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OPTIMIZATION OF FUSED DEPOSITION MODELING PROCESS PARAMETER FOR BETTER MECHANICAL STRENGTH AND SURFACE ROUGHNESS

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ABSTRACT

Rapid prototyping (RP) refers to a class of technology that can automatically construct physical models from computer aided design (CAD) data. Reduction of product development cycle time is a major concern in industries for achieving competitive advantage. So, the focus of industries has shifted from traditional product development methodology to rapid fabrication techniques. The Fused deposition modeling (FDM) is a one of the rapid prototyping (RP) technology by which physical objects are created directly from CAD model using layer by layer deposition of extruded material. The quality of FDM produced parts is significantly affected by various parameters used in the process. In this present work three important process parameter of the FDM process such as layer thickness, part builds orientation and raster width are considered.. The powerful Taguchi's method is used for design of experiments because of it can be provide simplification of design plans and reduced the number of experimental runs. Specimens are prepared for compressive test and impact test as per ASTM standards. The signal-to-noise (S/N) ratio is used to get the contribution of each parameter. The validity of process parameters and response is tested by using analysis of variance (ANOVA). Through this study the main process parameter that affects the quality of prototype can be found. At this end, Artificial neural network is carried out. The ANN models are developed in order to predict compressive and impact strength of test specimen. The experimental data and data obtained by ANN is closely correlated which validated the models. After completing the experiments we have found that the mechanical properties and surface roughness of the test specimens is increasing with the increase in layer thickness and decrease in the part build orientation. The major reason for weak strength of FDM processed parts may be attributed to distortion within the layer or between the layers while building the parts due to temperature gradients.

KEYWORDS: FDM, ANN, Rapid Prototyping, Taguchi Method, Layer Thickness

INTRODUCTION

Rapid Prototyping (RP) is the process in which physical parts are created by using layer by layer deposition of material directly from the 3-Dimentional computer aided design (CAD) data. The RP process is capable of building any complicated parts in the least possible time without any extra cost due to the absence of tooling. This model is very useful for communicating the ideas with co-workers or customers and it can be used for testing purpose time. Rapid prototyping reduced the product development cycle time for faster building of physical prototype so the new product can be reach to the market as soon as possible for achieving competitive advantage. If RP is used to manufacture the part which was conventionally manufactured by injection molding, it is not necessary to consider draft angle, ejection pin, gate marks, wall thickness and parting lines for part design. This directly means whatever can be design it can be manufactured. Because of its addictive nature, RP process is capable of building parts of any complicated geometry which can not be possible with conventional method.

Fused deposition modeling (FDM) is one of the RP systems that produced the prototype from plastic materials by laying tracks of semi molten plastic filament on to a platform in a layer wise manner from bottom to top. FDM is the most widely used rapid prototyping technology The FDM technology is marketed commercially by Stratasys Inc. (USA), which also holds a trademark on the term.

DESIGN OF EXPERIMENT

In industry, Design of experiment can be used to investigate the process variables that influence the product quality. Increasing productivity and improving quality is an important goal in any business. The method for determining how to increase productivity and improving quality are evolving. To identify the process condition and product components that influence the product quality, it can improve efforts to enhance the product manufacturability

Figure 1: FDM 360 MC Machine

Table 1: Polycarbonate Material Data Sheet (Stratasys Inc.)

Density (ρ)	1.20 g/cm3– 1.22 g/cm3
Water absorption rate	0.16 – 0.35%
Young's modulus (E)	2.0–2.4 GPa
Tensile strength (σt)	52 MPa
Flexural strength	97 MPa
Compressive strength (σc)	>80 MPa
Poisson's ratio (ν)	0.37
Rockwell Hardness	R 118
Melting temperature (Tm)	267 °C
Glass transition temperature (Tg)	161 °C

Prepared Specimen Using FDM 360 MC Machine

Figure 2

Compressive Test and Impact Test Specimen (ASTM)

