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Effect of Process Parameters on the Mechanical Behavior of FDM processed PLA Parts

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Abstract- Fused Deposition Modeling (FDM) is a fast growing rapid prototyping technique used to create functional prototypes as well as end use components.The mechanical behavior of FDM processed parts is studied earlier by various researchers and depends on the process variables like % infill, layer thickness and build orientation, raster angle etc. In the present work, mechanical properties of the FDM parts were studied varying three main parameters i.e., layer thickness, build orientation in XY plane, % infill. The geometry of the specimen is taken as per ASTM D638 standards. A total of 16 specimens are fabricated using Taguchis L_{16} orthogonal array approach. The Surface Roughness and Ultimate Tensile Strength (UTS) of the specimens were measured using Talysurf and Universal Testing Machine. Statistical analysis is performed using ANOVA and Multiple Regression to find out the relationship of process parameters on UTS, elongation at failure, Surface Roughness values. It has been observed that build orientation has more effect on R_z, Elongation at failure, UTS and layer thickness has more effect on R_a, R_q.

Keywords-- FDM, UTS, Surface Roughness, ANOVA, Multiple Regression

I.Introduction

Rapid prototyping is a process in which material is solidified to create a solid object, with material being added together in layer by layer. FDM is one such process in which a filament of thermo plastic or other material is fed into an extrusion nozzle head, which heats the material and is deposited on the part bed surface. FDM uses a .STL file of a model which is sliced by a slicing software into layers .Slicing software generates the tool path in X,Y and Z axes and is given as input to the FDM Machine. The extruder and part bed are maintained at a particular temperature so that the thermo plastic material is heated to semi liquid state. The extruder directs the solidified material based on the geometry of the object until the part is completely built up.

The quality of the FDM parts depends on different factors like process parameters, material used, working environment etc. A lot of research is done to improve the mechanical properties of the FDM processed parts.Farhad et al., [1] studied the effect of process parameters on the mechanical properties of FDM Parts using Taguchi method. They concluded that increase of infill density and layer thickness increases the mechanical properties, while the strength is high at 45^0 and less at 0^0 and 90^0 build orientations.A study on behavior of the mechanical performance of the printed part with respect to three process variablesviz. raster angle, raster width and layer height is conducted by Shilpesh et al., [2]. The behavior of FDM parts printed using newly developed open-source 3D printer by manipulating three parameters layer thickness, shell thickness and printing speed is studied by Sukindar et al., [3] . The printed parts were tested under tensile test machine and the analysis from ANOVA shows that the shell thickness contributes higher significant impact on tensile strength.Lanzotti et al.,[4] studied ultimate tensile strength and the nominal strain at break (ε f) of printed parts made from polylactic acid (PLA), by varying three important process parameters: layer thickness, infill orientation and the number of shell perimeters.MirigulAltan et al., [5] investigated the effects of process parameters on the quality of products fabricated by fused deposition modeling (FDM), such as surface roughness and tensile strength. Polylactic acid (PLA) samples were built on a FDM machine at various layer thickness, nozzle temperature and deposition head velocity. The results indicated that tensile strength and surface quality of the FDM samples improved at optimal process conditions. Fernandes et al., [6] studied the influence of 3d printing parameters on the mechanical properties of PLA parts and concluded that for each parameter the mechanical property reacts differently.Anitha et al., [7] investigated the FDM process parameters on surface roughness of ABS prototypes and obtained an inverse relation between layer thickness and surface roughness.

In the present work, the effect of process parameters on the mechanical behavior of Polylactic acid using FDM process is studied. Parts are manufactured on a 3D printer with varying layer thickness, build orientation and % infill. Experimentation is carried out based on Taguchi's orthogonal approach. Surface roughness and tensile strength is measured, Analysis of variance (ANOVA)and Multiple Regression analysis is performed on the obtained values to find the effect of input parameters on the surface roughness and tensile properties.

II. Experimentation

The material used for test specimen is polylactic

(PLA). The dimensions of the specimen is based on

the ASTM D638 standards as shown in Fig.1.The specimens were manufactured on a Flash Forge 3D-printer with varying the process parameters.

