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TESTING OF IMPACT TOUGHNESS OF ABS AND PETG SPECIMENS MANUFACTURED BY THE FFF PROCESS

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Abstract: This paper presents an testing of the impact toughness of 3D-printed specimens produced by the Fused Filament Fabrication (FFF) process, using polymer filaments made of acrylonitrile butadiene styrene (ABS) and polyethylene terephthalate glycol (PETG). One of the known drawbacks of 3D printing is that the manufactured parts often exhibit reduced mechanical properties; therefore, testing is required to determine the functionality of the final component. The impact toughness of plastic materials was evaluated according to the standard EN ISO 179-1:2023 Plastics — Determination of Charpy impact properties — Part 1: Non-instrumented impact test. Among the key adjustable parameters in 3D printing, this study focuses on examining the influence of layer height on impact toughness.

Keywords: Impact toughness, Charpy method, Fused Filament Fabrication (FFF), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG)

INTRODUCTION

Parts produced by 3D printing have inferior mechanical properties and lower surface finish quality, making it necessary to determine the following mechanical properties: toughness, hardness, tensile strength, as well as impact strength, compressive strength, bending, and fatigue strength, in addition to creep, aging, coefficient of friction, shear resistance, and crack propagation resistance according to ISO 17296-3: Additive Manufacturing - General Principles - Part 3: Main Characteristics and Corresponding Test Methods. Furthermore, this standard defines testing categories for metal, plastic, and ceramic parts and classifies them into three groups: Group H (testing of functional parts that are highly safety-critical), Group M (testing of functional parts that are not safety-critical), and Group L (testing of parts during design or prototype stages) [1].

The testing of toughness for plastic materials is defined by the standard EN ISO 179-1: Plastics - Determination of Charpy Impact Properties - Part 1: Non-Instrumented Impact Test [2].

Previous studies have shown that the impact energy value of unnotched PETG specimens produced by the FFF 3D printing process is 0.38 J. In this case, the layer orientation during 3D printing relative to the direction of force application during testing ranged from 15°-75°, while for a layer orientation of 30°-60° relative to the direction of force application during testing, the impact energy was 0.33 J. The impact energy value of unnotched ABS specimens produced by the

FFF 3D printing process is 1.08 J. In this case, the layer orientation during 3D printing relative to the direction of force application during testing ranged from 15°-75°, while for a layer orientation of 30°-60° relative to the direction of force application during testing, the impact energy was 1.06 J [3]. Similar results were obtained in a study where the toughness value of PETG specimens produced by the FDM 3D printing process was 2.8 kJ/m², which is equivalent to a impact energy of 0.1 J, while the toughness value of ABS specimens produced by the FDM process was 5.3 kJ/m², equivalent to a impact energy of 0.2 J [4].

On the other hand, a study conducted using the FDM printing process with PETG filament showed an impact toughness (Charpy impact strength) of 2.4 kJ/m², equivalent to a impact energy of 0.1 J. The same study conducted with ABS filament showed that the impact toughness of ABS specimens was 12.6 kJ/m², equivalent to a impact energy of 0.4 J [5].

In a study conducted with PETG filament using the FDM printing process, an impact toughness of 5 kJ/m² was measured, which is equivalent to a impact energy of 0.16 J [6].

The aim of this study is to determine, using the Charpy method, the impact toughness of ABS and PETG plastic specimens depending on the layer height applied in the shell and infill.

The research hypothesis is that the highest impact toughness of PETG specimens is achieved with the greatest layer height applied in both the shell and infill, while the highest impact toughness of ABS

specimens is achieved with the smallest applied layer height.

ADDITIVE MANUFACTURING

According to ISO 17296-2:2017 Additive manufacturing - General principles - Part 2: Overview of process categories and feedstock, additive manufacturing can be divided into: Vat Photopolymerization - laser stereolithography (SLA) and stereolithography based on complete layer exposure (DLP-SLA, LCD-SLA); Powder Bed Fusion - processes using lasers (SLS, SLM, DMLS) and processes using electron beams (EBM); Material Extrusion (FFF - Fused Filament Fabrication); Material Jetting (PolyJet, PolyJet Matrix); Binder Jetting (3D Print, 3D Print with suspension deposition); Sheet Lamination (LOM, PSL); and Directed Energy Deposition (DED) [7].

