REST Journal on Emerging trends in Modelling and Manufacturing
Vol: 6(1), 2020
REST Publisher
ISSN: 2455-4537

Website: www.restpublisher.com/journals/jemm

Experimental Investigation to optimise FDM process parameters for ABS material using RSM

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Abstract

Fused Depoition Modeling is a type of Additive Manufacturing technology, which has capability to construct final product by mean of adding layer by layer pattern automatically from data generated by Computer Aided Design (CAD) model. This research work focused over the study of effect of process parameters such as infill percentage, Shell wall thickness and extruion temperature with specimen material used as ABS. This Research work includes optimization of the process parameter using statistical method Response Surface Methodology(RSM(and validating parameter's significance using ANOVA. To overcome some of the drawbacks such as time consumption of printing, machine speed, quality of surface, required properties namely strength, thermal and mechanical properties optimization of process parameter is importand. It is also equally important to find out correlation between process parameters and response outcomes required. Hence, it was proposed to carry experimental investigation of FDM process parameters on polymeric materials because polymeric materials are easy to print as well as economical with wide range of application. FDM process is simple process as compared to other processes so on that basis FDM is chosen. In order to carry work methodology, sample specimens prepared according to ASTM standard for tensile test. Results carried out according to performing test to investigate the relationship between parameters and concomitant effect on strength. Major reason for weak strength of FDM processed parts owes to distortion within the layer or between the layers while building the parts due to temperature gradient. The utility of RP parts suggests that it is dependent on various loading conditions and hence needs to be optimized to gain effective practical implications and optimistic improvisation according to requirements.

Keyword: Fused deposition modeling, Process parameters, RSM, ANOVA, Response optimizer.

1. Introduction

Additive manufacturing which formerly known as Rapid Prototyping (RP) refers to 3D printing technologies, which can easily construct physical parts automatically using data generated fromComputer-Aided Design (CAD). This technique allows designers to create tangible prototypes consuming lesser time by means of "three dimensional printers", rather than two-dimensional pictures. A novel AM technique is Fused Deposition Modeling (FDM) which is operated by a heated nozzle laying down molten material in layers to generate a desired final part. According to ASTM designation, in order to prepare a 3-D model additive manufacturing process of joining materials will be followed as compared to the typical subtractive manufacturing technologies [1,2]. The techniques involved can be categorized as directed energy deposition (DED), binder jetting, material extrusion, material jetting, powder bed fusion(PBF), sheet lamination and vat photo-polymerization provide AM technology classes. In today's context, Rapid Manufacturing is known as Additive Manufacturing and is a rapidly evolving technology with vast growth in manufacturing sector. The 3D printer device is affordable and hence utilized in an array of industrial applications, in addition due to the variety of economical availability of filaments. Additive manufacturing techniques basically classified into different classes as continuously introducing new techniques according to day by day development in evolving research. Wide range of application of FDM technology found now a days such as prototyping, biomedical and jwellery product[3-7]. study of effect infill percentage over the strength is carried out by auther[7[.

2. Fused deposition modeling (FDM)

FDM is an additive manufacturing technique devised and patented by Scott Crump. The industrialized form of FDM is the property of STRATASYS, Inc. But rather using an array of lasers, resins, powders, FDM process uses thermo-plastic material (in filament form) which are heated and then extruded from the nozzle in a temperature controlled environment]7,8[. FDM technology shown in Fig. 1.2 is essentially G-code controlled vertical material extrusion process.FDM produces parts fit for mechanical, chemical and biochemical operating conditions (end use parts). Fig.1.2 presents the basic components of the FDM process. FDM process primarily used for Polymeric materials[4]. Fused deposition modeling process commences with the relevant slicer software. The slicer software performs the function of receiving the 3-D CAD information of the part in the form of stereo-lithography (STL) file. Examples of slicer software are Cura, Repetier, Slice3r, KisSlicer, 3DPrinterOS. Fused deposition modeling process basically 3D manufacturing in which thermo-plastic material extruded through heated nozzle tip. Material heated up to semi-molten state and layer extruded on machine bed. Then another layer extruded on previous layer so that to be fused together. This repetition of layer by layer extrusion will give final additively manufactured product]9[. Extrusion of heated material layer by layer is the basic principle of FDM process.

