Analysis of 3D Printing Thermoplastic Materials by Using FDM Technique

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Abstract: The size of the production run and the geometric complexity of the component are the primary factors limiting the use of standard manufacturing methods; thus, we are often compelled to employ procedures and equipment that raise the element's final cost. Since its rise to prominence as an additive manufacturing technique in the 2000s, 3D printing has been utilized extensively as a prototype technique. Through the gradual addition of materials, 3D printing, also known as additive manufacturing turns geometric representations into tangible items. Because of its quick and geometrically complex capabilities as well as its financial advantages, additive manufacturing (AM), often known as 3D printing, has completely changed the manufacturing industry. Over the past ten years, numerous companies in the automotive, aerospace, medical, and even food industries have implemented this strategy. The most widely used thermoplastic materials in FDM machines are ABS and PLA, making Fused Deposition Modeling (FDM) one of the easiest methods for artists to execute their work. Understanding the characteristics of these materials and the various degradation processes that these polymers may experience as a result of environmental action is crucial from the perspective of art conservation. This paper discusses on 3D printing process, chooses materials for 3D printing, such as ABS, PLA, and PET-G, and analyzes the printing process based on various criteria. This paper's primary goal is to analyze the dimensional accuracy of 3D printed objects made of various thermoplastic materials using a 3D printer. Though the finished parts have some dimension fluctuation, parts created in 3D design software can be successfully loaded into printing software because the accuracy of the printed material improves as the percentage error of the filament material decreases with layer thickness, compared to the design phase specifications.

Keywords: Fused Deposition Modelling (FDM), 3D Printing, Polyethylene Terephthalate Glycol (PET-G), Polylactic Acid (PLA), and Acrylonitrile Butadiene Styrene (ABS).
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1. Introduction

3D printing can print tangible items from a geometrical representation by gradually adding material [1]. 3D technology has become incredibly popular in recent years. The first 3D printing technologies were sold by Charles Hull in 1980 [2]. Currently, the majority of prosthetic heart pumps are made via 3D printing. [3], steel bridge in Amsterdam [4] 3D printed cornea [5], jewelry collections [6], Pressure-Compensated Gas Generator rocket engines [7], and other things related to the food and aviation industries. The earliest application of 3D printing technology was the exact layer-by-layer creation of 3D structures

using CAD models. [8]. 3D printing technology has evolved into a highly creative and flexible tool. It opens up new possibilities and offers hope for many different results for companies looking to boost industrial efficiency. Ceramics, conventional thermoplastics, graphene-based materials, and the utilization of 3D printing technology have made it feasible to make materials like metal. [9]

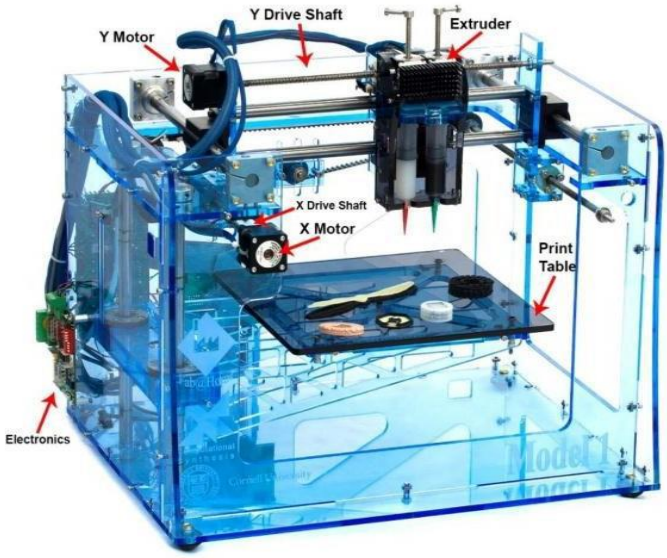


Fig 01 3D Printer

3D printing technology can revolutionize an industry and alter production lines. Cost reduction in the industrial industry with the utilization of 3D printing technologies. Additionally, the demand from customers will have a greater simultaneous impact on output. Consumers can request that the final product be made according to their requirements, giving them even more control over the final product. In addition to offering a far more flexible and quick manufacturing process, 3D printing equipment is now situated closer to consumers, improving quality control. [10].

