International Journal of Engineering & Technology, 7 (4.39) (2018) 457-461

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

An Experimental Investigations for Improving Part Strength in Fused Deposition Modeling

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Abstract

This paper aims to experimentally investigate the impact of process parameter on ultimate tensile strength & rate of fabrication through fused deposition modeling. For this purpose MakerBot Replicator -2, 3D desktop printer was used for the fabrication of test samples. ASTM D638 standard was selected for the preparation of test specimen of poly lactic acid (PLA) material. The process parameters used in this investigation were layer thickness, raster angle, infill pattern and orientation. Experiment was conducted as per the Taguchi orthogonal design array (L16). Finally Gray relational analysis (GRA) was employed to select the optimum best level of process parameter. A regression model was developed in terms of process parameters. For checking the goodness of fit for the model, a confirmation test was conducted which reveals that developed model was good enough to predict the response in the CI of 95%. The optimum level of process parameters was found to be layer thickness of 0.1 mm, raster angle 45^0, honeycomb infill pattern and flat orientation.

Keywords: *Design of experiment, FDM process, Grey relational analysis, Taguchi design and Tensile strength*

1. Introduction

Fused Deposition Modeling Process has huge demand in the market due to low cost. In this process plastic filaments were unwound and supplied to the extruded nozzle [1]. In this process material is deposited in the layer wise fashion. Most of the 3D printing technologies are based on the slicing of 3D object into 2D slice and building layer-upon-layer. Component fabricated through FDM process is poor in tensile strength as compared to the conventional manufacturing method. Several studies have been conducted to improve the part strength of the FDM component. *Durgun and Ertan, (2014) [2]* have conducted experimental studies to optimized the mechanical properties and cost of ABS component fabricated by FDM process. The process parameters raster angle and orientation was used in this investigation. The results revealed that process parameter raster angle ‘0’ degree and orientation ‘0’ degree were optimum conditions for mechanical properties and surface roughness. *Anna and Guceri, (2003) [3]* have conducted experimental and computational study to investigate the mechanical properties of ABS component fabricated by FDM process. Results revealed that material shows anisotropic behavior. Road, road to road interaction and path strongly affect the mechanical properties of the component. *Cantrell et al., (2016) [4]* have evaluated the tensile and shear properties of ABS component generated through FDM technology. It was found that process parameter raster angle and orientation have no effect on the tensile strength of material however shears strength varied up-to 33%.
Raut et al., (2014) [5] have highlighted the effect of orientation on mechanical properties and fabrication cost of ABS material. The results revealed that at ‘0’ orientation have maximum tensile strength. *Onwubolu and Rayegani, (2014) [6]* have investigated the impact of process parameters namely air gap, raster angle, raster width, layer thickness and orientation on tensile strength of ABS material. Results concluded that minimum layer thickness and raster width had improved the tensile strength. *Dawoud et al., (2016) [7]* investigated the mechanical properties of ABS component fabricated by FDM process and compared the results with injection moulded parts in both static and dynamic loading model. Process parameters raster angle and air gap was considered for the investigation. Results shows that raster angle -45/+45(degree) have maximum tensile strength where as flexural strength was found at 0/90 degree. *Wu et al., (2015) [8]* have suggested the optimum process parameters condition for fabrication of component of polyether-ether-ketone material through FDM process. The process parameter raster angle and layer thickness was used for investigation.
From the detailed study of literature it was observed that most of the research work carried out by using process parameter viz., layer thickness, raster angle, orientation and infill density etc. However, less work have been reported for the effect of infill patterns on tensile strength. This study deals with the effect of process parameters viz., layer thickness, raster angle, infill pattern and orientation on tensile strength (UTS) & fabrication time required (FTR). Some significant insight in terms of process parameters is achieved.

