

GOCE DELCEV UNIVERSITY - STIP
FACULTY OF COMPUTER SCIENCE

The journal is indexed in

EBSCO

ISSN 2545-4803 on line

DOI: 10.46763/BJAMI

BALKAN JOURNAL
OF APPLIED MATHEMATICS
AND INFORMATICS
(BJAMI)



YEAR 2026

VOLUME IX, number1

AIMS AND SCOPE:

BJAMI publishes original research articles in the areas of applied mathematics and informatics.

Topics:

1. Computer science;
2. Computer and software engineering;
3. Information technology;
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**BALKAN JOURNAL
OF APPLIED MATHEMATICS AND INFORMATICS
(BJAMI), Vol 9**

**ISSN 2545-4803 online
Vol. 9, No. 1, Year 2026**

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EXPERIMENTAL AND COMPARATIVE ANALYSIS OF COMPRESSIVE BEHAVIOUR AND ENERGY ABSORPTION OF FDM PRINTED PLA AND PETG

PEPI ZAFIROB, SARA SREBRENKOSKA, SASKO DIMITROV, ALEKSANDRA RISTESKA-KAMECESKI AND SIMONA NIKOLOVA

Abstract. This paper presents an experimental and comparative analysis of the compressive behaviour and energy absorption of FDM-printed PLA and PETG specimens. A total of five specimens were tested for each material under identical printing and loading conditions. The mechanical response was evaluated based on stress–displacement curves obtained from compression testing.

The results indicate that PLA exhibits higher peak stress values, reflecting greater stiffness and load-bearing capacity, but also shows more pronounced variability and less stable post-peak behaviour. In contrast, PETG demonstrates lower peak stress but more gradual and stable deformation, indicating higher ductility and improved energy dissipation. Energy absorption was determined by calculating the area under the force–displacement curves using numerical integration based on the trapezoidal rule. The results show that PLA can achieve higher energy absorption under specific conditions, but with significant variability, whereas PETG provides more consistent and predictable performance. For clarity of comparison, representative specimens were selected and presented in detail, while the full experimental dataset was used for overall analysis. The findings highlight the influence of material type and internal structure on compressive behaviour and provide useful insight for material selection in FDM applications.

1. Introduction

Additive manufacturing technologies, particularly fused deposition modelling (FDM), have gained significant attention in recent years due to their flexibility, cost-effectiveness, and ability to produce complex geometries [11,12]. Among the wide range of materials used in FDM processes, polylactic acid (PLA) and polyethylene terephthalate glycol (PETG) are two of the most applied thermoplastic polymers. Their popularity is mainly related to their ease of processing, availability, and relatively good mechanical performance.¹

While the tensile behaviour of FDM printed materials has been widely investigated, their response under compressive loading conditions has received comparatively less attention. However, compressive behaviour is of particular importance for applications where printed components are subjected to load-bearing or structural functions. In such cases, not only the maximum strength, but also the deformation characteristics and energy absorption capacity of the material play a crucial role [5]. Standardized testing procedures, including tensile and compressive testing methods, are commonly used to evaluate the mechanical performance of polymeric materials [10,1,2].

Date: March 31, 2026.

Keywords. FDM, PLA, PETG, Compression behavior, Energy absorption, Additive manufacturing.

The mechanical response of FDM printed materials is strongly influenced by their layer-based structure, which introduces anisotropy and nonlinear deformation mechanisms [4,6,7]. As a result, the interpretation of compressive behaviour requires more than a simple evaluation of maximum stress values. A detailed analysis of stress–strain curves provides additional insight into stiffness, deformation stages, and the ability of the material to absorb energy.

In this context, the present study aims to perform an experimental and comparative analysis of the compressive behaviour of PLA and PETG specimens produced by FDM technology. The analysis is based on stress–strain relationships obtained from compression tests, as well as on the evaluation of energy absorption through the calculation of the area under the stress–strain curves.

The main objective of this research is to identify the differences in compressive response between the investigated materials and to assess their suitability for applications involving compressive loading. The results are expected to contribute to the understanding of the mechanical performance of FDM printed polymers and to support material selection in engineering design.

2. Materials and experimental data

In this study, two commonly used thermoplastic materials for fused deposition modelling (FDM) were investigated [8]: polylactic acid (PLA) and polyethylene terephthalate glycol (PETG). Both materials are widely applied in additive manufacturing due to their good printability and favourable mechanical properties. For each material, five specimens were tested to ensure repeatability of the results. However, for clarity of presentation, only two representative curves are shown in the figures.