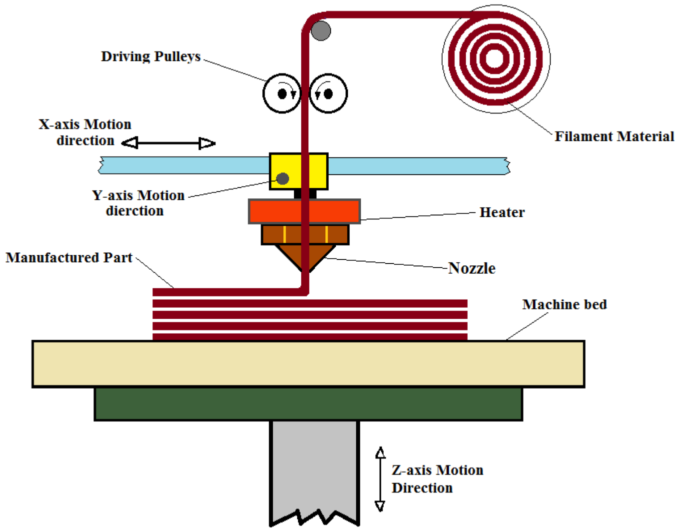


Fig. 1.2 Fused deposition modeling process

3. Reponse surface methodology

Response Surface Methodology is extremely valuable and modern technique for the prediction and improvement of machining results. In the current study, the quality of ABS material part made by combined testimony demonstrating machine has been anticipated and furthermore process variables have been optimized by RSM. Response Surface Methodology (RSM) is a combined approach of statistical and mathematical approach helpful for improvising, developing and optimise the process. RSM is a significant part of experimental design and optimization. It is additionally a basic innovation in growing new process and enhancing their performance (optimizing). The broadest utilization of RSM is in the spoecific circumtance where a few input variables conceivably impact some specific charecteritics of results and quality attribute of process. This measure of performance or quality attribute is know as response. Input factors are sometime dependent and sometomes independent. The Response Surface Methodology comprises of the test methodology for investigating process controll or independent factors, empirical statistics demonstrating to build up an approximated relation between reponse and the process parameters. Additionally, with assistance of RSM, optimization is possible for finding estimations of proces parameters to produce desirable results. The goals of value improvement, including decrease of inconstancy, improved process and product performance, can regularly be practiced legitimately utilizing RSM. It is notable that variety in key execution attributes can bring about helpless cycle and item quality.

4. Study Artefact

The aim of this research is to determine how strength of additively manufactured part varies with different process parameter settings during manufacturing (printing) process. This explains how process parameters will affect strength of product and to establish relationship between process parameter and mechanical properties involved in this study, so that to optimize the process parameter for best requirement of strength of FDM parts. The approach of quantitative method has been chosen for the study and conclusions are made based on the relationship between print settings and test results and dimensional accuracy. Concept generation which is done based on literature review, which helps to find out research gaps to work over the process parameters as it influences the most over the quality and the required properties for the 3D printed final product. Then next is to prepare design of experiments to study the experimental effect of process parameter by conducting experiments accordingly. After deciding the design of experiment, 3D modeling needs to be done on CAD modeling software which will be the starting phase of Fused deposition modeling. 3D model designed need to be sliced in the slicer software which will create ".gcode" file for the machining over printer. Uploading ". gcode" file to manufacture the specimens with various printer settings design as per DOE. For dimensional accuracy, specimens are measured with the standard measuring instruments as per standards. Finally, Tests are carried out and results are analyzed using statistical tools to get optimized printer settings as well as finding relationship between selected factors and the test results (i.e. Strength). Also study comprises the effect of process parameters and defects observed. Shell wall thickness also need to be optimize but it i found in the studies that it should be at least twice to thrice multiple of nozzle size[10]. Various studies have been conducted to find out influence of infill patterns and percentage over FDM manufactured ABS material specifications[9,11-16[. Studies also shows that there is effect of Shell wall thickness over the mechanical properties[17-19[. Some of studies for optimisation using RSM shows analystical and graphical results for FDM[20,21]

