ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20250101230414

Subject review
Received: 2025-01-01, Accepted: 2025-04-29

Comparative Evaluation of PLA and PETG's Mechanical Characteristics for 3D-Printed Bone Implant Applications

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Abstract: This study examines the mechanical properties of polylactic acid (PLA) and glycol-modified polyethylene terephthalate (PETG) in relation to 3D-printed cranial implants. Using fused deposition modelling (FDM) technology, the materials were tested for tensile, bending, and impact toughness under various printing conditions (layer thickness, infill density, and infill pattern). The findings indicated that PETG exhibited superior impact toughness and flexural strength, making it ideal for load-bearing applications, while PLA demonstrated lower tensile strength, making it suitable for temporary implants. The study highlights the literature background on PETG's resilience and processing efficiency along with PLA's biodegradability and bio absorption to satisfy specific medicinal needs. These findings demonstrate how 3D printing can be utilized to produce patient-specific, biocompatible implants, increasing precision and lowering costs in biomedical applications. The improvement of material properties and printing parameters provides the foundation for improving the functionality of implants tailored to particular requirements.

Keywords: Bone Implant; Glycol-modified Polyethylene Terephthalate (PETG); Mechanical Properties; Polylactic-Acid (PLA); 3D-Printer

1 INTRODUCTION

Three distinct materials (polyethylene terephthalate glycol - PETG, white resin, and Bone STN) were used to create 3D-printed skull samples using three distinct 3D print techniques (fused filament fabrication, stereo lithography [SLA], and material jetting). This is the first study to assess the safety of 3D-printed materials for burr hole surgical drilling, as far as the authors are aware. While resin-based materials will need safety controls to deal with airborne particles, PETG is recommended as a safe material [1]. polylactic acid (PLA) and polyethylene terephthalate glycol (PETG) specimens with Raster angles of ±45° were used for the infill in order to achieve a 100% infill density. A layer thickness of 0.15 mm was considered for printing. There were four thicknesses for each material. According to the ISO standard, a pendulum impact system was used to test the specimens. All specimens, regardless of thickness, showed brittle fracture in addition to comparable behavior in the elastic zone of deflection for the same thickness and material type. If the PETG specimens allow for a larger deflection, the PLA specimens exhibit a higher impact force; however, the IZOD impact strength values for the two materials are comparable [2]. Polyethylene terephthalate glycol (PETG) is a transparent, miscible thermoplastic have strong tensile qualities, high ductility, and resistance to heat and chemical exposure. There are several methods for producing PETG, but 3D printing is one of the most prominent. Although polylactic acid (PLA) is more biodegradable than PETG, because of its high tensile strength and high degradation temperature, PETG is a unique thermoplastic that is both economical and efficient. Tissue engineering, dentistry, optometry, vascular health, cardiology, orthopedics, neurology, gynecology, and surgery are just a few of the medical specialties that use it because of its advantageous qualities. Furthermore, PETG contributes significantly to biomedical engineering and research, advancing cell studies, it is expected that more medical research and development will solidify PETG's position as an affordable, adaptable biomaterial with a broad range of applications [3]. The use of polylactic acid (PLA) implants customized through 3-dimensional (3D) printing as an affordable and precise cosmetic option for cranioplasty was performed on two cases of skull defects. A 20-year-old woman with a history of severe traumatic brain injury (TBI) and epidural hematoma was the subject of the first case. The second case present an elderly man, 46, whose had previously experienced spontaneous intracerebral hemorrhage associated with arteriovenous malformation (AVM). A 3D model of the skull defect was created by reconstructing both of the CT scan data. A 3D printer was used to create the prosthesis using PLA. In both cases, cosmetic satisfaction was achieved and no postoperative complications were reported. outcome with no complications reported after the cranioplasty procedure, the use of PLA implants customized through 3D printing was shown to be economical and to provide good cosmetic satisfaction [4]. Fourteen distinct infill patterns were used to 3D print materials made of polylactic acid (PLA), enhanced polylactic acid (PLA+), and polyethylene terephthalate glycol (PETG). The printed specimens' mechanical characteristics and surface characteristics were evaluated and discussed. The mechanical properties of the produced specimens were determined to be ultimate tensile strengths, Young's modulus, and strain at break percentage, while the average, maximum, and total height of protuberances (*Ra*, *Rz*, and *Rt*) were measured as surface characteristics. On the other hand, the best *Ra*, *Rz*, and *Rt* were obtained from cross, quarter cubic, and concentric patterns. The cubic, gyroid, and concentric patterns were found to be the best overall patterns for the mechanical properties of PLA, PLA+, and PETG materials [5].