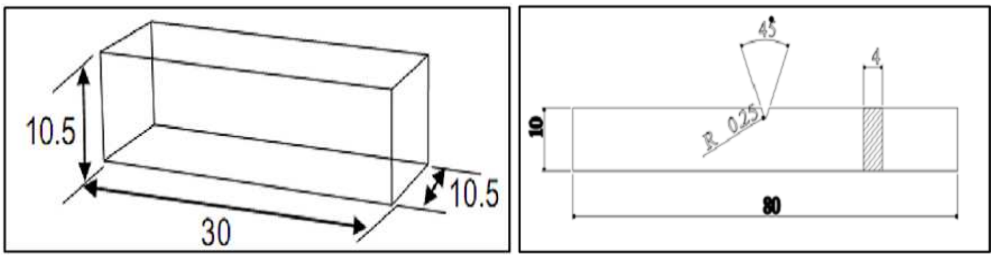


Figure 3: Taguchi Design

Selected FDM Process Parameters and Levels

Table 2

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

Planning for the Experiment

The specimens for compressive and impact test are prepared using FDM 360 mc machine as per ASTM standard. As per L9 orthogonal array total nine specimens are prepared for each test shown in Table 3. Other parameter like air gap, raster width and temperature are constant during the experiment. Here Minitab software used for Taguchi method.

Table 3

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	0.4564
9	0.254	30	0.4064

ANALYSIS OF RESULTS

ANALYSIS OF VARIANCE (ANOVA)

Table 4: Result of Compressive Strength

Sr. No.	Layer thickness (mm)	Orientation angle (Degree)	Raster width (mm)	Compressive strength (Mpa)
1	0.127	0	0.4064	53.21
2	0.127	15	0.4564	51.89
3	0.127	30	0.5064	49.76
4	0.178	0	0.4564	53.88
5	0.178	15	0.5064	52.84
6	0.178	30	0.4064	50.05
7	0.254	0	0.5064	58.94
8	0.254	15	0.4564	52.5
9	0.254	30	0.4064	52.3

Table 5: Summary of ANOVA Calculation for Compressive Strength

Factors	DOF	Sum of squares	Variance (mean square)	Variance ratio (F)	Percentage contribution (P)
Layer thickness	2	14.56482	7.282411	3.883653	25.5502
Orientation angle	2	33.04676	16.52338	8.811789	57.972
Raster width	2	5.642822	2.821411	1.504637	09.8989
Error	2	57.004691	1.875144	1	06.5789
Total	8	57.004691			100

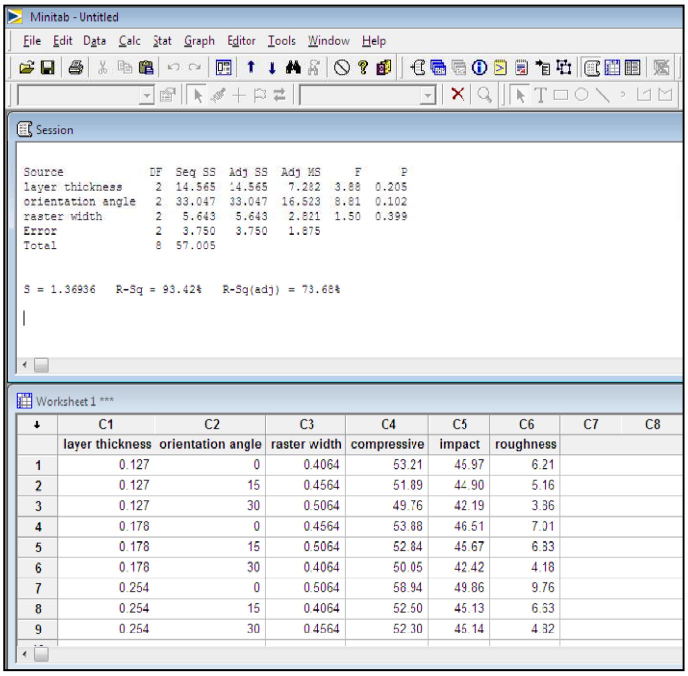


Figure 4: Analysis of Variance Using MINITAB 15

Table 6: Result of Impact Strength

Sr. No.	Layer thickness (mm)	Orientation angle (Degree)	Raster width (mm)	Impact strength (J/m)
1	0.127	0	0.4064	45.97
2	0.127	15	0.4564	44.9
3	0.127	30	0.5064	42.19
4	0.178	0	0.4564	46.51
5	0.178	15	0.5064	45.67
6	0.178	30	0.4064	42.42
7	0.254	0	0.5064	49.86
8	0.254	15	0.4564	45.13
9	0.254	30	0.4064	45.14

