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Optimization of the FDM Process Parameters to Attain the Desired Strength of ABS Specimens

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Abstract**:** ***The recent most admired additive manufacturing (AM) technique is the fused deposition method (FDM) because of its low cost and ease of operation. The FDM printed parts often suffered with lack of global or average strength, because of more strength in printed direction and leads to anisotropic mechanical properties. The most effective methods to obtain high tensile strength are the optimization of process parameters of FDM process to manufacture high strength Acrylonitrile Butadiene Styrene (ABS) samples. The present research paper objective is to analyze the process parameters effect on tensile strength of FDM printed specimen with ABS. The specimen is prepared as per the D638 ASTM standards. The specimens are printed in accordance with L9 matrix a Taguchi method. The chosen FDM process parameters are fill density with 40, 60 and 80(%), print speed with values of 60, 80 and 100(mm/min), and layer thickness 100, 200 and 300(microns). From the tensile strength investigation of ABS samples, the maximum tensile strength of 24.866 MPa is obtained with specimen build with the parameters, infill-80%, speed-100mm/min and layer thickness 0.2mm. This proposed research work is useful to decide the effective FDM process factors and their working ranges to manufacture the ABS components or parts.***

Keywords **:** ***Additive Manufacturing, Acrylonitrile Butadiene Styrene (ABS), Fused Deposition Modelling (FDM), Taguchi L9 approach.***

I. INTRODUCTION

The FDM technique becomes very popular in very short span due to its ease in operation, short production cycle and low production cost. This technology made easy in rapid prototyping of the functional objects, structures suitable for thermal resistance such as for aerospace application and electrical conductive parts for prosthesis application by using different materials. Complex parts are manufactured at low cost in comparison to conventional production process as this process does not require excess tooling. The process involves deposition of melted thermoplastic through heated nozzle by multiple layers on a build platform in the type of a prearranged two dimensional (x-y) layer platform. The deposited material solidifies and a desired shaped part is produced. Layer is deposited according to the cross section of geometry to be printed from a CAD file. The fig. 1 represents the working process of FDM technique. The density of ABS is 1.06g/cm^3, tensile strength 42MPa and produces excellent impact and heat resistance, exhibits good strength and machinability, provides fine corrosion and scratch resistance. This research work is focused on to identify the influencing fused deposition method working factors on the tensile strength of the prepared ABS material specimens. Taguchi L9 experimental design is used to prepare 9 experimental conditions and to optimize the process to get a meaningful conclusion. Zero part orientation and increase in the raster angle also resulted the gain in tensile strength is reported [1]. FDM process parameters to enhance the quality i.e. dimensional accuracy and strength of printed specimens with poly-lactic materials using Taguchi method and Response Surface Method to optimize the process parameters are carefully performed. Enhanced quality of prints with optimised parameters obtained with RSM in comparison to Taguchi method is concluded [2]. The influences of chosen working factors on the strength of poly-lactide (PLA) and ABS pieces manufactured by FDM are researched. Process parameter in-fill density is having major effect on strength is stated. PLA specimens are more rigid and having greater strength than ABS is concluded [3]. The experiments are carried out to study the impacts of FDM factors on mechanical properties of the ABS parts fabricated by FDM [4]. The conclusions are made that process parameter build orientation is critically affects the mechanical properties and porosity of ABS fabricated parts [5]. The various testings of the specimens printed with different deposition orientations and found that Z direction resulted in maximum tensile strength of FDM part and vertical direction to the layer results the decrease in tensile strength [6]. A mathematical model by using CCD and ANOVA techniques to obtain the desired properties of FDM processed parts is created. It is noticed that the overall increase in strength by reducing the amount of layers and by increasing the layer thickness [7]. The experiments performed to find the strength under compression of chemically treated and untreated ABS samples printed by FDM process. The results obtained as maximum strength of untreated sample is 44.01 MPa and treated sample is 44.66 MPa. Raster angle 30 and 60 degrees is having more impact on the strength is reported [8]. The different FDM processing factors are optimized to print ABS specimens to achieve the desire strength. The group modelling for data handling method is used to create a functional network to relate the input factors and output response.

