Comparison of the Charpy Resilience of Two 3D Printed Materials: A Study on the Impact Resistance of Plastic Parts

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ABSTRACT

Charpy impact testing is a widely used method for the evaluation of the toughness of materials, including 3D-printed plastic parts. This study performed Charpy test on 3D-printed samples made of PLA and ABS. Factors such as layer thickness and infill percentage varied (0.10, 0.15, and 0.20mm layer height and 50, 75, and 100% infill percentage) to investigate how they affect the mechanical properties of 3D printed parts, including their toughness.

Keywords-3D printing; FDM; Charpy test; resilience

I. INTRODUCTION

Charpy impact testing is a widely used method for evaluating the toughness of materials, including 3D-printed plastic parts. The Charpy test involves striking a notched sample with a pendulum and measuring the energy absorbed by it as it fractures. There is a growing interest in the use of 3D printing technologies for producing plastic parts, but concerns remain about their impact resistance and durability, leading to extensive studies on the Charpy resilience of 3D-printed plastic parts [1-3].

Some studies have shown that the Charpy resilience of 3D-printed plastic parts can vary significantly depending on the printing process, material properties, and design parameters, as factors such as layer thickness, infill density, and printing orientation can affect the mechanical properties of the 3D-printed parts, including their toughness [4-7]. Despite these challenges, there have been promising developments in the use of 3D printing technology for producing high-strength plastic parts with good impact resistance [3]. Various approaches have been explored, such as optimizing printing parameters and incorporating fillers into the printing material to improve the Charpy resilience of 3D-printed plastic parts [4, 8]. Overall, the Charpy resilience of 3D printed plastic parts remains an important area of research for improving the performance and durability of 3D printed products, particularly in applications where impact resistance is critical [9-12]. The Charpy resilience of 3D-printed plastic parts could play a crucial role in many applications, such as aerospace [3], automotive industry [7], medical industry [8], and sporting goods industry.

This study investigated how different printing parameters affect the mechanical properties of 3D-printed parts by varying layer height and infill percentage. The layer height is the thickness of each material layer deposited by the 3D printer. A smaller layer height can result in a smoother surface finish but may also decrease the strength of the part due to the lower interlayer bonding strength. The infill percentage refers to the amount of material used to fill the interior of the part. A higher infill percentage generally results in a stronger part, but may also increase weight and printing time [14-17]. The printing process can be optimized to produce parts with the desired balance of strength, weight, and surface finish by varying both these parameters [18]. This approach can lead to the development of new 3D printing materials and printing processes that can produce parts with improved mechanical properties, and ultimately expand the range of applications for 3D-printed parts [19-22]. In industrial equipment, 3D-printed plastic parts with good Charpy resilience could be used in the production of heavy machinery which can be subjected to high loads and impact forces [23-27]. In general, any application where the 3D-printed plastic part is expected to be subjected to impact loads, shock, or vibration, could benefit from improved Charpy resilience [27-28].

II. MATERIALS, METHODS, AND PROCEDURES

A. Parameters Setup

Table I shows the technical specifications provided by the filament producers (Raise for PLA and Verbatim for ABS). This study fabricated samples with 3 infill percentages: 50, 75, and 100%. Resilience tests were performed on both materials (PLA and ABS) to assess their mechanical characteristics, as shown in Table II. The height of the layer was also varied, taking values of 0.1, 0.15, and 0.20mm, as listed in Table II.

TABLE I. 3D-PRINTED SAMPLE CHARACTERISTICS

Parameters	**Material Specifications**	
	PLA	**ABS**
Nozzle diameter	0.40mm	0.40mm
Build orientation	Flat	Flat
Top solid layers	4 layers	4 layers
Bottom solid layers	4 layers	4 layers
Outline/perimeters shell	3 outlines	3 outlines
Internal fill pattern	Lines	Lines
External fill pattern	Rectilinear	Rectilinear
Internal infill angle offsets	45°-135°	45°-135°
Extruder temperature	210°C	240°C
Heated bed temperature	60°C	110°C
Default printing speed	70mm/s	45mm/s
Cooling fans	on	on
Filament diameter	1.75mm	1.75mm
Filament density	1.24g/cm^3	1.04g/cm^3

B. Sample Preparation

A Raise E2 3D printer was used to fabricate the samples with a volume capacity of 330×240×240mm. The samples were designed with the Solid Edge Software and were converted into STL format. The slicing parameters, including internal structure pattern, infill percentage, and layer thickness, were fine-tuned with the Idea Maker [29]. The samples were X-Y oriented and printed with a bed platform for better adhesion to the printing table, as shown in Figure 1. The tests were performed on an Instron Charpy resilience tester (Figure 3), according [30]. This test can be used to explore how particular types of 3D-printed samples behave under specified impact conditions and to gauge the brittleness or toughness of samples within the constraints of the standard test environment (20°C and 45% humidity). Figure 2 shows the dimensions of the samples. A type A notch was included in the sample design with a radius *rN*= (0.25±0.05)mm.