2. Material and Method

The material tasted in this research work was poly lactic acid (PLA) which was used for the fabrication of test samples in MakerBot Replicater-2, 3D desktop printer. The test geometry adopted for the investigation of tensile test was ASTM D-638 standard *Cantrell et al. [4]*. Taguchi orthogonal array (L16) was used for the fabrication of specimen samples. Selected dimension for the specimen sample is as shown in Fig. 1. Test sample was fabricated at the thickness of 4 mm. Test samples was fist fabricated in CATIA VI software, exported in .STL file format, and then imported into MakerBot slicing software to create G-code corresponding to the specimen orientation. For checking the repeatability of the results three samples for each experiment setting was conducted.

This study deals with the effect of process parameter viz, layer thickness, raster angle, infill pattern and orientation on tensile strength & fabrication time. The aim of this study was to find the best process parameter setting which improves both strength and rate of production. Table 1 show the selected process parameters and their levels. Fabricated specimen samples are shown in Figure 2. Tensile test was conducted on Instron 1195 machine. For the conduction of tensile test, cross head of the machine was kept at a constant at 1mm/min. Loading of specimen for the conduction of tensile test is as shown in Fig 3.

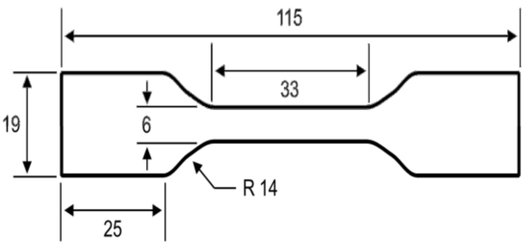


Fig. 1: Dimension of the ASTM D-638 type IV sample

Table 1: Process parameter and levels

S.N	L1	L2	L3	L4
Layer Thickness	.10mm	.16mm	.23mm	.30mm
Raster Angle	0	15	30	45
Infill Pattern	Rectangular	Triangular	Honeycomb	Wiggle
Orientation	Flat	Edge	Inclined	Upright

Table 2: Taguchi L16 orthogonal array and S/N ratio

Ex. No	Layer thick-ness	Raster angle	In-fill pattern	Orien-tation	Ultimate tensile strength	S/N ratio UTS	Time requirement	S/N ratio TR
1	1	1	1	1	51.0	34.2	56.0	-34.96
2	1	2	2	2	50.0	34.0	60.0	-35.56
3	1	3	3	3	49.0	33.8	51.4	-34.22
4	1	4	4	4	45.3	33.1	61.0	-35.71
5	2	1	2	3	42.0	32.5	45.5	-33.16
6	2	2	1	4	41.0	32.3	43.0	-32.67
7	2	3	4	1	46.0	33.3	40.3	-32.11
8	2	4	3	2	53.0	34.5	41.4	-32.34
9	3	1	3	4	36.0	31.1	32.3	-30.18
10	3	2	4	3	34.9	30.9	31.0	-29.83
11	3	3	1	2	46.8	33.4	41.7	-32.40
12	3	4	2	1	47.6	33.6	33.3	-30.45
13	4	1	4	2	28.8	29.2	30.0	-29.54
14	4	2	3	1	43.0	32.7	23.0	-27.23
15	4	3	2	4	34.9	30.9	26.4	-28.43
16	4	4	1	3	42.4	32.5	28.7	-29.16

Fig. 2: Fabricated test sample

Fig. 3: Experimental setup for the Tensile test

3. Result and Discussion

The tensile test data of PLA material for the different factors levels is as shown in Table 2. For tensile test, load was continuously increased until the specimen was breaked. The value of ultimate tensile strength was calculated by dividing the maximum load with minimum cross-sectional area. Time required for the fabrication was obtained from the MakerBot software during the slicing process.

Statistical analysis was carried out to investigate the impact of process parameter on ultimate tensile strength and fabrication time for the sample. For statistical analysis Mini Tab 14 software was used. The value of S/N ratio is reported in Table 2. Fig. 4 (a) & (b) shows the main effect plots of S/N ratio for the UTS and FTR.

