https://doi.org/10.22306/atec.v11i4.302 Received: 07 Oct. 2025; Final revised: 22 Nov. 2025; Accepted: 11 Dec. 2025

Mechanical testing of 3D printed samples made of flexible TPU material

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Keywords: TPU, 3D printing, Fused Deposition Modeling, mechanical testing.
Abstract: This scientific article deals with the mechanical testing of samples produced by 3D printing technology from thermoplastic polyurethane (TPU), which is a flexible polymer with elastomeric properties. The aim of the study was to evaluate the mechanical behaviour of TPU material under different printing parameters and loads, especially in compression. The samples were printed using the FDM (Fused Deposition Modeling) method with variable settings such as layer orientation, infill, layer thickness and printing speed, while a standardized shape of test specimens according to ISO 604 was used. Testing revealed a significant dependence of mechanical properties on layer orientation and infill degree. TPU showed high elasticity and energy absorption capacity, which confirms its potential for applications where flexibility, shock absorption and shape adaptability are required. The results point to the importance of optimizing printing parameters to achieve the desired mechanical properties in practice.

1 Introduction

With the increasing availability of 3D printing, flexible polymers such as TPU are becoming increasingly popular in applications requiring flexibility, impact resistance and repeated deformability. TPU combines the properties of plastic and rubber and is suitable for the production of components such as seals, damping elements and wearable devices. However, due to the anisotropic nature of FDM technology, the mechanical behaviour of TPU samples is strongly influenced by printing parameters, which requires their systematic evaluation. Mechanical testing of 3D printed samples made of flexible TPU thermoplastic polyurethane (Figure 1) is a key step in evaluating their functional properties and reliability in real-world applications. TPU is a material known for its flexibility, abrasion resistance, toughness, and shock absorption, making it suitable for use in a variety of industries, from automotive to footwear to medical and consumer products. However, its exceptional properties also place specific demands on the manufacturing and testing of mechanical properties, especially when used in additive manufacturing [1]. 3D printing, specifically Fused Deposition Modeling (FDM) technology, enables the rapid and cost-effective production of TPU parts with various geometric configurations and internal structures. These parameters have a significant impact on the resulting mechanical properties of the samples, such as tensile strength, elasticity, hardness, tear resistance, and fatigue strength. In addition, the layering direction, layer height, filling structure and nozzle temperature during printing are among the factors that can significantly affect the quality and consistency of prints [2]. Therefore, it is essential to take these variables into account when designing experiments and interpreting test results. The goal of mechanical testing of TPU samples is not only to quantify their basic physical and mechanical characteristics, but also to understand how the material behaviour changes depending on the technological conditions of printing and the type of load. Testing includes pressure tests that simulate repeated stress in practical use [3]. The results of these tests serve as a basis for optimizing production parameters, designing functional components and improving predictive models of TPU behaviour under various operating conditions. Given the increasing use of flexible materials in 3D printing, it is important to deepen knowledge about their mechanical behaviour and reliability [4-6]. Mechanical testing thus represents not only a scientific approach to evaluating material properties, but also a practical tool for developing innovative products that must meet demanding requirements for performance, durability and safety [7].

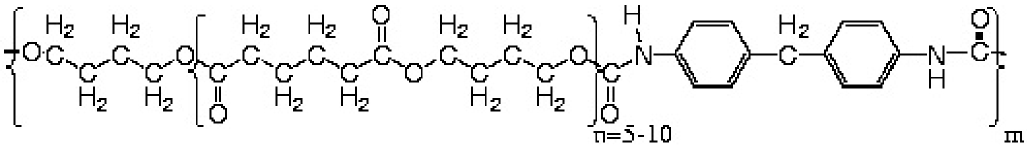

Figure 1 Molecular structure of thermoplastic polyurethanes [1]

2 3D printing of samples

2.1 Proposal for a methodology for testing materials

The samples were designed in the Simplyfy3D program according to the standards. The ISO 604 standard from 2002 was established for the pressure test. After designing the sample, we generated a good for the following 3D printing. In Figure 2 we can see the sample design before printing for the pressure test.

