Study of Various Key Process Parameters of FDM 3D Printed Parts using Ultimaker 2+ 3D Printer

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ABSTRACT

This research paper aims to investigate the effect of different Fused Deposition Modelling (FDM) printing parameters on the mechanical properties of printed parts. FDM is one of the most widely used 3D printing technologies due to its versatility and low cost. However, the mechanical properties of FDM printed parts depend largely on the printing parameters used. A series of tensile tests were conducted on FDM printed parts with varying printing parameters such as layer height, infill density, print speed, and nozzle temperature. The results showed that increasing the layer height and infill density improved the mechanical properties of the printed parts, while increasing the print speed decreased the mechanical properties. Nozzle temperature also had a significant effect on the mechanical properties of the printed parts, with a higher temperature resulting in stronger parts. Overall, this research provides valuable insights into the effects of different FDM printing parameters on the mechanical properties of printed parts and can be used to optimize FDM printing for specific applications. The research value of this case study is to obtain the best suitable key process parameters for FDM printing.

Keywords-- Fused Deposition Modelling (FDM), 3D Printing, Layer Height, Speed, Nozzle Diameter, Infill Percentage, Dimensional Accuracy, Surface Finish, Strength.

I. INTRODUCTION

Fused Deposition Modelling (FDM) is a 3D printing technology that is widely used for rapid prototyping and small-scale production due to its low cost and versatility. In FDM printing, a thermoplastic material is melted and extruded through a nozzle, which is then deposited layer-by-layer to create a 3D object. However, the mechanical properties of FDM printed parts depend largely on the printing parameters used, such as layer height, infill density, print speed, and nozzle temperature. Therefore, understanding the effects of these parameters on the mechanical properties of FDM printed parts is crucial for optimizing FDM printing for specific applications.

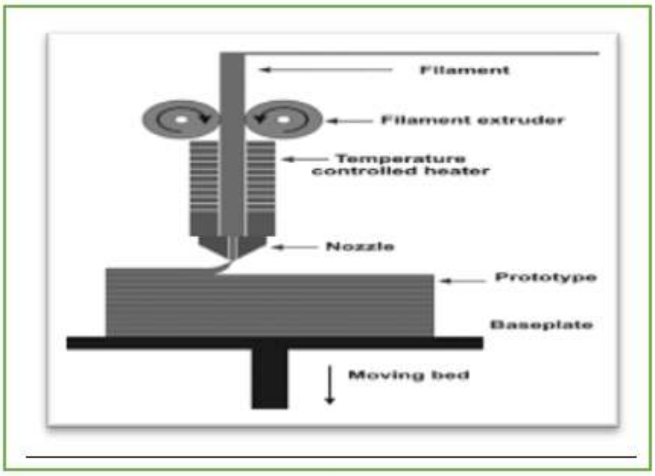

Figure 1: Schematics of FDM 3D Printer

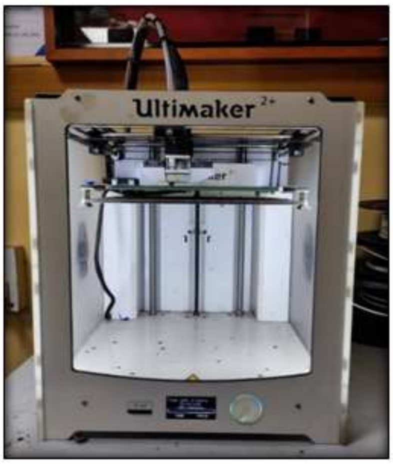

Figure 2: FDM 3D Printer

FDM is a popular 3D printing technology due to its ease of use, low cost, and ability to produce functional prototypes and end-use parts. The quality of FDM printed parts is highly dependent on various process parameters. This literature review summarizes the existing research on the influence of various key process parameters of FDM 3D printed parts.

Layer Height: The layer height is one of the most important process parameters in FDM 3D printing. It determines the resolution and surface quality of the printed part. Lower layer heights result in better surface finish and higher resolution. However, printing at a lower layer height increases the printing time and the risk of nozzle clogging. Several studies have shown that the optimal layer height depends on the geometry and size of the printed part. For smaller parts, a lower layer height is preferred, while for larger parts, a higher layer height is more efficient.