Analysis of variance (ANOVA) was calculated to check the impact of process parameters on the response factors. Table 3 & Table 4, shows the ANOVA for the response factors UTS and FTR respectively. A regression model was developed in terms of process parameter. Eq. 1 and Eq. 2 shows the regression models for the UTS and FTR. The higher value of 'R^2' closed to 1 indicates model was good. In this analysis value of R^2 is 0.892 for the time requirement and R^2 adj is 0.852 which implies that there was a good agreement between the R^2 and R^2-adj. In the regression model for UTS value of R^2 is 0.904 and R^2-adj is 0.86. For response factor UTS, all the selected process parameter have significant impact. However, for the FTR layer thickness have highest contribution. From Figure 4(a) & (b), it can be seen that the optimum condition for the response factors were different. Table 5 show the optimum condition for the process parameter.

$$UTS = 57.6 - 3.88\,LT + 2.48\,RA - 1.80\,IP - 2.54\,Orientation. \quad (1)$$

$$FTR = 66.1 - 9.82\,LT + 0.12\,RA - 0.96\,IP + 0.34\,Orientation. \quad (2)$$

Table 3: ANOVA table for the response factor UTS

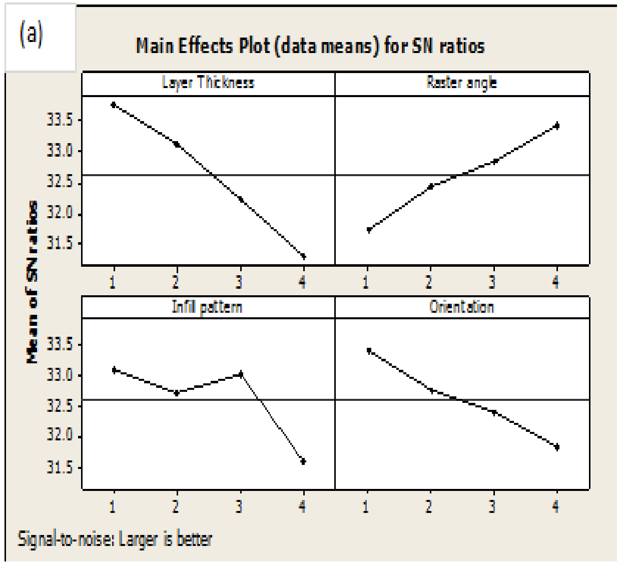
Source	DF	Seq SS	Seq MS	F	P	
Regression	4	618.49	154.62	25.48	0.000	
Layer Thickness	3	302.192	100.731	19.20	0.018	
Raster angle	3	123.902	41.301	7.87	0.062	
Infill pattern	3	114.367	38.122	7.27	0.069	
Orientation	3	129.057	43.019	8.20	0.059	
Error	3	15.737	5.246			
Total	15	685.254				

Table 4: ANOVA table for the response factor FTR

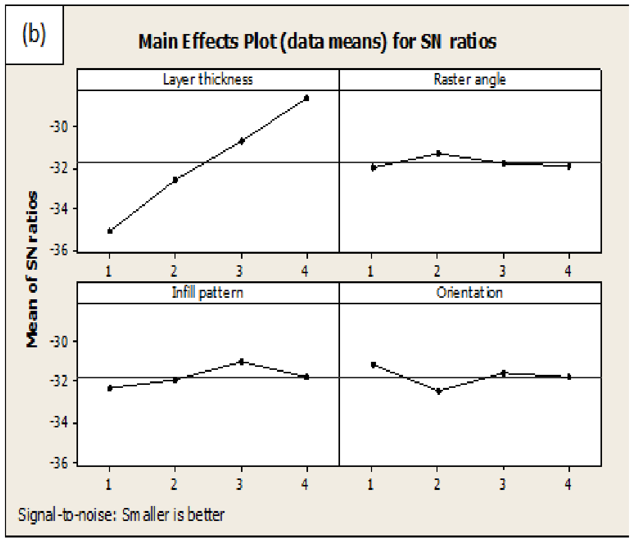
Source	DF	Seq SS	Seq MS	F	P	
Regression	4	1923.13	480.78	22.67	0.000	
Layer thickness	3	1985.21	661.74	51.83	0.004	
Raster angle	3	9.15	3.05	0.24	0.865	
Infill pattern	3	64.01	21.34	1.67	0.342	
Orientation	3	59.74	19.91	1.56	0.362	
Error	3	38.30	12.77			
Total	15	2156.42				