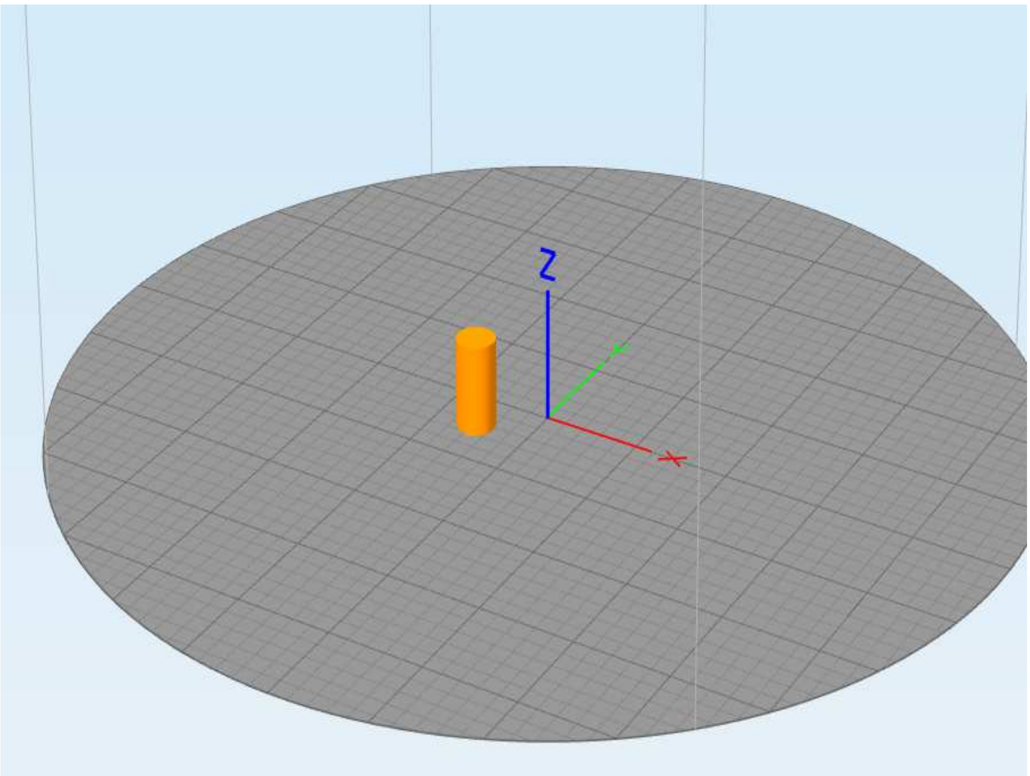

Figure 2 Sample design for static pressure test

2.2 3D printing of samples

3D printing of the samples was carried out in the laboratory on a Trilab DeltiQ 2 3D printer. For 3D printing of the samples, a Nimble extruder had to be used due to the TPU material we used to print the samples.

Before starting the print, we set the printing parameters. The Trilab DeltiQ 2 is a printer with a working area of Ø 250 mm (X,Y) x 300 mm (Z). We used a Nimble extruder, for which we set the nozzle diameter to 0.40 mm and the extrusion width to 0.40 mm. For the layer, we had to enter parameters for the height of the primary layer, which was 0.20 mm. Then we set the direction of the contour, which was made from the outside to the bottom. We set the parameters for the height of the first layer to 150%, the width of the first layer to 100% and the speed of the first layer to 50%. We also set the starting point closest to the specific location, namely X to -200.0 mm and Y to 200.0 mm. For the infill, we entered the parameters for the inner infill to 50%/75%/100%, the contour overlaps to 25%, the infill extrusion width to 150% and the minimum infill length to 1 mm. We set the substrate temperature to 200 °C. and the static speed of the supporting structure to 80%, the insufficient speed of the solid infill to 100%, the speed of movement of the X/Y and Z axes to 9000 mm/min. In Figure 3 we can see the 3D printing of the samples and its final printing. Subsequently, in Figure 4 there are printed samples for the pressure test with 50%, 75% and 100% infill.