The specimen with 100% filling showed more deformation in the compressive strength test than the specimen with 50% filling. This is explained by the PETG polymer's highly ductile mechanical properties. The PLA polymers with the highest filling percentages (100 and 50 percent) demonstrated less deformation until failure in the mechanical flexural strength tests, indicating that they were more ductile materials. However, specimens that had 30% filling showed more deformation than those that had 100%

filling. Because the internal spacing absorbs the impact of loads, PLA exhibits greater flexibility and tenacity for fillings of low percentages, when compared to the PETG polymer, the PLA polymer demonstrated superior mechanical qualities, including Young's modulus, ductility, and more satisfactory resistance. Because PLA is a biopolymer and has exceptional processability, it also describes the synthesis of PLA in a more sustainable manner [6]. Use PETG in 3D printing to create intricate, patient-specific implants that are impossible to make using conventional techniques, highlighting the significance of biocompatible materials for upcoming surgical applications [7, 22]. Several 3D-printable polymers, including polyetheretherketone (PEEK), polylactic acid (PLA), polymethyl methacrylate (PMMA), glycol-modified polyethylene terephthalate (PETG), polyvinylidene fluoride (PVDF), and polypropylene (PP), were subjected to tensile tests at varying crosshead speeds in order to examine the application temperature range. It was discovered that variations in body temperature had little effect on the mechanical characteristics of PETG, PEEK, PLA, and PMMA. The materials were further ranked based on their filling density, which is a gauge of their processability, in addition to their mechanical integrity (strength, stiffness, and its strain-rate and temperature dependency inside the body). As a result, helpful information is offered for the design process of 3D-printed implants as well as for choosing potential medical uses for each material [8]. Flexural testing of the 3D-printed bone pieces shows how the mechanical behavior of the parts is affected by sample geometry and printing orientations. The results were not significantly impacted by the printing orientation due to the high infill percentage, to find out how the sectioning technique affected the overall mechanical performance. Tests for lateral compression and frontal penetration were conducted on the dummy skulls. The findings show that PLA-based surrogates may accurately replicate the behavior of the cranium [9]. Characterizing the polylactic acid (PLA) and polyethylene terephthalate glycol (PETG) materials of FDM under four loading conditions (tension, compression, bending, and thermal deformation) using a range of printing temperatures and speeds. According to the findings, there is a clear tensile and compression asymmetry in PLA and PETG materials. Higher printing temperatures were found to improve the mechanical characteristics (tension, compression, and bending) of PLA and PETG, and speed had varying effects on the two materials. Furthermore, PLA has better mechanical qualities than PETG, for thermal deformation, however, the opposite is true. These findings will be very helpful to researchers who employ polymers and FDM processes to reach sustainability [10], studied maximize the mechanical properties of printed PETG by optimizing the printing parameters (nozzle temperature, printing speed, layer height, and filling). The optimal bending characteristics for PETG were found to be achieved at extrusion temperatures of 265 °C, printing speeds of 20 mm/s, layer heights of 0.4 mm, and an internal density of 100% [11]. The successful fabrication of simple implants for defect reconstruction was the aim of the project. Depending on the material choice, digitally created three-dimensional (3D) models addressing two representative mandibular bone defects were printed. Glycol-modified PET (PETG) were ultimately chosen. This polymer offered excellent printability, good mechanical qualities, and high cell acceptance. The following manufacturing procedure produced implant strategies: the PETG standard implant because the print time for the standard implant is less than three hours, even for larger skull defects, it is intended to be applied intraoperatively. Standard implants were found to be cleanly printed, well-fitting, and mechanically stable. This bio functional material is appropriate for pre-operative manufacturing based on radiological image scans of the defect and may be utilized in certain reconstructive patient cases [12]. In order to determine the optimal mechanical properties of the PLA material, polylactic acid was used through a fused deposition process to study combinations of process parameters (layer thickness, build direction, filling speed, filler density, etc.). Among these, fill rate is the most important component in compressive property, whereas build direction significantly affects tensile, bending, and surface roughness properties [13], how Charpy impact strength is affected by print speed, layer height, raster angle, and infill density. The most important factor is infill density, which is followed by raster angle, layer height, and print speed, according to analysis using S/N ratios and ANOVA. According to ANOVA, print speed and infill density have respective influences of 36.51% and 38.93%. Impact strength is increased by 1.39% to 38.54 kJ/m² using the Taguchi method with the optimized parameters of 100% infill density, 45/−45° raster angle, 0.25 mm layer height, and 75 mm/s print speed [14]. The mechanical properties of polylactic acid (PLA) components are examined in this study, along with the impacts of layer height, fill width, fill density, layer orientation, printing speed, and fill pattern on defect resistance. Through testing on various geometries using rotating and four-point bending machines, the optimal parameter set for maximal fiber resistance was discovered. According to the results, fill pattern and density have the least impact, whereas layer orientation has the biggest impact, followed by layer height, fill density, and printing speed [15]. This study investigates the need for bone implants to be composed of safe, long-lasting, and biocompatible materials. Despite being easily accessible for 3D printing, PLA and PETG may not be suitable for medical purposes due to their unique mechanical properties. This study is significant because:

1) Material Suitability: Comparing mechanical properties including tensile strength, impact, bending, and flexibility to determine which material best suits the needs of a bone implant.
2) Biocompatibility: Assessing PLA's ability to absorb biomaterials and PETG's resilience for secure uses. This research could greatly enhance the availability of patient-specific, accessible bone implant treatments.

