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EXPERIMENTAL INVESTIGATE THE EFFECT OF PROCESS PARAMETERS ON SURFACE ROUGHNESS AND STRENGTH OF POLYCARBONATE (PC) PARTS IN FUSED DEPOSITION MODELING PROCESS BY USING TAGUCHI'S METHOD

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Abstract — *Rapid Prototyping (RP) technology meets the current needs in the industry. Fused Deposition modeling (FDM) is one of the key technology of RP. This paper presents experimental investigations on influence of important process parameters viz. Raster Angle, Road width and air gap on Surface integrity and Strength of Fused Deposition Modeling (FDM) processed PC (Poly Carbonate) part. Fused Deposition Modeling (FDM) is a solid-based rapid prototyping method that extrudes material, layer-by-layer, to build a model. Knowledge of the Surface integrity and strength characteristics of FDM fabricated parts is vital. This extensively depends on process variable parameters. Hence, the Optimization of these process parameters of FDM is able to make the system more specific and repeatable and such progression can guide to use of FDM in rapid manufacturing applications rather than only producing prototypes. In order to understand this issue, this paper explains the results obtained in the experimental work on the cause of the main FDM process variable parameters namely, (A) raster angle, (B) road width, (C) air gap. The Polycarbonate (PC) material was used in this research work to build parts. Numbers of specimen are made by Full Factorial Design .Experiments were conducted using Full Factorial design of experiments with three levels for each factor. The results are analyzed statistically to determine the significant factors and their interactions***.**

Keywords- *Rapid prototyping, fused deposition modeling, Polycarbonate (PC) Surface roughness, Tensile strength*

I. INTRODUCTION

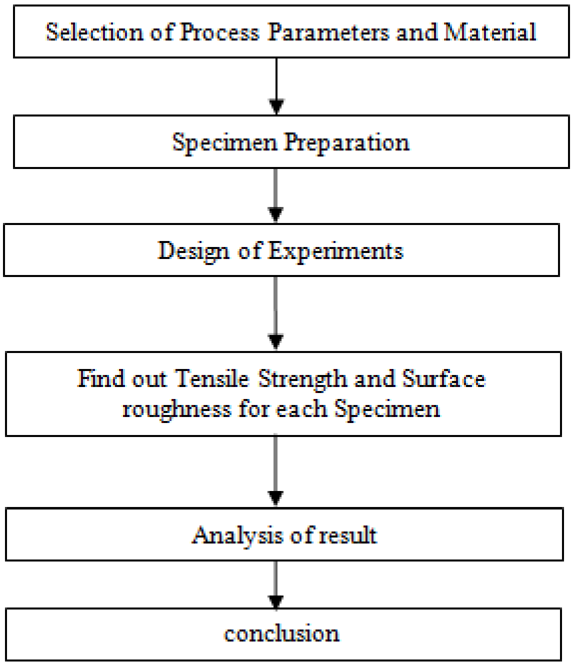
All manuscripts Rapid Prototyping (RP) is the solid free form manufacturing process which enables the quick fabrication of physical models using three-dimensional computer aided design (CAD) data. Fused Deposition modeling (FDM) is one of the key technology of RP. Rapid prototyping manufacture part directly from the CAD (computer aided design) model on a layer by layer deposition principle without tools, dies, fixtures and human intervention. The RP process is capable of building parts of any complicated geometry in least possible time without incurring extra cost due to absence of tooling. Due to compatibility of presently available materials with RP technologies full scale application of RP is not possible. To overcome this limitation, there are generally two approaches for the full scale application of RP process, one is to use of new materials with superior properties and another is to suitably adjust the process parameters for part fabrication for maximum improvement in part properties. Many of researchers have devoted towards the second approach. Less researchers work on polycarbonate material therefore polycarbonate material has been selected for experimental investigation on FDM. Literature presents that surface roughness and strength is the function of various process parameters and can be significantly improved with proper adjustment. The present study focus on assessment of surface integrity in terms of surface roughness and strength in terms of tensile strength of part fabricated using fused deposition modelling (FDM) technology. As the relation between surface roughness and process parameters and Tensile Strength and process parameters is difficult to establish, attempt has been made effect of each process parameter on surface roughness and tensile strength is analyzed with the help of Taguchi Analysis.