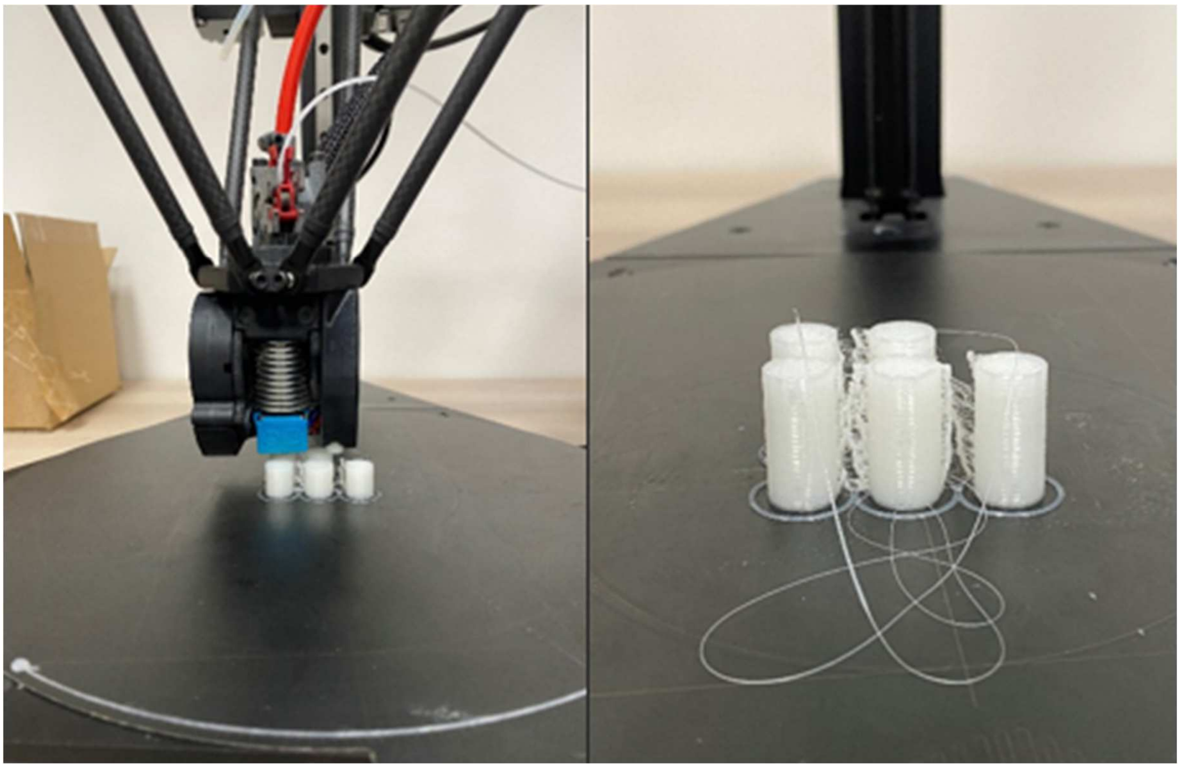

Figure 3 3D printing of samples for static pressure testing

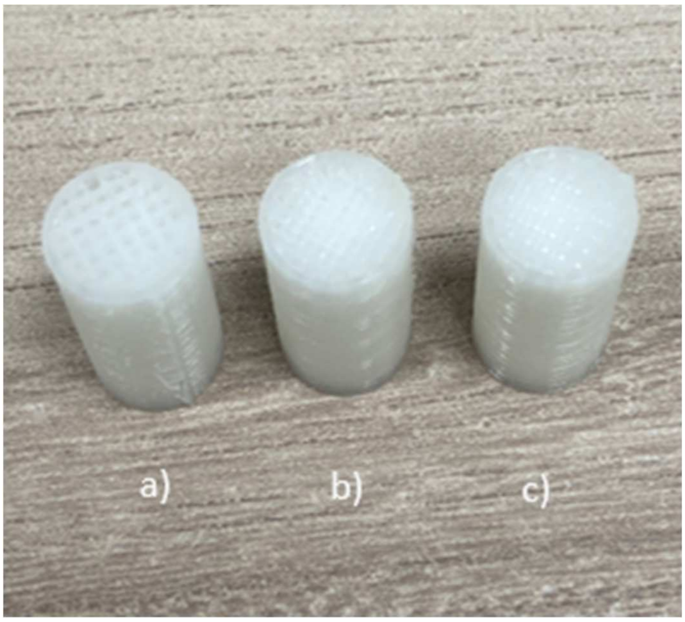

Figure 4 Samples for static pressure test a) 50% infill b) 75% infill c) 100% infill

3 Mechanical testing, evaluation of pressure tests

Using compression tests, we investigated the deformation behaviour of the material and the conditions of external forces. For mechanical testing, a simple cylinder was printed, the dimensions of which were determined according to the ISO 604 standard from 2002, which describes methods for determining the compression properties of plastics. The samples were printed from TPU material with 50%, 75% and 100% infill. The