Table 7: Summary of ANOVA Calculation for Impact Strength

Factors	DOF	Sum of squares	Variance (mean square)	Variance ratio (F)	Percentage contribution (P)
Layer thickness	2	9.215267	4.607633	4.12932	22.4633
Orientation angle	2	26.44447	13.22223	11.84965	64.4616
Raster width	2	3.1322	1.5661	1.403525	7.6351
Error	2	2.231667	1.115833	1	5.44
Total	8	41.023604			100

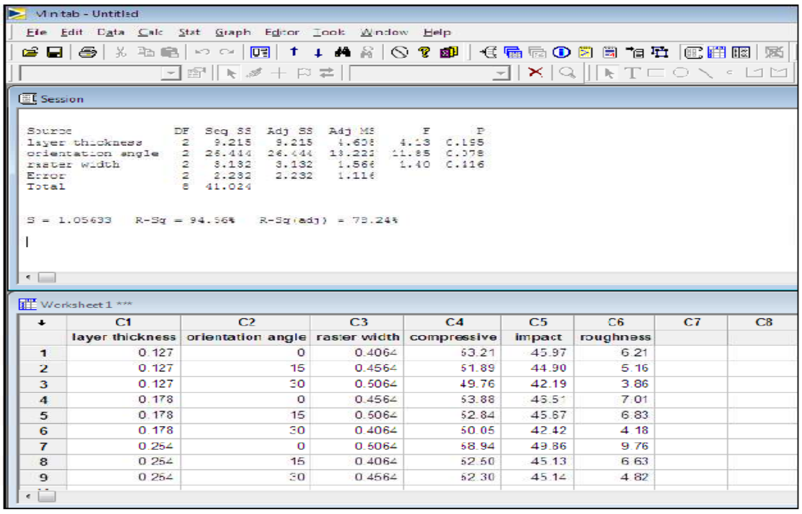


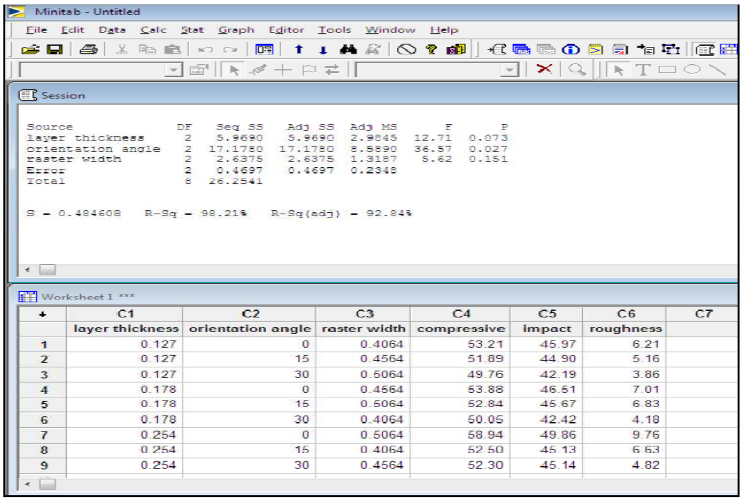
Figure 5: Analysis of Varia NCE Using MINITAB 15

Table 8: Result of Roughness Strength

Sr. No.	Layer thickness (mm)	Orientation angle (Degree)	Raster width (mm)	Roughness (μ)
1	0.127	0	0.4064	6.21
2	0.127	15	0.4564	5.16
3	0.127	30	0.5064	3.86
4	0.178	0	0.4564	7.01
5	0.178	15	0.5064	6.83
6	0.178	30	0.4064	4.18
7	0.254	0	0.5064	9.76
8	0.254	15	0.4564	6.63
9	0.254	30	0.4064	4.82