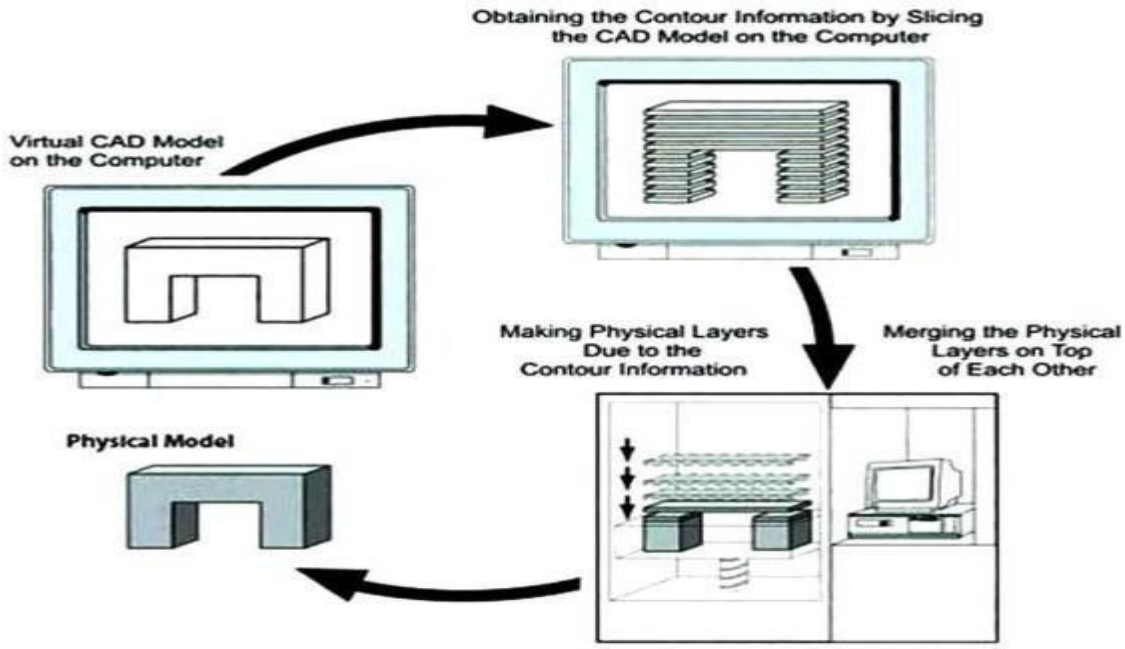


Fig 02 3D Printing Procedure

Nowadays, 3D printing is widely used worldwide in different types of industries, including the automotive, aerospace, healthcare, and agricultural sectors. A lot of people are using 3D printing technology to manufacture and customize open-source designs in large quantities [11]. Nevertheless, 3D printing has some disadvantages in the industrial industry. The use of 3D printing technology, for example, reduces the demand for manufacturing workers, which has an immediate and substantial effect on the economies of nations that primarily depend on low-skilled jobs. Users of 3D printing can also produce a wide range of components, such as blades, guns, and other hazardous items. The use of 3D printing should be limited to a small number of individuals to stop terrorists and criminals from importing firearms undetected. At the same time, anyone who manages to get their hands on a blueprint will be able to easily make counterfeit goods. Because 3D printing technology is easy to operate and can create 3D items with just a drawing and data entered into the printer. [12].