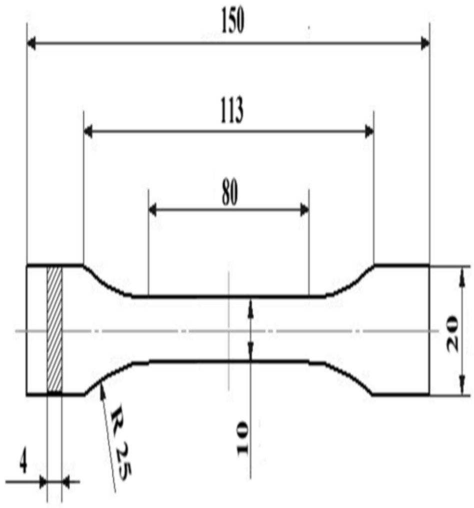

Fig.1: Dog bone specimen as per ASTM D638 Standards

Table1.shows various levels of process parameters chosen as per Taguchi's orthogonal array approach. The layer thickness is changed from (0.06 to 0.12mm), % infill is varied from 20% to 50% and build orientation is at 0^0, 45^0, 60^0, 90^0.

Table1:Specimens Manufactured at Different Process Variables

Specimen	Layer thickness	Orientation	% infill
1	0.06	0°	20
2	0.06	45°	30
3	0.06	60°	40
4	0.06	90°	50
5	0.08	0°	30
6	0.08	45°	20
7	0.08	60°	50
8	0.08	90°	40
9	0.1	0°	40
10	0.1	45°	50
11	0.1	60°	20
12	0.1	90°	30
13	0.12	0°	50
14	0.12	45°	40
15	0.12	60°	30
16	0.12	90°	20

III.Tensile &Surface Roughness Testing

Tensile tests has been carried out on a Instronuniversal testing machine to determine the tensile properties of the given specimen. The tensile tests are conducted at a speed rate of 3mm/min. Surface roughness is measured using talysurf equipment, in which R_a, R_q, R_z are measured for the specimens.

IV. Results and Discussions

Fig.2 shows the stress strain diagram for the specimen manufactured at 0^0 build orientation, 0.06mm layer thickness, 20% infill. The ultimate tensile strength and the elongation at failure are 7.47MPa and 1.12% respectively.

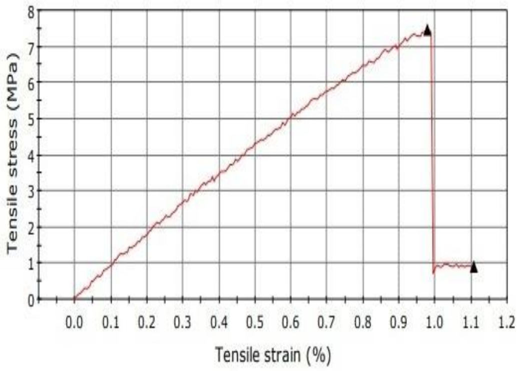

Fig.2: Stress-Strain Diagram For Specimen at 0.06mm layer thickness,0^0 Orientation,%20 Infill

As the layer thickness increases, the adhesion between the layers decreases and leads to less tensile strength. Similarly with decrease in layer thickness, the bonding between layers increases and tensile strength improves. Table No.2 shows the UTS, Elongation at Failure, Surface Roughnessvalues for different levels of experimentation. When the Layer Thickness is increased from 0.06 to 0.12mm, the maximum tensile strength is observed at 45^0 orientation and 40% infill orientation. As the % infill has been increased from 20% to 50%, the maximum value of tensile strength is observed at 0.12mm layer thickness and 45^o orientation As the build orientation is changed from 0^0 to 90^0, the maximum tensile strength is at 0.12mm layer thickness and40% infill. Maximum surface roughness is observed at 90^0

Table 2: Tensile Properties and Surface Roughness Values For Different Specimens.

