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EXPERIMENTAL ANALYSIS OF SURFACE ROUGHNESS AND DIMENSIONAL ACCURACY OF ABS - SSD 0150 FDM COMPONENTS

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ABSTRACT

Purpose

Rapid prototyping (RP) or rapid manufacturing is a booming technology, with its ability to shorten product design and development cycle. FDM parts are strong enough to allow functional testing and the technology allows complex in geometries to be made easily. FDM enables functional assemblies by consolidating sub assemblies into a single unit at the computer aided design stage and thus reduces part count, handling time, storage requirement and avoids mating and fit problems.

Design/Methodology/Approach

The present research is focussed on investigating the influence of the ABS-SSD 0150 based on Design of Experiments. The aim is to optimize the process parameters of the FDM machine such as filler density, shell thickness and layer thickness for improving the surface roughness and dimensional accuracy of FDM specimens using ABS filament as feedstock.

Findings

The present research aims to investigate the effect of surface roughness and interaction effects of the process parameters, on the surface roughness of FDM specimen based on ABS. Three parameters, namely layer thickness; shell thickness and Infill density, each at three levels were selected for the investigation of their influence on the ABS specimens fabricated by FDM technique. This paper describes an associate experimental style technique for deciding the optimum surface and dimensional accuracy of an engineered design of the Deposition Modelling (FDM) method.

Originality/Value

Shell thickness and layer thickness influenced compression specimen surface roughness of FDM processed parts. Multiple Regressions were used to predict the strengths of the fused deposition model specimens with good accuracy. As per the Gray relational grade, tensile and flexural strengths are maximized at a layer thickness of 0.1 mm, shell thickness of 1.5 mm and an infill density of 40 %. FDM specimen showed a significant deviation ranging from 0.1–0.7µm radial distances occurred.

KEYWORDS: Fused Deposition Modelling, Surface Roughness, Multiple Regression, Gray Relational Grade

INTRODUCTION

Rapid prototyping (RP) is an advanced manufacturing technology commercialized in the middle of 1980s. At present, RP technology is widely used in engineering for conceptual models and functional models. The application of RP has been shown greatly to shorten the design-manufacturing cycle and hence reducing the cost of products and increasing competitiveness [1]. Rapid Prototyping has been undergoing great advances in the last few years. RP enables building parts with complex geometries in a short time and at low costs. Its main advantages lie in the ease of generation of a 3D prototype of a concept along with simplified manufacturing and assembly tasks [2]. Advantage with RP is to produce functional assemblies by consolidating subassemblies into a single unit at the computer aided design (CAD) stage and thus reduces part count, handling time, storage requirement and avoids mating and fit problems [3]. Vikram Shende et.al [4] reported the development and testing of the front grill, tail lamp housing, and fuel cap assembly gauge of automobiles Yonghua Chen et.al [5] author reported different pin joint designs analyzed using rapid prototyping. Drum shaped pin joint design gives the minimum joint clearance in layer-based fabrication without weakening the joint strength compared to the traditional cylindrical pin joint design.

Alberto Boschetto et.al [6] explains to predict the surface roughness of the part after barrel finishing operation using process parameter layer thickness, deposition angle and the material removed during barrel finishing operation. The trend of surface roughness as a function of working time, for layer thickness 0.254 mm is reported. Peng An Hua et.al [7] reported part errors in FDM are due to dimension error, shaped error and roughness of surface including warpage deformation, stair-stepping effect. With the increase of slicing thickness, warpage deformation decreases and stair stepping errors increase. Enhancing temperature, warpage deformation decreases and incur rough surface to improve parts accuracy during rapid prototyping is to optimize process parameters. Galantuccia L. M. et.al [8] reported influence of raster width, slice height and tip size on the dimensional accuracy of Fused Deposition Modelling (FDM) specimens. The authors observed that the deviation from the ideal dimension was encountered on the first layer material deposition due to the material adhesion problems which had an effect on the increase in height of other layers. Nur Saaidah Abu Bakar et.al [9-10] reported optimization of raster angle, tool path, slice thickness, build orientation and deposition speed to achieve minimum deviation in the specimen dimensions.

Grzegorz Dyrbus [11] reported parametric study on layer thickness for linear, angular dimensions and curvatures and also to determine the dimensional errors and quality (surface roughness). The model to perform with higher accuracy smaller nozzle was selected.

T. Manchuria et.al [12] explains the effect of the process parameters layer thickness, road width, raster angle and air gap on the surface finish and dimensional accuracy. Layer thickness is strengthened by correlation analysis with surface roughness of 0.6608m and a dimensional value of 0.352mm. Decking Ahn et.al [13] reported parameter cross-sectional shape, surface, angle and layer thickness affect the surface roughness of the parts. Roughness increase as layer thickness increases. P. Vijay [14] author observed the effect of Build Orientation and Layer Thickness used to provide more insight on the sensitivity of surface finish to process parameter variation. Fahraz Ali et.al [15] reported parameters slice height, road width, raster angle, number of contours and air gap. The optimal top surface roughness value of 7.434 m was obtained due to some influential process parameters, such as road width of 0.4064 mm, raster angle of 90°, and no air gap. P. Sreedhar [16] reported the effect of different angled surfaces on the surface roughness of the FDM modelled part. The effects of surface angle, layer thickness, cross-sectional shape of the filament and overlap interval on surface roughness were analyzed and evaluated. The relationship between the part orientation and the surface roughness is analyzed. Dinesh Kumar. S, et.al [17] reported parameters layer thickness, air gap, raster width, contour width and raster orientation. Negative air gap at (-0.01 mm), layer thickness at (0.254 mm) and raster width at (0.508 mm) used to reduce surface roughness. Part orientation leads to reduce building time and improve the surface finish.