2. Materials and Methods

2.1 Fused Deposition Modeling

The most popular type of 3D printing at the consumer level is fused deposition modeling (FDM), often referred to as fused filament fabrication (FFF), which has been driven by the rise of hobbyist 3D printers. This method works well for simple proof-of-concept models and for rapid and inexpensive prototyping of simple pieces, such as those that could normally be machined. When compared to other plastic 3D printing methods, consumer level. FDM is not a good option for creating complex designs or finely detailed items because it has the lowest

resolution and accuracy. Higher-quality finishes can be achieved with chemical and mechanical polishing processes. Industrial FDM 3D printers use soluble supports to solve some of these issues and offer a wider range of technical thermoplastics or even composites, but they come at a high cost. Sometimes, when the layers don't attach completely, voids may remain between them as the melted filament builds each layer. When designing parts that are intended to withstand loads or resist tugging, it is crucial to take into account the fact that this leads to anisotropic parts.

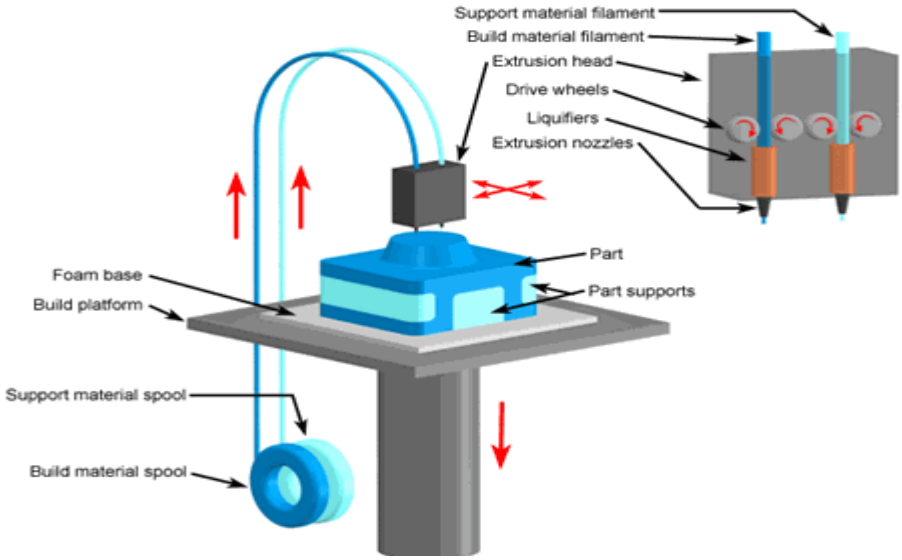


Fig 03 Fused deposition modeling

2.2 FDM 3D Printing Materials

ABS, PLA, and their different blends are the commonly used materials for FDM 3D printing. More sophisticated FDM printers can also print using additional specialty materials that have better rigidity, impact resistance, heat resistance, and chemical resistance.

Table 01 Different FDM 3D Printing Materials

S. No	Material	Applications	Features
01.	PETG (polyethylene terephthalate glycol)	Waterproof applications Snap-fit components	Lower printing temperature compatibility for quicker output Resistance to chemicals and humidity Food safety can be achieved through high transparency.
02.	ABS (acrylonitrile butadiene styrene)	Functional prototypes	Robust and long-lasting Impact and heat-resistant needs a heated bed to print. Ventilation is necessary.
03.	TPU (thermoplastic polyurethane)	Flexible prototypes	Stretchable and pliable resistant to impacts Outstanding damping of vibrations
04	PLA (polylactic acid)	Concept models Looks-like prototypes	The most straightforward FDM printing materials Strong and rigid, yet brittle Less resilient to chemicals and heat

05	Nylon	Functional prototypes Wear resistant parts	robust, long-lasting, and lightweight Hard and somewhat pliable Impact and heat-resistant incredibly difficult to print on FDM
06	HIPS (high-impact polystyrene)	Support material	The most popular soluble support for ABS dissolves in a chemical solvent.

2.3 Selection of 3D Printing Materials

Typically, materials are ranked according to three criteria: method, visual quality, and mechanical performance. To better illustrate the characteristics of the polymer in this instance, further divide these categories. Since the user's preferences greatly influence the material they select to print, the following list of essential criteria will help you make that decision.