Printing Speed: Printing speed is another important process parameter that affects the quality of FDM 3D printed parts. High printing speeds result in faster printing times, but also in lower part accuracy and surface quality. Lower printing speeds result in higher part accuracy and surface quality but increase the printing time. Several studies have shown that the optimal printing speed depends on the material used and the geometry of the printed part. For example, printing speed should be reduced for parts with intricate geometries or overhangs to ensure better surface quality.

Nozzle Temperature: Nozzle temperature is a critical process parameter in FDM 3D printing as it determines the melt flow of the material. Higher nozzle temperatures result in faster melting of the material and faster printing times but also lead to a higher risk of stringing and warping. Lower nozzle temperatures result in better surface quality and lower risk of stringing and warping, but also increase the printing time. Several studies have shown that the optimal nozzle temperature depends on the material used and the geometry of the printed part.

Infill Density: Infill density is another key process parameter in FDM 3D printing. It determines the strength and weight of the printed part. Higher infill densities result in stronger parts but also increase the printing time and material usage. Lower infill densities result in lighter parts but also reduce the strength of the printed part. Several studies have shown that the optimal infill density depends on the application and the geometry of the printed part. For example, parts that require high strength should have higher infill densities.

Part Orientation: Part orientation is a critical process parameter in FDM 3D printing as it affects the part accuracy, strength, and surface quality. The orientation of the printed part affects the cooling rate of the material, which affects the warping and dimensional accuracy of the part. Several studies have shown that the optimal part orientation depends on the geometry and size of the printed part. For example, parts with long and thin features should be printed vertically to reduce warping, while parts with complex geometries should be printed at an angle to improve surface quality.

II. LITERATURE REVIEW

The following is a literature review of the research on Fused Deposition Modelling (FDM) 3D printing technology.

Reviews recent developments in FDM technology, focusing on advancements in materials, processes, and applications. They discuss the advantages and limitations of this technology and provide suggestions for future research. Provide a detailed overview of the FDM process, including the materials used and applications of this technology. They emphasize the importance of understanding the process parameters and their impact on the quality of the printed parts. Discusses the transformative impact of 3D printing on the industrial sector, highlighting its potential to disrupt traditional manufacturing processes and enable new product development. Reviews different techniques for optimizing FDM process parameters, including Taguchi optimization, response surface methodology, and genetic algorithms. They emphasize the need to optimize the process parameters to improve the quality and performance of the printed parts. Studies the effect of printing parameters on the mechanical properties of 3D printed ABS polymer using FDM technology. They find that the layer thickness, printing speed, and infill density significantly affect the mechanical properties of the printed parts. Overall, the literature review emphasizes the importance of understanding the FDM process parameters and their impact on the quality and performance of the printed parts. Researchers are continuously working to improve the FDM technology, including the materials used, the printing process, and the applications, to enable new possibilities in manufacturing and product development.

III. OBJECTIVES

The objective of this study is to investigate the FDM printing technology and its various process parameters that affect the print quality. We also aim to explore the advantages and limitations of this technology and compare it with other 3D printing technologies.

IV. METHODOLOGY

In this study, we used an FDM printer to create test prints with varying parameters such as layer height, printing speed, nozzle diameter, and infill percentage. We also used different thermoplastic materials such as PLA, ABS, and PETG to analyze the effect of material properties on print quality. We measured the dimensional accuracy, surface finish, and strength of the prints to evaluate the quality of the FDM prints.

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V. CASE STUDY

To print 3D component from solid model and observe changes by changing its Process Parameters. In this Case Study we will print the same model with different Key Process Parameters (Case-1 & Case-2)