5. Experimentation

Generally, AM technologies typically involve use of powders, resins, laser but this process uses thermoplastic filaments which are heated and then extruded from the nozzle in a temperature controlled environment. In this research work, Experimentation work needs manufacturing of specimen on FDM 3D printer machine. FDM printer used for the specimen manufacturing is Aion 500 MK2 which is product of the Divide by Zero industry. Fused deposition modeling process involves various process parameters such as part build orientation, layer thickness, infill pattern, infill density, layer width, raster width, raster angle, air gap, bed temperature, nozzle temperature etc. which directly effect on overall quality of final part, surface quality, strength, mechanical properties]3,4[. In this research, process parameters considered are infill density (%), shell wall thickness (mm) and extrusion temperature(ºC). Infill density directly influences the mechanical strength, whereas increase of infill density from 50% to 75% will give increase in strength about 10-20%. Similarly adding more shell wall thickness will add more strength to your final product. If we look at extrusion temperature, basically it will affect the process of fusing layers together. Indirectly it influences the strength as final product needs to be well fused layers to get better strength. Material selection is done as per review of all available materials for the available machine. Materials available for the available machine is shown in table 3.1, whereas selection criteria are basically maximum strength with economic availability. As, it is found that ABS is commonly used globally while ABS has comparatively more strength than PLA, PETG, HIPS and Polycarbonate. ABS is cheaper material available in market as compared to others. Acrylonitrile Butadiene Styrene (ABS) (for which chemical formula C8H8-C4H6-C3H3N)n) is a commercial thermoplastic commonly used to produce light, rigid, molded goods such as piping components, musical instruments, protective head gear , automotive body parts , enclosures for furniture and joinery panels, toys (like Lego bricks). In order to build empirical model for Tensile strength, experiments were conducted based on Box Behnken Design (BBD). The Box Behnken Design is capable of fitting second order polynomial and is preferable if curvature is assumed to be present in the system. Maximum and minimum value of each factor is coded into +1 and -1 respectively using, so that all input factors are represented in same range. Factor considered and their levels considered for current research work is shown in table 1.1

Table 1.1 Factor and their levels

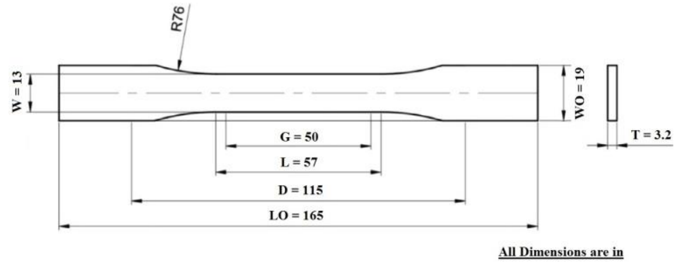
Factors	Units	Symbol	Level		
			-1 (Low)	0 (Medium)	+1 (High)
Infill Density	%	A	25	50	75
Shell Wall Thickness	mm	B	0.8	1.2	1.6
Extrusion Temperature	°C	C	230	240	250

Tensile test specimens modeled with dimensions 60 mm x 20 mm x 5 mm. Tests have been conducted according to ASTM D638 measuring Tensile strength [22]. Test specimen modeled USING Solidwork 2017 Academic and converted as .STL format. Then STL file imported to FDM slicer software (KISSlicer is used in this research work). In KISSlicer, print settings are modified as per the Box Behnken design combinations according to experimentation planned work.

$$\theta_{ij} = 2 \text{ x } \frac{X_{ij} - (X_{i.max} + X_{i.min})/2}{(X_{i.max} + X_{i.min})/2}$$

Where, θ_{ij} and X_{ij} are coded and actual value of j^{th} level of i^{th} factor respectively.

Specimens for the experiments are manufactured using 3D printer Aion 500 MK2 according to Box Behnken Design for response surface methodology i.e. 15 runs. Material used for specimen manufacturing is ABS (Acrylonitrile Butadiene Styrene). Specimen with desired specific dimensions for Tensile test according to ASTM D638 standard is shown in fig. 1.3, respective notations are described as LO is overall length of the specimen, D is Distance between grips, L is Length of narrow shaped section, G is gauge legth required for testing, WO described as overall width, W is considered Width of narrow shaped section and T is thickness of specimen



(A) (B)

Fig. 1.3. (A) ASTM D-638 standard (B)3D printed Specimens as per standard

Table 4.3 shows combinations of coded levels of factors and actual factors which are based on Box Behnken design for RSM [23,24]. DOE is performed on Minitab 19 which is a statistical tool. Coded factors are named as A, B, C for Infill Density, Shell wall thickness and Extrusion Temperature respectively. Tensile test as per standards carried out on UTM machine. Specifications of UTM machine which is of standard product of Aimil ltd. And has capacity of 300 KN.