The material extrusion process (FFF - Fused Filament Fabrication or FDM - Fused Deposition Modeling, a trademark of the company Stratasys) uses a solid thermoplastic material - filament, which is pushed through a heated nozzle, the temperature of which depends on the type of polymer. The material, in a viscous molten state, is deposited onto a heated or unheated build platform, after which it solidifies and forms the desired part layer by layer [8].

The most important 3D printing parameters that can be adjusted on 3D printers using the material extrusion (FFF) process are: printing speed, extrusion speed, layer height applied in the shell and infill, and the temperature of the nozzle and build plate.

The main limitations of the material extrusion process are related to the anisotropic nature of the parts. Material extrusion layer by layer results in parts that are inherently weaker in one direction. The orientation of the part during the printing process affects its strength in each direction. The infill percentage also affects the strength of the part. Most parts and prototypes produced by 3D printing use 20% infill, which significantly affects production costs and printing time, while areas intended to be load-bearing use 100% infill, which increases both production time and cost [9].

POLYMER MATERIALS ABS AND PETG

There is a large number of polymers with different mechanical, physical, chemical, electrical, thermal, and other characteristics, which have a wide range of applications.

ABS is one of the most versatile polymer materials available for 3D printing today and is supplied in the form of filament. It is used in the material extrusion process FFF (FDM). Printed objects have somewhat higher strength, flexibility, durability, and resistance to impact, as well as wear and stress. ABS can be recycled, like many other thermoplastic polymers. It is used for electronic

housings, pipe fittings, and similar applications. Its Izod impact toughness is 200-215 J/m [10].

Polyethylene terephthalate glycol (PET-G) is a thermoplastic polyester with significant chemical resistance, heat resistance, impact resistance, and formability. PET-G is used for packaging, machine guards, advertising displays, and electrical insulators. It is widely used in 3D printing because it has good interlayer adhesion, minimal warping, no odor during printing, and is non-toxic [11].

The impact toughness (Charpy impact strength) of PET-G filament, at the recommended 3D printing parameters: nozzle temperature of 210-235 °C, bed temperature of 50-80 °C, and printing speed of 30-70 mm/s is 4.5 kJ/m² [12].

EXPERIMENTAL PART

The specimens were manufactured using the FFF process on a Creality Creality 5 Pro printer using Creality CR-ABS and CR-PETG filaments with a diameter of 1.75 mm.

The 3D printing parameters on the Creality 5 printer were as follows: extrusion speed for ABS was 30 mm/s, while for PETG it was 100 mm/s; applied layer heights were 0.1 mm and 0.2 mm in both the shell and infill; nozzle temperature was 240 °C for ABS and 235 °C for PETG; build plate temperatures were 100 °C for ABS and 90 °C for PETG; and the infill density was 100%.

Charpy impact toughness testing was performed on notched specimens, type A1, produced by the FFF 3D printing process using ABS and PETG polymer filaments. The specimen shape and dimensions were defined according to the standard EN ISO 179-1:2023 Plastics - Determination of Charpy Impact Properties - Part 1: Non-Instrumented Impact Test Method and are shown in Figure 1. The layers were arranged such that, with respect to the impact direction, they were oriented parallel to the laminate plane and edgewise relative to the specimen thickness (parallel-edge wise).

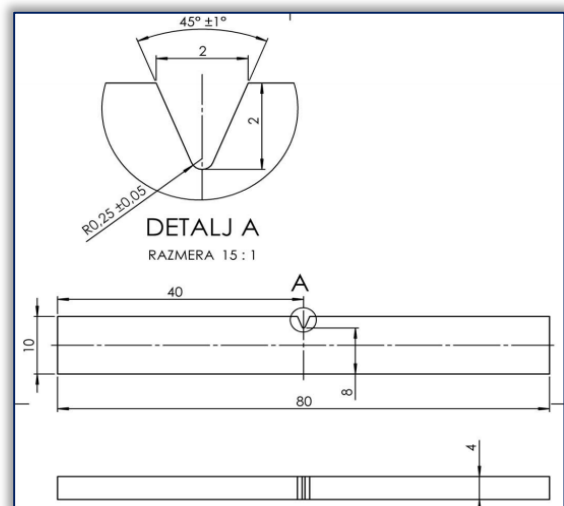


Figure 1. Notched specimen

The 3D CAD model of the specimen used for Charpy impact toughness testing is shown in Figure 2.