II. LITERATURE REVIEW ON FDM PROCESS

R.anitha et.al. [1] Evaluates the Critical Parameters like Road width, layer of thickness, speed of deposition influencing the quality of prototypes in fused deposition modeling with ABS material. Taguchi Method is used for Design of experiments. Finally they found that without pooling; only layer thickness is effective to 49.37%at 95%level of significance. But on pooling, it was found that layer thickness is effective to 51.57%at 99%level of significance. According to S/N analysis it was found that layer thickness is most effective when it is at 0.3556mm, road width 0.537mm, and speed of deposition 200mm. Anoop K. Sood et.al.[2] evaluates critical parameters layer thickness, part build orientation, raster angle, raster width and air gap. Of FDM process for compressive strength improvement. Part is fabricated by acrylonitrile butadiene styrene (ABS P400) material. They use particle swarm optimization (PSO) and surface roughness methodology for Design of experiments. And for prediction purpose ANN used. Finally they found that increase in raster angle will decrease the raster length and improve the compressive stress. Air gap is increased, it increases spacing between two rasters resulting in weak bonding and void structure. Optimization of process by QPSO gives the maximum compressive stress of 17.4751 MPa and the optimum value of layer thickness, orientation, raster angle, raster width and air gap as 0.254 mm, 0.036°, 59.44°, 0.422 mm and 0.00026 mm respectively. S.Dinesh Kumar et.al. [3] Evaluates the effect of layer thickness, air gap, raster width, contour width, raster orientation on minimum surface roughness by FDM with ABS-M30i material. With the help of full factorial design of experiments they found that Air gap is mainly influence on the surface Roughness. Small layer thickness to increase Surface Quality. Using the optimal part orientation is vital to reduce support material, which will lead to reduce building time and improve the surface finish. Tejendrasinh S. Raol et.al. [4] Investigate the Effect of Process Parameters on Surface Roughness of Fused Deposition Modeling Built Parts. The Fabricated design part material is polycarbonate. Layer thickness, part built orientation and raster angle are Input parameters. Experiments were conducted using 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. C K Basavaraj et.al. [5] Evaluates the Effect of Fused Deposition Modelling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon material. Layer thickness, Orientation angle and shell thickness are considered as an input parameter. An experiment is carried out using Taguchi method. Finally they found that layer thickness is the most affected process parameter on the response characteristics. Because the thinner layer thickness gives better bonding strength and gives good axial loading capability. When the orientation angle changes the bonding strength between layers is varied with layer thickness. Omar Ahmed Mohamed et.al. [6] Evaluates Analytical Modeling and Optimization of the Temperature-Dependent Dynamic Mechanical Properties of Fused Deposition modeling Parts Made of PC-ABS material. Slice thickness, raster air gap, deposition angle part print direction, bead width, number of perimeters are consider as an input parameters. They use response surface methodology (RSM) and multilayer feed-forward neural networks (MFNNs).for design of experiments. Finally they found that raster to raster air gap, slice thickness and numbers of perimeters are found to be the most influential variables. Slice thickness of 0.2540 mm, 0.0air gap, disposition angle of 0, part print direction of 40.13, bead width of 0.4572 mm and 10 perimeters seem to be the favorable values to improve the temperature-dependent dynamic mechanical properties of the parts printed by FDM. J. Santhakumar et.al. [7] Evaluates Impact Strength of Fused Deposition Modeling Built Parts using Polycarbonate Material. Layer thickness, build orientation, raster angle and raster width are consider as an Input Parameters. Taguchi Method is used for Design of experiments. Finally they found that Layer thickness influences Impact Strength the most as compared to the other considered process parameters. Optimum input parameters of layer thickness, 0.254 mm, build orientation 30°, raster width, 0.904 mm and raster angle 60°, was found to be 68.4J/m. O.Y.Venkatasubbareddy et.al.[8] evaluates Dimensional Accuracy And Surface Roughness of FDM ABS M-30 Parts material. Layer thickness, orientation, raster width, raster angle and air gap are consider as an Input Parameters. Grey Relational Analysis (GRA) is used for Design of experiments. Finally they found that the optimal parameters affecting Surface Roughness4.059 microns are found at Layer thickness0.254, orientation0°, Raster angle 0 raster width 0.4564 and Air gap 0mm. Azhar Equbal et.al. [9] Evaluates the Process parameters of FDM part for minimizing its Dimensional Inaccuracy. For that Part is fabricated by ABS material with input parameters are raster angle, air gap, raster width. Also Response surface methodology (RSM) coupled with the composite desirability function (CFD) is used to optimize the process parameters to achieve minimum overall deviations. Finally they found that dimensional accuracy is mainly affected by raster angle and raster width and air gap don't impart significant effect on dimensional accuracy minimizing raster angle (30º), maximum air gap (0.004 mm) and minimum raster width (0.4064 mm) is desirable. Ala'aldin Alafaghania et.al. [10] Evaluates dimensional accuracy and mechanical properties of FDM parts. For that they take input Parameters are building direction, extrusion temperature, layer height, infill pattern and printing speed. Build material is PLA. For design of experiments they use Finite element Analysis. Finally they found that dimensional accuracy and mechanical properties are affected by building direction, extrusion temperature and layer height more than infill percentage, infill pattern, and printing speed. Generally, to improve the dimensional accuracy in a certain direction for FDM parts the critical dimension should be parallel the layer orientation instead of the building direction, in addition to using lower extrusion temperature and layer height. To improve the mechanical properties, higher extrusion temperature and larger layer height are needed in addition to appropriate building direction, that makes the layers and the load direction in the same plane.