Table 1.2 Printer setting combinations coded and actual factors as per Box Behnken Design

S. No.	Coded factors			Actual factors			Response (Tensile Strength)
	A	B	C	(%)	(mm)	(°C)	(MPa)
1	-1	-1	0	25	0.8	240	31.8
2	+1	-1	0	75	0.8	240	33.4
3	-1	0	-1	25	1.2	230	31.6
4	0	0	0	50	1.2	240	33.5
5	0	0	0	50	1.2	240	33.2
6	0	-1	-1	50	0.8	230	32.5
7	-1	+1	0	25	1.6	240	31.9
8	+1	0	-1	75	1.2	230	34.0
9	0	+1	-1	50	1.6	230	33.0
10	0	+1	+1	50	1.6	250	32.2
11	+1	0	+1	75	1.2	250	33.9
12	-1	0	+1	25	1.2	250	32.1
13	0	0	0	50	1.2	240	33.5
14	+1	+1	0	75	1.6	240	34.4
15	0	-1	+1	50	0.8	250	32.8

6. Reults and Dicussion

Statistical analysis of the results obtained from experiments performed as per Box Behnken design is done on Minitab 19 software using full quadratic response surface model, which is as follows,

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i X_i + \sum_{i<j} \sum \beta_{ii} X_i X_j$$

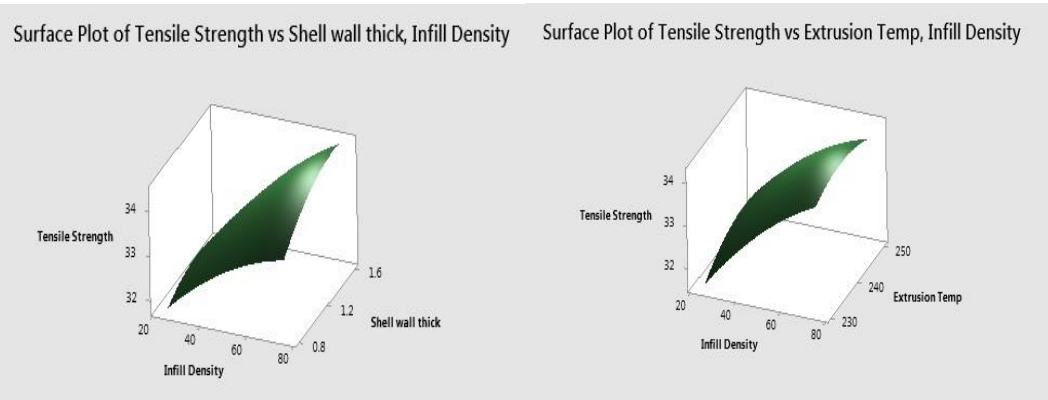
Where Y is response, X_i is i^{th} factor,

Significance of process parameters are validated using ANOVA (Analysis of Variance) technique. Table 5.1 shows results of Analysis of Variance. P-value is the most important point of interest for decision making to prove significance level of factors. P-value is the indication probability of change in F-value of actual than calculated F-value. According to ANOVA, if p-value is less than 0.05 for α equals to 95% then the factor is considered as significant (i.e. null hypothesis fount satisfied). If p-value is greater than 0.05 for α equals to 95% then null hypothesis not satisfied so that go for alternate null hypothesis and factor not considered as significant. This meant in other words as standard mean of two group is different than other, which gives difference between predicted and calculated from actual dataset. Significance of process parameters are validated using ANOVA (Analysis of Variance) technique. Table 5.1 shows results of Analysis of Variance. P-value is the most important point of interest for decision making to prove significance level of factors. P-value is the indication probability of change in F-value of actual than calculated F-value. According to ANOVA, if p-value is less than 0.05 for α equals to 95% then the factor is considered as significant (i.e. null hypothesis fount satisfied). If p-value is greater than 0.05 for α equals to 95% then null hypothesis not satisfied so that go for alternate null hypothesis and factor not considered as significant [26,27]. This meant in other words as standard mean of two group is different than other, which gives difference between predicted and calculated from actual dataset.