Table 5: Optimum process parameter condition

S.N	Response factor	Layer Thickness	Raster angle	Infill Pattern	Orientation
1	Tensile strength	0.1mm	450	Honeycomb	Flat
2	Time Requirement	0.3mm	150	Honeycomb	Flat



(a) Ultimate tensile strength.



(b) Fabrication time requirement.

Fig. 4: Main effect plot for S/N ratio

4. Optimization

In order to find out the optimum process parameters which optimize both the response factors multi objective optimization technique was required. Part strength of PLA component may be improved along with fabrication time with the help of GRA technique. Several researchers have successfully optimized the response factors by using GRA [9-10]. GRA works on the basis of three steps.

- Data preprocessing.
- Calculation of grey relational coefficient.
- Calculation of grey relational value.

The calculated value of data processing, grey relational coefficient and grey relational value is reported in Table 6. In this work GRA value was calculated with 60% weightage of tensile strength and 40% of fabrication time. Value of best process parameter condition was calculated by considering the GRA value as a single response factor. The value of best process parameter condition was calculated from the main effect plots (Fig. 5) of the S/N ratio. Table 7 shows the ANOVA table of the GRA value. From Table7, it can be seen that the layer thickness and orientation were the most significant process parameters. However, the impact of process parameters raster angle and infill pattern was less.

Table 6: Gray Relational Analysis

Exp No	UTS (S/N ratio)	FTR (S/N ratio)	Sequencing after pre processing		Deviation sequence		Grey relational coefficients		Grade values
			UTS	FT	UTS	FT	UTS	FT	
1	34.2	34.1514	0.94	0.09	0.06	0.94	0.914	0.299	0.67
2	34.0	33.9794	0.91	0.02	0.09	0.91	0.864	0.302	0.64
3	33.8	33.8039	0.87	0.18	0.13	0.87	0.820	0.306	0.61
4	33.1	33.1220	0.74	0.00	0.26	0.74	0.694	0.322	0.55
5	32.5	32.4650	0.62	0.30	0.38	0.62	0.614	0.338	0.50
6	32.3	32.2557	0.58	0.36	0.42	0.58	0.591	0.344	0.49
7	33.3	33.2552	0.77	0.42	0.23	0.77	0.726	0.317	0.56
8	34.5	34.4855	1.00	0.40	0.00	1.00	1.000	0.293	0.72
9	31.1	31.1261	0.36	0.65	0.64	0.36	0.483	0.393	0.45
10	30.9	30.8565	0.32	0.69	0.68	0.32	0.469	0.404	0.44
11	33.4	33.4049	0.79	0.39	0.21	0.79	0.743	0.315	0.57
12	33.6	33.5521	0.83	0.62	0.17	0.83	0.779	0.310	0.59
13	29.2	29.1878	0.00	0.73	1.00	0.00	0.375	0.560	0.45
14	32.7	32.6694	0.66	1.00	0.34	0.66	0.639	0.332	0.52
15	30.9	30.8565	0.32	0.86	0.68	0.32	0.469	0.404	0.44
16	32.5	32.5473	0.62	0.77	0.38	0.62	0.614	0.338	0.50

Table 8: Comparison of model and Experimental value.