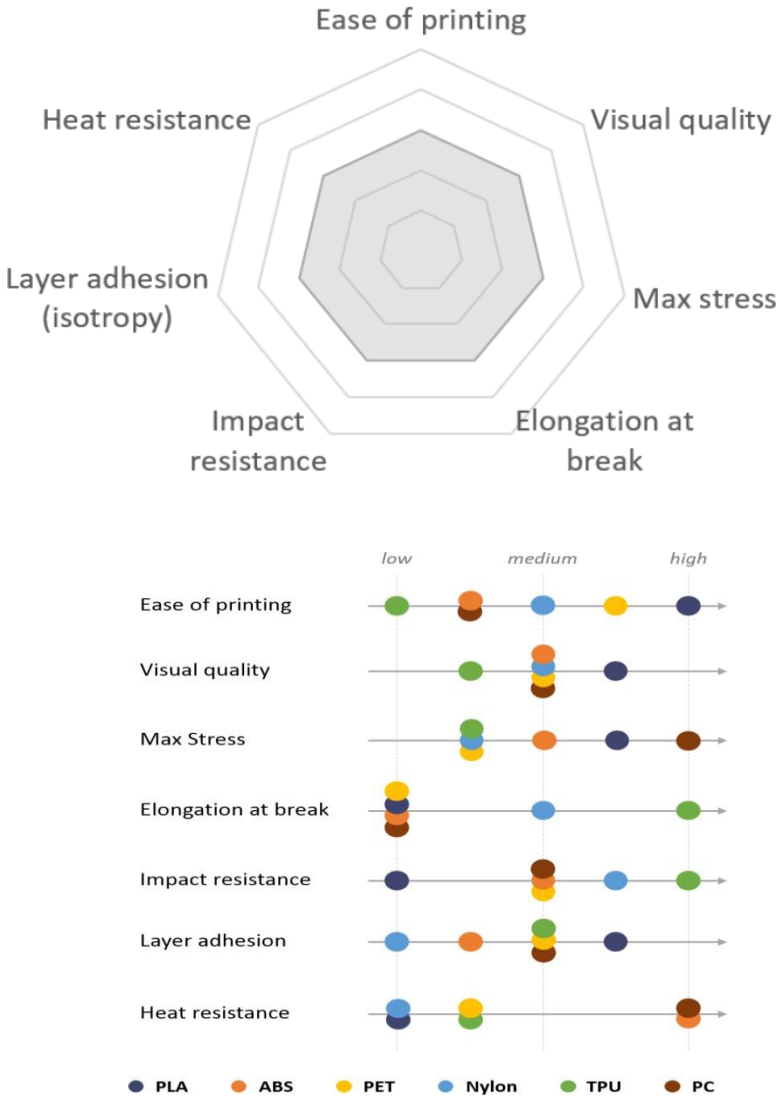


Fig 04 Printing Material Properties

On a scale of 1 (low) to 5 (high), each item has been ranked according to the following criteria.

(i). **Visual quality:** How attractive the final product is. Here is more information about how we test it.

(ii). **Max stress:** Pulling on an object slowly can cause it to experience the maximum amount of stress before breaking.

(iii). **Ease of printing:** The following factors indicate how easy a material is to print: bed adhesion, maximum printing speed, frequency of unsuccessful prints, flow accuracy, ease of feeding into the printer, etc.

(iv). **Elongation at break:** The longest an object may be stretched before breaking.

(v). **Impact resistance:** Energy required for a sudden impact to shatter an object.

(vi). **Heat resistance:** The highest temperature a thing can withstand before becoming pliable and undergoing deformation.

2.4 Specifications of Materials

The specifications of each material have been described with their material properties and their pros and cons are discussed below.

2.4.1 PLA

PLA offers good visual quality and is the most straightforward material to print. It is extremely brittle despite being extremely stiff and strong.