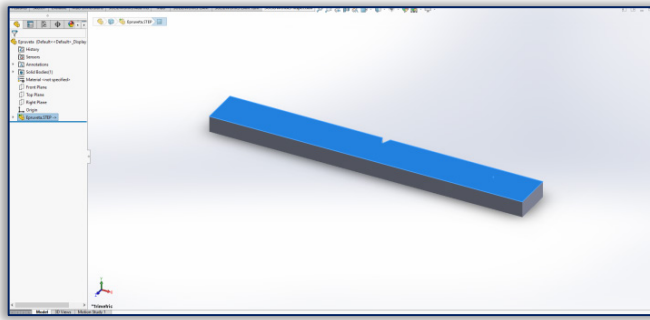


Figure 2. 3D CAD Model

The STL file of the specimen used for Charpy impact toughness testing is shown in Figure 3.

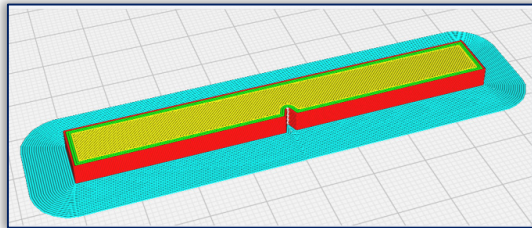


Figure 3. Imported STL File

The appearance of the specimens used for Charpy impact toughness testing is shown in Figure 4. Specimen number 5 represents an ABS specimen with 100% linear infill and a layer height of 0.2 mm while specimen number 6 represents an ABS specimen with 100% linear infill and a layer height of 0.1 mm. Specimen number 7 represents a PETG specimen with 100% linear infill and a layer height of 0.2 mm and specimen number 8 represents a PETG specimen with 100% linear infill and a layer height of 0.1 mm.

The measuring instrumentation used was the Galdabini Impact 300 Charpy impact toughness testing device. The specimens were oriented flat on the build platform and positioned horizontally.

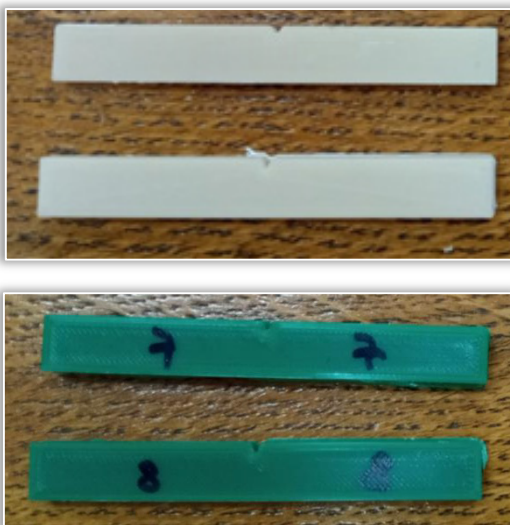


Figure 4. Appearance of the specimens

RESEARCH RESULTS

The surface quality of workpieces made from ABS and PETG plastics depends on the applied layer height in the shell and infill. The smaller the applied layer height, the higher the quality of the

part and the greater the ability to produce fine details; however, the manufacturing time increases linearly.

The values of Impact energy and Charpy impact strength for different infill patterns and applied layer heights are presented in Table 1.

Table 1. Values of Impact energy and Charpy impact strength for different applied layer heights

Material	Layer height (mm)	Impact energy W (J)	Charpy impact strength a_{cN} (kJ/m ²)
ABS	0,2	0,7	21,88
	0,1	0,9	28,13
PETG	0,2	0,2	6,25
	0,1	0,1	3,13

Microscopic images of ABS specimens with layer heights of 100 and 200 microns, at 5x magnification, along with a cross-sectional view of the 4 mm thick layers, are shown in Figure 5.