Specimen	UTS(MPa)	(Ɛ f)	R_a (μm)	R_q(μm)	R_z(μm)
1	7.47	1.1	NA	NA	NA
2	19.52	1.79	2.92	3.5	11.3
3	21.72	1.94	3.3	4.15	15.63
4	20.94	1.61	3.27	4.5	14.63
5	11.22	1.44	NA	NA	NA
6	20.13	2.02	3.93	4.66	16.9
7	24.46	2.0	2.43	2.83	9.59
8	21.39	1.84	4.28	4.98	16.98
9	14.89	1.42	1.15	1.41	5.5
10	22.7	1.94	2.55	2.98	9.59

11	19.82	2.05	2.87	3.43	11.27
12	19.83	1.75	2.61	3.39	13.81
13	18.37	1.86	2.28	2.96	12.51
14	25.79	2.4	2.25	2.7	9.62
15	21.73	2.24	3.05	3.61	11.96
16	19.39	1.86	2.8	3.27	14.03

Orientation and 50% infill with increase in layer thickness. Maximum surface roughness is at 90^0 Orientation and 0.08 Layer Thickness for change in % Infill. The maximum surface roughness is at 40% infill and 0.08mm layer thickness for change in thebuild orientation.

a)Analysis of Variance(ANOVA):

ANOVA is performed for different groups of Layer Thickness(0.06-0.12mm), % Infill(20%-50%), Build orientation(0^0-90^0) as shown in Table No.3. Analysis of variance is a test used for comparing three or more group means for statistical significance. It is well suited for a wide range of practical problems to identify the effect of process parameters on the given output.

Table 3: ANOVA Results for UTS

Process parameter	Source of Variation	D_f	MS	F	p-value
Layer Thickness	Inter Groups	3	10.18	0.413	0.746
	Intra Groups	12	24.61		
Build Orientation	Inter Groups	3	73.91	8.51	0.002
	Intra Groups	12	8.68		
% Infill	Inter Groups	3	21.77	1.00	0.42
	Intra Groups	12	21.71		

From the Table No.3 it can be concluded that, as the p-value is less, build orientation has more effect than layer thickness, % infill on the tensile strength. Similarly analysis is performed between different group means of process parameters for surface roughness and elongation at failure. The results conclude that layer thickness more effect on R_a, $R_q$and Build orientation has more effect on Rz, Elongation at Failure.

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b) Multiple Regression Analysis:

Multiple Regression analysis studies the relationship between dependent (response) variable and p independent variables. The regression in the present case can be expressed as

$$Y = A0 + A1(layer\ thickness) + A2(orientation) + A3(\%\ infill)$$

where Y can be UTS or Surface roughness values Ra or Rq or Rz

$X1 = layer\ thickness;\ X2 = orientation;$

$X3 = \%\ infill$

From Multiple Regression analysis the relationship between different parameters is obtained as follows

1.

$$UTS = 3.59 + 58.66 \times (LayerThickness) + 0.08 \times (Orientation) + 0.17 \times (\%\ Infill)$$

2.

$$Ra = 3.80 - 12.00 \times (Layer\ Thickness) + 0.01 \times (Orientation) - 0.014 \times (\%\ Infill)$$

3.

$$Rq = 4.51 - 16.18 \times (Layer\ Thickness) + 0.01 \times (Orientation) - 0.01 \times (\%\ Infill)$$

4.

$$Rz = 14.81 - 35.78 \times (layer\ thickness) + 0.05 \times (orientation) - 0.05 \times (\%\ of\ Infill)$$

5.

$$\mathcal{E}f = 0.75 + 8.26 \times (layer\ thickness) + 0.004 \times (orientation) + 0.002 \times (\%\ of\ Infill)$$

From the given equations it can be concluded that layer thickness strongly influence the mechanical properties with in the given range of process parameters. As the layer thickness increases, surface roughness decreases and UTS increases.

V. CONCLUSION

The mechanical behavior of FDM processed parts is analyzed and the optimum parameters are suggested. The Layer Thickness is 0.12mm, % Infill 40%, Build Orientation is to be at 45^0 for better results of Surface Finish and Tensile Strength. ANOVA results conclude that layer thickness has more effect on Ra, Rq, and elongation at failure values and build orientation has more effect on UTS, Rz values. According to Multiple regression analysis, Layer Thickness has more effect on tensile strength and surface roughness values.

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