2.1. Specimen preparation

Compression test specimens were manufactured using FDM technology in accordance with the ASTM D695 standard [10]. The specimens had nominal dimensions of $12.7 \times 12.7 \times 25.4$ mm, ensuring consistency with standard testing requirements.

All specimens were fabricated under identical printing conditions to ensure a reliable comparison between the materials investigated. The common printing parameters were as follows:

Infill density: 100%
Infill pattern: lines
Raster orientation: $0^\circ/90^\circ$
Printing orientation: vertical (Z-direction)
Layer height: 0.15 mm

Wall line count: 4
Print speed: 35 mm/s
Initial layer speed: 20 mm/s
Z-hop height: 0.3 mm

The specimens were produced using an FDM 3D printer.

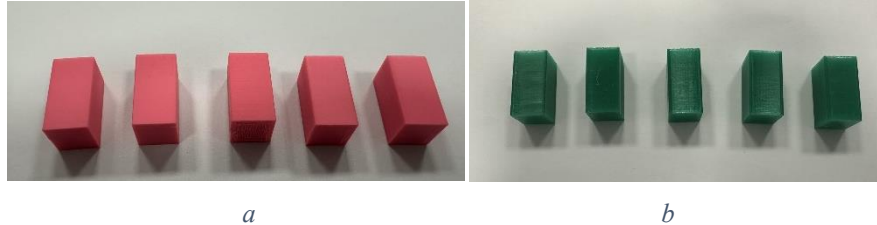


Figure 1. FDM printed a) PLA and b) PETG specimens prior to testing

2.2. Printing parameters

Material-specific printing parameters were adjusted according to the requirements of each material.

For PLA:

Nozzle temperature: 210°C
Bed temperature: 60°C
Cooling fan: approximately 100%
Retraction: 0.8–1 mm at 30 mm/s

For PETG:

Nozzle temperature: 235°C
Bed temperature: 80°C
Cooling fan: 40–50%
Retraction: 0.8–1 mm at 30 mm/s

2.3. Compression testing

Compression tests were performed using an electromechanical universal testing machine. The tests were conducted at a constant crosshead speed of 5 mm/min, ensuring uniform loading conditions for all specimens.

A preload of 0.1 kN was applied before the test to ensure proper contact between the specimen and the compression plates.

During testing, the force–time data were recorded using the machine software and subsequently exported for further analysis.

A total of five specimens were tested for each material to ensure the reliability and repeatability of the experimental results.

However, for clarity of presentation and comparative analysis, two representative specimens per material were selected and presented in detail in the graphical and tabular results.



Figure 2. *Universal testing machine used for compression testing*

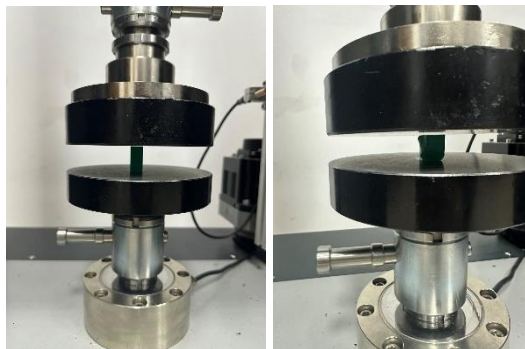


Figure 3. *Compression test setup showing specimen placement*

2.4. Data processing

The experimental data obtained in the form of force–time curves were transformed into engineering stress–strain relationships.

The compressive stress was calculated using the following expression:

$$\sigma = \frac{F}{A} \quad (2.1)$$

where:

- σ is the compressive stress (MPa),
- F is the applied force (N),
- A is the cross-sectional area of the specimen (mm²).

The strain was determined based on the testing speed and recorded time using:

$$\varepsilon = \frac{v \cdot t}{L_0} \quad (2.2)$$

where:

- ε is the strain,
- v is the crosshead speed,
- t is the time,
- L_0 is the initial specimen height.

The energy absorption was evaluated by calculating the area under the stress–strain curve, providing a quantitative measure of the material’s ability to absorb energy under compressive loading.

3. Mechanical and Experimental Behaviour Analysis

3.1. Stress–strain behaviour

The compressive behaviour of the FDM printed PLA and PETG specimens was analysed using stress–strain curves obtained from the experimental data.

Both materials exhibited an initial linear elastic region, followed by non-linear deformation behaviour as the applied load increased. However, significant differences between the two materials were observed.

PLA specimens showed a relatively steep initial slope, indicating higher stiffness. The material reached its maximum compressive stress rapidly, followed by a sudden drop associated with localized failure and cracking.