STEP-1:- Create a CAD Model for 3D Printing

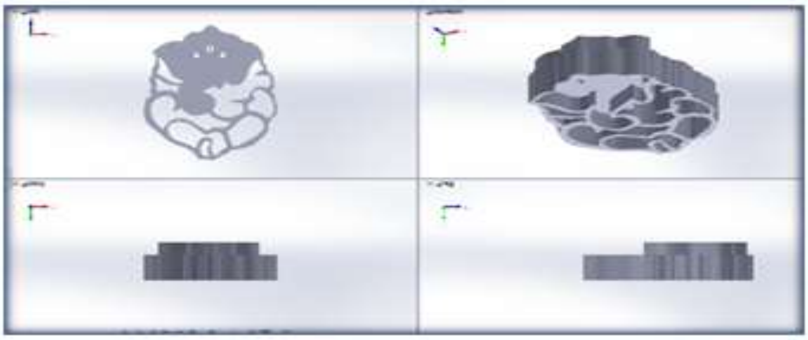

Figure 3: CAD-MODEL

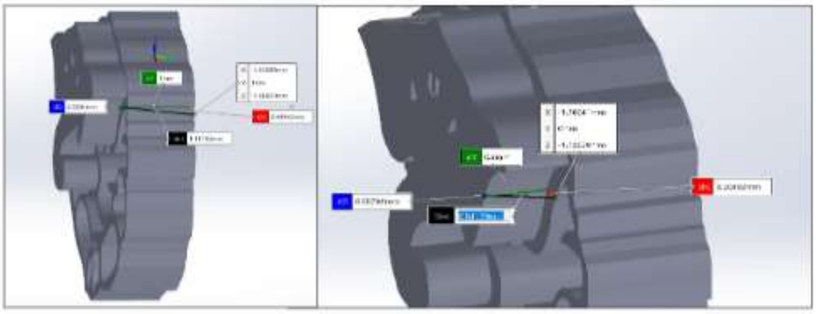

Figure 3

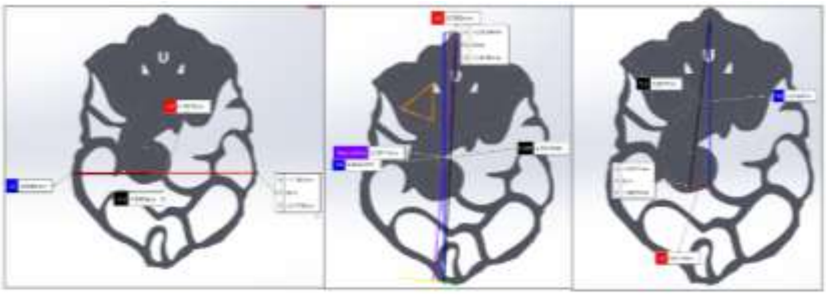

Figure 4

STEP-2:- Convert CAD Model file (IGES , STEP , JT) to .Stl File. Then Import this File into the CURA Software for 3D Printing.

STEP-3:- Scaling of 3D Model

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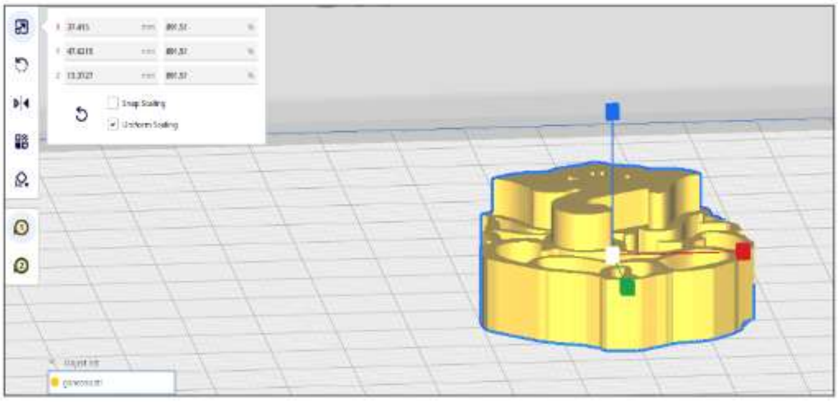

Figure 5: Scaling Interface

STEP-4:- After scaling the model, we will define the Key Process Parameters for Case-1 & Case-2. The material in both the Cases will keep same that is PLA.

Table 1: Process Parameters

PROCESS PARAMETER	CASE-1	CASE-2
1. Quality (Layer Height)	0.20mm	0.30mm
2. Infill Density	15 %	50 %
3. Infill Pattern	Triangles	Grid
4. Wall (Thickness)	0.8mm	1mm
5. Speed of Printing	Normal	Fine

STEP-5:- Define the Key Process Parameters.