2 MATERIALS AND METHODS

Because of their suitability for creating cranial implants and their biocompatibility with the human body, two types of materials polylactic acid (PLA) and polyethylene terephthalate glycol (PETG) were chosen. These materials were obtained from Uruk Tech Co., based in Baghdad, Iraq,

and manufactured by Torwell Co., Ltd., China. The tensile test was conducted by a WDW-200E tensile testing machine measuring control software manufactured by People's Republic of China Time Group Inc. in the strength laboratory of the College of Production and Metallurgical Engineering, University of Technology, Baghdad, Iraq. The impact test was also performed by a Chinese-made XJU-22 impact tester to compare their mechanical properties. A FDM 3D printer was used to create filament out of these materials.

2.1 Polylactic Acid (PLA)

For bone implants, polylactic acid (PLA) is a biodegradable polymer that has been thoroughly studied due to its mechanical properties, biocompatibility, and bio absorption. Self-reinforced PLA implants demonstrate sufficient mechanical strength for bone fixation and gradual bio absorption, with a low inflammatory response and effective osteotomy healing over a 48-week period [16], [20], [21]. Because PLA improves toughness and bioactivity, it works incredibly well for bone tissue engineering [17]. This material was used in this study, and Tab. 1 shows the material parameters as provided by the manufacturer. Additionally, Fig. 1 depicts the PLA and FDM Creality K1 Max 3D printer filament.

Table 1 Description Material parameters of PLA

Material parameters	Limitation
Density	1.24 g/cm^3, ASTM D1505
Melt Flow Index	6 g/10 min, 190 °C/2.16 kg
Heat Distortion Temp	50 °C
Tensile Strength	6.08012 MPa
Tensile Elongation	4.4 %
Flexural Strength	6.47239 MPa
Flexural Modulus	2 745.862 MPa
Impact Strength	4.2 kJ/m²
Diameter Accuracy	1.75 mm : 1.70 - 1.78 mm

Table 2 Description Material parameters of PETG

Material parameters	Limitation
Density	1.27 g/cm^3, 21.5 °C
Melt Flow Index	20 g/10 min, 200 °C/5 kg
Heat Distortion Temp	70 °C
Tensile Strength	4.90332 MPa
Tensile Elongation	120 %
Flexural Strength	70.60788 MPa
Flexural Modulus	2 147.65635 MPa
Impact Strength	8.7 kJ/m²
Diameter Accuracy	1.75 mm : 1.70 - 1.78 mm

2.2 Polyethylene Terephthalate Glycol (PETG)

PETG exhibits strong mechanical qualities, biocompatibility, and adaptability for bone implants, making it a viable option for load-bearing and bioactive applications. Its use in high-stress or long-term applications is still subject to considerations regarding stress response and degradation in specific environments. When compared to other polymers, PETG scaffolds made for bone tissue engineering have greater mechanical strength and improved cell attachment and proliferation, suggesting that they are suitable for load-bearing applications [3]. Tab. 2 will show some parameters of the material produced by the manufacturer, and Fig. 2 shows the filament of PETG and the FDM Sanlu S9 Plus 3D printer machine.

2.3 3D-printing Machine

Two types of printers were used in this study, as shown in Fig. 1a. 3D printer, the CREALITY K1 MAX, was used to print PLA material Fig. 1b. The second printer, the SANLU S9 PLUS, was employed for printing PETG. Tab. 3 presents the specifications of the 3D printers used for both materials.

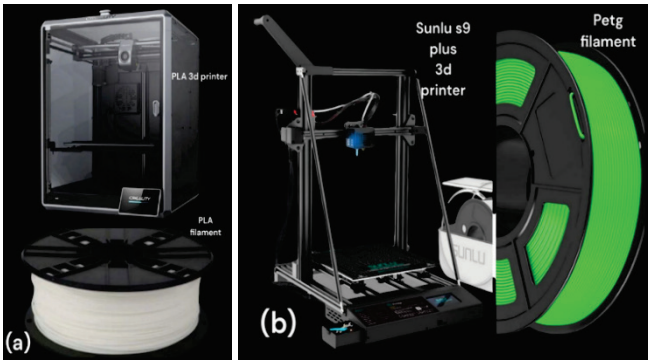


Figure 1 (a) k1 max creality 3d printer for PLA material, (b) sanlu s9 plus 3d printer for PETG material

Table 3 The specifications of the 3D printer

Specification	PLA	PETG
Brand	Creality	SANLU
Printing Technology	FDM	FDM
Product Dimensions	435×462×526 mm	309.88×309.88×400mm
Filament diameter	1.75 mm	1.75 mm
Printing Speed	≤600 mm/s	250 mm/s
printing temperature	0 - 40 °C	260 °C
Heatbed Temperature	≤100 °C	100 °C
Nozzle Diameter	0.4 mm (compatible with 0.6/0.8 mm)	0.4 mm (compatible specifications: 0.4 - 0.8 mm)

This study looked into how printing parameters, such as (infill density, infill pattern, and layer thickness) affected mechanical performance. In order to compare the performance of PLA and PETG, the parameters were assessed using mechanical tests like the Charpy impact test, bending test, and tensile test.