III. METHODOLOGY

Below shows the methodology adopted for the FDM work.



IV. EXPERIMENTAL SETUP

4.1 FDM machine and selection of material

The experiment was conducted using ULTIMAKER 2+ FDM Machine. Material is PLA, ABS, CPE, CPE+, PC, and Nylon, TPU 95A, and PP supported. Software used for machine is ultimaker cura. We print the part at 260 °C. [11]

Fig.1.Ultimaker 2+ FDM Machine

When the semi- molten thermoplastic material is solidified, volume shrinkage takes place which. Results in weak interlayer bonding, high porosity and hence reduces load bearing area. Hence, finding out parameter level that will give maximum Tensile strength has to be found out, along with those parameters influencing Surface roughness is also to be found out. The major part of output quality is dependent on few primary control factors. Based on this, three factors viz., Raster Angle (A), Road width (B), and air gap(C) are considered. Polycarbonate material is used in this study for making specimens. Polycarbonate has a Tensile strength of 55-75MPa.According to ASTM D-638 Standard Tensile Specimen are made as shown in Figure.

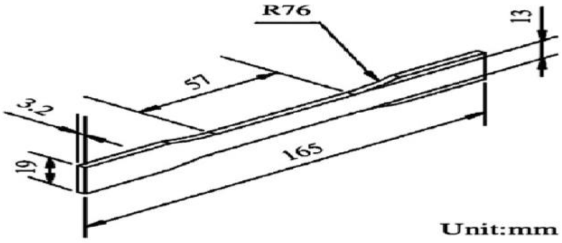


Fig.2.Tensile Speciman

Based on Literature Survey and Machine specification Table 1 describes the various levels of process parameters used to carry out the experiment.

