iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** XI **Month of publication:** November 2022

DOI: https://doi.org/10.22214/ijraset.2022.47741

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue XI Nov 2022- Available at www.ijraset.com

Parametric Investigation of FDM Process Parameter on Impact Strength of 3D-Printed Part

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***Abstract:** The method of producing three-dimensional solid items from digital data is known as additive manufacturing (AM), sometimes known as 3-D printing. A rapidly expanding additive manufacturing technique with several applications is fused deposition modeling (FDM). In this study, we investigate how the orientation, infill pattern, and density of the infill affect the impact strength of the ASTM D-256 specimens. A 3- printer with Acrylonitrile Butadiene Styrene (ABS) filament material has been used in this study. To evaluate the impact strength of the printed object and represent their quality, an ASTM D256 specimen standard has been used. The various parameters for the experiment were selected using OVAT analysis. With the help of a design of experiments (DOE) using Taguchi's L9 Array along with infill pattern, orientation, and density, the operational dependence is examined. When analysis of variance (ANOVA) is used to identify the relevant 3D printing process parameter it is shows that orientation and infill pattern are most significant parameters for impact strength.*
***Keywords:** 3D-printing, process parameters, Impact strength, Fused deposition modeling(FDM), Acrylonitrile Butadiene Styrene (ABS).*

I. INTRODUCTION

There has been an increase in additive manufacturing (AM) techniques over the past few decades, which has benefited engineering design and production operations. Recent advancements in 3D printing technology have significantly decreased the time and cost involved with the technique modern electrical technologies are developing. Many researchers have started to investigate the method as a result of the reducing operating costs of 3D printing. The technology provides benefits over traditional manufacturing methods, including the ability to manufacture multi-material objects with great dimensional accuracy and highly complicated geometries without the need of tools.

The method of fused deposition modeling (FDM), which uses thermoplastic filaments that are melted, extruded, and deposited, is one of the various types of additive manufacturing(AM) techniques. [1 2] The most significant benefit of 3-D printing, out of all its many positive aspects, is that it allows for the layer-by-layer construction of practically any complicated design. As a result, there is minimal to no waste created throughout the process, making this technique extremely advantageous from the perspective of waste management. The influence of FDM 3-D Printing Process parameter on the mechanical characteristics of an (FDM)-printed item is the subject of several research. As a response, it's essential to evaluate how an object's mechanical qualities respond to changes in the process parameters. [3]

II. LITERATURE REVIEW

B. Aloyaydi et al. in 2020 studied the effect of infill-patterns on mechanical behaviour of 3-D printed poly-lactic-acid (PLA). In the current study the influence of several infill patterns- grid, triangle, tri-hexagon and quarter cubic pattern on mechanical characteristic of the (PLA) material discussed. The results showed that the mechanical characteristic of both impact and compression Strength were highly influenced by the type of infill pattern used during printing.[5] P. Kumar Mishra et al. in 2020 studied the overall effect of various infill patterns and densities on the impact resistance of 3D printed polylactic-acid(PLA) object. The influence of the several process variables, such as infill density and infill pattern of PLA by 3D printing on impact strength, is described in the current study.

The result shows a tendency towards infill pattern had an effect on Impact strength of PLA sample.[6] H. Dave et al. in 2021 studied the impact of the infill patterns and densities at different component orientations here on mechanical characteristics of the (PLA) object manufactured by FDM printing. A full-factorial experiment was carried out to investigate the influence of FDM process variables, and statistical analysis was performed used a ANOVA. [7]

III. EXPERIMENTAL SETUP

In this study, the printing of test specimen is done with the Acrylonitrile Butadiene Styrene (ABS) material. As seen in figure 3, these test specimens were manufactured using a single extruder FDM type 3D printer. For material like PLA, ABS, etc., the maximum nozzle temperature that can be achieved with this machine is $260^o C$. Table no. 1 gives technical details of 3D printing device utilized for the experiment. The impact test uses a standard specimen that refers to ASTM D256. The exact testing specimen printed for testing is shown in the Figure 1 & 2, together with its standard dimensions. The specimen for the impact strength test was manufactured using a 3D printing machine (Pratham 3D printer) and an ASTM D256 standard. The specimens were created using the FDM technique with ABS filament in the 'Ultimaker Cura 4.4.0' 3D printer using the appropriate process parameters, also we used some fixed parameter like nozzle temperature at $235^o\ C$, layer thickness is 0.1mm and printing bed temperature at $80^o C$.The 'Ultimaker Cura 4.4.0' software was used to choose the infill density and infill pattern. The Specimens were tested on the Analogue Izod Impact Tester machine shown in the figure 4 at the Maharashtra Institute of Technology's testing lab facilities in Aurangabad (MH), India. It is a recognized industry leader in the polymer and plastics. Table no.2 contains the machines specification for the Analogue Izod Impact Tester.

