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Mechanical Characterization of PETG/TPU Multi-Material 3D-Printed Samples and Fabrication of a Test Part †

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Abstract

The present article aims to explore the feasibility of manufacturing multi-material components from PETG and TPU using FFF/FDM 3D printing. The mechanical characterization includes Shore hardness measurements of the individual materials and Izod impact strength testing of samples produced with different structural configurations. Furthermore, a test part based on a rover wheel is fabricated using a PETG/TPU multi-material structure to validate the practical applicability of the proposed multi-material concept.

Keywords: multi-material 3D printing; TPU; PETG; Izod impact strength test; shore D hardness test

1. Introduction

In modern engineering applications, the combination of materials with different properties within a single structure represents an effective approach to enhancing mechanical performance [1]. Various manufacturing techniques are used for the creation of multi-material parts, such as casting, welding, injection molding, etc. [2–4]. Such structures are used in medicine, electronics, aviation, architecture, robotics, etc. [5–10]. With the advancement of additive manufacturing technologies, new opportunities have emerged for the design and fabrication of complex multi-material structures with a high degree of precision [11–13].

In nature, materials with diverse mechanical properties—ranging from rigid to flexible—are frequently combined to achieve high durability, strength and functionality. Inspired by such natural systems, engineering practice increasingly focuses on the development and investigation of interfaces between rigid and elastomeric polymers in order to improve structural integrity and fracture resistance [14–17].

Polymer blends of polyethylene terephthalate glycol (PETG) and thermoplastic polyurethane (TPU) have emerged as promising materials for such applications. PETG provides good shape fixity but exhibits limited recovery capability, whereas TPU, as an elastomer, offers excellent shape recovery but low fixity. Consequently, blending PETG with TPU represents a strategic approach to achieving a balance between these complementary shape-memory properties [18].

The present study aims to investigate and assess the feasibility of fabricating multi-material structures from PETG and TPU polymers using FDM 3D printing. The work

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examines whether combining these two materials influences key mechanical properties, such as impact strength and hardness. A test part is also produced to demonstrate the practical applicability of the proposed multi-material approach.

2. Materials and Methods

3D Printing of Test Samples

Two filaments are used for the study: Sunlu PETG filament and Bambu TPU for AMS. All samples are printed using a Bambu Lab X1C 3D printer (Bambu Lab, Shenzhen, China) equipped with AMS. For the Izod impact strength tests, a total of four different sample types are designed, with five specimens fabricated for each type:

- PETG samples—3D-printed specimens entirely from PETG;
- TPU samples—3D-printed specimens entirely from TPU;
- PETG + 3 TPU samples—3D-printed specimens with a PETG core and three outer walls of TPU;
- PETG + 5 TPU samples—3D-printed specimens with a PETG core and five outer walls of TPU.

The samples are prepared for the Izod unnotched impact test according to ASTM D256 (for polymers) [19] with the following recommended dimensions: length: 63.5 mm, width: 12.7 mm, and thickness: 3.2 mm. The mass of one specimen is about 3 g.

For printing the specimens with both materials, the following key slicer settings in Bambu Studio are used:

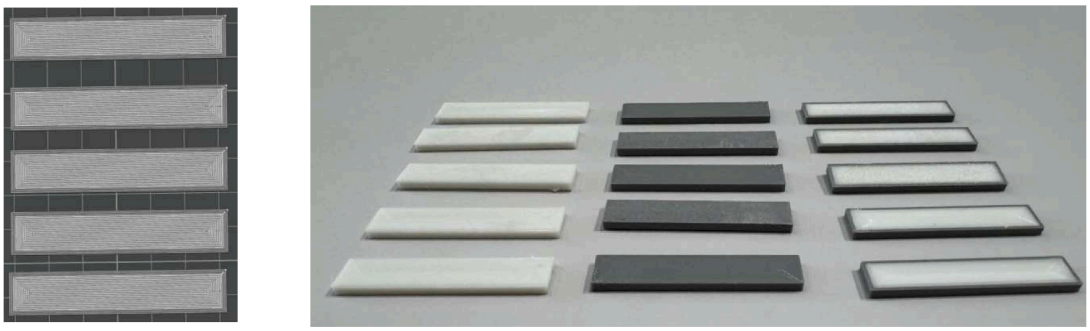
- Nozzle temperature: 240 °C;
- Bed temperature: 70 °C;
- Layer height: 0.20 mm;
- Line width: 0.42 mm;
- Elephant foot compensation: 0 mm;
- Slice gap closing radius: 0.04 mm;
- Wall loops: 1;
- Top shell layers: 0;
- Bottom shell layers: 0;
- Infill: 100% (concentric);
- Nozzle diameter: 0.4 mm;
- Infill/wall overlap: 15%;
- Printing speed (for all parameters): 70 mm/s.