Table 9: Summary of ANOVA Calculation for Surface Roughness

Factors	DOF	Sum of squares	Variance (mean square)	Variance ratio (F)	Percentage contribution (P)
Layer thickness	2	5.968956	2.984478	12.70832	22.7353
Orientation angle	2	17.17796	8.588978	36.57305	65.4296
Raster width	2	2.637489	1.318744	5.615396	10.0046
Error	2	0.469689	0.234844	1	1.789
Total	8	26.2557			100



↓	C1 layer thickness	C2 orientation angle	C3 raster width	C4 compressive	C5 impact	C6 roughness	C7
1	0.127	0	0.4064	53.21	45.97	6.21	
2	0.127	15	0.4564	51.89	44.90	5.16	
3	0.127	30	0.5064	49.76	42.19	3.86	
4	0.178	0	0.4564	53.88	46.51	7.01	
5	0.178	15	0.5064	52.84	45.67	6.83	
6	0.178	30	0.4064	50.05	42.42	4.18	
7	0.254	0	0.5064	58.94	49.86	9.76	
8	0.254	15	0.4064	52.50	45.13	6.63	
9	0.254	30	0.4564	52.30	45.14	4.82	

Figure 6: Analysis of Variance Using Minitab 15

RESULTS AND DISCUSSIONS

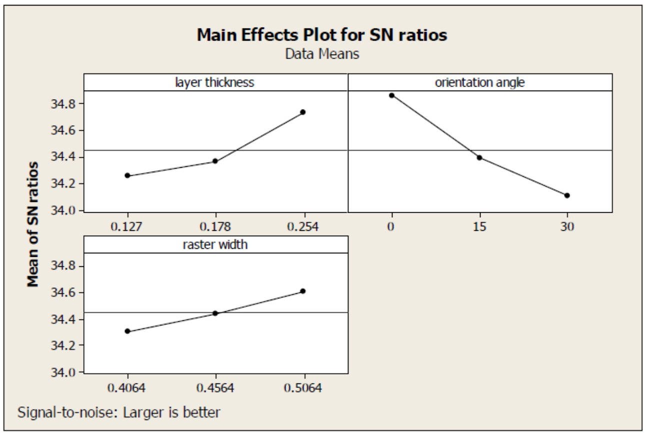


Figure 7: Main Effect Plots for Compressive Strength

The compressive strength data of polycarbonate sample with different level of process parameters are shown in response table for compressive strength. the ultimate strength was the highest (58.94 mpa) for the layer thickness 0.254 mm, orientation angle 0° and raster width 0.5064 mm combination set the compressive strength was lower (49.76 mpa) for layer thickness 0.127 mm, orientation angle 30° and raster width 0.5064 mm.

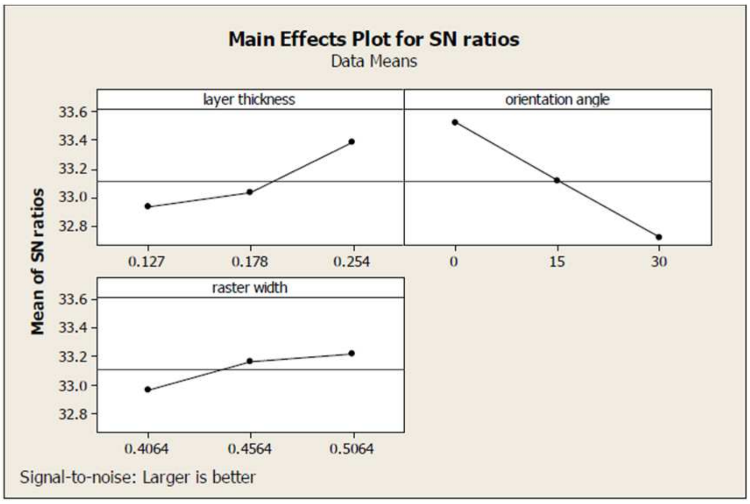


Figure 8: Main Effect Plots for Impact Strength

The Impact Strength Data of Polycarbonate Sample with Different Level of Process Parameters are Shown in Response Table for Flexural Strength. The Ultimate Strength was the Highest (49.86 J/M) for the Layer Thickness 0.254 Mm, Orientation Angle 0° and Raster Width 0.5064 Mm Combination Set. The Impact Strength was Lower (42.19 J/M) for Layer Thickness 0.127 Mm, Orientation Angle 30° and Raster Width 0.5064 Mm Main Effect Plots for Surface Roughness