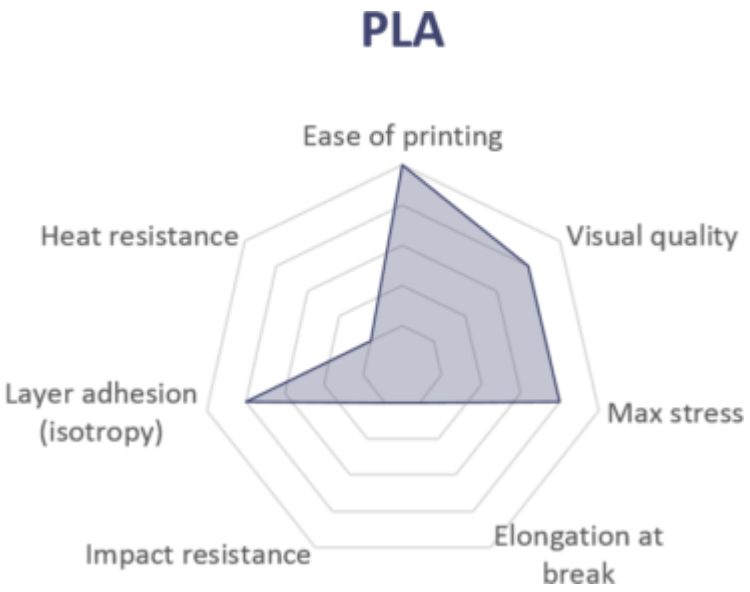


Fig.05 Material Profile of PLA

2.4.2 ABS

When greater temperature resistance and durability are needed, ABS is typically used over PLA.

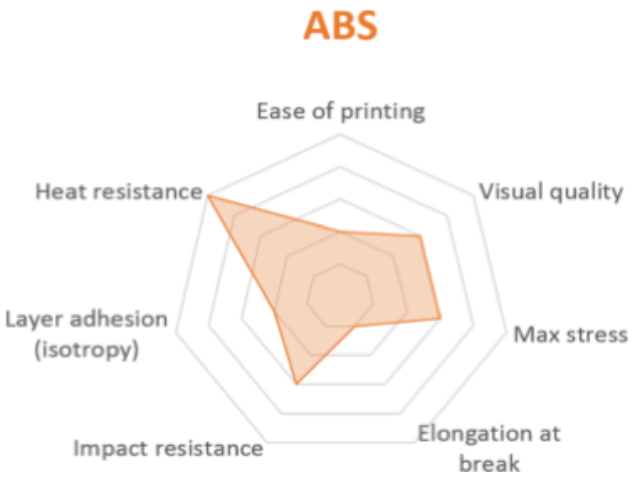


Fig 06 Material Profile of ABS

2.4.3 PET-G

PET-G is a well-rounded, slightly softer polymer with intriguing extra qualities and few significant disadvantages.

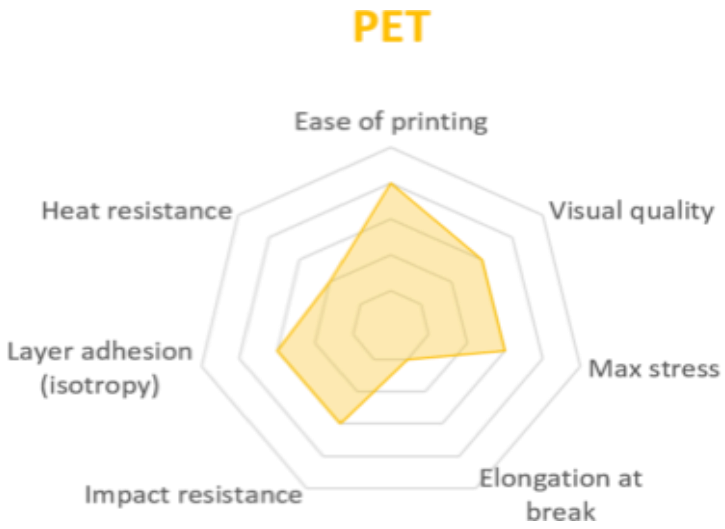


Fig 07 Material profile of PET-G

2.4.4 Material Filament

It is material that is inserted in an extruder to make an object. Filament with a 1.75mm or 3mm diameter is frequently used for 3D printing. This material is fed into an extruder via a motor in the shape of a wire. The most often used printing materials are PET-G and PLA ABS.



