EXPERIMENTAL INVESTIGATION OF IMPACT STRENGTH FOR ABS PLUS F.D.M. PARTS USING TAGUCHI

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Abstract-*3D PRINTING is an additive manufacturing process which builds the prototypes directly from CAD data. Fused deposition modeling is one of the rapid prototyping technique builds prototype in layer by layer process and directly dependent on process parameters. present study illustrates the performance of ABS Plus built parts fabricated by STRATASYS make dimension1200 es machine Fused Deposition Modeling(FDM). The effect of FDM parameters on Impact Strength is investigated. Experiments were conducted according to DOE with three different parameters such as model interior, build orientation angle and direction of rotation. The process parameters are optimized by using Taguchi method, s/n ratio is evaluated and the effect of the process parameters on Impact strength was estimated by the analysis of variance. Regression analysis is carried out to estimate the percentage of error between the experimental results and predicted results. The analysis shows that parameter having major effect on Impact strength is Angle of orientation.*

***Key Words*:ABS plus, F.D.M, Impact Tester, Impact strength, Mini tab-17, ANOVA, S/NRatio.**

1. INTRODUCTION

Rapid prototyping is an additive manufacturing process which builds the prototypes directly from cad data by adding material layer by layer. Fused deposition modeling is one of the most widely used technique in which layers of material is extracted from nozzle head in molten form. The material is supplied to the nozzle in wire forms & melted in nozzle head above the melting point of material. This makes material to available in pool of molten state before extraction. The nozzle movement and extraction process is controlled by the slicing software which generates tool paths based on the cad model.Many research works are going on to improve the mechanical properties of FDM made components.Several researches were alsodone on ABS material to investigate its mechanical propertiesby optimizing some of the process parameters like conductingexperiments on five different build style orientations to achieve good impact resistance. This work emphasizes on model interior, direction of rotation and build orientation angle on impact strength of ABS plus parts fabricated by fused deposition modeling process on stratasys make dimension 1200es machine using taguchi method.

2. FUSED DEPOSITION MODELLING PROCESS

FDM is a process where a thermoplastic material is melted to near liquid state and then deposited as previously deposited material, building up a physical model layer by layer as shown in Fig.1 the part geometry is fed using a 3-D CAD model which is then converted into a machine understandable format called STL (sterolithography) file format.Since the component is prepared in FDM by addition of layers the component model is sliced into layers and the layers are defined by CATALYST software. slicing is a process in which a mathematical description of 3-D object is intersected with a series of parallel planes to generate the cross sectional data needed to form layers. After slicing the part is built by dimension1200es machine. The layers are deposited according to the parameter settings that have already been fed and those parameter levels must be with in the range of STRATASYS dimension 1200es machine. The parameters setting is very important as it directly influence the properties of the component. FDM uses two materials to execute the print job: modeling material, which constitutes the finished component and support material acts as scaffolding during building process, and can easily be removed after printing.

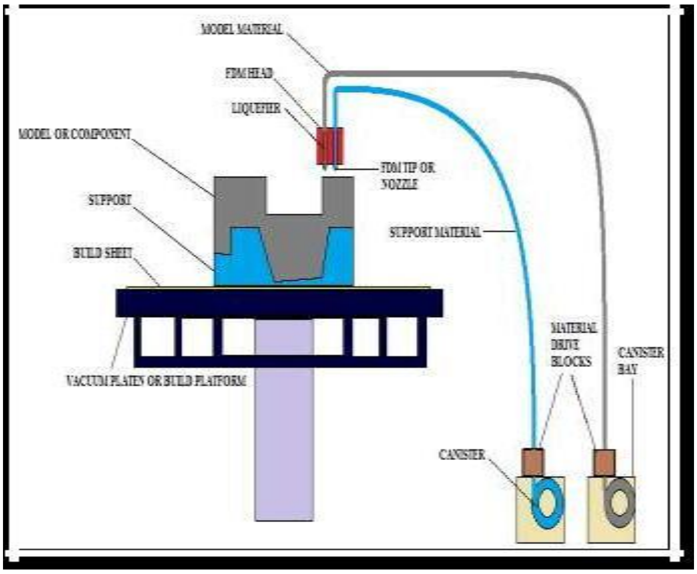

Fig 1. FDM –Working Principle

3. LITERATURE REVIEW

R. Anitha et al. [1] Have studied the effect of various process parameters, i.e. layer thickness, road width and speeddeposition of fused deposition modeling part. These process parameters influence the quality characteristics of the FDM parts. Taguchi method was used for design of experiments. L18 orthogonal array was selected for experiments. The result shows that the layer thickness is effective to 43.37% at 95% without pooling. On the other hand the layer thickness is effective to 51.57% at 99% with pooling. The layer thickness is most effective at 0.3556mm, the road width at 0.537mm and the speed of deposition at200mm