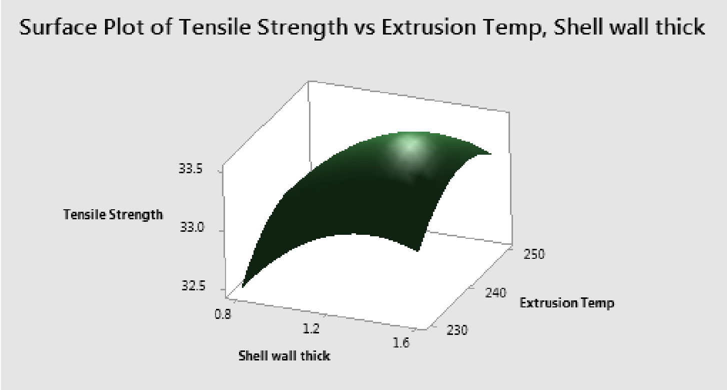
Table 1.3 ANOVA table for response surface quadratic

Source	*DF*	*Adj. SS*	*Adj. MS*	*F-value*	*p-value*	
regression	*9*	*10.1498*	*1.12776*	*83.54*	*0.000*	*significant*
Infill Denity (%)	*1*	*8.6112*	*8.61125*	*637.87*	*0.000*	*significant*
Shell wall thickness (mm)	*1*	*0.5000*	*0.50000*	*37.04*	*0.002*	*significant*
Extrusion Temp (°C)	*1*	*0.1012*	*0.10125*	*7.50*	*0.041*	*significant*
Interaction	*3*	*0.2950*	*0.09833*	*7.28*	*0.028*	*significant*
Residual error	*5*	*0.0675*	*0.01350*			
Lack of fit	*3*	*0.0075*	*0.00250*	*0.08*	*0.963*	*Confidence interval 95%*
Pure error	*2*	*0.0600*	*0.03000*			
R^2	*99.67%*					

R^2 is the coefficient of determination, which shows percentage of suitability of fit for the model. As R^2 value is 99.67% which concludes high significance of the model and confirms well suitability. As Lack of fit shown in above table is 0.963 which is far greater than 0.05, confirms non significant, while all other terms with interaction are significant. So ANOVA test confirms the model suitability and validate process parameter significance for this thesis work [26]. Fig. 1.4 (A) Shows surface plots generated from response surface methodology using MINITAB 19. Fig. (A) Shows surface plot for tensile strength vs infill density and shell wall thickness, according to which it is observed that the tensile strength increases significantly with increase in infill density and shell wall thickness. We can conclude that, more numbers of layers according to denser model will give more resistance against tensile force. Simply the greater dense part with more number of layers will results greater tensile strength. Similarly significantly increase in shell wall thickness along with infill density is found with curvature interaction of both parameters together. That might be because of increase is numbers of layers which gives more strength while shell wall thickness plays an important role in failure because internal area of part is not completely filled which tends to concentration of tension on part wall. Fig 1.4 (B) shows interactive surface plot for response tensile strength. According to surface plot, as discussed material infill density increases dictly tensile strength also increases. Simultaneously, interaction plot showing temperature change affects strength. This might happen because, temperature affect on fusing process between layer by layer. As during specimen manufacturing, it is observed that, insufficient temperature affects incomplete melting of material which indirectly affects layer fusion (layer bonding). Simply material setting is important for better material fusion process so that it will give more strength by well fused layer by layer bonding. This simply resists more against tension force so that can help in better tensile strength. Interaction plot shows curvature edges, which are used to identify week point in manufacturing process.