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The maximum strength is reported as 38.9MPa [9]. It is reported that a robust experimental design is prepared to analyse the impact of process parameters by following the optimum guidelines. The design is reported as simplex form of process parameters selection by reducing the noise factors to improve the rate of production [10].

II. EXPERIMENTAL DETAILS

The ABS material specimens are printed as per ASTM standard D 638 by using a 3D printer. The complete set up and printed ABS specimens are represented in fig. 1 and 2 respectively. The FDM input process parameters are print speed, fill density, layer thickness and their working ranges are given in table I. The Taguchi L9 approach experimental condition which is followed to prepare the ABS test samples is given in the table II. The 3D printed ABS specimens are undergone for the tensile testing in the universal testing machine. The obtained tensile results are tabulated in the table II. Statistical software named as Minitab is used to draw a valid and meaningful conclusion by optimizing the 3D printing process parameters. The variance analysis technique (ANOVA) is used to find the trueness of the achieved relationship. In this technique F ratio called fishers test is used to measure the fitment of the experimental data to the 95% confidence interval statistically. In this technique F ratio called fishers test is used to measure the fitment of the experimental data to the 95% confidence interval statistically. In this technique F ratio called fishers test is used to measure the fitment of the experimental data to the 95% confidence interval statistically. In this technique F ratio called fishers test is used to measure the fitment of the experimental data to the 95% confidence interval statistically. For static experimental design the optimum condition i.e. signal to noise ratio (S/N) “larger is better” is applied to get the desired strength in 3D printed ABS specimens. The formula used to determine the S/N ratio is base 10log and summation of the ratio of response tensile strength ‘Y’ for the given combination of the various levels of factors and ‘n’ is the number of responses and that is the: $S/N=-10\times\log(\Sigma(1/Y^2)/n)$. (1)

Fig. 1. FDM machine set-up

Fig. 2. 3D printed ABS specimens

Table- I: Input process parameters and their ranges

3D printing input process parameters	Working ranges		
	1	2	3
Print speed (mm/min)	60	80	100
Fill density (%)	40	60	80
Layer thickness (microns)	100	200	300

Table- II: Taguchi 09 experimental conditions and obtained tensile strength of FDM printed ABS specimens

Expt. No.	Print speed mm/min	Fill density %	Layer thickness Microns	Ultimate tensile strength (MPa)
1	60	40	100	12.36
2	60	60	200	14.16
3	60	80	300	21.33
4	80	40	200	10.72
5	80	60	300	22.62
6	80	80	100	12.26
7	100	40	300	20.97
8	100	60	100	13.06
9	100	80	200	24.86

III. RESULT AND DISCUSSIONS

The observations made from the experiment, tabulated in the table II, are when print speed is kept constant at 60 rpm, fill density is changed as 40, 60, 80 (%) and layer thickness is varied as 100, 200, 300 microns, the strength of 3D printed ABS specimens are obtained as 12.369, 14.164 and 21.337 MPa. When the print speed increased to 80rpm and kept constant with varying the fill density and layer thickness the tensile strength of the ABS samples are obtained as 10.72, 22.62, 12.265MPa. Further increase in print speed to 100 rpm and with the change in fill density and layer thickness the strength of the ABS samples is obtained as 20.974, 13.064, 24.866 MPa. Particularly the strength of ABS samples is obtained to be higher such as 21.337, 22.62 and 24.866 MPa when the layer thickness is maintained at 200 and 300 microns. The chosen optimum condition is larger the better.