compression test was carried out on the Inspect 5 testing device, where the tested sample was inserted between the jaws (Figure 5).

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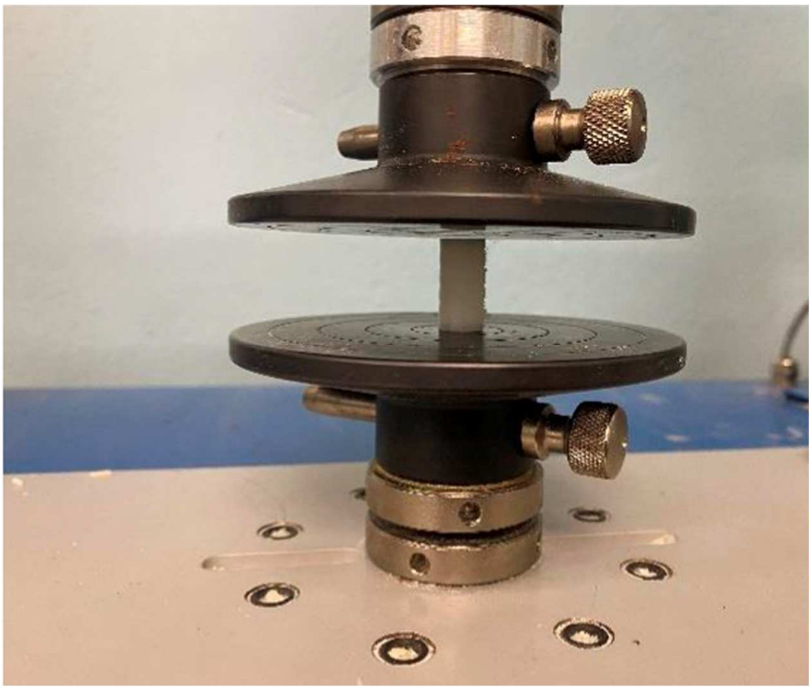

Figure 5 Test sample inserted between jaws

The output of the testing device was a data table. The following figures show graphs that describe the deformation on the X-axis and the pressure in megapascals on the Y-axis. From the graphic representation in Figure 6, we can assess that the samples have low resistance to pressure and pass into the deformation region. It follows that the material has the ability to withstand compressive forces reducing the infill cross-section.