(A) (B)



(C)

Fig. 1.4 suface plot result for Infill denity, shell wall thickness, Extrusion temperature vs Tensile strength

Fig. 1.4 (C) gives more curvature interaction for tensile test, while according to ANOVA test, this interaction is less significant as compared to other two parameters. Graph shows that increase in shell wall thickness is giving increase in tensile strength wit interaction of change in temperature. But when we observe the temperature function along with shell wall thickness, there is no significant effect found. Increase in temperature gives increase in tensile strength but up to some certain limit. As graph shows, after peak point, it suddenly falls down for strength. This might caused because of overheating cause over melting of material which affects layer deposition in non-uniform way. As plot shows more curvature portion in graph. Main effect plot is shown in fig. 1.5, where all input parameters individual role shows with their impact on strength. As first shows infill density, It is clearly found that, trend of increase in tensile strength with increase in infill density. If we observe the graph, we found that, increase of infill density from 25% to 50% will give more increase in tensile strength as compared to effect of change in infill density from 50% to 75%. It is clearly observed that from increase in infill density from 25% to 75% will give increase in strength approx. >20%. In other hand, if we observe the shell wall thickness also shows effective increase in tensile strength with increasing shell wall thickness from 0.8 mm to 1.2 mm as compared to increase in shell wall thickness of 1.2 mm to 1.6 mm. Even though, there is no significant change in strength noticed for change in shell wall thickness from 1.2mm to 1.6mm. Extrusion temperature in main effect plot still not give satisfactory result, means still can't conclude anything for effect of temperature. Extrusion temperature of 240°C gives more strength as compared to 230°C and 250°C extrusion temperature setting according to plot.

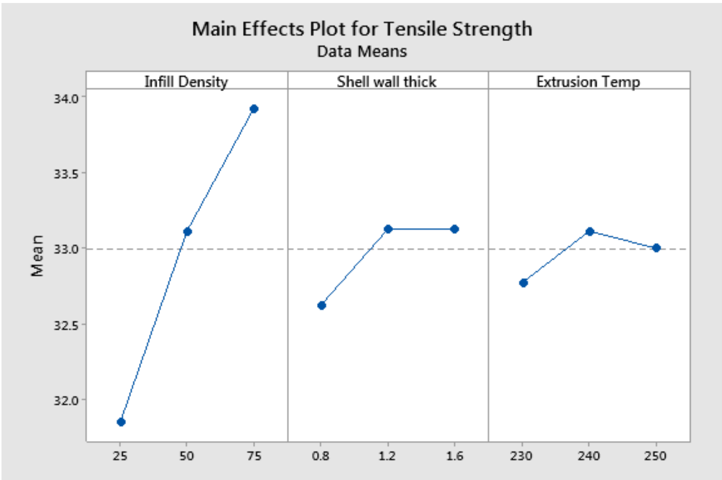


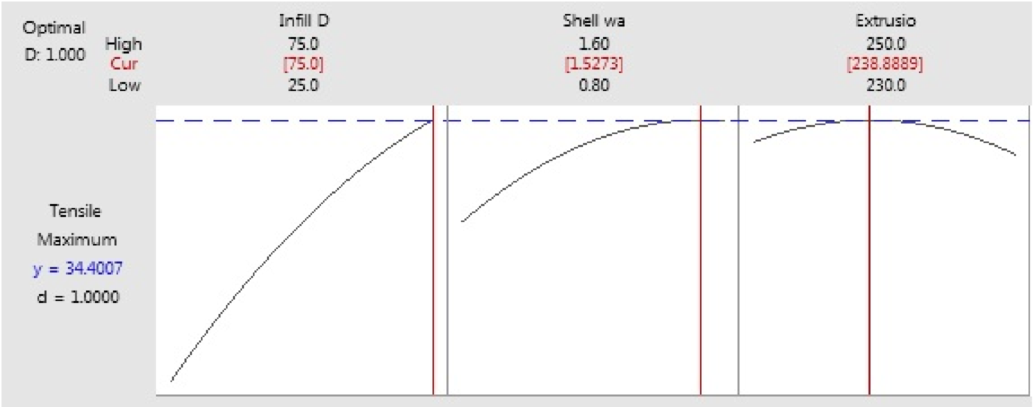
Fig. 1.5 Main effect plot of Infill denity, shell wall thickness, Extrusion temperature over Tensile strength

Response Surface Methodology gives better visualization identification for effect of process parameter as different plots such as surface plot, contour plots gives clear conclusion with dataset analysis. Also with the help of MINITAB 19, By using tool response optimizer we conclude the optimized process parameters which can give best tensile strength output with optimistic inputs. Table 1.4 shows optimized values of input process parameters from the statistical analysis. Infill density of 75%, shell wall thickness 1.53mm with extrusion temperature 238.9°C will give predicted tensile strength up to 34.4 Mpa, which is maximum value we obtained in our experimental work. Also it shows graph for parameter effect in a line chart.