Table 4 Process parameters of the printing material

Printing parameters	Low level	Mid-level	High level
Layer thickness	0.15	0.225	0.3
Infill density	20 %	50 %	80 %
Infill pattern	grit	concentric	Tri-hexagonal

First, a 3D virtual geometry of the (impact, bending, tensile) test specimens was produced using SolidWorks software as shown in Fig. 2. After the virtual test specimens were created, the SolidWorks file was exported into the slicing program in.(stl) format. The same printing factors were established for both materials at three levels, as indicated in Tab. 4.

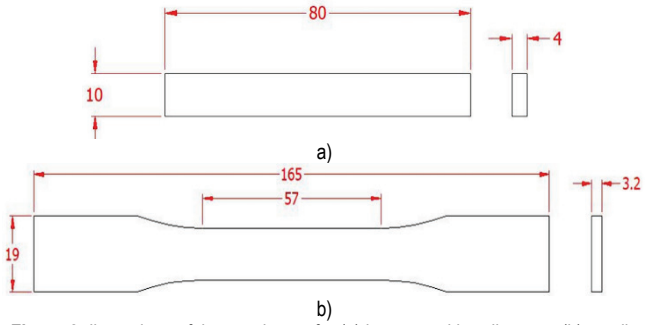


Figure 2 dimensions of the specimens for (a) impact and bending test, (b) tensile test.

2.4 The Impact, Bending, and Tensile Test

To assess the impact, bending and tensile properties of the specimens, the impact test or so-called Charpy tester with ISO179 standard, was performed using a shock device, and the specimen is placed between the two columns at the bottom of the holder. To release the paddle, it is taken and placed at a specified height, depending on the load capacity. The specimen is violently struck by the paddle as it is released down for testing, which causes it to split into two parts with an energy of 5.5 joules. The impact toughness was measured by the law in Eq. (1) [18] to find out the value of the energy absorbed for each specimen and for both materials.

$$Impact\ Toughness = \\ = \frac{Absorbed\ Energy\ (\text{Joules})}{Cross\text{-}sectional\ Area\ of\ the\ Test\ Specimen\ (\text{mm}^2)}. \quad (1)$$

The bending test was conducted on the same samples according to ISO 178 standard, where the bending test was carried out using a 3-point contact bending test device. The test sample was placed on the support and a vertical force was applied to the sample at a rate of (40 N) and at a speed of (2 mm/min) to measure the maximum force that the sample can withstand before failure to measure the value of the flexural strength according to Eq. (2) [19] shown below.

$$\sigma = \frac{3PL}{2bd^2}, \quad (2)$$

where L is the length of the support span, b is the specimen's width, d is its thickness, and P is the load at a specific location on the load-deflection curve.

Lastly, tensile samples with the dimensions displayed in Fig. 2b were made in compliance with ASTM 638. The maximum tensile strength and ductility values of the two materials were ascertained by testing these samples with a tensile testing device at a speed of 1 mm/min and a load of 40 N.

3 EXPERIMENTAL DESIGN USING THE BOX-BEHNKEN DESIGN BY RESPONSE SURFACE METHODOLGY

The Box-Behnken design (BBD) is a response surface method for optimizing experimental designs with many variables. In this study, three factors—layer thickness, infill density, and infill pattern—that significantly affect the mechanical properties and functionality of 3D-printed components are examined. BBD is ideal for examining the interactions between these variables because it requires fewer experimental runs while maintaining efficiency compared to a full factorial design. The design generates a set of combinations by systematically varying the levels of these parameters in order to investigate their effects both individually and in combination. With this method, the printing process can be precisely optimized for desired results, like strength, durability, or material efficiency. Finally, based on three levels for each factor, the Box-Behnken design designed 15 experiments shown in Tab. 5.