The only difference between the printing settings of the materials is the limitation of the Max Volumetric Speed parameter for the TPU for AMS material to 3.2 mm/s for better interlayer adhesion and for prevention of filament jamming. Prior to printing, the filaments are dried in a Creality Filament Dry Box (Creality 3D Technology Co, Shenzhen, China) for 12 h at 50 °C. The samples are printed with a constant cross-section, as shown in Figure 1a. Some of the printed specimens are shown in Figure 1b.

Two 20 × 20 × 20 mm test cubes are also printed using the same settings—one entirely from PETG and another entirely from TPU for AMS, as shown in Figure 2. These samples are used for the Shore hardness measurements.

The Izod impact toughness test is performed using a pendulum with an impact energy of 5.5 J. Five specimens from each sample type are tested, and the arithmetic mean values are calculated for the pendulum deflection angle, absorbed energy, energy normalized by specimen width, and energy normalized by cross-sectional area. The specimens are unnotched in order to evaluate the quality of the material interface without introducing an

additional stress concentrator. The tests are conducted using a Pendulum Impact Tester (GT-7045-HM, Gotech Testing Machines, Dongguan, China), shown in Figure 3a.



(**a**) (**b**)

Figure 1. (**a**) A cross-section of the PETG + 3 TPU samples in Bambu Studio; (**b**) 3D-printed specimens—PETG (left), TPU (middle) and PETG + 5 TPU (right).

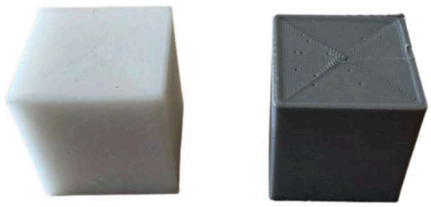
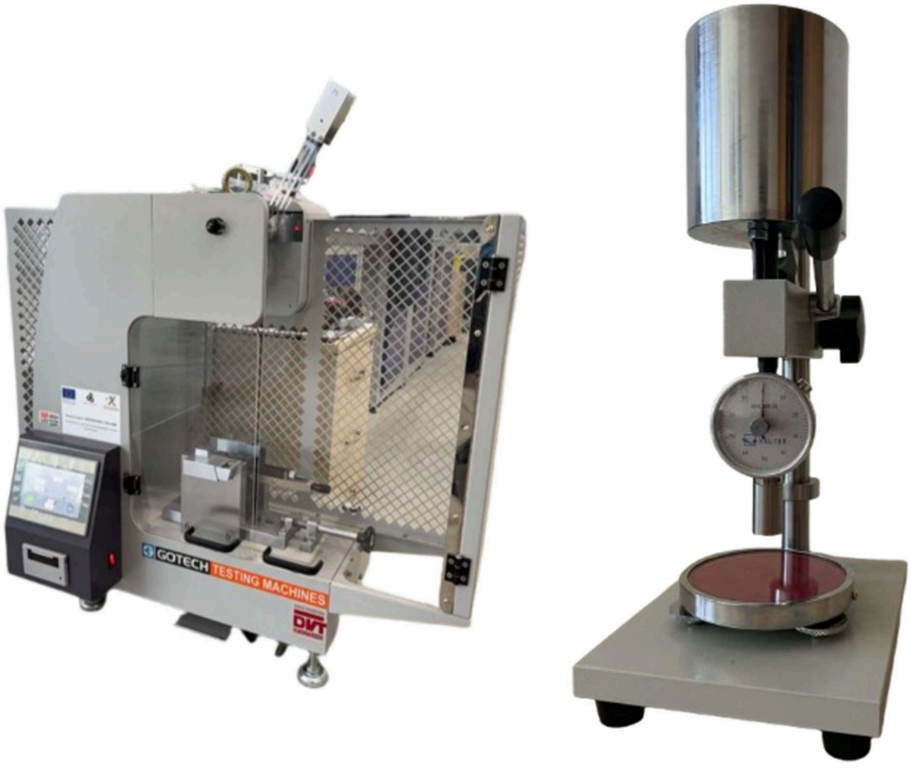


Figure 2. Test cubes from PETG (**left**) and from TPU (**right**) for Shore hardness measurements.



(**a**) (**b**)

Figure 3. (**a**) A Pendulum Impact Tester (GT-7045-HM); (**b**) an analog Sauter Shore D hardness tester (HDD 100-1), mounted on a manual Shore test stand (TI-D).