In contrast, PETG specimens demonstrated a more gradual transition from elastic to plastic deformation. The stress–strain curves of PETG showed smoother behaviour without abrupt stress drops, indicating better ductility and energy dissipation capability.

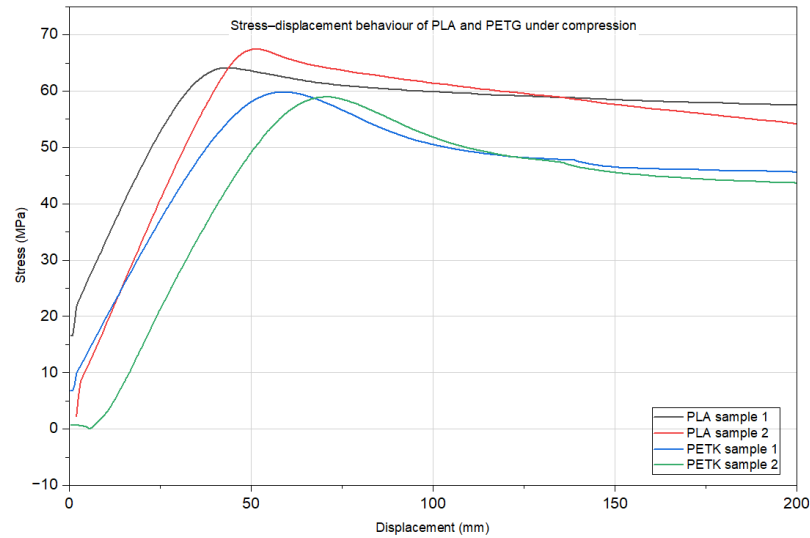


Figure 3. *Stress–displacement behaviour of PLA and PETG specimens under compression loading.*

Figure 3 presents the stress–displacement curves obtained during the compression testing of PLA and PETG specimens produced by FDM technology. It can be observed that both materials exhibit an initial linear increase in stress, followed by a peak value and subsequent softening behaviour.

PLA specimens demonstrate higher peak stress values compared to PETG, indicating greater compressive strength. However, after reaching the maximum stress, PLA shows a more pronounced reduction in load-bearing capacity. In contrast, PETG specimens exhibit lower peak stress but a more gradual decrease in stress with increasing displacement, indicating higher ductility and better deformation capability under compression.

Overall, the results suggest that PLA provides higher strength, while PETG offers improved deformation behaviour and energy absorption characteristics.

3.2. Maximum compressive stress

To further evaluate the mechanical performance, the maximum compressive stress values were extracted from the experimental data and compared, as shown in Figure 4.

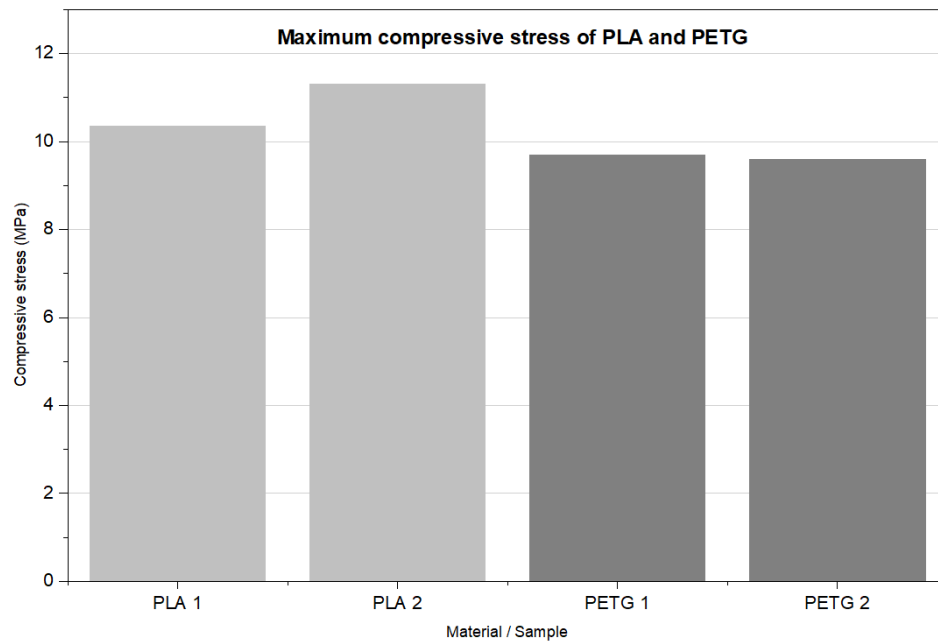


Figure 4. *Maximum compressive stress of PLA and PETG samples.*

PLA specimens exhibit higher maximum compressive stress values compared to PETG, confirming their superior strength under compression. On the other hand, PETG shows slightly lower peak stress values, which is consistent with its more ductile behaviour observed in the stress–displacement curves.