- Layer: Layer height. Line width, initial layer height
- Shell: Wall thickness, Top/bottom thickness, wall line count
- Infill: Pattern, Density, Infill line distance, Infill overlap;
- Material: wall flow, Infill flow
- Speed: Print speed, Travel speed, Top/bottom speed, Initial layer speed
- Travel: Enable Retraction, Travel avoid distance.
- Cooling: Fan speed, Initial fan speed, Regular fan speed at height,
- Support: Pattern, Distance;

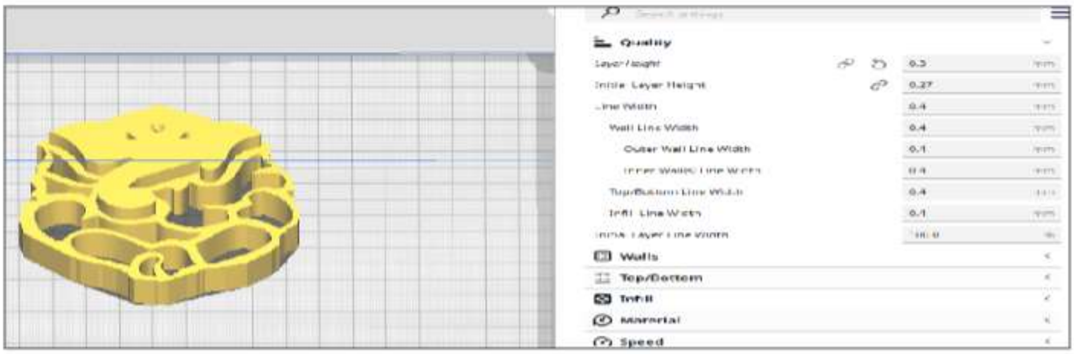

Figure 6: Quality – (Layer Height changed from 0.20 to 0.30

Figure 7: (Infill Density changed from 15% to 50%)

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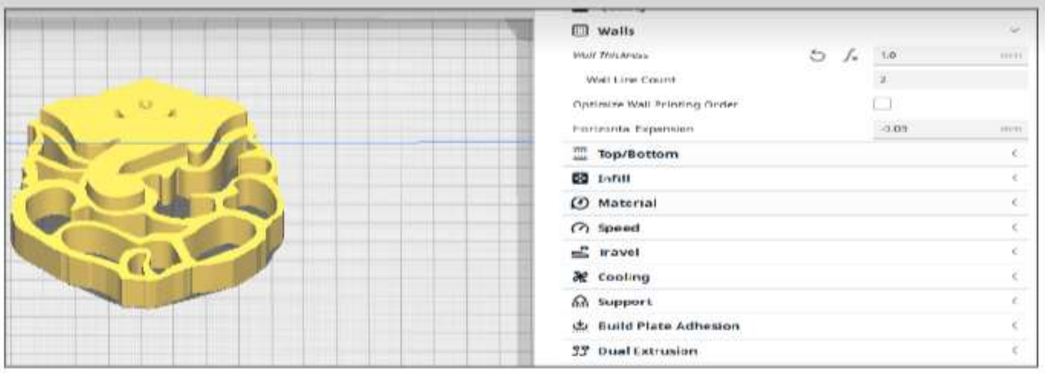

Figure 8: (Infill Pattern changed from Triangles to Grid)

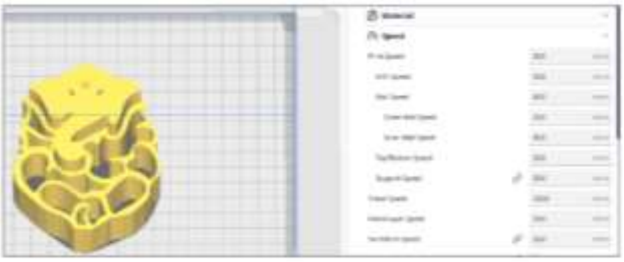

Figure 9: WALLS – (Wall Thickness changed from 0.8 to 1mm)

STEP-6:- Now Slice the Model after defining all the Key process Parameters.

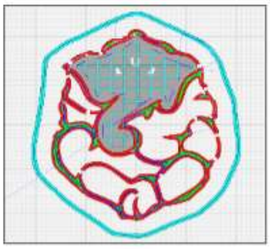

Figure 10: Sliced Base View (0%)

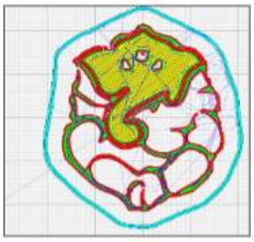

Figure 11: Sliced Front view (30%)

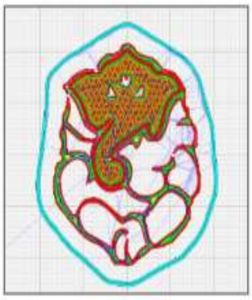

Figure 12: Sliced Top View (60%)

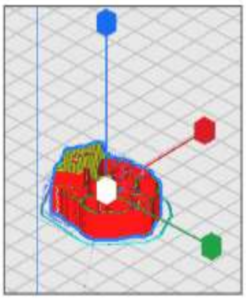

Figure 13: Sliced Isometric view (100%)

STEP-7:- Printing of 3D Component in Ultimaker 2+ 3D Printer.