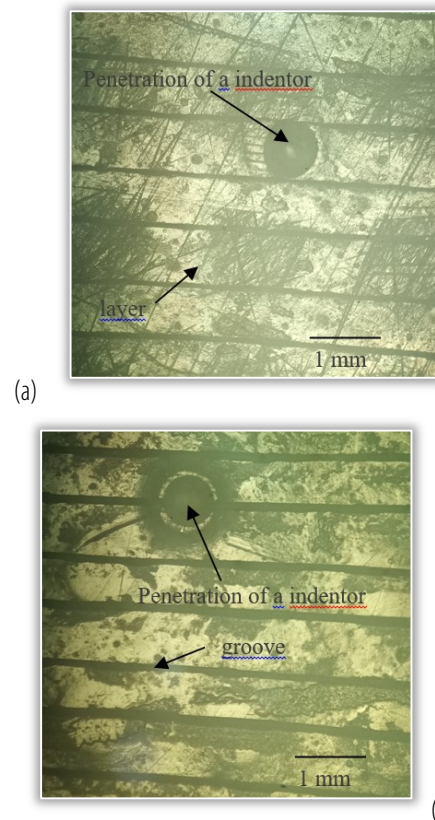


Figure 5. Microscopic images of ABS samples with a) layer heights of 100, b) layer heights of 200 microns at 5x magnification

Microscopic images of PETG specimens with layer heights of 100 and 200 microns, at 5x magnification, along with a cross-sectional view of the 4 mm thick layers, are shown in Figure 6.

In Figure 5 and Figure 6, the darker lines represent grooves between the layers, which are locations of stress concentration, and the wider these grooves are, the rougher the surface becomes. Microscopic examination revealed that the width of the applied layer is greater when a larger layer height is used. The Charpy impact strength of ABS samples produced by FFF 3D printing technology depends on the applied layer height, such that it is greater for smaller layer heights. The impact energy is 0.9 J

for a layer height of 0.1 mm and 0.7 J for a layer height of 0.2 mm.

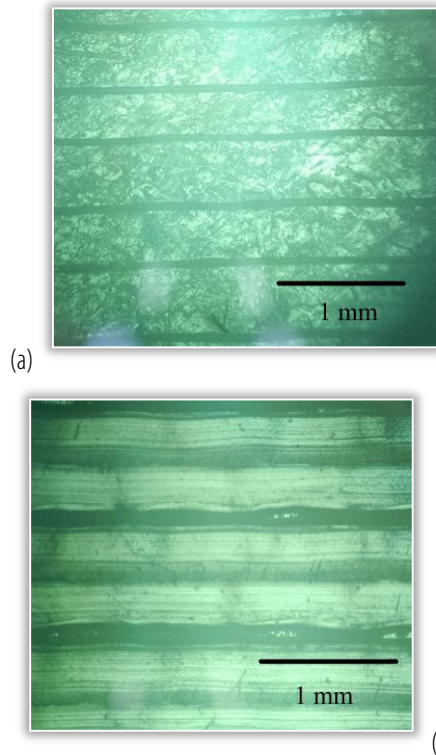


Figure 6. Microscopic images of PETG samples with a) layer heights of 100, b) layer heights of 200 microns at 5x magnification

The Charpy impact strength of PETG samples produced by FFF 3D printing technology also depends on the applied layer height, such that it is greater for smaller layer heights. The Impact energy is 0.1 J for a layer height of 0.1 mm and 0.2 J for a layer height of 0.2 mm.

CONCLUSION

3D printing using the FFF material extrusion process has relatively poor surface finish quality. From the standpoint of impact toughness, the hypothesis was confirmed that the highest impact toughness of PETG specimens is achieved at the larger layer height of 0.2 mm with full shell and infill density, while the impact toughness is reduced by half for the layer thickness reduced by half under linear infill conditions. The reason for this is that a larger layer height reduces the number of layers in the specimen, leading to better interlayer bonding and a smaller number of crack initiation sites, thereby increasing impact resistance.

For ABS specimens produced by the FFF 3D printing process, the results were opposite, meaning that the highest impact toughness of ABS specimens was achieved at the smaller layer height of 0.1 mm with full shell and infill density, while the impact toughness decreases by 28% for the doubled layer height under linear infill conditions.

Based on all of the above, it can be concluded that ABS exhibits significantly higher impact energy and Charpy impact strength compared to PETG, regardless of layer height. In this case, ABS

demonstrates considerably better behavior under impact loading and is more suitable for applications requiring greater toughness and impact resistance.

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