Pandey et.al [18-19] reported previous studies adopted to improve the quality of rapid manufacturing products by predicting the surface roughness of parts processed on different rapid manufacturing platforms. Poor surface roughness have been introduced as the main limitation of rapid manufacturing processes.

Dietmar Drummer et.al [20] reported influence of layer thickness and infill density used for optimizing the strength and improving properties. Canny Mendonsa et.al [21] demonstrates the influence of process parameters, print speed, Layer thickness and Infill density on the build time and optimization of FDM parts. ANOVA approach analysis showed that the print speed, layer height and infill density affect the build time by 2.13%, 85.49%and 8.92%. The build time for a given print can be reduced by positively decreasing the layer thickness and negatively reducing the infill density.

Review of Literature [1-21] outlines the parametric study and surface roughness and dimensional accuracy of FDM specimens and influence of layer thickness, part build orientation, raster angle, raster width and air gap. Latest versions of FDM machine have inbuilt technology of the Rapid Prototyping components by changing infill density, shell thickness and layer thickness, which leaves scope for detailed investigation and parametric study of surface roughness of FDM specimens. Software Pronterface with Slic3r is used in the process to set the parameters such as infill density, shell thickness and layer thickness which have the feasibility of less material consumption and improvement in the strength with the honeycomb patterns.

EXPERIMENTAL

Parameters and Levels for Design of Experiments

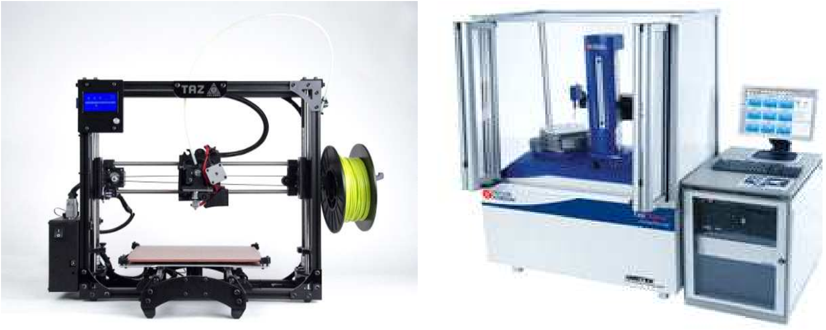
Fused Deposition Modelling Rapid Prototyping Machine, 3D Protomaker IMEC Technologies, Bangalore was studied for parametric optimization. Details of Machines are highlighted in Table 1. Three build parameters, namely layer thickness; shell thickness and Infill density, each at three levels were selected for the investigation of their influence on the ABS specimens fabricated by FDM technique. Layer thickness or layer height directly influences the quality of final print. The default layer thickness is 0.2 mm which gives decent prints. For high quality prints layer thickness of 0.1 mm may be used at the cost of building time, which is twice that of 0.2 mm. Shell thickness refers to the thickness of the outside walls. In case of a cube shell thickness controls the front, back and side thickness. Normal thickness of 0.8 mm gives good results. But depending on the size of the specimen it may be lowered. Infill density is the amount of material deposited within the specimen. It is generally expressed in percentage. While infill density influences the weight and material content it also adversely influences the mechanical properties such as toughness.

Table1: Details of 3D Protomaker IMEC Technologies, Bangalore

Parameter	Details	Parameter	Details
Print Accuracy	50 microns	Printing modes	Solid, honeycomb and hollow
Build material	PLA and ABS plastics	Printing temperature	170 to 200 C for PLA 200 to 240 C for ABS
Power requirements	12V Dc, 15A	Operating system	Windows XP, Windows 7
Filament Diameter	1.75 mm and 3 mm	CAD input data file	STL

		format supported	
Maximum build size	180 x 180 x 200 mm^3	Power consumption	180 W Max
Layer thickness	0.1 to 0.3mm	3D printing software	Cura by Ultimaker

Tensile and flexural specimens as per ASTM D638 and ASTM D695 were fabricated using the FDM machine for the parametric investigation based on the CAD models. The Dimensional deviation is measured from profile measurement. Magnification up to 67X and an Accuracy 5microns for 100mm and lateral resolution 8.8 m from Nebula Technologies, Bengaluru, shown in Figure 1. And surface roughness was measured by Portable Surface Roughness Tester for tensile and flexural specimens Stylus speed=0. 5mm/s (variable), diameter of stylus =2m, stylus scanning length =4. 8mm, max stylus scanner length = 25mm and compression specimens with Taylor Hudson surface roughness tester with testing parameters of 0.005 m, Weight of 400g, Sample length: 0.25 mm to 8 mm CMTI, Bengaluru, shown in Figure1. Experiments were conducted as per L9 Orthogonal Array layout.