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Figure 14

Figure 15: Case-1 Product

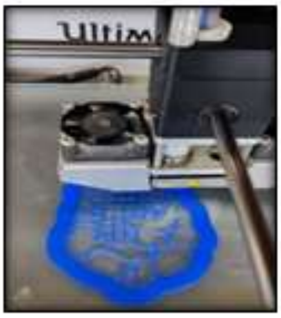


Figure 16: Case-2 Product

STEP-8:- Post Processing (Final Products Obtained after Printing.)

Figure 17: Case-1 Final Product

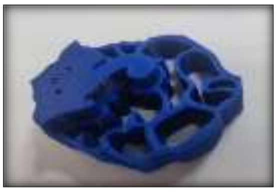


Figure 18: Case-2 Final Product

VI. COMPRESSION TESTING OF SPECIMEN

A popular technique for assessing the mechanical qualities of 3D-printed things is compression testing. During this test, the specimen is squeezed, and data on deformation and failure are recorded. Selecting the appropriate test parameters, such as the testing speed, load range, and specimen form, is one of the most crucial aspects in the compression testing procedure.

Figure 14: Case-1 Specimen Deformation

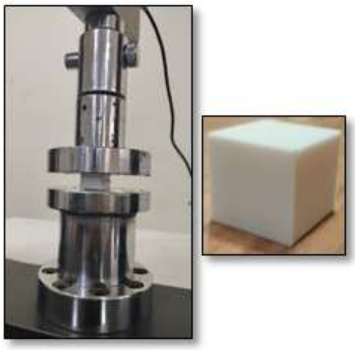
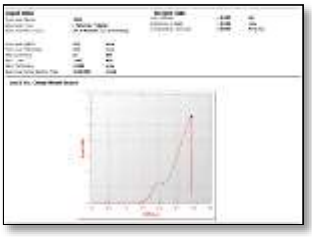


Figure 15: Case-2 Specimen Deformation

The material and printing technique used to create the specimen should be taken into consideration while choosing these parameters. The results of compression testing can also be analysed using a variety of techniques, including fracture analysis, stress-strain analysis, and failure mode analysis. These techniques can help uncover any defects or problems with the material as well as provide useful information on the behaviour of the Material. To guarantee the reliability and toughness of our printed parts, it's necessary for us to carry out Compression Testing. Our printed components were created with the specific features stated in Table 1, and now we have a collection of specimens ready for testing their compression properties. These specimens will help us determine the ability of our printed parts to withstand external forces and pressure. When the Compression Load test is conducted on Specimen in Case-1 and Case-2, some degree of deformation can be observed in the specimens.



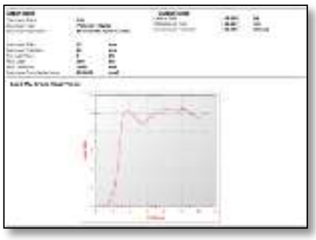


Figure 15 Case-1 & 2 Sample Specimen Results (Load V/S Displacement

This is what the specimen looks like after undergoing deformation on a UTM machine. Following are the results obtained after performing the Compression testing of Case-1 & Case-2 Specimen.

VII. RESULTS AND DISCUSSION

Our findings demonstrate that FDM printing technology can generate prints of excellent quality, good dimensional accuracy, surface finish, and robustness. We studied that the Nozzle diameter has little bearing on print quality, while the Layer Height, Printing Speed, and Infill Percentage do. We also studied that the quality of the print is influenced by the type of thermoplastic material used, with PLA giving the greatest surface finish, ABS having the highest strength, and PETG being the most flexible. The mechanical qualities of the printed items were enhanced by increasing layer height and infill density. The layer height at which the highest compressive strength was attained was 0.3mm (Case-2 Specimen). The mechanical characteristics of the printed items were reduced as print Speed was increased. The print speed of 20 mm/s produced the highest Compressive strength. The mechanical characteristics of the printed pieces were also significantly influenced by nozzle temperature, with higher temperatures producing stronger parts. The nozzle temperature of 210°C produced the best tensile strength. The findings of this study suggest that altering the printing parameters can improve the mechanical characteristics of FDM produced items. The mechanical qualities of printed items can be improved by raising layer height and infill density; However, they can be negatively impacted by increasing print speed. The mechanical characteristics of FDM printed items are also significantly influenced by nozzle temperature, with higher temperatures producing stronger pieces. Based on the results of conducting a physical experiment using the UTM, it can be inferred that there is a positive correlation between the compression strength of the specimen and an increase in the layer height and infill. Additionally, it was observed that by reducing the printing speed, the surface finish of the object improved, resulting in a smoother surface texture. After analysing the outcomes of CASE-1 and CASE-2, it was found that CASE-2 yielded better results. This improvement in the output was attributed to the variation of key process parameters during the printing process.