<table>
<tr><th>S.N</th><th>Response factor</th><th>Layer Thickness</th><th>Raster angle</th><th>Infill Pattern</th><th>Orientation</th><th>Calculated From Model</th><th>Experimental Value</th></tr>
<tr><td>1</td><td>Ultimate Tensile strength (MPa)</td><td rowspan="2">0.1 mm</td><td rowspan="2">45^0</td><td rowspan="2">Honeycomb</td><td rowspan="2">Flat</td><td>55.7 ±3.57</td><td>58.53</td></tr>
<tr><td>2</td><td>Fabrication time (minute)</td><td>54.20 ±5.3</td><td>57.0</td></tr>
</table>

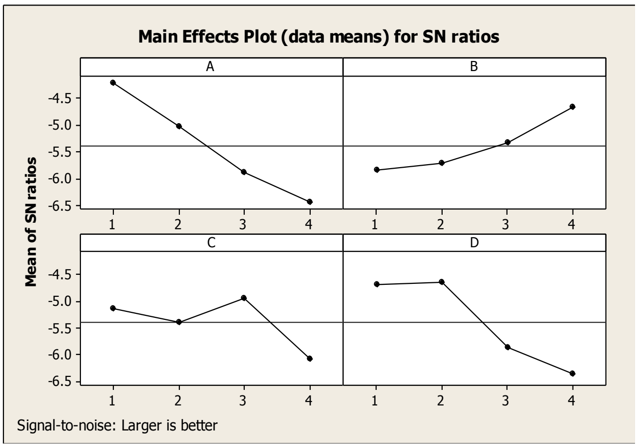


Fig. 5: Best process parameter condition

Table 7: ANOVA table for the best process parameter

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	3	0.045475	0.045475	0.015158	15.03	0.026
Raster angle	3	0.013125	0.013125	0.004375	4.34	0.130
Infill pattern	3	0.012325	0.012325	0.004108	4.07	0.139
Orientation	3	0.036225	0.036225	0.012075	11.98	0.035
Error	3	0.003025	0.003025	0.001008		
Total	15	0.110175				

Confirmation experiment was conducted to check the validity of the developed regression models. The optimum best level of process parameters was selected for the confirmation test. Owing to the uncertainty of results, the expected value of the selected response factors was calculated within the confidence interval (Roy 1990) [11].Two experiment was performed at best level and average value of UTS was selected. the UTS was evaluated by using Eq. 3. UTSmodel and FTRmodel value can be calculated by using Eq. 1 & 2. Table 8 shows the model and experimental value of selected response factors at optimum level. Results of confirmation test depicts that experimental results were within the CI. Fig 6 (a) & (b) shows the load (kN) - displacement (mm/mm) curve at optimum best level of process parameter.

Expected UTS = UTSmodel ± CI. (3)

Expected FTR = FTRmodel ± CI. (4)

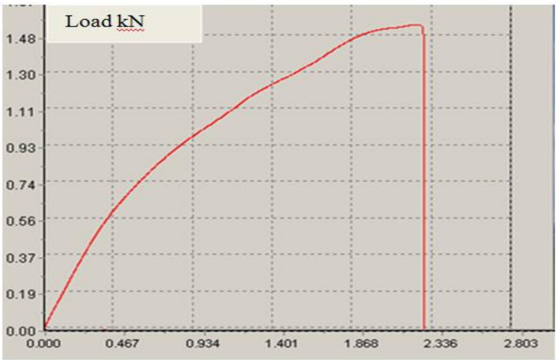
CI may be calculated by using Eq.5 & 6 suggested by [12]

$$CI = \sqrt{\frac{F_{(1,\,DoFe)} \times V_e}{N_e}} \quad (5)$$

$$N_e = \frac{n}{DOF_m + \sum_{i=1}^{n_p} DOF_i} \quad (6)$$

Where, F (1, DOFe) is the fisher value which is equal to the DOFe of error terms. Ve is the variance of the error terms and Ne is the effective number of replication. DOFm, is the degree of freedom of mean term which is always equal to one, DOFi is the degree of freedom of ith significant process parameters and np is the number of design parameters which are affecting the quality characteristics. The value of best process parameter is reported in Table 8. Results of conformation test shows that GRA analysis was a power full tool for the optimization of multi response factor. The best value of process parameters that optimizes both UTS & FTR were layer thickness of 0.1 mm, raster angle 450, infill pattern hexagonal and flat orientation.