Fig 8 Filament Material

3. Results and Discussion

Materials were printed using PET-G, PLA, and ABS. Layer thickness, object accuracy i.e., 0.25, 0.2, 0.15, and 0.10 mm, and printing speed were all taken into consideration. It has been observed that during printing, the precision of the printed part rises as the layer thickness lowers. Additionally, a number of polymers were examined one at a time, including PET-G, ABS and PLA.

3.1 Analysis of Polyethylene Terephthalate Glycol (PET-G)

Four rectangular pieces with 50% infill density were printed using PET-G thermoplastic filament material with varying layer thicknesses. The accuracy of the printed part increases as the number of printing layers increases as the layer thickness decreases. For each printed object, the bed temperature and filament melting temperature are set at 80°C and 240°C, respectively, during printing. Compared to PLA, PET-G exhibits a slight difference in accuracy; the best accuracy of 99.8% in super quality 0.12mm layer thickness is attained with PET-G. Its glossy finish, flexibility, and heat resistance are all higher.



Fig. 9 PET-G Printed objects in different Qualities.

3.2 Analysis of Acrylonitrile Butadiene Styrene (ABS)

Four rectangular pieces of 50% infill density were printed using ABS thermoplastic filament material with varying layer thicknesses. The accuracy of the printed part increases as the number of printing layers increases as the layer thickness decreases. For each printed object, the bed temperature and filament melting temperature are set to 90°C and 250°C, respectively, during printing.

The rectangular samples exhibit shape defects due to heat shrinkage, and the ABS material warps most along the height axis. By hiding the printer inside an acrylic cover, this material may be printed more effectively.



Fig. 10 ABS printed objects in different qualities

3.3 Analysis of Polylactic Acid (PLA)

Four rectangular pieces with 50% infill density were printed using PLA thermoplastic filament material with varying layer thicknesses. The precision of the printed item increased as the number of printing layers increased as the layer thickness decreased. The filament and bed temperatures are set to 220°C and 70°C, respectively, for every printed object. A smoother, glossier substance that is more environmentally friendly and produces no toxic fumes when printed, PLA

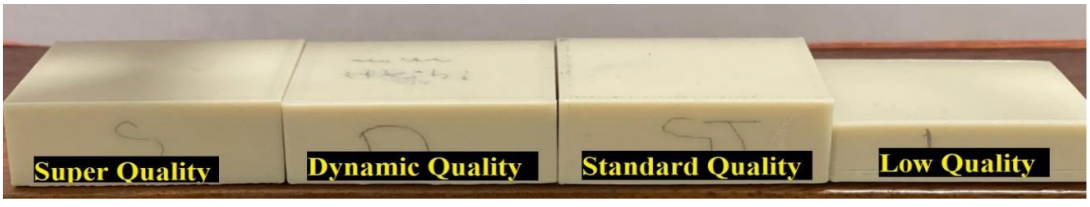


Fig.11 PLA Printed objects in different Qualities

4. Result Analysis

The nozzle diameter, printing speed, and various layer thicknesses were set at 0.4 mm, 100 mm/s, and as follows: Low 0.25 mm, Standard 0.20 mm, Dynamic 0.15 mm, and Super 0.10 mm during the printing process. It is observed that 50% infill density parts made by an FDM 3D printer using various thermoplastic filament materials, such as PET-G, ABS, and PLA,

exhibit improved quality as the layer thickness decreases, thereby increasing the accuracy of printed parts. A Vernier caliper gauge was used to measure geometric precision, and the divergence from the original STL file format was calculated. The printed parts' dimensional precision is displayed in Figures 09, 10, and 11. The 3D parts printed using Fused Deposition Modelling (FDM) and the real measurements of 15 mm Height (H), 40 mm Width (W), and 40 mm Length (L), differ in terms of dimensional precision. However, the thermoplastic filament material ABS exhibits notable waviness, surface roughness, and primary behavior. It was shown that PLA thermoplastic filament material is more precise and exhibits better surface behavior. Both PET-G and PLA exhibit good surface performance. The formula below is used to calculate the accuracy and percentage error.