P. M. PANDEY et al. [2] have studied the orientation for part deposition as it affects part surface quality, productiontime and the requirement for support structure and cost in the RP processes. They used Multicriteria Genetic Algorithm to determine optimal solutions for part deposition orientation for the two contradicting objectives i.e. surface roughness and built time. The minimum average part surface roughness can be obtained at the maximum production time. On the other hand the minimum production time with maximum average part surface roughness. The best surface roughness were obtained at 240.001 angles about the axis 0.034, 0.369, and 0.289and the minimum production time at 89.97 about axis 0.749, 0.011, and 0.009

SANDEEP RAUT et al. [3] have studied the critical factor affects the different areas of the FDM model like main material,support material, built up time, total cost per part and most important the mechanical properties of the part. Investigated the effect of built orientation on the mechanical properties and total cost of the FDM parts. The responses are considered the mechanical property of FDM produced parts such as tensile and bending strength should be studied. The test specimens were prepared for the STRATASYS FDM type rapid prototyping machine coupled with CATALYST software and used the ABS material

LEVY et al. [4] Have introduced a new co mposite material for the FDM process. The new composite materialsinvolving ABS and metals. The experiments have been conducted to characterize the thermal, mechanical, and rheological properties. The analyses have been carried out to investigate main flow parameters such as temperature, pressure drop and velocity using two CFD software, two -d imensional and three-dimensional analysis. The entrance velocity of filament at a rate of 0.001 m/s is maintained along the tube until it gets to the nozzle t ip. The melt flow speed in the center is the highest while lowest at the wall due to no -slip condition. The results obtained fro m both of the analyses have been compared and show a very good correlation in predicting the flow behavior.

AHN et al. [5] compared the tensile and compressive strengths of the FDM prototypes made of ABS P400, with the injection-molded parts of the same material. The factors considered in tensile strength measurements were raster orientation, air gap, bead width, color, and model temperature. On the other hand, build orientation was the factor that was considered in compressive strength measurement. It was shown that the build orientation significantly affects the compressive strength of the FDM specimens.

KIM HG et. al.[6]compared the FDM, 3D printer, and Nanocomposite deposition (NCDS) processes by performing experiments on directionally fabricated cylindrical parts.
The effect of build direction on the compressive strength of parts was examined

BYUN AND LEEet. al[7] aimed at determining the optimal buildup direction of a part for different RP systems using simple additive weighting method. Factors under their consideration were average weighted surface roughness, build time, and part cost appraised by build cost, labor cost, and material cost etc.

ES-SAID et al. [8] studied the tensile strength, modulus of rupture, and impact resistance of ABS models produced using various raster orientations. The results suggested that the 0° raster orientation demonstrated

superior strength and impact resistance among the five raster orientations examined. From the literature it is suggesting that minimum layer thickness is influencing mechanical properties and surface roughness. Even though building time increases with lower layer thickness of extracted material. Hence considered low value of model material thickness 0.100 mm for building the prototypes to investigate the effect.

4. MATERIAL AND METHODLOGY

The quality of prototypes produced by fused deposition modeling process is highly dependent on the process parameters used in this process. Model interior is the characteristic that is how filling and distribution of model material takes place. In this work it is considered at three levels such as solid, sparse high density and sparse low density. Direction of rotation is considered for 3 levels as x-axiz (yz plane), y-axis (zx plane) and zaxis (xy plane). Build orientation angle is the process parameter by which printing takes place accordingly in angular manner the available angles for building the component are ranges from 0, 30, -30, 45, -45, 60, 90 degree in stratasys dimension 1200es machine.

Table 1 Process Parameters And Levels

EXP No.	Model interior	Direction of rotation	Angle of rotation
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The experiments were carried out by using an FDM STRATASYS dimension-1200es. For impact test, specimen is designed in CATIA-V5 software as per ASTM D256 standards (64mm length X 12.7mm height x 4 mm thickness). The Work piece is modeled as per ASTM D256 standards. Parts are fabricated by the use of FDM STRATASYS dimension-1200es for the experiment. ABS

Plus is the material used for fabricated the designed part. Statistical software minitab 17 is used to obtain results for the analysis of variance (ANOVA). s/n ratio derived from taguchi gives the information of best combination to predict the output response. Regression analysis is carried out to estimate the percentage of error between the experimental results and predicted results.

Table 2 Mechanical Properties OfABS Plus Material

LEVELS	PROCESS PARAMETERS		
	Model interior	Direction of rotation	Build orientation angle
1	Solid	X	0
2	Sprase H.D	Y	45
3	Sparse L.D	Z	90

The experimental layout was developed based on TaguchiOrthogonal Array was selected to satisfy the minimum number of experimental conditions for the factors and levels presented in table 3 with coded form generated from the minitab software according to the process parameters and their levels

Table 3 L9 Orthogonal Array Coded Form

Youngs modulus	2.3 GPa
Tensile strength	36 MPa
Flexural strength	52 MPa
Impact strength	106 J/M
Rockwell hardness	103-112
Elongation @ break	6%

The experiment is repeated for 3 times to observe the repeatability and the results were plotted down to express the significance of process parameters.