Table 1. (FDM) 3D Printer Specifications

3D-Printer's Specification:	
Manufacturer	Pratham 3-D Printer
Machine type	FDM Single-Extruder Type Maximum Printable Area (Width, Breath and Height) 200 * 200 *250 mm
Material	Acrylonitrile Butadiene Styrene (ABS) White
Diameter of Filament	Φ 1.75mm
Diameter of Nozzle	Φ 0.4mm

Table 2. Analogue Izod Impact Tester's Specifications

Particulars	Specification
Capacity	Up to 21.68 Joules
Release angle of pendulum	150 degree
Range of four scales	0 - 2.71 joules, 0 – 5.42 joules, 0 – 10.84 joules, 0 – 21.68 joules
Minimum resolution on scale	0.02 joule, 0.05 joule, 0.1 joule and 0.2 joule respectively

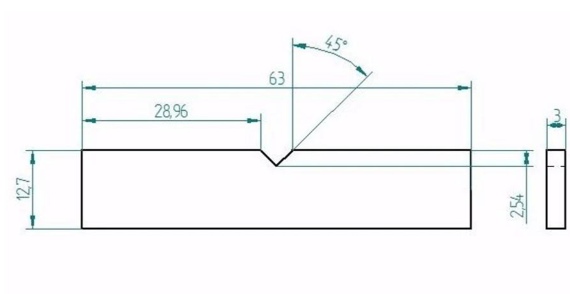

Figure 1. Izod impact test sample in accordance with ASTM D256.

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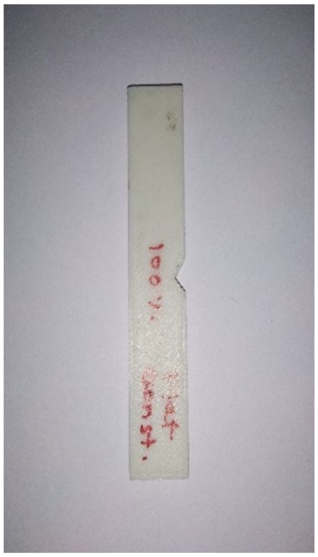

Figure 2. Specimen of Impact

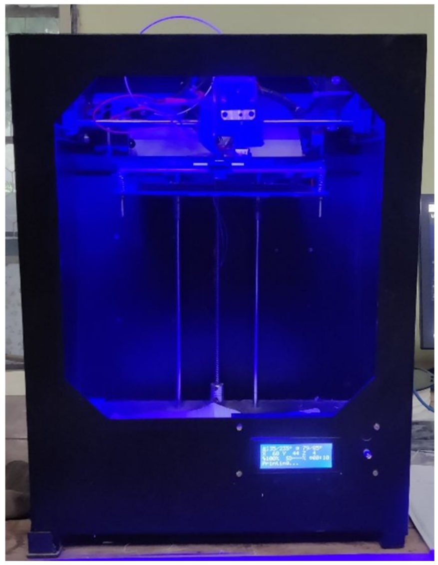

Figure 3. (FDM) 3D-Printer

Figure 4. Izod-Impact Tester

IV. DESIGN OF EXPERIMENT

In this investigation, the specimen was subjected to an impact test to examine its mechanical characteristics. The design of the experiment was done using the L9 orthogonal array of the Taguchi method. To identify the crucial parameter range for ANOVA analysis, a One-variable-at-a-time (OVAT) study is conducted on each of the three optimization parameter that were selected. The values of (OVAT) analysis's process parameters are displayed in table 3 below. The behaviour of the graphs is taken into consideration while selecting the proper ranges of the value for optimization.