$$\text{Accuracy} = \frac{Printed\ Object\ Dimensions}{CAD\ Model\ Dimensions} \times 100$$

$$\text{Percentage Error} = \frac{Printed\ Object\ Dimensions - CAD\ Model\ Dimnesions}{CAD\ Model\ Dimensions} \times 100$$

Results analysis of dimensional accuracy of each material PET-G, ABS and PLA with different layer thickness at constant speed i.e 100 mm/s is discussed in Table no: 05.

Table 5: Results of Different Materials

Quality	**Layer Thickness (mm)**	**No: of Printing Layers**	**Weight (Grams)**	**Temp (◦C)**	**Time (Mint)**	**Speed (mm/s)**	**CAD Model Dimensions (mm)**	**Printed Object Dimensions (mm)**	**Accuracy (%)**	**Percentage Error**
Polyethylene Terephthalate Glycol (**PET-G)**										
Low	0.25	50	15	220-260	50	100	H=15 W=40 L=40	H=14.5 W=39.4 L=39.4	93.78	-6.22
Standard	0.2	60	14	220-260	60	100	H=15 W=40 L=40	H=14.5 W=39.8 L=39.6	95.22	-4.78
Dynamic	0.15	80	13	220-260	80	100	H=15 W=40 L=40	H=14.7 W=40 L=39.8	97.51	-2.49
Super	0.10	110	12	220-260	110	100	H=15 W=40 L=40	H=14.8 W=39.95 L=39.9	98.29	-1.70
Acrylonitrile Butadiene Styrene (**ABS)**										
Low	0.25	40	10	220-260	45	100	H=15 W=40 L=40	H=14.2 W=39.4 L=39	90.91	-9.08
Standard	0.2	48	08	220-260	54	100	H=15 W=40 L=40	H=14.5 W=39.1 L=39.2	92.60	-7.39
Dynamic	0.15	56	06	220-260	63	100	H=15 W=40 L=40	H=14.6 W=39.5 L=39.4	94.67	-5.32
Super	0.10	64	04	220-260	72	100	H=15 W=40	H=14.6 W=39.5	95.40	-4.60

							L=40	L=39.7		
Polylactic acid (PLA).										
Low	0.25	45	12.5	205-225	47	100	H=15 W=40 L=40	H=14.4 W=40 L=39.8	95.53	-4.47
Standard	0.2	54	10	205-225	56	100	H=15 W=40 L=40	H=14.8 W=39.8 L=39.7	97.43	-2.56
Dynamic	0.15	63	7.5	205-225	63	100	H=15 W=40 L=40	H=14.8 W=39.95 L=39.95	98.42	-1.58
Super	0.10	72	05	205-225	70	100	H=15 W=40 L=40	H=14.9 W=40 L=40	99.33	-0.67

5. Conclusion

- The ability of 3D printing to produce intricate structures with little waste, mass customization, and design freedom are its main advantages. A thorough analysis of the materials and processes used in 3D printing.
- The ease of usage, low cost, and rapid processing speed of Fused Deposition Modeling (FDM) make it a popular 3D printing method.
- This paper's primary goal is to analyze the dimensional accuracy of 3D printed objects made of various thermoplastic materials using a 3D printer. Parts made in 3D design software can be successfully loaded into printing software; however, the final product has some dimension variance because the accuracy of the printed material improves as the percentage error of the filament material decreases with layer thickness, compared to the design phase specifications.

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