Table 1.4 optimized parameter set obtained from analysis

Solution	Infill Density	Shell wall thick	Extrusion Temp	Tensile Strength Fit	Composite Desirability

1	*75*	*1.52727*	*238.889*	*34.4007*	*1*



Strength difference caused by residual stresses formed during manufacturing as well as cyclic process of heating and cooling of material during machining process. Also it is found there are some weak inter-layer bonds within manufactured specimen which effectively influenced over strength of the specimen. In fracture examination, it is found that inter-layer porosity also affects the strength as material density indirectly results decrease in strength (tensile). Weak inter-layer bonding is caused due to temperature difference as well as uneven cooling of previous layer built over. Residual stress most commonly forms during machining process, in heating and cooling in our case of Fused deposition machining. Due to formation of residual stress affects the resistant to forces. Which effect as weakening of final product, so final resulting it decreases strength of final product. Also volumetric shrinkage is common cause of residual stress formation in FDM process. During the cooling process of melted layer, it shrinks with decrease in temperature which causes formations of residual stress throughout the layer. Additionally, inter-layer weak bonding caused with low cross linking because of temperature difference and low molecular diffusion. In effect internal porosity results reduced load bearing area as similar infill density too.

Conclusion

ABS material tensil test data is shown in table 4.3 which shows the process parameters considered and response for the combinations of setting according to Box Behnken design for Response surface methodology. It is observed that, experiment number 14 gives high strength (34.4 Mpa) which having setting of Infill density 75%, shell wall thickness of 1.6mm and extrusion temperature 240°C. Experiment number 3 gives low tensile strength (31.6 Mpa) which settings were Infill density 25%, shell wall thickness 1.2mm and extrusion temperature 240°C. Empirical relation between each response and process parameter were determined and validated using the Analysis of Variance (ANOVA). Response surface plots for strength shows that process parameters dependent on each other as interaction shows. Also plot concludes that their optimal solution depends on selection of level of settings of process parameter. Influential reason for weak strength is distortion between the internal layers and weak inter-layer bonding. For optimization, response surface optimizer is used to find out exact values of process parameters to get maximum strength i.e. optimizing setting for maximizing response.

Reference

1. Wiedemann, B. Jantzen. Strategies and applications for rapid product and process development in Daimler-Benz AG, Computers in industries, 39(1):11–25.
2. Kamrani, A. K., & Nasr, E. A. *Engineering design and rapid prototyping*. Springer Science & Business Media.
3. Stratasys (2014a). ABS-M30 Production-Grade Thermoplastic for Fortus 3D Production, http://www.stratasys.com/~/media/Main/Secure/Material%20Specs%20MS/Fortus-Material-Specs/FortusABSM30MaterialSpecSheet-US-09-14Web.pdf
4. Solomon, I. J., Sevvel, P., & Gunasekaran, J. (2020). A review on the various processing parameters in FDM. *Materials Today: Proceedings*.
5. Stratasys. (2014b). Finishing touch smoothing station: Expanding possibilities, from http://www.stratasys.com/solutions/finishing processes/smoothing-fdm-parts
6. Stratasys. (2014c). Stratasys Data Sheets: The truth about speeds, from www.stratasys.com
7. S. El-Gizawy, S. C., B. Graybill. (2011). Process-induced Properties of FDM Products. www.stratasys.com/fdmproducts.pdf. [7] T. Tolio, H. A. Maraghy, A. Fischer, S.J. Hu, L. Laperrière, S.T. Newman, J. Váncza 59 (2010) 672-693.
8. Sood, A. K., Ohdar, R. K., & Mahapatra, S. S. (2010). Parametric appraisal of mechanical property of fused deposition modelling processed parts. *Materials & Design*, *31*(1), 287-295.
9. Pham, D. T., & Gault, R. S. A comparison of rapid prototyping technologies. *International Journal of machine tools and manufacture*, *38*(10-11), 1257-1287.
10. Alvarez, K. L., Lagos, R. F., & Aizpun, M. (2016). Investigating the influence of infill percentage on the mechanical properties of fused deposition modelled ABS parts. *Ingeniería e Investigación, 36(3)*, 110-116. DOI: 10.15446/ing.investig.v36n3.56610.