FDM Machine **Taylor Hudson Surface Roughness Tester**

c) Profile Measurement

Figure1: Equipment Used in Specimen Preparation and Roughness Measurement Instruments

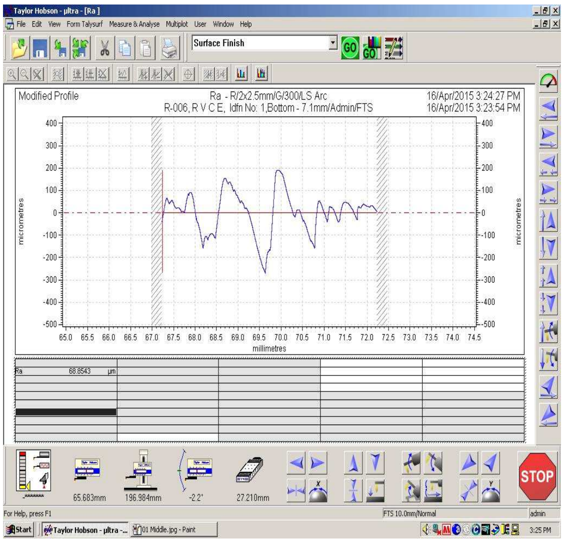
The surface roughness experimental responses for the nine treatment combinations are presented in Table 2.

Table 2: L$_9$ Orthogonal Array Experimental Layout

Expt. No	Experimental Factors			Measured Experimental Responses		
	Layer Thickness, Mm	Shell Thickness, Mm	Infill Density, %	Tensile Specimen, M	Compression Specimen, M10	Flexural Specimen, M
1.	0.1	0.5	20	4.812	4.5313	2.846
2.	0.1	1	30	3.640	3.2469	2.286
3.	0.1	1.5	40	2.523	2.8575	3.958
4.	0.2	0.5	30	2.832	4.5304	6.208
5.	0.2	1	40	3.787	2.7501	3.403
6.	0.2	1.5	20	3.124	2.9579	4.409
7.	0.3	0.5	40	5.920	5.5169	4.423

8.	0.3	1	20	4.926	4.0203	4.798
9.	0.3	1.5	30	3.349	3.5454	4.432

Surface Roughness v/s FDM Parameter



Ra 68.8543 µm

Surface Roughness Measured using Taylor Hudson Surface Roughness Tester

Figure 2: Surface Roughness

Surface finish is critical parameters which affect the part accuracy, reduce the post processing costs and improve the functionality of the parts. Polar diagram Surface Roughness v/s Process Parameter shown in Figure 2 represents the roughness for tensile, compression and flexural specimens. The surface roughness values are measured at the top surfaces of FDM specimens at three different points. With the tensile specimen layer thickness of 0.1mm shell thickness of 1.5mm and an infill density of 40% proved to show minimum deviation. With the Flexural layer thickness of 0.1mm shell thickness of 1.0mm and an infill density of 30% proved to be shown minimum deviation. The Surface roughness increases and decreases because of the heated filament, porosity in the material and infill density percentage which cause warping in the infill pattern chosen, here linear grid structure pattern.

Examination of Variance (ANOVA) for Experimental Responses

ANOVA was executed to research the influence of the parameters at a confidence level of 95% with MINITAB sixteen versions. The assessment was created from the fairness of F and P distributions. Multivariate analysis is summarized in Table 3 for tensile, compression and flexural specimens.

Table 3: Examination of Variables

Source	DOF	Tensile Specimen				Compression Specimen				Flexural Specimen			
		SS	MS	F_{test}	P	SS	MS	F_{test}	P	SS	MS	F_{test}	P
Layer Thickness	2	3.522	1.7615	3.49	0.223	158.16	79.08	11.51	0.080	158.16	2.514	1.36	0.424
Shell Thickness	2	3.733	1.8668	3.69	0.213	538.47	269.23	39.17	0.025	538.47	0.819	0.44	0.693
Infill Density	2	1.716	0.8584	1.70	0.371	2.47	1.24	0.18	0.848	2.47	0.119	0.06	0.940
Error	2	1.010	0.5053			13.75	6.87			13.75	1.851		
Total	8	9.983				712.85				712.85			
DOF-degree of freedom; SS-sum of square; MS-mean sum of square, $F_{Test\ 2,8}$ =4.46													

Based on analysis of variance (ANOVA), Compression specimen layer thickness and shell thickness is contributing to the surface roughness of the FDM specimens. Flexural and tensile specimen is not contributing the surface roughness of the FDM specimen. Layer thickness is going to affect the occurrence of stair steps on the surfaces, leading to high roughness on FDM specimens. The thickness of the layers will determine the built part including surface roughness, build time, ability to accurately represent a feature on the part. The surface roughness increases marginally with an increase in layer thickness. This is attributed to the increased staircase effect and the effect is very small for the range of layer thickness values for FDM specimens shown in table 3.