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The hardness of the test cubes is measured using a Sauter Shore D hardness tester (HDD 100-1) form Kern & Sohn GmbH, Balingen-Frommern, Germany mounted on a 50 N test stand (TI-D), shown in Figure 3b. For each specimen, five measurements are performed on the top surface, parallel to the printed layers, and five tests are carried out on a side wall, perpendicular to the printed layers. The arithmetic mean value is then calculated for each sample type based on the results obtained from both orientations.

3. Results and Discussion

The detailed results of the Izod impact strength tests are presented in Table 1.

Table 1. Detailed results of Izod impact strength tests.

Sample Type	Impact Energy, J	Angle, °	E (J)	E/W, J/m	E/A, J/m^2
PETG					
1	5.50	72.23	0.91	71.68	22,399.32
2	5.50	77.86	0.82	64.20	20,060.85
3	5.50	86.27	0.66	52.24	16,324.42
4	5.50	82.94	0.73	57.06	17,830.24
5	5.50	87.62	0.64	50.27	15,708.67
TPU					
1	5.50				
2	5.50				
3	5.50		No fracture observed.		
4	5.50				
5	5.50				
PETG + 3 TPU					
1	5.50	77.50	0.88	64.69	20,215.20
2	5.50	75.74	0.85	67.09	20,964.67
3	5.50	86.9	0.65	51.32	16,037.33
4	5.50	70.75	0.93	73.53	22,976.65
5	5.50	72.14	0.91	71.79	22,435.07
PETG + 5 TPU					
1	5.50	64.76	1.02	80.50	25,157.56
2	5.50	61.79	1.06	81.64	25,514.10
3	5.50	60.85	1.07	82.52	25,788.14
4	5.50	42.12	1.20	93.02	29,067.84
5	5.50	62.33	1.06	81.12	25,350.33

Table 2 presents the mean values of the obtained results for the impact strength of the samples.

Table 2. Average Izod impact strength values.

Sample Type	Impact Energy, J	Angle, °	E (J)	E/W, J/m	E/A, J/m^2
PETG	5.50	81.38	0.75	59.09	18,464.70
TPU	5.50		No fracture observed.		
PETG + 3 TPU	5.50	76.61	0.84	65.68	20,525.78
PETG + 5 TPU	5.50	58.37	1.08	83.76	26,175.59

The mean values of the different quantities are presented as graphs in Figure 4, namely: (a) deflection angle, (b) absorbed energy, (c) absorbed energy per width, and (d) absorbed energy per cross-sectional area.