The S/N ratio and mean value of the obtained tensile strength is tabulated in the table III. Ranking of each delta value is defined in terms of, largest delta value (layer thickness) is rank 1 and smallest delta value (print speed) is rank 3. From the table IV, the regression optimization is carried to found a relationship between the chosen process parameters and response values to analysing their individual as well as combined impact. F value explains the significance of the process parameters upon the tensile strength such as layer thickness (0.02) represents to be more significant than print speed (0.237) and fill density (0.14). The 'P' value (0.05) describes the regression coefficient is in the chosen range of the controlled FDM factors. The contour plots described in fig. 2 are the two dimensional descriptions of the obtained strength under tension of the ABS samples presented as a surface in relation to the process parameters. In the contour images the red colour areas describes the ranges of the low strength from 12 to 18 MPa and green colour areas are the ranges of maximum strength from 18 to 24 MPa. The regression expression is shown in equation 2 can be successful applied to assume the strength (TS) of ABS samples printed by FDM process considering the chosen ranges of the process parameters tabulated in table I.

Regression Equation:

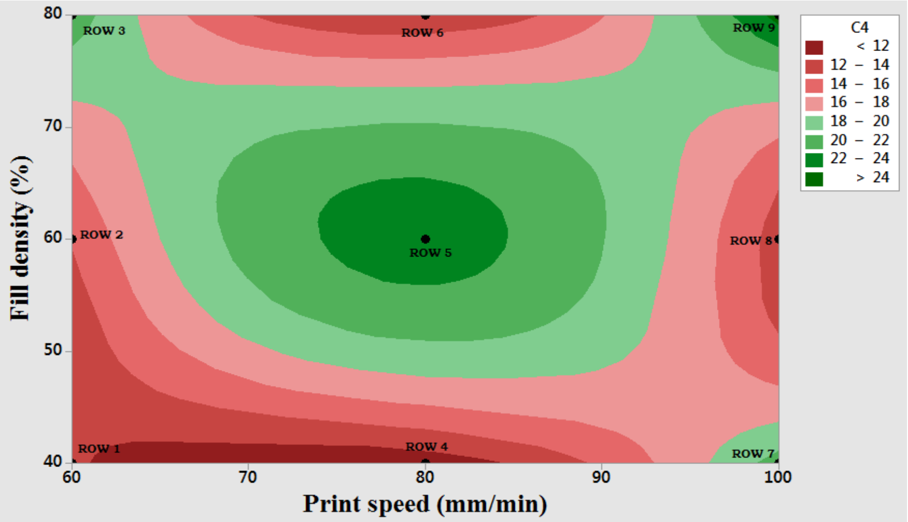
$$\text{Tensile Strength} = -6.71 + 0.0920 \times \text{Rotational speed} + 0.1200 \times \text{Tilt angle} - 0.0454 \times \text{Feed} \quad (2)$$

Table- III: Process parameters and their S/N ratio and Mean values

Level	Print speed (mm/min)		Fill density (%)		Layer thickness (microns)	
	S/N ratio	Mean values	S/N Ratio	Mean values	S/N ratio	Mean values
1	23.8	15.96	22.9	14.69	21.9	12.57
2	23.1	15.2	24.1	16.62	23.8	16.58
3	25.5	19.63	25.4	14.49	26.7	21.64
Delta	2.40	4.43	2.46	4.80	4.72	9.80
Rank	3		2		1	

Table- IV: Regression Analysis: tensile strength versus rotational speed, tilt angle, feed

Source	Degrees of freedom	Adjusted Sum of Square	Adjusted Mean Square	F - Value	P - Value
Regression	3	178.48	59.49	5.28	0.05
Print speed (mm/min)	1	20.29	20.29	1.80	0.237
Fill density (%)	1	34.58	34.58	3.07	0.14
Layer thickness (microns)	1	123.61	123.61	10.96	0.02
Error	5	56.38	11.28		
Total	8	234.86			