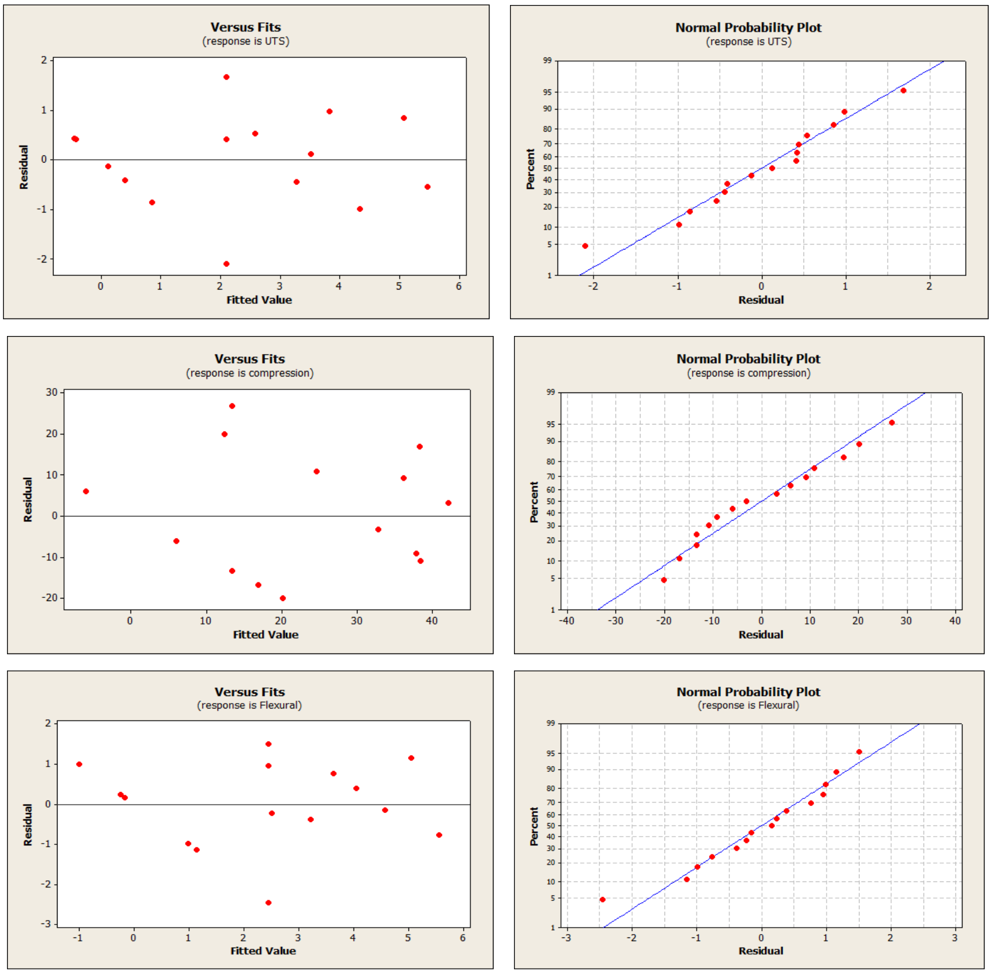


Figure 3: Residual Plot (a) Tensile Specimen (b) Compression Specimen (c) Flexural Specimen

Residual plot for Tensile, compression and Flexural specimen shown in Figure 2. The points lie approximately on the straight line and indicate that the underlying distribution is normal. The normal probability plot of the residuals shows the error terms are normally distributed with the range of +2 to -2. The normal probability plots are normally distributed and a few points lying away from the line implies a distribution with outliers. The surface roughness measurements carried out to analyses the sensitivity of various parameters were analyzed for their effects. The effect of these parameters and their interaction shown in figure 3.

Analysis Using Multiple Regression Model for Experimental Responses

The test data were analyses using MINITAB 16 version. The output obtained for the Multiple Regression model is summarized in Table 4 for Tensile, compression and flexural surface roughness of FDM specimen.

Analysis of the experimental data runs is done on MINITAB R16 software using the full quadratic response

……..(1)

Where y is the response, x_i is i^{th} factor; k is the total number of factors. Final response surface equations for UTS and flexural strength are given in the table 4 obtained from equation 1. The coefficient of determination (R^2) which indicates the percentage of total variation in the response explained by the terms in the model is 89.88% and 85.09% for UTS and flexural surface roughness respectively.

Table 4: Analysis of Response Using Multiple Regression Models

Response	Regression Model	R^2	Experimental (m)	Predicted (m)	Error (%)
Tensile Specimen	Tensile = 6.55737-8.93208A-2.685B-0.0465500C	89.88%	2.523	1.21	4
Compression Specimen	Compression = 0.1583-4.930A-7.099B+ 0.775C	98.07%	27.50	24.91	3
Flexural Specimen	Flexural = -6.01450+.02596A -1.29633B+ 0.224275 C	85.09%	2.286	0.66	2
A= Layer Thickness, B=Shell Thickness, C=Infill Density					

From, multiple regression models it can be concluded that the average relative error between the predicted value obtained by the model and experimental result shown in Table 4 are found to be 4%, 3% and 2% for tensile, compression and flexural surface roughness respectively. Small percentage of errors prove the suitability of the models. The surface roughness is a combination of roughness from layer composition and sub perimeter voids. The sub-perimeter region is full of voids and contributes enormously to the roughness of a surface.