Table 3. Process Parameters for (OVAT) Analysis

Parameter	I	II	III	IV	V
Orientation	Flat Edge	Side On Edge	Top Edge	Inclined Edge	-
Infill Patterns	Cubic	Cubic-Subdivision	Concentric	Tri- Hexagon	Linear
Infill Density	20	40	60	80	100

1) *Analysis of Orientation using (OVAT):* Throughout the (OVAT) analysis of orientation, Infill Pattern and Infill Density were kept constant at Cubic and 20 % respectively with 0.3mm layer height thickness. This inverted curve was generated by increasing the impact strength for the orientation from flat edge to side on edge and then decreasing with the top edge to inclined edge.
2) *Analysis of Infill Pattern using (OVAT):* Throughout the (OVAT) analysis of Infill Pattern, Orientation and Infill Density were kept constant at Flat edge and 20 % respectively with 0.3mm layer height thickness. With infill patterns such cubic-subdivision, concentric, and tri-hexagon, it was found that impact strength was significantly increased. Thus, it was observed that the crucial range for an infill pattern included cubic-subdivision, concentric, and tri-hexagon patterns.
3) *Analysis of Infill Density using (OVAT):* Throughout the (OVAT) analysis of Infill Density, Orientation and Infill Pattern were kept constant at Flat edge and cubic pattern respectively with 0.3mm layer height thickness. The Impact strength goes on increasing with increase in infill density. Impact strength was shown to significantly increase with an increase in infill density. For infill density below 60 % impact strength obtained is very low. 60 % to 100 % was found to be critical range for infill density.

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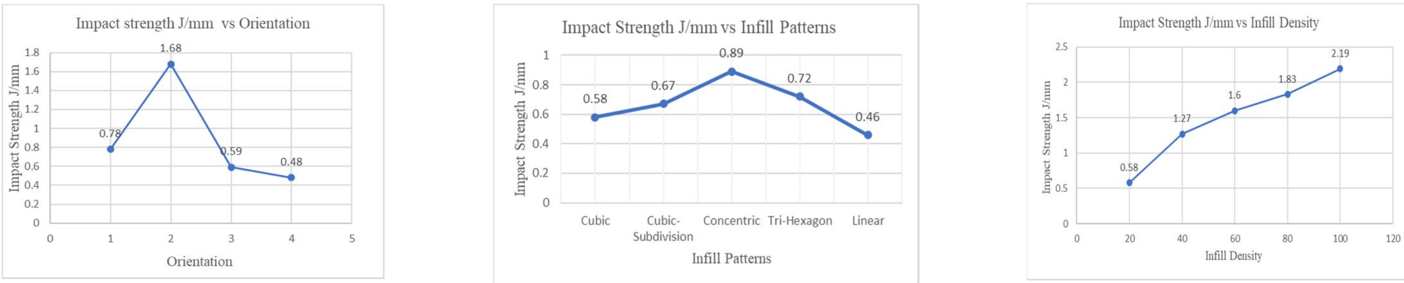

Figure 5 (OVAT)- Analysis Graphs for the Impact Strength vs (1) Orientation, (2) Infill Pattern and (3) Infill Density

According to the results of the (OVAT) analysis, the following ranges of process parameters were evaluated for (ANOVA) analysis, as shown in table no.4

Table 4. Levels of Process Parameters for Variance Analysis

Prosses Parameter	I	II	III
Orientation	Flat Edge	Side on Edge	Top Edge
Infill Pattern	Cubic-Subdivision	Concentric	Tri-Hexagon
Infill Density	60 %	80 %	100 %

Using these parameter levels, 9 specimens were constructed for the ANOVA analysis using combinations of the L9 orthogonal array. These specimens were then tested on the previously mentioned Izod Impact tester equipment.

V. RESULT & ANALYSIS

In this study, the impact of three distinct fused deposition modeling (FDM) 3D-printing process variables was investigated for the Impact strength criterion. Table no. 5 shows the experimental result of Impact Strength. The experimental results were analyzed using the Minitab 2020 software.

Table 5. Response Table for (Impact strength)

Experiment No.	Orientation	Infill pattern	Infill density	Impact Strength (J/mm)
1	Flat	Cubic-Subdivision	60	1.23
2	Flat	Concentric	80	4.27
3	Flat	Tri-Hexagon	100	2.62
4	Side on	Cubic-Subdivision	80	2.90
5	Side on	Concentric	100	6.87
6	Side on	Tri-Hexagon	60	2.04
7	Top	Cubic-Subdivision	100	1.20
8	Top	Concentric	60	1.03
9	Top	Tri-Hexagon	80	1.05

This is an overview of how various process factors affect impact strength.