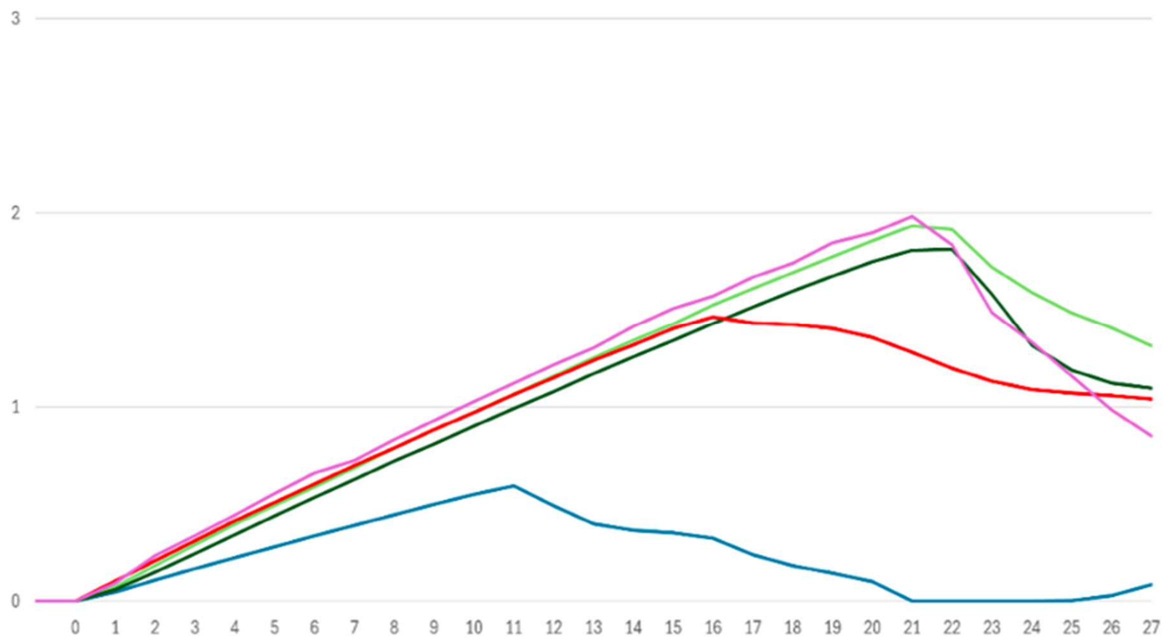

Figure 6 Graphical representation of compression test for TPU material with 50% infill

From the graphic representation in Figure 7 we can assess that the linear region is approximately the same for all the tested samples. The region of plastic deformation is indicated on the graph when it is gradually compressed without interruption of the material. From the graphic representation it follows that the material has the ability to resist compressive forces reducing the cross-section of the infill.