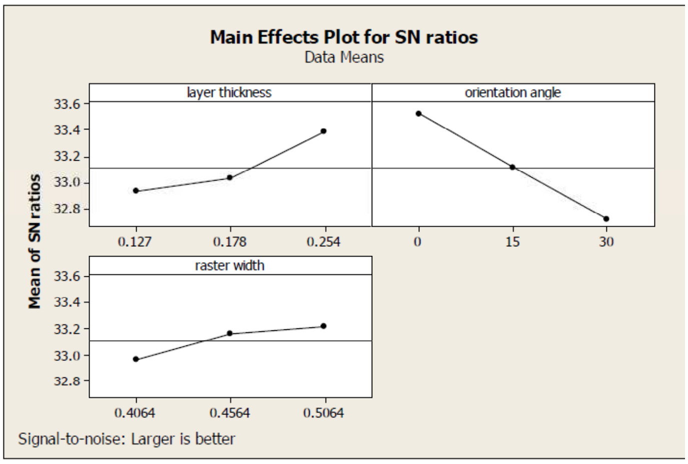


Figure 9: Main Effect Plots for Surface Roughness

In this we are generally discussing the results obtained throughout the experimental research analysis on compressive strength, impact strength and surface roughness of fdm made polycarbonate parts over a period of machining process. Here the number of experiments depends on the design of experiments carried out and the results in the terms of the output parameters (compressive strength, impact strength and surface roughness) are measured. The effect of the control factors is investigated through the analysis of variance. Control factor a (layer thickness) and control factor are (orientation angle) are the most significant factors influencing the assessment of mechanical strength and surface roughness compare to the control factor c (raster width).

Table 10: ANN Model Generation Normalize Data for Input and Out Put

Sr. No.	Layer thickness (mm)	Orientation angle (Degree)	Raster width (mm)	Compressive strength (Mpa)	Impact strength (J/m)	Surface roughness (µ)
1	0	0	0	0.3758	0.4146	0.3983
2	0	0.5	0.5	0.232	0.3533	0.2203
3	0	1	1	0	0.5625	0
4	0.4016	0	0	0.4488	0.5632	0.5338
5	0.4016	0.5	0.5	0.3355	0.4537	0.5033
6	0.4016	1	1	0.0315	0.029	0.0542
7	0	0	0	1	1	1
8	0	0.5	0.5	0.2984	0.3833	0.4694
9	0	1	1	0.2766	0.3846	0.1627