1) *Effect of Orientation:* According to the AVOVA analysis, orientation is a highly significant parameter, Orientation has a 45.19% percentage contribution. Level 2 of orientation (side on) reflects the better result of the studied parameters.
2) *Effect of Infill Pattern:* For each sample the infill pattern had significant influence on the impact strength of ABS. The Concentric infill pattern seemed to encourage higher impact strength in this study. The infill pattern's level 2 (Concentric) ultimately indicates the highest value.

3) *Effect of Infill Density:* The infill density has huge influence on the number of layers required to print a part, which in turn has an impact on printing time. The analysis shows that infill density has a 23.97% percentage contribution indicating it is a less significant parameter as compared to infill patterns. Effect of infill density on response factor i.e Figure 6 and 7 shows how impact strength is maximum between 80% and 100%.

Table.6 (ANOVA) calculations for Means (Impact Strength).

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
Regression	5	2.36719	2.36719	0.47344	22.32	0.014	97.38%
Infill Density	1	0.58172	0.58172	0.58172	27.42	0.014	23.93%
Orientation	2	1.09838	1.09838	0.54919	25.89	0.013	45.19%
Infill Patterns	2	0.6871	0.6871	0.34355	16.19	0.025	28.27%
Error	3	0.06365	0.06365	0.02122			2.62%
Total	8	2.43084					100.00%

The P-value indicates that the three factors most significantly influencing impact strength are infill density, orientation and infill pattern. The percentage contribution of Orientation, Infill Pattern, and Infill Density are 45.19%, 28.27% and 23.97% respectively. While doing optimization, "Larger is better" criteria are taken into consideration. Figure 6 and 7 represent the signal-to-noise (S/N) ratio and mean of the means, respectively. The values obtained for highest impact strength under the present investigation circumstances are level 2 of Orientation, level 2 of the Infill pattern, and level 3 of the infill density.

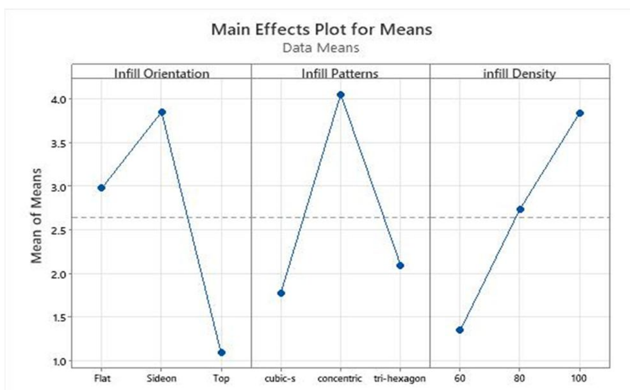

Figure 6. Main Effects Plot for Means

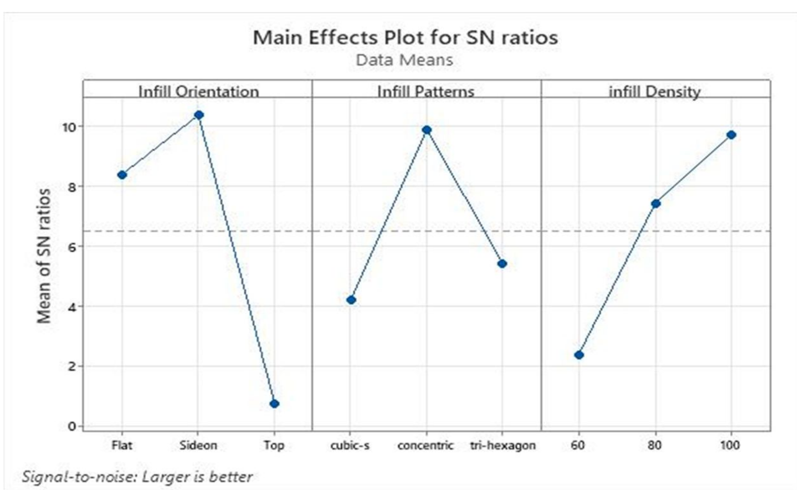

Figure 7. Main Effect Plot for S/N ratio

VI. CONCLUSION

The impact strength of the 3D-printed object was thoroughly investigated to determine the influence of orientations, infill patterns, and infill density. The outcomes of the regression analysis using the Taguchi technique were 93% fitted. The orientation was the primary factor that influenced the impact strength. The results showed equal contributions from the infill patterns and densities. The most significant process parameter according to an ANOVA analysis, is orientation, which is followed by infill patterns and infill densities. The optimum process parameter of (side on) orientation, concentric infill pattern, and 100% of infill density results in the highest impact strength. This procedure is used to enhance the mechanical properties of various components made of various materials.