Table1.Variable Parameters and their Levels

Sr.No.	Process Parameters	Level		
		Minimum	Centre Point	Maximum
1	Raster Angle(A)	0	15	30
2	Road Width(B)	0.4064mm	0.4564mm	0.5064mm
3	Air gap(C)	0.00mm	0.004mm	0.008mm

The experiment was conducted using ULTIMAKER 2+ FDM Machine. We use Full Factorial Design for Design of Experiments. Tensile test is conducted using TUE-C600 (Fine spavy Associates & engineers Pvt.Ltd.). ASTM D638 standard was followed for tensile testing. For measuring Surface roughness Mitutoyo SJ400 machine is used. Polycarbonate has a Tensile strength of 55-75MPa. Since FDM specimens have lower strength than molded or extruded specimens since layer by layer manufacturing results weak bonding between layers and also presence of air gap further weakens the part. Full Factor Design includes 32 experimentation runs and its experimental results for surface roughness and Tensile Strength are shown in Table2

Table 2 Full Factor Design includes 32 experimentation runs and its result

SPECIMEN NO.	Raster Angle(A)	Road width(B)	Air gap(C)	Surface roughness (micron)	Tensile Strength (Mpa)
1	0	0.4064	0	10.32	32.969
2	0	0.4064	0.004	11.52	31.14
3	0	0.4064	0.008	11.79	30.464
4	0	0.4564	0	15.6	30.029
5	0	0.4564	0.004	18.32	29.45
6	0	0.4564	0.008	19.8	30.035
7	0	0.5064	0	15.65	29.728
8	0	0.5064	0.004	18.62	26.94
9	0	0.5064	0.008	20.14	30.392
10	30	0.4064	0	4	42.935
11	30	0.4064	0.004	4.03	38.205
12	30	0.4064	0.008	6.13	36.15
13	30	0.4564	0	7	35.885
14	30	0.4564	0.004	9.52	32.291
15	30	0.4564	0.008	10.57	32.381
16	30	0.5064	0	7.78	36.84
17	30	0.5064	0.004	9.8	29.111
18	30	0.5064	0.008	8.84	35.916
19	60	0.4064	0	5.98	34.52
20	60	0.4064	0.004	7.95	33.866
21	60	0.4064	0.008	10.08	30.558
22	60	0.4564	0	11.58	30.511
23	60	0.4564	0.004	12	27.357
24	60	0.4564	0.008	12.42	26.479
25	60	0.5064	0	12.84	24.468
26	60	0.5064	0.004	12.49	22.831
27	60	0.5064	0.008	12.64	22.51

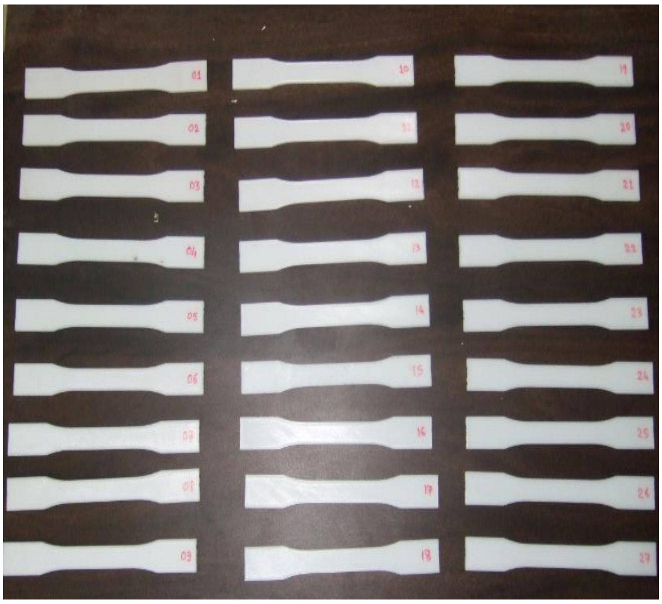


Fig.3 Fabricated Tensile Specimen

V. RESULTS AND DISCUSSION

The analysis of variance was used to found statistically significant parameters and proportion of contribution of these factors on Surface roughness (Ra) and ultimate tensile strength (UTS). Analysis of variance is similar to regression in that it is used to investigate and model the relationship between a response variable and one or more independent variables. Analysis of the experimental data for surface roughness and Tensile strength obtained from full factorial design runs is done in MINITAB 18 software. ANOVA is used to determine the influence of Raster angle, Road width and Air gap on surface roughness and Tensile Strength. Taguchi's philosophy includes three general ways to evaluate the relationship between input Factor and Output. They are: Nominal is better approach, Smaller is better approach, Larger is better approach. In this present work, for minimum Surface roughness, smaller is better Approach is used. And for higher Tensile Strength, Larger is better Approach is used.