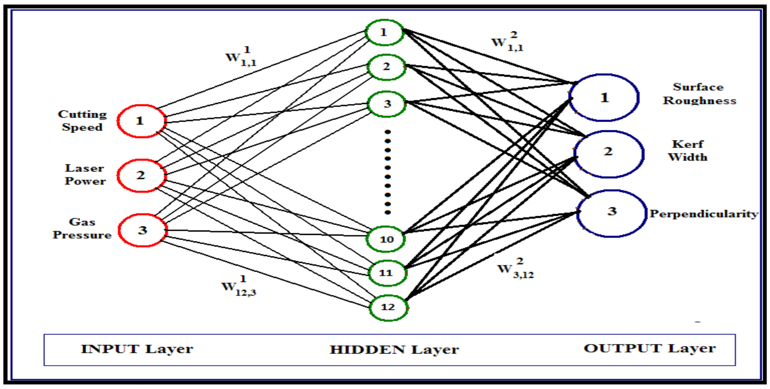


Figure 10: ANN Model with its Layer

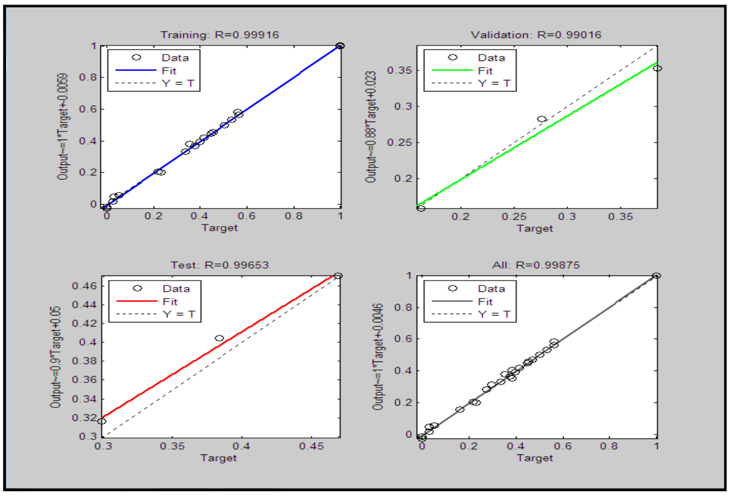


Figure 11: Regression Graph in MATLAB

Table 11: Comparisons of ANN Model with Experimental Values of Compressive Strength, Impact Strength and Surface Roughness

	Input parameter			Output parameter								
Sr. No.	Layer thickness	Orientation angle	Raster width	Comp. strength	AI comp strength	Error (%)	Impact strength	AI impact strength	Error (%)	Surface roughness	AI surface roughness	Error (%)
1	0.254	0	0.4564	56.12	51.98	7.37	47.9	45.6	4.80	4.3	4.1	4.65
2	0.254	15	0.4064	57.84	54.11	6.44	46.82	41.72	10.89	4.9	4.5	8.16
3	0.254	30	0.4564	58.98	54.87	6.96	49.2	45.90	6.70	4.2	3.98	5.23
4				Total Error In %		6.92	Total Error In %		7.46	Total Error In %		6.01s

CONCLUSIONS

An increment in the layer thickness results in batter mechanical strength of the test specimens because of as the layer thickness increases less number of heating and cooling cycles and thus accumulation of thermal stress reduce and distortion effect is minimized so the strength is increased. It is found that with increase in orientation angle the mechanical strength is decreased. This may be due to the stepped effect in which one layer does not coincide with the next layer exactly. This ultimately reduced the strength of the parts. Numbers of layers also increase with increase in orientation angle so for same layer thickness as a result, distortion on the part will increase resulting in less bond strength. Mechanical strength is increasing as the raster width is increased. The reason may be that at a small raster width the numbers of layers are more so the distortion chances are higher. Thus the strength is increased with the increase in raster width. Fine surface finish is achieved at smaller values of layer thickness and it is found to be rough with increment in layer thickness. Because of Increase in layer thickness results in a significant increase in the stair-stepping effect, so surface of the parts become rough. If a layer thickness is small, the stair-step produced on the prototype is very small this means cause smoother the surface. It is found that smooth surface is obtained at higher values of orientation angle. Orientation affects the stacking of layers on top of each other. At lower angles the adjacent layers are offset by a greater distance, thus resulting in coarser surfaces. When the orientation angle increases the adjacent layers are offset by a smaller distance which will cause fine surface. The raster width did not have much influence on the surface finish of the parts so it can be negligible. At last the experimental results for compressive strength, impact strength and surface roughness are predicted by using artificial neural network. ANN results and experimental results are found closely correlated with each other.

FUTURE SCOPE

The main reason attributed to weak strength is the distortion within the layer or between the layers. To summarize, it can be said that reduction in distortion is a necessary requirement for future in this dissertation work we have studied the effect of different fdm process parameters on the mechanical properties such as compressive strength, impact strength and surface finish of polycarbonate material. In the future work it can also find the same effective results for different material.

- The present work was only concern with the experimental investigation of three process parameters like layer thickness, part builds orientation and raster width on compressive strength, impact strength and surface finish
- It will be important to study the influence of other FDM process parameters like raster angle and air gap on mechanical properties.
- In the present work, due to time constraint optimization of three FDM responses is considered are compressive strength, impact strength and surface finish. In the future hardness test, fatigue test, wear test and dimensional accuracy may be carried out. Scope

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