Table 5 Design of experimental of process parameters

Run	Coded matrix			Un coded matrix		
	A	***B***	***C***	Layer thickness	Infill density	Infill pattern
1	–1	–1	0	0.15	20	Concentric
2	1	–1	0	0.3	20	Concentric
3	–1	1	0	0.15	80	Concentric
4	1	1	0	0.3	80	Concentric
5	–1	0	–1	0.15	50	Grid
6	1	0	–1	0.3	50	Grid
7	–1	0	1	0.15	50	Tri-hexagonal
8	1	0	1	0.3	50	Tri-hexagonal
9	0	–1	–1	0.225	20	Grid
10	0	1	–1	0.225	80	Grid
11	0	–1	1	0.255	20	Tri-hexagonal
12	0	1	1	0.225	80	Tri-hexagonal
13	0	0	0	0.225	50	Concentric
14	0	0	0	0.225	50	Concentric
15	0	0	0	0.225	50	Concentric

4 RESULTS AND DISCUSSION

In this study, 15 experiments were conducted using identical and controlled printing conditions (layer thickness, fill density, and fill shape) to compare the PLA and PETG's mechanical characteristics. The findings show clear variations in the two materials' performance attributes, emphasizing both their advantages and disadvantages when manufactured under the same conditions.

For both materials PLA and PETG used in orthopaedic implant analysis, impact test images were obtained for 15 specimens under the same test conditions and are shown in Fig. 3. The purpose of these tests was to ensure that the results for both materials were comparable and consistent.

Experimental findings for PLA and PETG materials' impact toughness under various 3D printing scenarios are shown in Tab. 6. An analysis of the findings is provided below. Eq. (3) and Eq. (4) represent the mathematical model for the response variable, impact toughness for PLA and PETG respectively.

$$impact\ toghness = 0.276 - 0.79\ layer\ thickness + 0.00356\ infill\ density - 0.0396\ infill\ pattern + 3.19\ layer\ thickness * layer\ thickness + 0.000006\ infill\ density * infill\ density - 0.0071\ infill\ pattern * infill\ pattern - 0.0111\ layer\ thickness * infill\ density + 0.167\ layer\ thickness * infill\ pattern - 0.000833\ infill\ density * infill\ pattern \quad (3)$$

$$\textit{impact toughness} = 0.0345 - 0.241\ \textit{layer thickness} + 0.000152\ \textit{infill density} + 0.01911\ \textit{infill pattern} + 0.635\ \textit{layer thickness} * \textit{layer thickness} - 0.000002\ \textit{infill density} * \textit{infill density} + 0.00782\ \textit{infill pattern} * \textit{infill pattern} + 0.00033\ \textit{layer thickness} * \textit{infill density} - 0.0792\ \textit{layer thickness} * \textit{infill pattern} + 0.000083\ \textit{infill density} * \textit{infill pattern} \quad (4)$$

Table 6 printing parameters and impact toughness of PLA and PETG material.

Runs	Parameters			Impact toughness of PLA (J/mm^2)	Impact toughness of PETG (J/mm^2)
	Layer thickness	Infill density	Infill pattern		
1	0.15	20	Concentric	0.00625	0.015
2	0.3	20	Concentric	0.00875	0.0225
3	0.15	80	Concentric	0.01	0.0175
4	0.3	80	Concentric	0.01	0.028
5	0.15	50	Grid	0.01	0.01625
6	0.3	50	Grid	0.00875	0.0375
7	0.15	50	Tri-hexagonal	0.0075	0.035
8	0.3	50	Tri-hexagonal	0.0076	0.0325
9	0.225	20	Grid	0.0078	0.02
10	0.225	80	Grid	0.01125	0.015
11	0.255	20	Tri-hexagonal	0.00625	0.03
12	0.225	80	Tri-hexagonal	0.0075	0.035
13	0.225	50	Concentric	0.0076	0.02375
14	0.225	50	Concentric	0.0071	0.0125
15	0.225	50	Concentric	0.01	0.0205

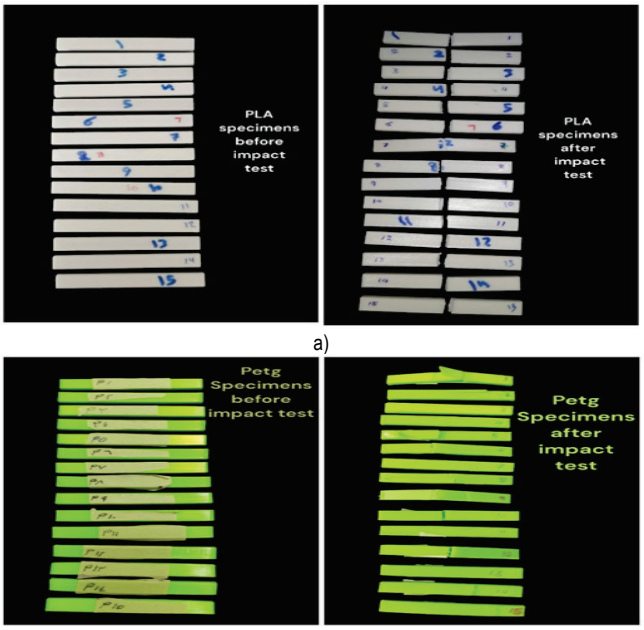


Figure 3 impact test for (a) polylactic acid specimens, (b) polyethylene terephthalate glycol specimens