Gray Relation Analysis

In gray relational analysis, experimental data are measured features of quality characteristics are first normalized ranging from zero to one. This process is known as a gray relational generation. Based on normalized experimental data, the gray relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall gray relational grade is determined by averaging the gray relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated gray relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function which is the overall gray relational grade. The optimal parametric combination is then evaluated which would result in the highest gray relational grade. The optimal factor setting for maximizing overall gray relational grade can be obtained by Taguchi method.

In gray relational generation, the normalized Ra values corresponding to the larger-the-better criterion which can be expressed as:

…………….(2)

Where xi (k) is the value after the gray relational generation, min Yi (k) is the smallest value of Yi (k) for the *quiet* response, and max Yi (k) is the largest value of Yi (k) for the *quiet* response. An ideal sequence is [x_0 (k) (k=1, 2, 3......, 9)] for the responses. The definition of gray relational grade in the course of jury relational analysis is to reveal the degree of relation between the 9 sequences [x_0 (k) and xi (k), i=1, 2, 3,......., 9]. The gray relational coefficient I (k) can be calculated as:

Where $\Delta_{0i} = x_o\ (k) - x_i\ (k)$ the absolute value of the difference of $x_0\ (k)$ and $x_{\mathrm{i}}\ (k)$; is the distinguishing coefficient $0 \leq \leq 1$; $\Delta\mathrm{min} = \forall j^{\mathrm{min}} \in i \forall k^{\mathrm{min}}\ x_o\ (k) - x_i\ (k)$ = the smallest value of $_{0i}$; and $\Delta_{\mathrm{max}} = \forall j^{\mathrm{max}} \in i \forall k^{\mathrm{max}}\ x_o\ (k) - x_i\ (k)$ is the largest value of $_{0i}$. After averaging the gray relational coefficients, the gray relational grade *I* can be computed as:

Where *n* is the number of process responses. The higher value of the gray relational grade corresponds to an intense relational degree between the reference sequence $x_0\ (k)$ and the given sequence $x_i\ (k)$. The reference sequence $x_0\ (k)$ represents the best process sequence. Therefore, higher gray relational grade means that the corresponding parameter combination is closer to the optimum. The mean response for the gray relational grade with its grand mean and the main effect plot of gray relational grade are very important because optimal process condition can be evaluated from this plot

Table 5: Influence of Process Parameters of Gray Relational Grade

Expt. No.	Gray Relational Grade				Order
	UTS	Compression Strength	Flexural Strength	Grade	
1.	0.0473	0.0485	0.0864	0.1246	3
2.	0.0670	0.0817	0.1111	0.1857	6
3.	0.1111	0.1030	0.0590	0.2337	9
4.	0.094	0.0485	0.0370	0.1548	4
5.	0.0634	0.1111	0.0707	0.1980	8
6.	0.0820	0.0965	0.0533	0.1962	7
7.	0.0370	0.0370	0.0531	0.0917	1
8.	0.0460	0.0579	0.0531	0.1216	2
9.	0.0746	0.0705	0.0530	0.1627	5

The grey relation coefficients of each performance characteristic are calculated using (5) and are shown in Table 5. Table 6 shows the grey relational grade and order using the experimental layout. The higher value for layer thickness of 0.1mm, shell thickness of 1.5mm and infill density of 40% of the grey relational grade represents the stronger relational degree the reference sequence $x_o(k)$ and the given sequence $x_i(k)$.

Table 6: Response for Grey Relational Grade

Process Parameter	Level 1	Level 2	Level 3	Max-Min	Order
Layer Thickness	0.2548	0.3794	0.4721	0.2173	1
Shell Thickness	0.3119	0.3503	0.3882	0.0763	2
Infill Density	0.3434	0.3543	0.3527	0.0109	3
Mean value of grey relational grade = 0.2972					

The mean response refers to the average value of the performance characteristic for each parameter at different levels. The difference of raw data between level 1 and 3 indicates that shell thickness has the highest effect (= max-min =0.2173) followed by layer thickness (= max-min =0.0763) and infill density (= max-min =0.0109).

Table 7: Analysis of Variance for Analysis of Variance

Source	DF	Sum Of Squares	Mean Squares	F	P	Contribution (%)
Layer Thickness, mm	2	0.006462	0.003232	27.91	0.035	39.93
Shell Thickness, mm	2	0.008292	0.004149	35.84	0.027	52.24
Infill Density, %	2	0.001185	0.000592	5.12	0.163	7.32
Error	2	0.000231	0.000115			
Total	8	0.016180				
DOF-degree of freedom; SS-sum of square; MS-mean sum of square, $F_{\mathrm{Test}\ 2,8}$ =4.46						

ANOVA of the response quality characteristics as shown in Table 7 and it is observed that layer thickness of 39.93%, shell thickness of 52.24% and infill density of 7.32% is contributing the surface roughness of the FDM specimen.

Analysis of Experimental Parameters and Their Results

Response surface methodology measure the performance of the quality characteristic called response and optimization can be done for finding the values of the process variables that produce desirable values of the response.