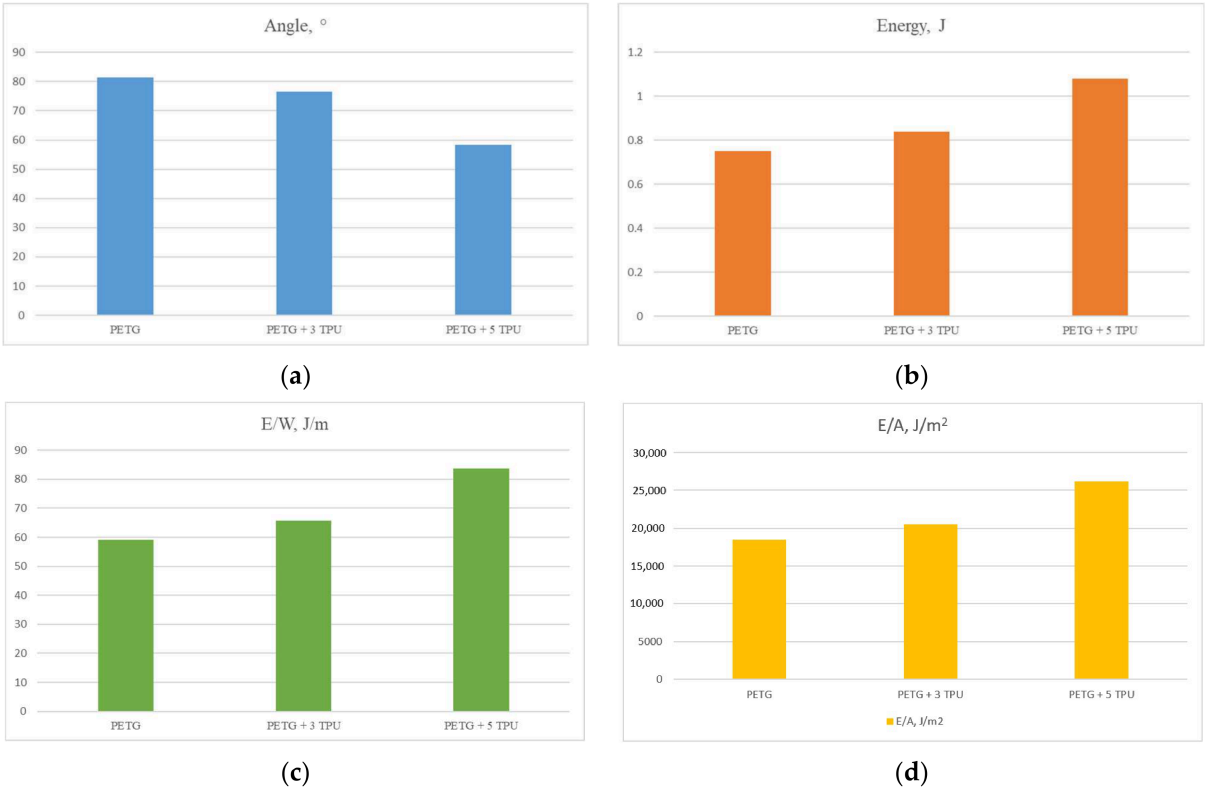


Figure 4. Graphs of mean values: (**a**) deflection angle; (**b**) absorbed energy; (**c**) absorbed energy per width; (**d**) absorbed energy per cross-sectional area.

Table 3 presents the Shore D hardness test results for the two test cubes, produced from PETG and from TPU.

Table 3. Hardness (Shore D) of PETG and TPU samples.

Sample Type	Top Surface	Side Wall	Mean Value
PETG			
1	80	81	
2	78	85	
3	86	83	**81.7**
4	84	81	
5	81	78	
TPU			
1	69	67	
2	68	68	
3	66	67	**67.6**
4	67	70	
5	68	66	

The mean Shore D hardness values for both specimens are close to the expected values—68 Shore D for TPU for AMS and 82 Shore D for PETG. The test results indicate that the TPU for AMS is around 20% softer than the PETG filament. In combination with the elastomeric nature of TPU, this further enhances the elastic properties of the outer region of the specimens.

Based on the obtained results, the following observations can be made for the different types of samples:

- PETG: The mean deflection angle indicates moderate plastic deformation, demonstrating good impact resistance without failure through brittle fracture. The energy parameters (E/W and E/A) confirm a uniform stress distribution across the cross-section. PETG specimens after fracture are shown in Figure 5a;
- TPU: The TPU specimens do not fracture during testing—only deformation is observed. A deformed TPU sample is shown in Figure 5b;
- PETG with three outer TPU walls: In this configuration, an improvement in impact strength is observed compared to the specimen made of pure PETG. The difference in the mean absorbed energy values is about 12% in favor of the PETG + 3 TPU specimens.
- PETG with five outer TPU walls: In this configuration, a significant improvement in the impact strength of the specimens is observed compared to the two produced from pure PETG and those produced from PETG with three outer TPU walls. The mean absorbed energy value for PETG + 5 TPU is about 44% higher than that of the pure PETG specimens and slightly over 28% higher than that of PETG + 3 TPU. Figure 5c shows fractured specimens of the PETG + 5 TPU type.



(**a**) (**b**) (**c**)

Figure 5. (**a**) Fractured PETG specimens; (**b**) a TPU specimen showing deformation without fracture; (**c**) fractured PETG + 5 TPU specimens.

A rover wheel similar to the one used in the Perseverance rover is selected as a test part to be manufactured using a combination of PETG and TPU. Such components require a rigid hub (PETG) and a flexible outer tire that comes into contact with the terrain (TPU). The 3D model of the element is shown in Figure 6.

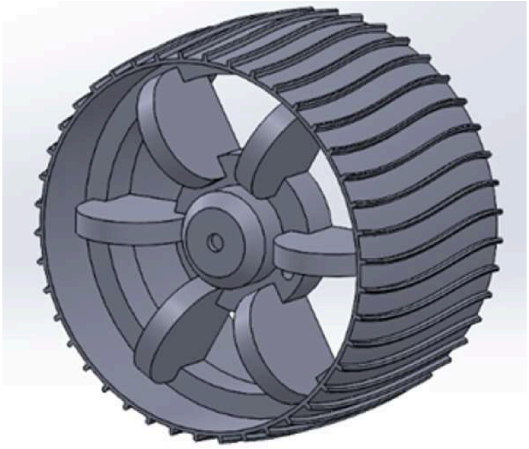


Figure 6. A 3D model of the test part—a rover wheel.