5.1 S/N ratio and Analysis of Variance (ANOVA) for Surface roughness

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 signal-to-noise ratio measures the sensitivity of the quality investigated to those uncontrollable factors (error) in the experiment. The quality characteristic used in this study was 'smaller-the-better' for surface roughness. Figure4 displays the key effects plot for Surface roughness. [12][13]

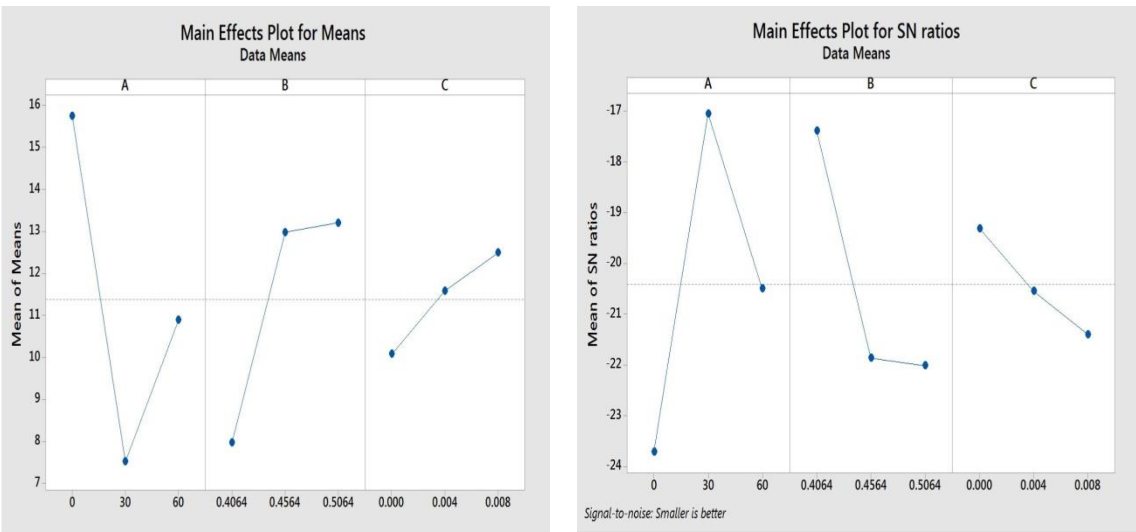


Fig.4.Main effect plots for means and S/N Ratio for all parameters for surface roughness

From the graph we see that Surface roughness is mainly affected by Raster angle (A), followed by Road width (B) and Air gap(C). Raster Angle increases up to 30˚surface finish is good but after increases value it will decreases. When Road width (B) increases surface roughness increases. Also in Air gap when Air gap increases surface roughness increases. We got best surface roughness4.0µ in Specimen10 where A=30˚, B=0.4064mm, C=0mm.
ANOVA analysis is used to find out the influence of each parameter affecting the Surface roughness. ANOVA tool is utilized using statistical software Minitab18. It exhibits the percentage of factor influence for each parameter in a very simple way.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	%Contribution
A	2	308.32	154.161	128.54	59.76%
B	2	156.99	78.497	65.45	30.43%
C	2	26.59	13.296	11.09	5.15%
Error	20	23.99	1.199		4.65%
Total	26	515.90			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.09515	95.35%	93.96%	91.53%

From the ANOVA we see that percentage Contribution for Surface roughness Parameter A (Raster angle) is 59.76%, (B) Road width30.43%, Air gap(C) 5.15%.

5.2 S/N ratio and Analysis of Variance (ANOVA) for Tensile Strength

The quality characteristic used in this study was 'Larger-the-better' for Tensile Strength Figure4 displays the key effects plot for Tensile strength.