VII. ACKNOWLEDGMENT

I am grateful that the Government College of Engineering Aurangabad (GECA), in Aurangabad Maharashtra offered the 3D-printing production facilities for the study. I also appreciate the Maharashtra Institute of Technology in Aurangabad, Maharashtra for providing the Impact testing facilities for this work.

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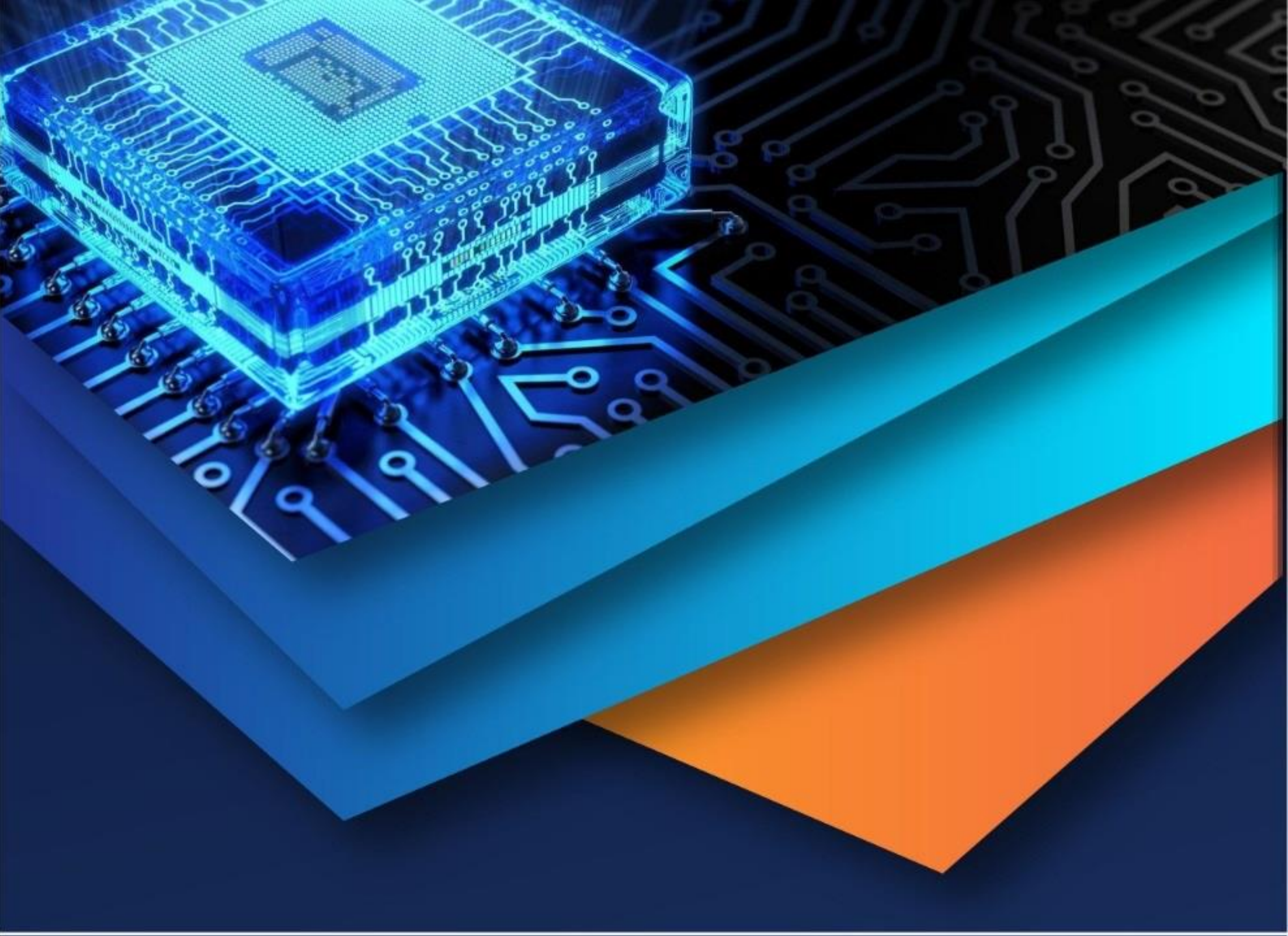

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