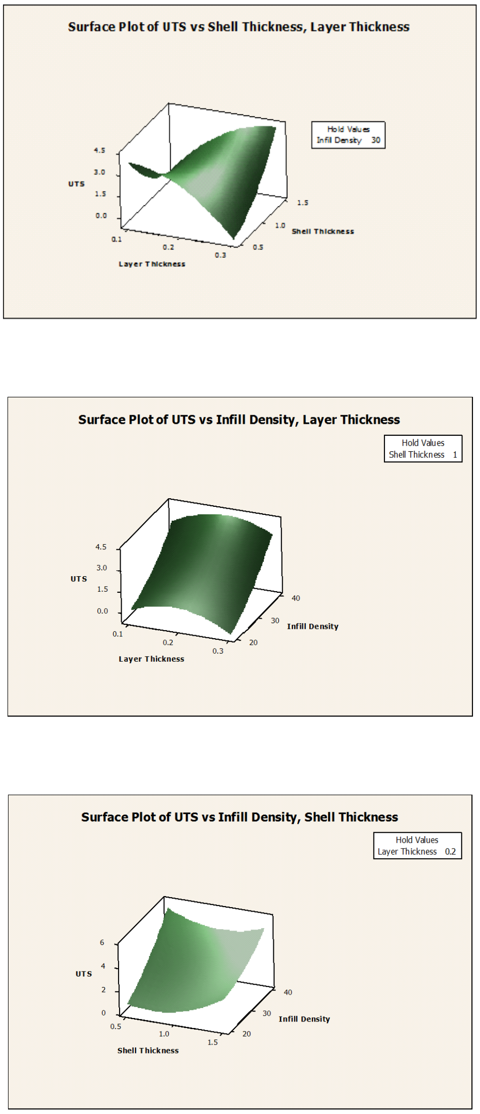


Figure 4: A) To C) Response Surface Plots for Tensile Specimen

From response surfaces plots (Figure 3a to 3c), it can be noted that tensile specimens surface roughness decreases while decrease in layer thickness, shell thickness and infill density.

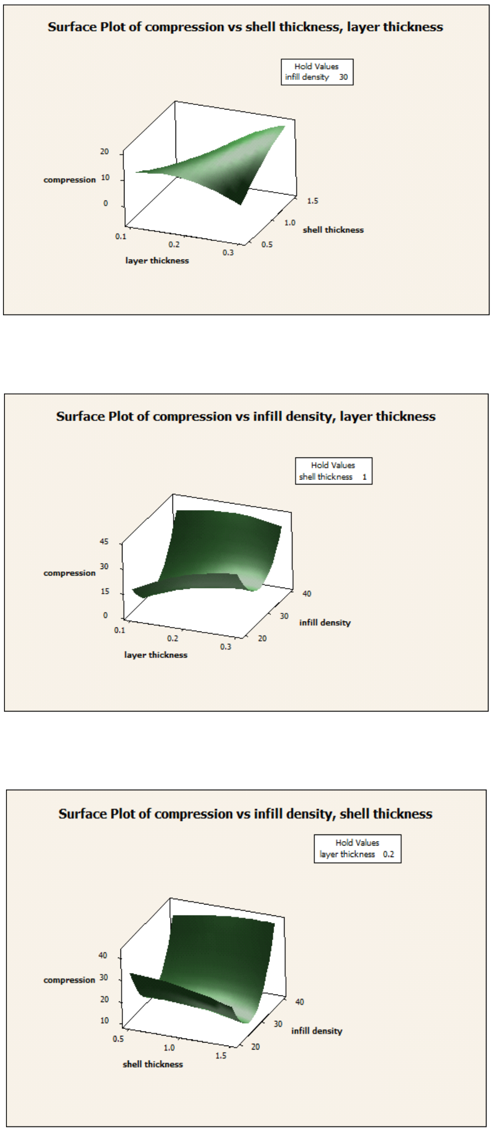
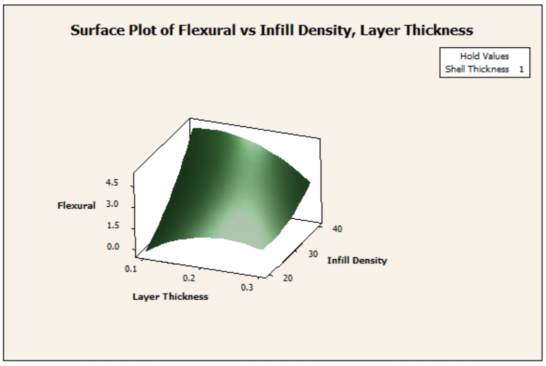


Figure 5: A) To C) Response Surface Plots for Compression Specimen

From response surfaces plot (Figure 4a to 4c), it can be noted that compression specimen surface roughness decreases with decrease in shell thickness, layer thickness and infill density.