When compared to PLA, PETG continuously shows greater impact toughness in the same circumstances. For instance: Run 1: PETG (0.015) versus PLA (0.00625) PLA (0.00875) versus PETG (0.0375) in Run 6 This demonstrates the superior energy absorption capabilities of PETG. Differences Particular to Patterns: PETG reacts favorably to the tri-hexagonal pattern, while PLA appears to gain more from the Concentric and Grid patterns. Material Selection for applications needing greater impact toughness, PETG is typically a better option. Parameter Optimization, Impact resistance can be increased for both materials by carefully choosing infill patterns and optimizing infill density. PLA benefits from thinner layers, while PETG can withstand or even benefit from thicker layers. A spider chart (radar chart) comparing the impact toughness of PETG (orange) and PLA (blue) is shown in Fig. 4.

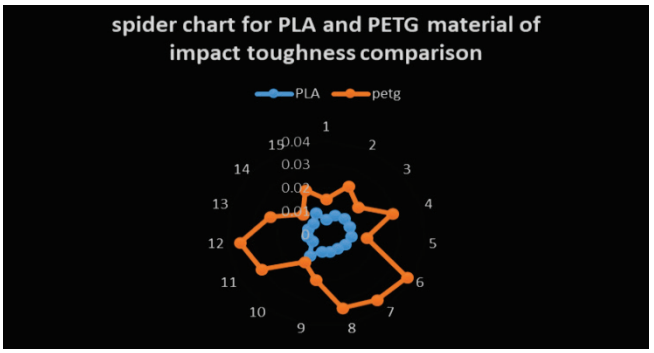


Figure 4 comparing the impact toughness of PETG and PLA

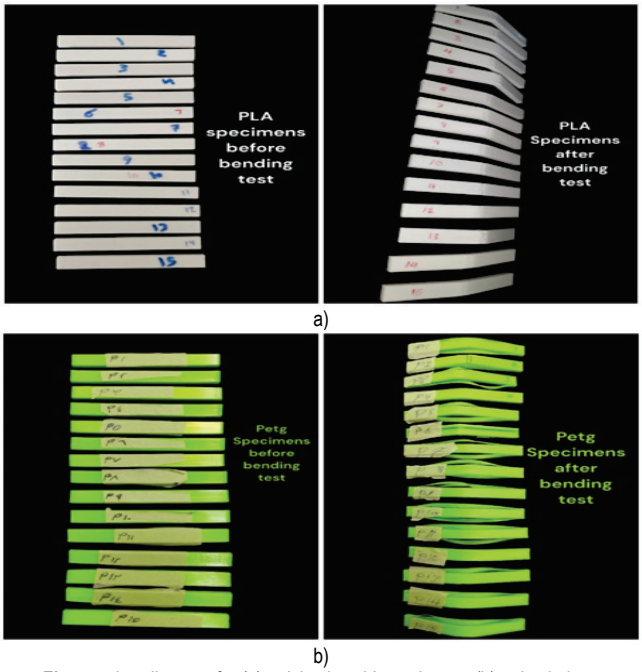


Figure 5 bending test for (a) polylactic acid specimens, (b) polyethylene terephthalate glycol specimens

In most regions, the orange polygon (PETG) is farther from the center than the blue polygon (PLA). This suggests that PETG has greater impact toughness across a range of parameters. Features of PLA: The blue polygon is more centralized and smaller. This illustrates PLA's limited capacity to absorb impact energy and brittle nature. PETG Features: The orange polygon is more flexible and energy absorption due to its larger coverage area. Compared to PLA, PETG is less prone to fracture under dynamic loads. This has been observed during laboratory experiments because it has greater ductility than PLA. Finally, the spider diagram effectively depicts the superior performance of PETG over

PLA in terms of impact strength. The ductility and toughness of PETG make it a better choice for applications that require resistance to mechanical stress, such as orthopedic implants, while PLA is better suited for applications where stiffness is more important than toughness.

The PLA and PETG bending samples are shown in Fig. 5 following testing under the same printing conditions listed in Tab. 7.

Table 7 Flexural strength of PLA and PETG material specimens.

Runs	Parameters			Flexural strength of PLA (MPa)	Flexural strength of PETG (MPa)
	Layer thickness	Infill density	Infill pattern		
1	0.15	20	Concentric	50	93
2	0.3	20	Concentric	54	72
3	0.15	80	Concentric	72	63
4	0.3	80	Concentric	59	64
5	0.15	50	Grid	48	45
6	0.3	50	Grid	45	47
7	0.15	50	Tri-hexagonal	54	73
8	0.3	50	Tri-hexagonal	63	54
9	0.225	20	Grid	59	36
10	0.225	80	Grid	54	55
11	0.255	20	Tri-hexagonal	53	50
12	0.225	80	Tri-hexagonal	50	70
13	0.225	50	Concentric	55	48
14	0.225	50	Concentric	59	65
15	0.225	50	Concentric	53	68

The PLA and PETG materials' bending properties (flexural strength) were measured and contrasted over 15 different runs, as seen in Fig. 6.