Fig. 2 STRATASYS dimension 1200 es F.D.M machine

5. FABRICATION OF ASTM D256 PARTS

The fabrication of ABS plus parts were fabricated using stratasys dimension 1200es machine, according to the design given from the taguchi orthogonal array.The process involves design of cad model and converting o .STL file format which is read by the machine accordingly the process parameters setting is done and parts are produced.

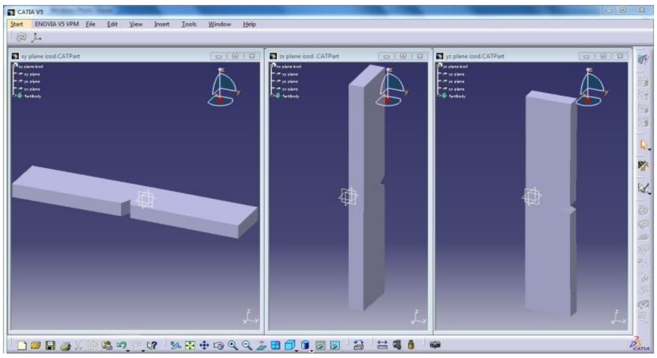

Fig. 3 Cad Model OfASTM D 256 Standard For Impact Test

Slicing is the technique where the entire cad model is formed into small triangles and the number of layers in slicing is dependent on the build orientation angle and corresponding plane through which printing is required.

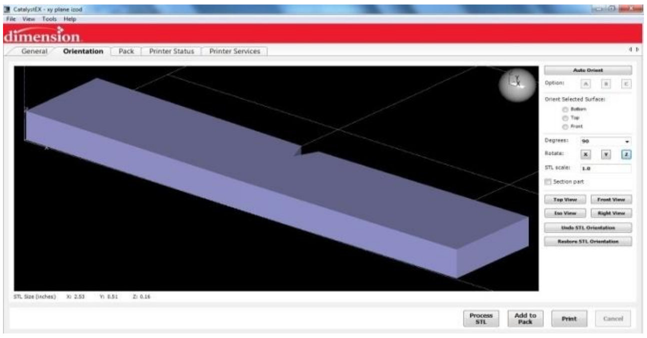

Fig. 4 .STL Format Of Impact Test Specimen

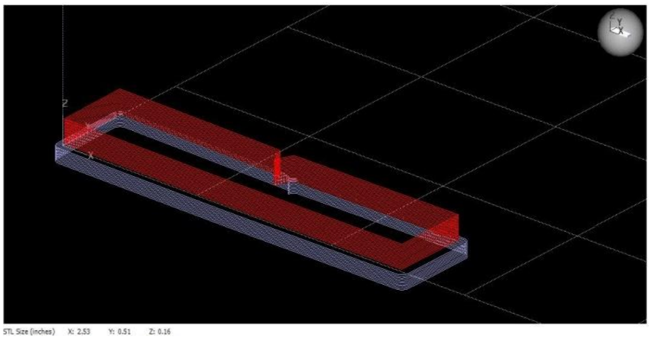

Fig.5 Impact Test specimen After Slicing

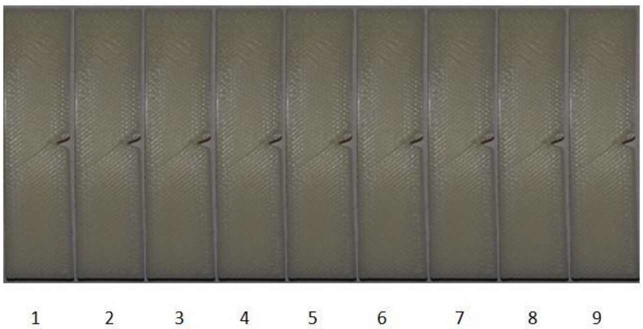

Fig.6 Fabricated Abs Plus Components ByF.D.M

6. IMPACT TEST

Impact strength is defined as ratio of absorbed energy to the thickness of the component. The fabricated components according to the process parameters setting is tested for impact strength using impact tester and the results are tabulated for statistical analysis, test apparatus consists of free oscillating pendulum which when strikes down the component fixed in cantilever position the stored energy in parts is read from the dial indicator.

Fig.7 Impact Test Machine

The maximum testing capacity of machine is 22J and can accommodate the specimens of thickness 15 mm . the weight of pendulum considered here is in terms of R3 the specimen is clamped vertically and fixed for testing.