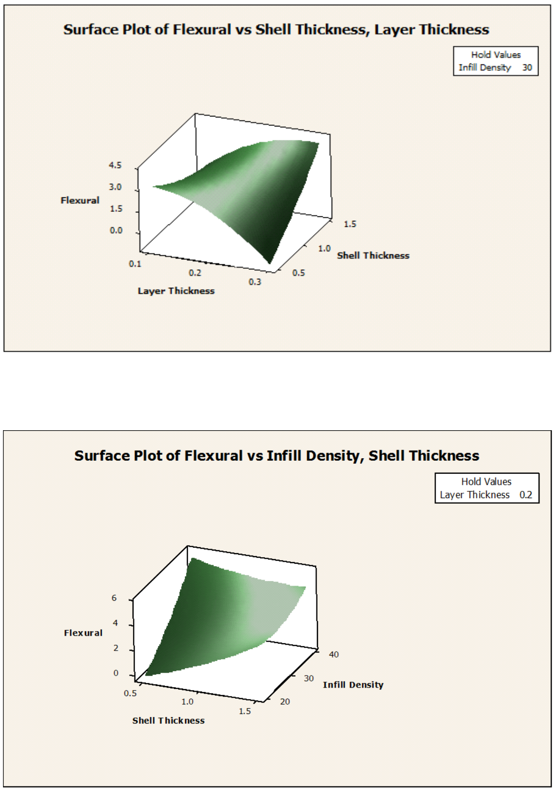


Figure 6: A) To C) Response Surface Plots for Flexural Specimen

From response surfaces plot (Figure 5 a to c), it can be noted that Flexural specimen surface roughness decreases with decrease in layer thickness, shell thickness and infill density.

Dimensional Deviation

The functional requirements of a rapid prototyping system are speed and accuracy which are functions of manufacturing parameters. Accuracy is evaluated by dimensional errors of the manufactured parts. A specially designed specimen with dimensions has been used in the rapid prototyping manufacturing processes. The minimum deviation between fabricated part dimension and CAD model dimension was selected as part accuracy criteria to measure the deviation.

Table 8: Dimensions Deviations of Tensile Specimen

Part No.	Overall Length	Span Length	Dumble Length 1	Radius	Width Of Span Length	Dumble Length 2	Dumble Width 1	Thickness	Dumble Width 2
Actual Dimensions	*150 mm*	*80 mm*	*30 mm*	*5 mm*	*10 mm*	*30 mm*	*20 mm*	*4 mm*	*20 mm*
Measured Dimensions									
1	150.5692	81.7163	31.3449	4.5246	11.2349	31.2713	20.8613	4.2168	20.3213
2	150.4228	80.2412	30.5776	4.9600	11.3705	30.3987	21.4654	4.3284	21.2554
3	150.2589	80.7680	30.9802	4.4548	10.5018	30.8712	20.8719	4.3866	20.2119
4	150.2955	80.6880	30.4705	5.4614	10.3436	30.4093	20.7435	4.5226	20.2735
5	150.8292	81.5763	31.4949	4.3146	11.1349	31.7713	20.8913	4.4568	20.3413
6	150.7092	81.74.63	31.4449	4.4146	11.0349	31.0713	20.9713	4.1968	20.4213
7	150.4428	80.5412	30.6376	4.9500	11.2705	30.4987	21.2454	4.2984	21.2654
8	150.5789	80.1680	30.8402	4.7548	10.8018	30.4712	20.8319	4.3366	20.1119
9	150.2855	80.7880	30.5405	5.0614	10.5436	30.4093	20.6535	4.4426	20.0935

Table 9: Dimensions Deviations of Flexural and Compression Specimen

Part No.	Flexural Specimen			Compression Specimen	
	Overall Length	**Width**	**Thickness**	**Overall Length**	**Diameter**
Actual Dimensions	*125 mm*	*12.7 mm*	*3.2 mm*	*25.4 mm*	*12.7 mm*
Measured Dimensions					
1	124.7787	13.7550	3.1512	25.8374	12.9873
2	124.44	13.2644	3.3958	25.4336	12.8264
3	125.1114	13.3485	3.4146	25.3587	12.5593
4	124.6701	13.9179	3.4849	25.7189	13.0183
5	125.3984	13.1287	3.5019	25.1314	12.9241
6	124.5733	13.0862	3.0489	25.5309	12.6894
7	124.8703	13.9543	3.3226	25.7531	12.9014
8	124.3573	13.2760	3.0949	25.3825	12.3209
9	124.4895	13.2950	3.4709	25.3037	12.6724

The deviation between fabricated part dimension and CAD model dimension was selected as the part accuracy criteria. The FDM machine is accurate when making specimens to the required dimensions. However the author [9] observed FDM specimen showed a significant deviation, ranging from 0.1–0.7μm radial distances occurred. This is because that the gantry mechanism constraints the movement of the deposition head dimensions less than 2 mm will cause to deviate from its accuracy.

RESULTS

Parametric study of Fused Deposition Modelling was performed by fabricating tensile, compression and flexural specimens using ABS material by considering layer thickness, shell thickness and infill density. Based on the experimental results the following conclusions were arrived at:

- The significant influence of layer thickness and shell thickness of compression specimen was observed based on Analysis of Variance. However, none of the three parameters were found to influence the tensile, flexural and impact roughness of FDM specimen.
- Multiple Regression models for tensile, flexural and compression strengths predicted the responses with 4, 2 and 3 % errors respectively.
- As per the Gray relational grade, tensile, compression and flexural strengths are maximized at a layer thickness of 0.1 mm shell thickness of 1.5 mm and 40 % infill density. It was observed for analysis of variance for the optimized gray relation analysis that layer thickness of 39.93%, shell thickness of 52.24% and an infill density of 7.32% is contributing the surface roughness of the FDM specimen.