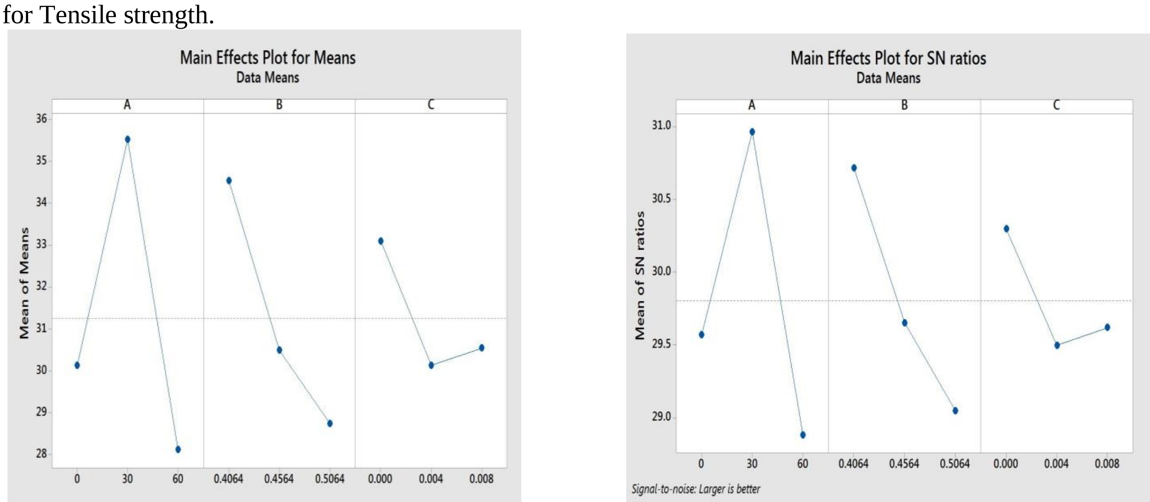


Fig.5.Main effect plots for means and S/N Ratio for all parameters for Tensile strength

From the graph we see that Tensile Strength is mainly affected by Raster angle(A),followed by Road width(B) and Air gap(C).Raster Angle increases up to 30˚Tensile Strength is increases but after increases value it will decreases. When Road width (B) increases Tensile strength decreases. Also in Air gap when Air gap increases Tensile strength decreases. We got best Tensile Strength 42.935MPA in Specimen10 where A=30˚, B=0.4064mm, C=0mm.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	%Contribution
A	2	263.77	131.887	25.69	46.15%
B	2	158.57	79.287	15.44	27.78%
C	2	46.49	23.245	4.53	8.13%
Error	20	102.69	5.134		17.96%
Total	26	571.52			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.26592	82.03%	76.64%	67.25%

From the ANOVA we see that percentage Contribution for Tensile strength Parameter A (Raster angle) is 46.15% , B(Road width) 27.78% , C(Air gap) 8.13%.

VI. CONCLUSION

The percentage contribution shows the effect of process parameter on response characteristics. By noticing the all three figures we became to know that the Raster Angle is the most affected process parameter on the response characteristics. Surface roughness decreases when raster angle increases up to 30˚and then after it will increases. Tensile Strength Increases when raster angle increases up to 30˚and then after it will decreases. This may be due to the stepped effect in which one layer is not coinciding with next layer perfectly. This ultimately reduces Strength. Surface roughness increases when road width increases. This may be due to that at a maximum road width, the neighboring road laid down will be far away to previous one.so, and it give un-uniform structure and give maximum surface roughness. Tensile Strength Decreases when road width increases. This may be due this is due to that when road width is more at that time nozzle moves fast and no.of layers are less give less strength .Surface roughness increases when air gap increases. Tensile strength decreases when air gap increases. This is due to that if air gap is more than there is a void between the layers so it reduce the strength and increases surface roughness. The major reason for low strength and high surface roughness of FDM processed parts may be attributes to distortion between the layer or within the layers while fabricate the parts due to temperature gradient. We got best result at 30˚ raster angle, 0.4064mm road width and 0.00mm Air gap.

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