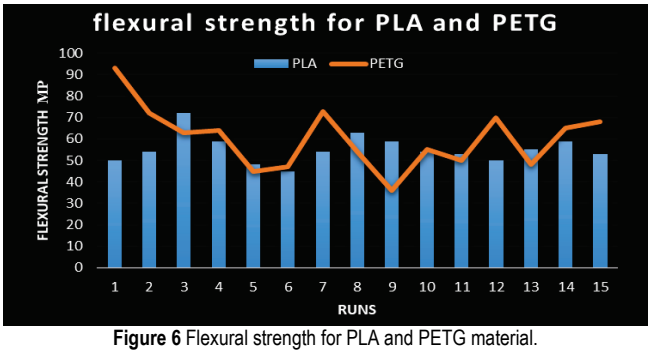


Figure 6 Flexural strength for PLA and PETG material.

The PLA's flexural strength values vary slightly but are generally constant throughout the runs. The PETG's flexural strength fluctuates more. Beginning at a high value, it declines over a number of runs before rising once more in the later runs. In most runs, PETG exhibits greater flexural strength than PLA, suggesting better bending properties under the same circumstances. Nonetheless, PETG's performance fluctuation may indicate sensitivity to printing or testing circumstances as in run 9 and others shown in Tab. 7. A Box–Behnken design was used to create a mathematical model that better explains how print parameters affect flexural strength. The second-order regression model that is produced in Eq. (5) and Eq. (6) for PLA and PETG material, respectively

$$\textit{flexural strength}\ (\text{MPa}) = 45.1 + 26\ \textit{layer thickness} + 0.250\ \textit{infill density} - 8.1\ \textit{infill pattern} + 141\ \textit{layer thickness} * \textit{layer thickness} + 0.00255\ \textit{infill density} * \textit{infill density} - 3.96\ \textit{infill pattern} * \textit{infill pattern} - 1.89\ \textit{layer thickness} * \textit{infill density} + 40.0\ \textit{layer thickness} * \textit{infill pattern} + 0.017\ \textit{infill density} * \textit{infill pattern} \quad (5)$$

$$\textit{flexural strength}\ (\text{MP}) = 182.3 - 771\ \textit{layer thickness} - 1.14\ \textit{infill density} + 23.3\ \textit{infill pattern} + 1304\ \textit{layer thickness} * \textit{layer thickness} + 0.00593\ \textit{infill density} * \textit{infill density} - 12.92\ \textit{infill pattern} * \textit{infill pattern} + 2.44\ \textit{layer thickness} * \textit{infill density} - 70.0\ \textit{layer thickness} * \textit{infill pattern} + 0.008\ \textit{infill density} * \textit{infill pattern} \quad (6)$$

PETG is better suited for applications needing greater mechanical strength, like bone implants, due to its higher flexural strength. PLA is appropriate for other areas of medical use where moderate mechanical properties are acceptable, but its consistent but lower flexural strength may make it less suitable for load-bearing applications.

Fig. 7 displays pictures of the PLA and PETG samples following the tensile test. Both materials' ultimate tensile strength was assessed using the same printing parameters as the other tests. Tab. 8 provides a summary of the related test results.

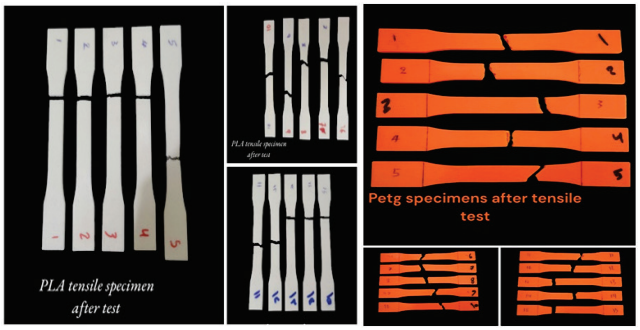


Figure 7 Tensile specimens after testing for PLA and PETG material.

Table 8 Ultimate tensile strength values of PLA and PETG material specimens.

Runs	Parameters			Ultimate tensile strength for PLA (MPa)	Ultimate tensile strength for PETG (MPa)
	Layer thickness	Infill density	Infill pattern		
1	0.15	20	Concentric	28.07	28.26
2	0.3	20	Concentric	32.69	30.38
3	0.15	80	Concentric	45.57	46.34
4	0.3	80	Concentric	39.61	39.8
5	0.15	50	Grid	29.03	27.69
6	0.3	50	Grid	32.11	29.23
7	0.15	50	Tri-hexagonal	32.12	33.65
8	0.3	50	Tri-hexagonal	32.11	32.3
9	0.225	20	Grid	25.76	25.76
10	0.225	80	Grid	33.26	34.03
11	0.255	20	Tri-hexagonal	28.65	27.88
12	0.225	80	Tri-hexagonal	37.11	41.34
13	0.225	50	Concentric	34.61	35
14	0.225	50	Concentric	34.42	36.53
15	0.225	50	Concentric	35	36.15