7. STATISTICAL ANALYSIS

The optimization of the measured control factors was provided by signal-to-noise (S/N) ratios. The higher value of impact Strength is very important for parts made of FDM. For this reason, the larger-the-better"" equation wasusedS/Nratio. Design for the ofcalculation Experiment DOEAnalysis & ANOVA for Main effects plot has been done using Minitab 17 application software. The results of the same with their respective graphs & interpretations are mentioned below in the sequential order.

LEVEL	Model interior	Direction of rotation	Angle of orientation
1	37.53	38.43	36.27
2	40.02	38.72	37.81
3	39.07	39.48	42.54
Delta	2.50	1.05	6.27
rank	2	3	1

Response Table4 For S/N Ratio Of Impact Strength

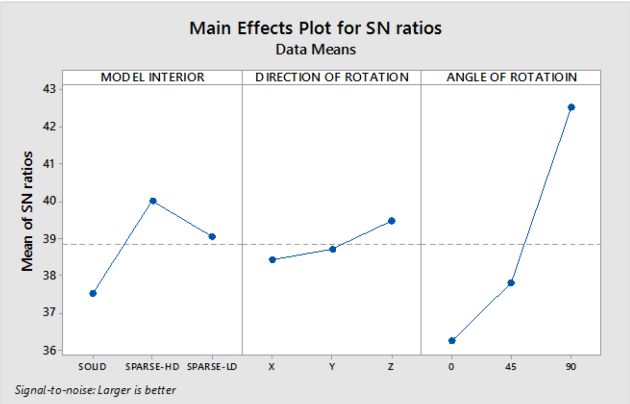

Fig 8 Main Effect Plots For Larger S/N Ratio

The graph of s/n ratio explains that for combination of model interior sparse high density, direction of rotation is z and build orientation angle is 90 gives maximum impact strength for the taken process parameters with in the range of machine. The table gives information that larger s/n ratio evaluates the experiment with highest impact strength and also the parameters suggests the minimum building time for the part in printing parameters. For calculation of s/n ratio larger the better is chosen in order to maximize the output response.

ANOVA analysis is performed to investigate the significant process parameter showing highest influence on output response. From the results of response table the significant process parameter showing highest influence on impact strength is build orientation angle due to value of p is less than 0.05

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model Interior	2	9.5265	4.7632	9.71	0.093
Direction Of Rotation	2	1.7651	0.8826	1.80	0.357
Angle of rotation	2	64.117	32.0586	65.34	0.015
Error	2	0.9814	0.4907		
Total	8	76.3901			

Fig. 9 Response Result For ANOVA Analysis

Exp no.	Model interior	Direction of rotation	Build orientation angle	Impact strength	s/n ratio
1	Solid	X	0	58.333	34.8688
2	Solid	Y	45	81	36.3302
3	Solid	Z	90	122	41.3822
4	Sparse high density	X	45	82.666	38.0926
5	Sparse high density	Y	90	158.333	43.9239
6	Sparse high density	Z	0	76.934	38.0543
7	Sparse low density	X	90	132.333	42.3252
8	Sparse low density	Y	0	66.333	35.8947
9	Sparse low density	Z	45	101.366	38.9988

Table 5 Experimental Data For Impact Strength

Regression analysis is performed to predict the percentage of error and the error calculated is experimental value – predicted value divided by obtained experimental result multiplied by 100. Linear multiple regression analysis is performed to obtain the percentage of error.

Regression equation

Impact strength

= 55.004*(MI^0.152)*(DR^0.108)*(BA^0.594)

Where MI represents model interior, DR represents direction of rotation and BR represents build orientation angle.

Ex. No	Mi	Dr	Br	Predicted Value	Experimental Value	Error (%)
1	1	1	1	55.004	58.333	5.707
2	1	2	2	89.478	81	-10.466
3	1	3	3	118.941	122	2.506
4	2	1	2	92.249	82.666	-11.591
5	2	2	3	126.494	158.273	20.078
6	2	3	1	68.814	76.934	10.553
7	3	1	3	124.832	132.333	5.668
8	3	2	1	70.053	66.333	-5.607
9	3	3	2	110.473	101.366	-8.984

Table 6 Regression Analysis For Impact Strength

8. CONCLUSIONS

The following conclusions can be drawn based on the results of the experimental study on ABS Plus material parts made of Fused Deposition Modeling.

- Significant process parameter combination for better impact strength is observed from s/n ratio and the main plots.
- From ANOVA analysis the significant process parameter which influence the output response impact strength is build orientation angle (p – value <0.05) followed by direction of rotation and model interior parameters
- From regression analysis percentage of error is calculated for predicted impact strength and experimental impact strength and the %error is found to 80% with in the significant level.
- The optimum process parameters to obtain maximum impact strength is sparse high density model interior, direction of rotation Y about zx plane and angle of orientation is 90 degree.

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