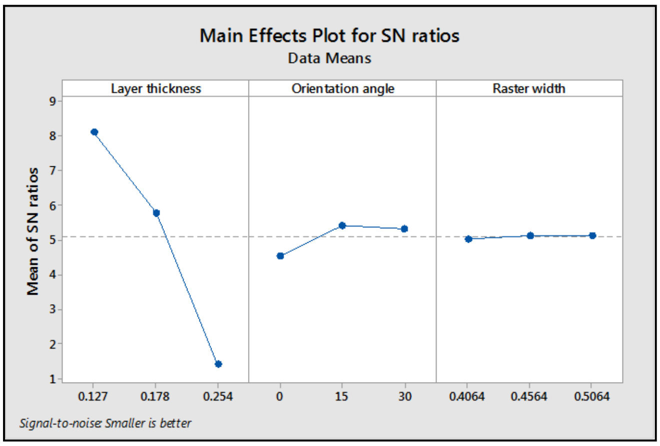

Fig. 13: Main Effect Plot of Grey Relational Grade Vs Layer Thickness, Orientation Angle and Raster Width

D. Analysis Of Variance for Grey Relational Grade:

Source	DF	Sum of square	Adj SS	Adj MS	Variation ratio	P-value	Contribution
Layer Thickness	2	0.34 4102	0.34 4102	0.17 2051	9.97	0.0 03	87.11 %
Orientation angle	2	0.01 3706	0.01 3706	0.00 6853	0.40	0.7 16	3.47%
Raster width	2	0.00 2724	0.00 2724	0.00 1362	0.08	0.9 27	0.69%
Error	2	0.03 4503	0.03 4503	0.01 7252			8.73%
Total	8	0.39 5035					100%

Table 13: ANOVA of Grey Relational Grade for percentage change in Length, Width and Thickness

From this optimization technique of Grey relational analysis we have conclude that as per grey relational grade the second combination set is the best set among nine experiments the value of it is Layer thickness of 0.254, Orientation angle of 0° and Raster width of 0.5064mm.

IX. CONCLUSION

An experimental investigation were carried out to study the influence of three important FDM process parameters like layer thickness, orientation angle and raster width on three response viz. percentage change in Length, percentage change in Width and percentage change in Thickness of test specimen fabricated by Fused Deposition Modeling process. The analysis of variance revealed that the layer thickness, orientation angle and raster width all are the influential parameters on percentage change in Length, percentage change in Width and percentage change in Thickness, but layer thickness is the main factors that contribute much more in percentage change in Length, percentage change in Width and percentage change in Thickness rather than Orientation angle and raster width. Based on experimental results, analysis of variance and the effect of process parameters we have conclusion can be drawn for FDM process as follows:

From the analysis of variance we have found that the Percentage contribution of layer thickness, orientation angle and raster width on percentage change in Length is 63.71%, 21.11% and 7.97% respectively. All the value of variance ratio and percentage contribution for percentage change in Length is tabulated in Table 3.

From the analysis of variance we have found that the percentage contribution of layer thickness, orientation angle and raster width on percentage change in Width is 83.50, 3.89 and 7.06 respectively. All the value of variance ratio and percentage contribution for percentage change in Width is tabulated in Table 4.

From the analysis of variance we have found that the percentage contribution of layer thickness, orientation angle and raster width on percentage change in Thickness is 91.76, 0.85 and 1.33 respectively. All the value of variance ratio and percentage contribution for percentage change in Thickness is tabulated in Table 5.

From SN Ratio we conclude that Increment in the layer thickness results in higher percentage change in Length, Width and Thickness of the test specimens because of the layer thickness is small more number of layers is required to fabricate the parts which cause high temperature gradient towards the bottom of part. But high temperature gradient is responsible for distortion within the layers or between the layers. Moreover, increase in number of layers increases the number of heating and cooling cycles and thus accumulation of thermal stress increases. This may results in small air gap between two adjutant layers. Hence, optimum Length, Width and Thickness is achieved.

For validation we use regression technique and we conclude that this model is conforming at 95% confidence level.

After optimization technique of grey relational analysis we conclude that the best combination set of Layer thickness, Orientation angle and Raster width is 0.254mm, 0degree, and 0.5064mm for Dimensional accuracy.

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