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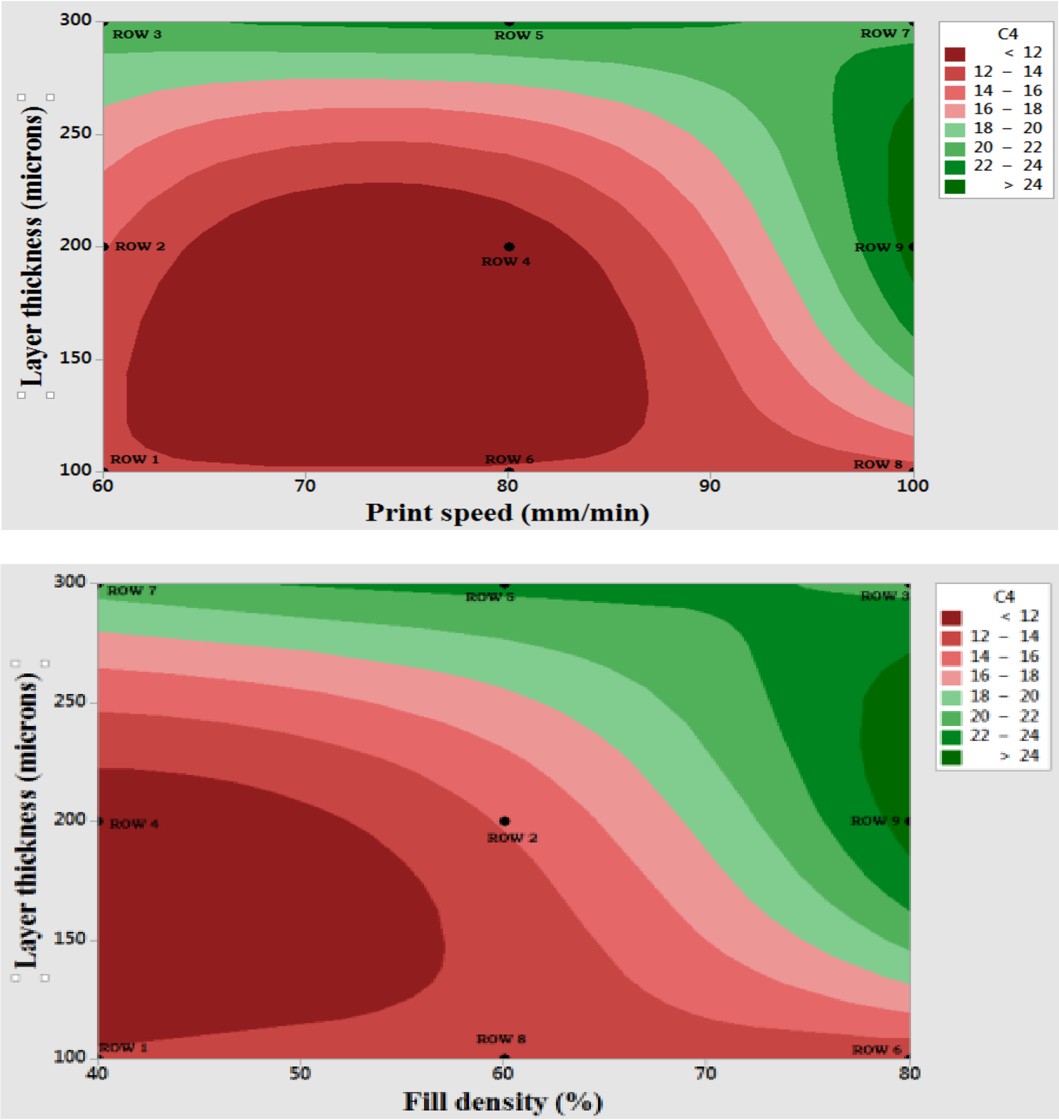

Fig. 3. Counter plots between tensile strength (C4) and FDM process parameters

IV. CONCLUSION

The chosen FDM process parameters is optimized using Taguchi L9 approach and the regression expression is generated which can be employed to get 95% confidence interval. The maximum tensile strength is obtained as 24.86 MPa with the process parameters print speed 100 mm/min, fill density 80 % and layer thickness 200microns. The layer thickness is having major effect on the tensile strength of ABS samples printed by the FDM process than fill density and print speed. The combination of the all three process parameters is also observed when print speed 80 rpm, fill density 60 % and layer thickness 300 microns at which the tensile strength obtained as 22.620 MPa. The FDM process is found as suitable, quick and low cost manufacturing technique for the mass production system.

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