A bar graph comparing PLA and PETG's Ultimate Tensile Strength (UTS) over 15 distinct runs or samples is shown in Fig. 8. Variability in UTS across the various runs is seen in both PLA and PETG. A number of variables, including testing conditions, material composition, and manufacturing procedures, and interference with printing agents, as shown in the quadratic regression equation Eq. (7) for PLA and Eq. (8) for PETG, may be responsible for this variation. may be responsible for this variation. Generally speaking, PETG slightly higher UTS than PLA. PLA and PETG comparison PETG seems to be a stronger material than PLA, according to the UTS data. In some bone implant applications where mechanical stability and load-bearing capacity are essential, this increased strength might be beneficial.

$$UTS = 23.50 - 16.6\ layer\ thickness + 0.340\ infill\ density + 3.15\ infill\ pattern + 174\ layer\ thickness * layer\ thickness + 0.000923\ infill\ density * infill\ density - 4.312\ infill\ pattern * infill\ pattern - 1.176\ layer\ thickness * infill\ density - 10.3\ layer\ thickness * infill\ pattern + 0.0080\ infill\ density * infill\ pattern \quad (7)$$

$$UTS = 13.40 + 90.4\ layer\ thickness + 0.3196\ infill\ density + 2.31\ infill\ pattern - 110\ layer\ thickness * layer\ thickness + 0.001020\ infill\ density * infill\ density - 4.559\ infill\ pattern * infill\ pattern - 0.962\ layer\ thickness * infill\ density - 9.63\ layer\ thickness * infill\ pattern + 0.0432\ infill\ density * infill\ pattern \quad (8)$$

PETG consistently exhibits high tensile strength (UTS) in the majority of experiments across various printing parameters, indicating its strong potential for orthopaedic implant applications where mechanical strength is of primary concern, according to the data shown in the Tab. 8. However, concerns about biocompatibility and biodegradability require further study as the addition of other materials improves the material and increases its biodegradability. Since PLA is biocompatible and biodegradable, it is still a good choice for temporary implants, even though it is weaker.

5 CONCLUSIONS

The study focuses on the suitability of PLA and PETG for orthopedic implant applications by highlighting the mechanical performance differences between the two materials under identical 3D printing conditions. When compared to PLA, PETG continuously exhibits higher impact toughness, flexural strength, and slightly higher ultimate tensile strength (UTS). Because of these benefits, PETG is a viable option for applications like bone implants that call for load-bearing capacity and resistance to mechanical stress. PETG is less likely to crack under dynamic loads due to its superior energy absorption, flexibility, and toughness, as demonstrated by the spider chart. The ability of PETG to withstand thicker layers and its ideal infill patterns particularly the tri-hexagonal design further enhances its impact resistance.

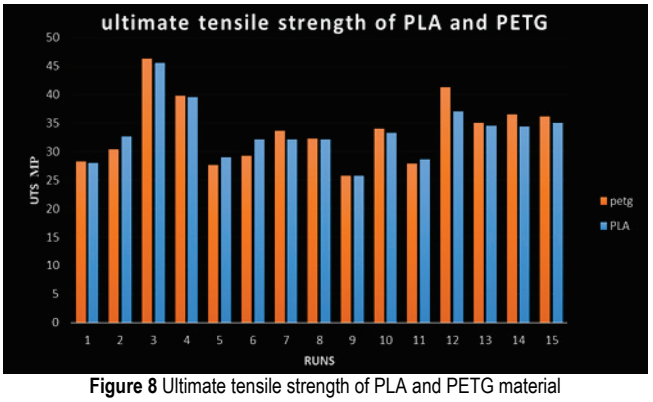


Figure 8 Ultimate tensile strength of PLA and PETG material

Despite its worse mechanical performance, PLA has consistent flexural strength, thinner layers, and specific infill patterns like Concentric and Grid. Its low energy absorption capacity and brittleness are two major disadvantages. However, due to its biocompatibility and biodegradability, PLA is a good choice for temporary implants where stiffness is more crucial than toughness. Changes in PETG's flexural strength reveal how sensitive the material is to testing and printing circumstances. This suggests that precise parameter control is necessary when using PETG for important applications. PLA's lower strength and impact resistance limit its use in demanding environments, despite its generally consistent performance.

When all is said and done, PETG turns out to be a more durable and stronger material that performs admirably in load-bearing and mechanical stress applications, such as orthopedic implants. Its biocompatibility and biodegradability need to be further investigated in order to increase its suitability for medical applications. For short-term medical applications, PLA is still a sustainable and biocompatible option. The performance of both materials can be optimized by modifying printing parameters, ensuring their effective use in a range of applications.

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