These results indicate that the choice of material significantly influences the mechanical response. PLA is more suitable for applications requiring higher strength, while PETG is preferable in cases where higher deformation capacity and energy absorption are required.

3.3. Deformation behaviour

The deformation behaviour of the specimens was analysed based on visual observations after compression testing.

PLA specimens exhibited brittle-like behaviour under compression. Cracks and localized fractures were observed, primarily along the printing layers. The failure occurred abruptly after reaching the maximum stress, with limited plastic deformation. This behaviour can be attributed to the relatively low ductility of PLA and the layer-by-layer structure produced by FDM technology, which promotes crack initiation and propagation along interlayer boundaries.

In contrast, PETG specimens showed pronounced plastic deformation without visible cracking. The specimens experienced significant shape changes, including bulging and material flow, indicating ductile behaviour. The smoother deformation response of PETG is associated with its higher toughness and better interlayer adhesion.

These observations are consistent with the stress–strain results, confirming that PLA behaves as a stronger but more brittle material, while PETG provides improved deformation capability and structural integrity under compressive loading. The deformation characteristics observed after testing are illustrated in Figure 5.

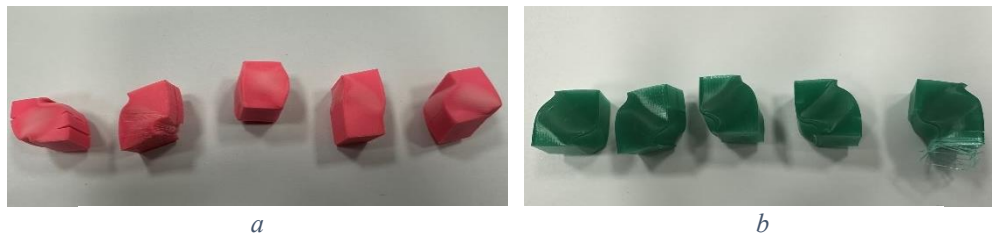


Figure 5. Deformation behaviour of FDM printed specimens after compression testing: (a) PLA specimens showing brittle failure and cracking, (b) PETG specimens showing ductile deformation and bulging.

3.4. Energy absorption

The energy absorption capability of the selected specimens was evaluated as the area under the force–displacement curve obtained during compression testing [2,3]. The calculation was performed using numerical integration based on the trapezoidal rule, according to the relation:

$$EA = \int F \cdot d\delta \quad (3.1)$$

where F represents the applied force, and δ is the displacement.

For this analysis, representative specimens of PLA and PETG materials were selected to provide a clear comparison of their deformation behaviour.

The calculated energy absorption values are presented in Table 1.

Table 1. Energy absorption of selected PLA and PETG specimens

Material	Energy absorption (J)
PLA (S1)	1.648175837
PLA (S2)	6.149835975
PETG (S1)	2.611051909
PETG (S2)	2.80592491

The results show a significant variation within the PLA specimens, with energy absorption values ranging from approximately 1.65 J to 6.15 J. This indicates that the mechanical response of PLA is highly dependent on internal structure, printing parameters, and deformation mechanisms.

In contrast, PETG specimens exhibit more consistent energy absorption values, ranging between approximately 2.61 J and 2.81 J. This behaviour is associated with the ductile nature of PETG, which enables more uniform plastic deformation and energy dissipation.

Although the maximum energy absorption observed for PLA is higher than that of PETG, the variability of PLA is considerably greater. On the other hand, PETG demonstrates more stable and predictable performance under compressive loading.

These results suggest that PLA has the potential to absorb higher amounts of energy under specific conditions, while PETG provides more reliable mechanical behaviour due to its ductile deformation characteristics. The observed variability in PLA further highlights the sensitivity of FDM-printed materials to processing conditions and internal structural features.