11. Vishwas, M., & Basavaraj, C. K. (2017). Studies on optimizing process parameters of fused deposition modelling technology for abs. *Materials Today: Proceedings*, *4*(10), 10994-11003.
12. Rodríguez-Panes, A., Claver, J., & Camacho, A. M. (2018). The influence of manufacturing parameters on the mechanical behaviour of PLA and ABS pieces manufactured by FDM: A comparative analysis. *Materials*, *11*(8), 1333.
13. L. Baich, G. Manogharan, Study of infill print parameters on mechanical strength and production cost-time of 3D printed ABS parts. International Solid Freeform Fabrication Symposium, Austin, TX (2015) 209–218.
14. E. Ebel, T. Sinnemann, Fabrication of FDM 3D objects with ABS and PLA and determination of their mechanical properties, RTejournal (2014) https://www.rtejournal.de/ausgabe11/3872 (accessed Sept 12, 2017).
15. M. Fernandez-Vicente, W. Calle, S. Ferrandiz, A. Conejero, Effect of Infill Parameters on Tensile Mechanical Behavior in Desktop 3D Printing. 3D printing and Additive Manufacturing, 3(3) (2016) 183-192.
16. S. Mahmood, A.J. Qureshi, K.L. Goh, D. Talamona, Tensile strength of partially filled FFF printed parts: experimental results. Rapid Prototyping Journal, 23(1) (2017) 122-128.
17. K. Raney, E. Lani, D.K. Kalla, Experimental characterization of the tensile strength of ABS parts manufactured by fused deposition modeling process. Materials Today: Proceedings 4 (2017) 7956-7961.
18. Mahmood, S., Qureshi, A. J., Goh, K. L., & Talamona, D. (2017). Tensile strength of partially filled FFF printed parts: experimental results. Rapid Prototyping Journal.
19. Harun, W. S. W., Sharif, S., Idris, M. H., & Kadirgama, K. (2009). Characteristic studies of collapsibility of ABS patterns produced from FDM for investment casting. *Materials Research Innovations*, *13*(3), 340-343.
20. Khabia, S., & Jain, K. K. (2020). Comparison of mechanical properties of components 3D printed from different brand ABS filament on different FDM printers. *Materials Today: Proceedings*.
21. Srivastava, M., Maheshwari, S., Kundra, T. K., & Rathee, S. (2017). Multi-response optimization of fused deposition modelling process parameters of ABS using response surface methodology (RSM)-based desirability analysis. *Materials Today: Proceedings*, *4*(2), 1972-1977.
22. Srinivasan, R., Pridhar, T., Ramprasath, L. S., Charan, N. S., & Ruban, W. (2020). Prediction of tensile strength in FDM printed ABS parts using response surface methodology (RSM). *Materials Today: Proceedings*.
23. ASTM International. *Standard test method for tensile properties of plastics*. ASTM International.
24. Mohamed, O. A., Masood, S. H., & Bhowmik, J. L. (2017). Experimental investigation for dynamic stiffness and dimensional accuracy of FDM manufactured part using IV-Optimal response surface design. *Rapid Prototyping Journal*.
25. Zhang, Y., Huang, H., Xu, S., Wang, B., Ju, J., Tan, H., & Li, W. (2015). Activation and enhancement of Fredericamycin A production in deepsea-derived Streptomyces somaliensis SCSIO ZH66 by using ribosome engineering and response surface methodology. *Microbial cell factories*, *14*(1), 64.
26. Wankhede, V., Jagetiya, D., Joshi, A., & Chaudhari, R. (2020). Experimental investigation of FDM process parameters using Taguchi analysis. *Materials Today: Proceedings*, *27*, 2117-2120.
27. Andrade, C. (2019). The P value and statistical significance: misunderstandings, explanations, challenges, and alternatives. *Indian Journal of Psychological Medicine*, *41*(3), 210-215.
28. Kennedy-Shaffer, L. (2019). Before p< 0.05 to beyond p< 0.05: Using history to contextualize p-values and significance testing. *The American Statistician*, *73*(sup1), 82-90.