VIII. FUTURE SCOPE

The fused deposition modelling FDM or fused filament fabrication method of 3d printing a common approach for quick prototyping and small-scale production is called FFF which is melting plastic filament and layer-by-layer extruding it through a heated nozzle to create a three-dimensional object due to its capacity to make intricate shapes and designs that are challenging to construct using conventional production techniques FDM technology has grown in popularity in recent years this printing method has also improved in accessibility and affordability making it a desirable choice for both enterprises and individuals. Material Advancements: FDM technology is currently limited to using plastic filaments, but there is scope for the development of new materials that can be used with FDM printers. Researchers are exploring the use of biodegradable materials, conductive filaments, and even metal filaments for use in FDM printing. Increased Speed and Efficiency: FDM technology has already made significant advancements in Speed and efficiency, but there is still room for improvement. As printing Speeds increase and print times decrease, FDM technology will become more viable for larger-scale

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manufacturing. Integration with Other Technologies: FDM technology can be integrated with other manufacturing technologies such as robotics, automation, and artificial intelligence (AI). This integration can help increase productivity, reduce waste, and improve quality control. Customization and Personalization: FDM technology has the potential to enable mass customization and personalization of products. As the technology improves, it will become easier to create personalized products that meet the specific needs of individual customers. Overall, the FDM technology future is fascinating and extensive and we may anticipate numerous developments in the upcoming years

IX. CONCLUSION

Although FDM printing technology is a flexible and affordable 3d printing technology with many benefits such as usability and accessibility it also has certain drawbacks such as a restricted selection of material possibilities and lower resolution than other 3d printing technologies. The study's findings can be applied to streamline the FDM printing procedure and raise the standard of FDM prints. From the aforementioned case study, we noticed that the part printed in case-2 is of greater strength better surface finishing and smoothness as compared to case1 printed product due to change in key process parameters. Further research is required to explore new materials and improve the resolution of FDM printing technology.

REFERENCES

[1] S. S. Jadhav & S. R. Ghorpade. (2019). *Optimization of process parameters for FDM 3D printing using Ultimaker 2+ printer*.

[2] M. C. Oliveira, R. T. Lopes & M. C. Silva. (2020). *A systematic study on the effect of process parameters on the quality of FDM 3D printed parts using Ultimaker 2+*.

[3] M. R. Iqbal, M. F. Ali & M. A. Bari. (2020). *Investigating the effect of nozzle diameter on the mechanical properties of FDM 3D printed parts using Ultimaker 2+*.

[4] N. K. Naik & S. K. Padhi. (2018). *Optimization of printing speed and layer thickness for FDM 3D printing using Ultimaker 2+*.

[5] S. M. Shaikh & N. M. Bhat. (2019). *An experimental investigation of the effects of temperature and infill density on the quality of FDM 3D printed parts using Ultimaker 2+*.

[6] M. A. Chowdhury & M. A. Hossain. (2021). *Study of the effect of printing orientation on the mechanical properties of FDM 3D printed parts using Ultimaker 2+*.

[7] S. K. Reddy & S. D. Bhosale. (2020). *Optimization of process parameters for high-quality FDM 3D printing using Ultimaker 2+*.

[8] S. M. Shirke & V. M. Patil. (2018). *Analysis of the effect of nozzle temperature on the dimensional accuracy of FDM 3D printed parts using Ultimaker 2+*.

[9] A. S. Mujawar & A. R. Chavan. (2019). *Investigation of the effect of infill pattern on the mechanical properties of FDM 3D printed parts using Ultimaker 2+*.

[10] S. B. Deshpande & S. P. Kamble. (2021). *Optimization of process parameters for high-strength FDM 3D printed parts using Ultimaker 2+*.