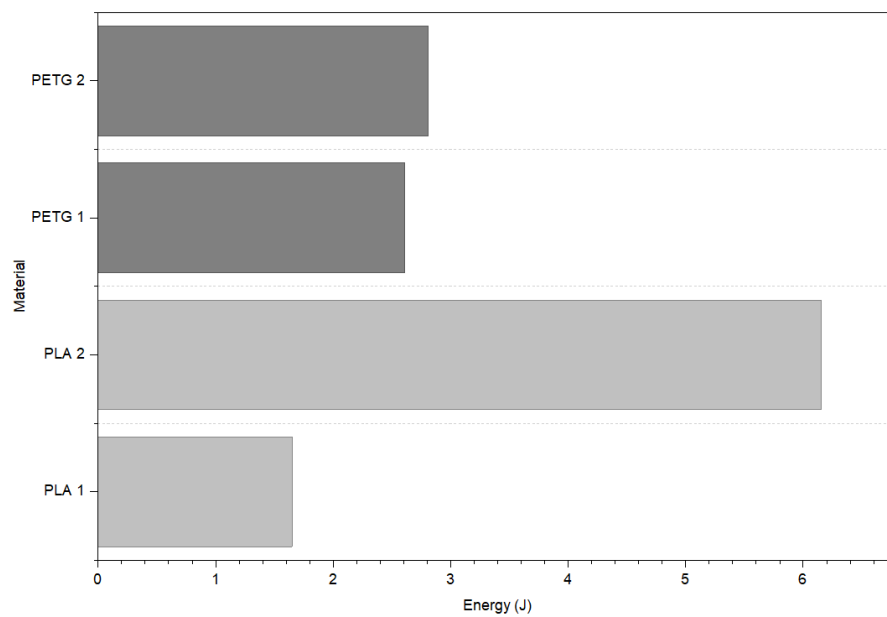


Figure 6. *Energy absorption comparison of PLA and PETG specimens obtained from compression testing*

Figure 6 illustrates the variation in energy absorption between PLA and PETG specimens. It can be observed that PLA exhibits a wider range of energy absorption values, while PETG shows more consistent behaviour.

4. Results and discussion

The stress–displacement curves obtained from the compression tests of PLA and PETG specimens are presented in Figure 3. It can be observed that both materials exhibit a similar deformation pattern, characterized by an initial linear region corresponding to elastic behaviour, followed by a nonlinear region leading to a peak stress value and subsequent softening, which is consistent with typical polymer behaviour [1,2].

PLA specimens demonstrate higher peak stress values compared to PETG, indicating greater stiffness and load-bearing capacity. In contrast, PETG exhibits a more gradual deformation behaviour, which can be associated with its higher ductility and ability to undergo larger strains before failure. This difference in mechanical response is typical for FDM printed polymers and is influenced by their material structure and interlayer bonding [6,7,12].

The deformation behaviour after the peak stress shows a reduction in load-carrying capacity for both materials, which is related to internal structural changes such as layer separation and localized deformation. PLA shows a more pronounced drop in stress, indicating a more brittle-like response, while PETG maintains a smoother transition, suggesting more ductile behaviour, as also reported in previous studies on FDM polymers [8,9].

The energy absorption capacity of the materials was evaluated based on the area under the stress–displacement curves. The calculated values are presented in Table 1. The results indicate that PLA exhibits higher energy absorption compared to PETG, primarily due to its higher stress levels during deformation. This approach for evaluating energy absorption is commonly used in compression testing of polymeric materials [10].

This suggests that PLA is more suitable for applications requiring higher stiffness and energy absorption, such as load-bearing components. On the other hand, PETG may be preferable in applications where higher deformation capability and toughness are required, which agrees with findings reported in the literature [6,8].

It should be noted that although five specimens were tested for each material to ensure repeatability, only two representative curves are shown in Figure 3 for clarity of presentation. The overall trends, however, remain consistent across all samples tested.

5. Conclusion

This study investigated the compressive behaviour of FDM-printed PLA and PETG specimens through stress–displacement analysis and energy absorption evaluation. The results demonstrated clear differences in mechanical response between the two materials.

PLA specimens exhibited higher peak stress values, indicating greater initial stiffness and load-bearing capacity. However, their post-peak behaviour was less stable, with a more pronounced drop in stress, reflecting increased sensitivity to internal structure and printing conditions.

In contrast, PETG specimens showed lower peak stress but more gradual and stable deformation after the maximum load. This ductile behaviour resulted in more consistent energy absorption and improved reliability under compressive loading.

The calculated energy absorption values confirmed these observations, revealing higher variability in PLA and more uniform performance in PETG. Although PLA can achieve higher energy absorption under certain conditions, PETG provides more predictable and stable mechanical behaviour.

Overall, the findings highlight the importance of material selection in FDM applications [1,11]. PLA is more suitable for applications requiring higher stiffness [6], while PETG is preferable for applications demanding ductility, stability, and repeatable performance [9]. Furthermore, the results emphasise the need for careful control of processing parameters to reduce variability and improve the mechanical reliability of additively manufactured components.

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