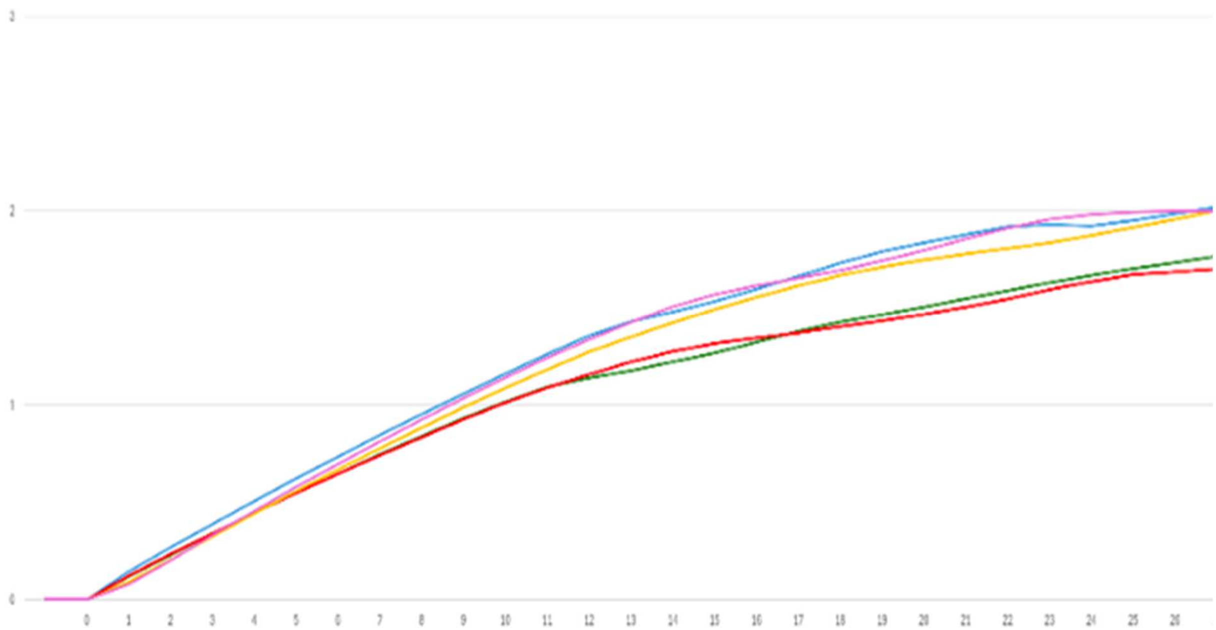

Figure 7 Graphical representation of compression test for TPU material with 75% infill

In Figure 8 we can observe very similar behaviour as in the previous testing.

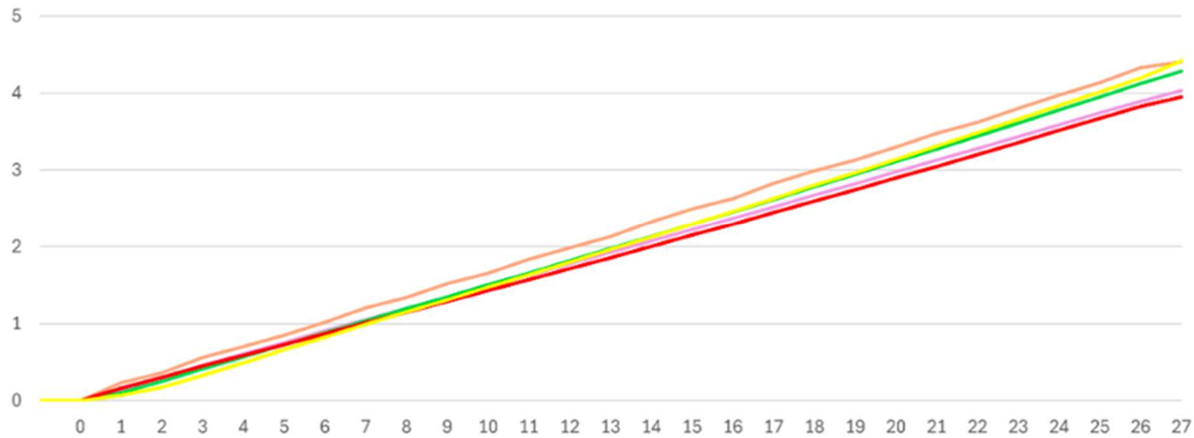

Figure 8 Graphical representation of compression test for TPU material with 100% infill

4 Conclusion

This scientific research provides an insight into the field of testing flexible TPU, where compression tests were performed on cylindrical samples with 50%, 75% and 100% infill. Compression testing of 3D printed samples of flexible TPU is a key step in verifying their mechanical properties, reliability and functional behaviour in real-world conditions. The results of these tests provide a deeper understanding of how the material behaves under load, how it deforms and whether it can maintain its integrity after repeated or long-term pressure. Flexible materials such as TPU are increasingly used in technical applications where a combination of flexibility, strength and wear resistance is required – whether it is for damping elements, protective components, soft joints or functional prototypes. From an experimental point of view, the testing has shown that the quality and set infill of 3D printing significantly affects the behaviour of TPU material under load. The findings suggest that TPU as a 3D printing material has great potential in areas where flexibility and durability are needed. The pressure testing also highlighted the need for a comprehensive evaluation not only of the material itself, but also of the way the object is designed and printed. The results of these tests can serve as a basis for further research and development aimed at optimizing the design of 3D printed components from flexible materials, thereby expanding their application in various industrial and consumer areas.

Acknowledgement

This scientific study was created thanks to support APVV SK-CZ-RD-21-0056 Bioresorbable materials for additive manufacturing of vessel substituents and their biomechanical characterization and thank to project VEGA 1/0387/22 - Development and testing of systems for controlled stimulation of cell growth in a bioreactor environment using computer vision and KEGA 054TUKE-4/2025 - Use of CAx systems in prosthetic and orthotic practice.

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Review process

Single-blind peer review process.