(a)



(b)

Fig.6: (a) & (b) Load (kN) v/s displacement curve at optimum level process parameter condition.

5. Conclusion

This research work was carried out to analyze the effect of process parameter on part strength and fabrication time required for the fabrication of sample. An empirical model was developed with the help of Taguchi design. Grey relation analysis (GRA) was utilized to find out the best process parameter for optimizing the response factors. All the selected process parameters were significant in the confidence level of 90% for the ultimate tensile strength, whereas for the FTR only layer thickness was the significant process parameter. Results depict that smaller layer thickness have higher UTS. At 45^0 raster angle, ultimate tensile strength was maximum. Honeycomb infill pattern has better response for both UTS and as well as FTR. Orientation has more impact on UTS. In 'flat' orientation reinforcement direction was parallel to the loading direction which yields higher ultimate tensile strength. A confirmation test was conducted at the best level of process parameter. Confirmation test shows that results were within the CI. However, developed model was valid within the experimental domain, further experiment needs to be conducted to obtain more holistic model.

Reference

[1] Cheah CM, Chua CK, Lee CW, Feng C & Totong K (2005), Rapid prototyping and tooling techniques: a review of applications for rapid investment casting. Int J Adv Manuf Technol 25, 308–320.

[2] Durgun I & Ertan R (2014), Experimental investigation of FDM process for improvement of mechanical properties and production cost. Rapid Prototyping Journal 20 (3), 228 – 235.

[3] Bellini A & Guceri S (2003), Mechanical characterization of parts fabricated using fused deposition modeling. Rapid Prototyping Journal 9(4), 252–264.

[4] Cantrell J, Rohde S, Damini D, Gurnani R, Sandro LD, Anton J, Young A and Jerez A (2016), Experimental Characterization of the Mechanical Properties of 3D-Printed ABS and Polycarbonate Parts. Rapid Prototyping Journal 23(4), 811-824.

[5] Raut S, Kumar V, Jatti S, Khedkar NK and Singh TP, (2014), Investigation of the effect of built orientation on mechanical properties and total cost of FDM parts. Procedia Materials Science. 6, 1625 – 1630.

[6] Onwubolu GC & Rayegani F (2014),Characterization and Optimization of Mechanical Properties of ABS Parts Manufactured by the Fused Deposition Modelling Process. International Journal of Manufacturing Engineering. http://dx.doi.org/10.1155/2014/598531.

[7] Dawoud M, Taha I & Ebeid SJ (2016), Mechanical behaviour of ABS: An experimental study using FDM and injection moulding techniques. Journal of Manufacturing Process 21,39–45.

[8] Wu W, Geng P, Li G, Zhao D, Zhang H & Zhao J (2015), Influence of Layer Thickness and Raster Angle on the Mechanical Properties of 3D-Printed PEEK and a Comparative Mechanical Study between PEEK and ABS, Materials 8, 5834-5846.

[9] Sajan N, John TD, Sivadasan M & Singh NK (2018), An investigation on circularity error of components processed on Fused Deposition Modeling (FDM). Materials Today: Proceedings 5, 1327–1334.

[10] Wang CC, Lin TW & Hu SS (2010), Optimizing the rapid prototyping process by integrating the Taguchi method with the Gray relational analysis. Rapid Prototyping Journal 13(5), 304–315.

[11] Roy R, (1990). A primer on the Taguchi method, Society of Manufacturing Engineers.

[12] Jain PK, Pandey PM & Rao PVM (2008), Experimental investigations for improving part strength in selective laser sintering. Virtual and Physical Prototyping 3(3), 177-188.