SUMMARY AND OUTLOOK

REFERENCES

1. Dario Croccolo, Massimiliano De Agostinis and Giorgio Olmi, Experimental characterization and analytical modelling of the mechanical behaviour of fused deposition processed parts made of ABS-M30, Elsevier, Science Direct, Computational Materials Science Computational Materials Science 79 (2013), pp-506–518.

2. Hopkinson N, Hagur RJM and Dickens PH, Rapid manufacturing: an industrial revolution for the digital age. England: John Wiley & Sons Ltd.; 2006.
3. Bernarand A and Fischer A, New trends in rapid product development. CIRP annals-Manufacturing Technology (2002), 51(2), pp-635–52.
4. Vikram Shende, Dr. Prafulla Kulkarni, Decision Support System for Rapid Prototyping Process Selection, International Journal of Scientific and Research Publications, Volume 4, Issue 1, January 2014, ISSN 2250-3153, pp-1-6.
5. Yonghua Chen and Jianan Lu, Minimise joint clearance in rapid fabrication of non-assembly mechanisms, International Journal of Computer Integrated Manufacturing, Vol. 24, No. 8, August (2011), pp-726–734.
6. Alberto Boschetto and Luana Bottini, Roughness prediction in coupled operations of fused deposition modeling and barrel finishing, Journal of Materials Processing Technology, science direct Elsevier 219, (2015), pp-181–192.
7. Peng AnHua and Xiao XingMing, Investigation on Reasons Inducing Error and Measures Improving Accuracy in Fused Deposition Modeling, Advances in information Sciences and Service Sciences(AISS), Volume4, Number5, March (2012), pp-149-157.
8. L. M. Galantuccia, I. Bodib, J. Kacanib and F. Lavecchiaa, Analysis of dimensional performance for a 3D open-source printer based on fused deposition modeling technique, 3rd CIRP Global Web Conference, science direct, Elsevier, Procedia CIRP 28, (2015), pp-82 – 87.
9. Nur Saaidah Abu bakar, Mohd rizal alkahari and Hambali boejang, Analysis on fused deposition modelling performance, Journal of Zhejiang University-Science A (Applied Physics & Engineering) (2010), 11(12), pp-972-977.
10. Nur Saaidah Abu Bakar, Mohd Rizal Alkahari and Hambali Boejang, Analysis on Fused Deposition Modeling (FDM) Performance The 11th Asia, Pacific Industrial Engineering and Management Systems Conference Melaka, 7 – 10 December (2010), pp-1-6.
11. Grzegorz Dyrbus, Investigation on quality of rapid prototyping FDM method, 14th International Research/Expert Conference, Trends in the Development of Machinery and Associated Technology, TMT 2010, Mediterranean Cruise, 11-18 September 2010, pp-629-632.
12. T. Nancharaiah D. Ranga Raju and V. Ramachandra Raju, An experimental investigation on surface quality and dimensional accuracy of FDM components, International Journal on Emerging Technologies 1(2): (2010), ISSN: 0975-8364, pp-106-111.
13. Daekeon Ahna, Jin-Hwe Kweona, Soonman Kwon, Jungil Song, Seokhee Lee, Representation of surface roughness in fused deposition modeling, Journal of Materials Processing Technology 209 (2009) pp-5593–5600.
14. P. Vijay, P. Danaiah, K. V. D. Rajesh, Critical Parameters Effecting the Rapid Prototyping Surface Finish, Journal of Mechanical Engineering and Automation 2011; 1(1): pp-17-20.
15. Fahraz Ali, Boppana V. Chowdary, Justin Maharaj, Influence of Some Process Parameters on Build Time, Material Consumption, and Surface Roughness of FDM Processed Parts: Inferences Based on the Taguchi Design of Experiments, Proceedings of The 2014 IAJC/ISAM Joint International Conference ISBN 978-1-60643-379 pp-.
16. P. Sreedhar, C. Mathikumar Manikandan, G. Jothi, Experimental Investigation of Surface Roughness for Fused Deposition Modeled Part with Different Angular Orientation, International Journal of Advanced Design and

Manufacturing Technology, Vol. 5/ No. 3/ June – 2012, pp-21-28.

17. S.Dinesh Kumar, V.Nirmal Kannan and G.Sankaranarayanan, Parameter Optimization of ABS-M30i Parts Produced by Fused Deposition Modeling for Minimum Surface Roughness, International Journal of Current Engineering and Technology, ISSN 2277 – 4106, 2014, pp-93-97.
18. Pandey, P.M, N. Venkata Reddy, and S.G. Dhande, Improvement of surface finish by staircase machining in fused deposition modeling. Journal of Materials Processing Technology, 2003. 132(1–3): p. 323-331.
19. Pandey, P.M, N.V. Reddy, and S.G. Dhande, Real time adaptive slicing for fused deposition modelling. International Journal of Machine Tools and Manufacture, 2003. 43(1): pp-61-71.
20. Dietmar Drummer, Sandra Cifuentes Cuellar and Dominik Rietzel, Suitability of PLA/TCP for fused deposition Modelling, Rapid Prototyping Journal, Emerald, ISSN 1355-162546, (2012), pp-500–507.
21. Cany Mendonsa, KV Naveen, Prathik Upadhyaya and Vyas Darshan Sheno, Influence of FDM Process Parameters on Build Time Using Taguchi and ANOVA Approach, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064, (2013), pp-330-333.