The completed model is imported into Bambu Studio, where it is prepared for printing with two different materials:

- The inner part (hub and spokes) is printed in Sunlu PETG (yellow) to provide structural strength and stability;

- The outer part (tire) is printed in TPU for AMS (gray), providing elasticity and impact strength.

The same printing settings as those used for the tested specimens are applied. The model is oriented vertically, with its central axis perpendicular to the print bed. Figure 7 shows the appearance of the part in Bambu Studio after slicing. The figure displays the number of layers, material usage, filament change times, flush volumes, and the estimated printing time.

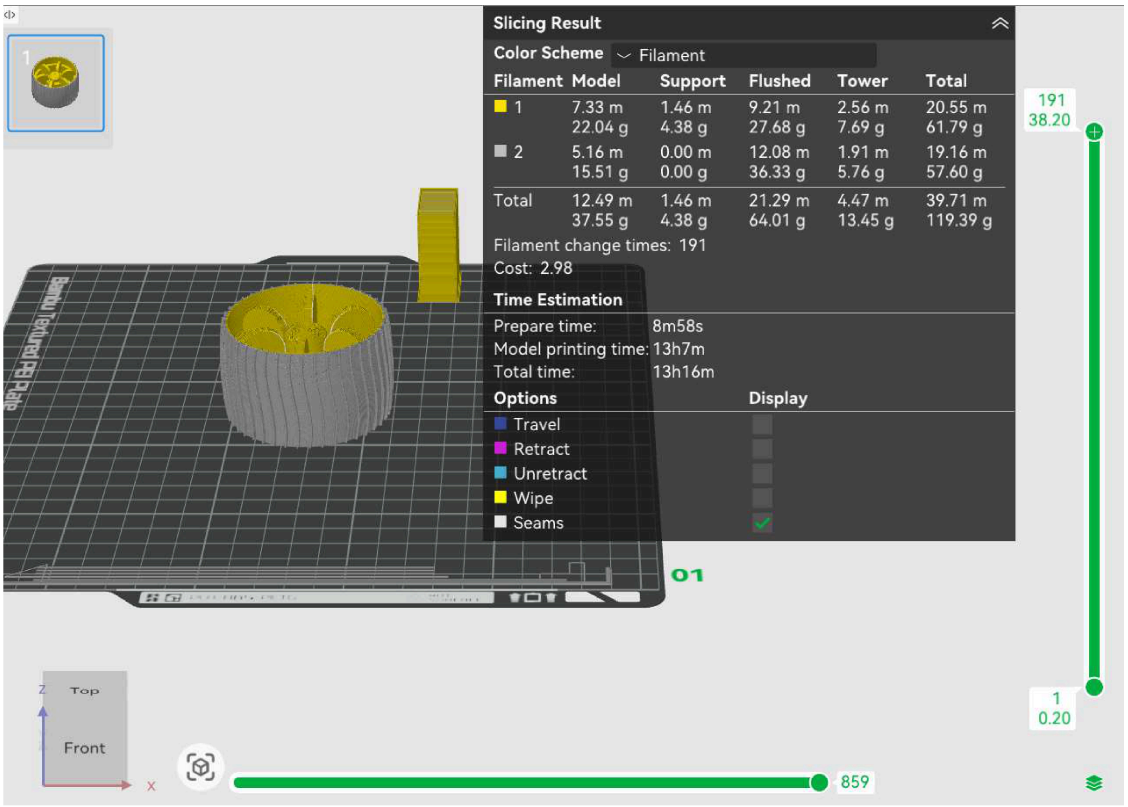


Figure 7. Sliced view of the PETG + TPU test part in Bambu Studio, showing number of layers, material usage, flush volumes, filament change times and estimated print time.

Views of the 3D-printed test part are shown in Figure 8.



Figure 8. Views of the manufactured multi-material PETG/TPU test wheel.

4. Conclusions

This study demonstrates that multi-material structures combining PETG and TPU, produced via FDM 3D printing, achieve significantly enhanced impact strength and energy absorption without compromising the structure. The configuration with a PETG core and

five outer TPU walls provides the optimal balance between rigidity and flexibility. The test PETG/TPU wheel confirms the practical potential of this multi-material approach, inspired by natural combinations of hard and soft materials.

These findings contribute to additive manufacturing technologies by offering solutions for functional components in sectors such as robotic wheel systems and manipulator robots. Future work may focus on optimizing material transition zones, incorporating additional polymers, and using lower-hardness TPU to increase elasticity in outer layers.

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Abbreviations

The following abbreviations are used in this manuscript:

FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
PETG	Polyethylene Terephthalate Glycol
TPU	Thermoplastic Polyurethane

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