C. Charpy Test

A series of tests were conducted to assess the mechanical performance and impact resistance. Table II shows the sample sets number for each printing parameter. The impact properties test was performed at the Liea laboratory, in ISIM Timișoara, on an Instron Pendulum Charpy tester.

TABLE II. PRINTING PARAMETERS

Constant parameters					
Building orientation				X, Y	
Extrusion temperature:				T_e	
Bed temperature:				T_p	
Speed:				V_p	
Variable parameters				**Spur gears**	
Layer hight (H_s)	**Infill percentage (P_u)**			***ABS***	***PLA***
(mm)	**(%)**			**No. samples**	
0.10	50	75	100	15	15
0.15				15	15
0.20				15	15

(a) (b) (c)

Fig. 1. Printed samples for 3 different layer thicknesses: 0.10, 0.15, and 0.20mm.

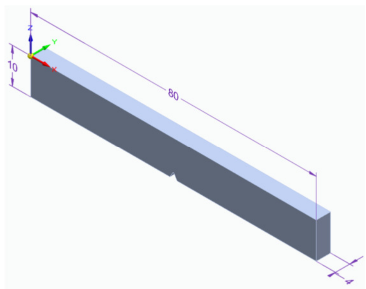

Fig. 2. Sample dimensions.

Fig. 3. Instron testing machine.

III. RESULTS AND DISCUSSION

Charpy impact tests were conducted to examine the energy absorption and damage type of the various configurations. This test utilizes a dynamic three-point bending experiment on a notched specimen using a Charpy device. The experimental arrangement involves the specimen, anvils that provide free support for it, and a pendulum attached to a rotating arm that is pinned to the machine frame. The pendulum is elevated to a predetermined height and then released to fall along a circular path, striking the specimen at its midpoint. This impact transfers kinetic energy to the specimen and causes the pendulum to rise to a measurable height [31]. Tables III and IV show the values and averages of maximum energy absorbed for each combination of layer height and infill percentage of the PLA and ABS materials studied. The total fracture energy was determined by [31]:

$$E_T = mg\left(h_0 - h_f\right) \pm 0.2 \text{ (J)} \quad (1)$$

where E_T is the total energy, m is the mass, g is the gravitational acceleration, h_o is the original height, and h_f is the final height.

TABLE III. AVERAGE VALUES OF PLA IMPACT ENERGY

Sample no. PLA	Energy (J)
0.10 100%	0.0781374
0.10 75%	0.0884992
0.10 50%	0.071886
0.15 100%	0.0809428
0.15 75%	0.0749916
0.15 50%	0.0780908
0.20 100%	0.0821652
0.20 75%	0.0799704
0.20 50%	0.0764726

TABLE IV. AVERAGE VALUES OF ABS IMPACT ENERGY

Sample no. ABS	Energy (J)
0.10 100%	0.3244052
0.10 75%	0.2304624
0.10 50%	0.287763
0.15 100%	0.2698752
0.15 75%	0.247020
0.15 50%	0.2491146
0.20 100%	0.313584
0.20 75%	0.2775298
0.20 50%	0.2841294

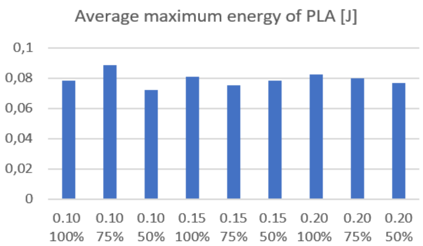

Fig. 4. Range of maximum energy absorbed for PLA samples.

The maximum impact energy was significantly different when using PLA or ABS. As shown in Table III, the average values of layer thickness and infill percentage for PLA samples were very similar. In particular, layer thickness did not influence the dispersion of the average values. As expected, some notable values were noticed for the 100% infill specimens. In addition, the ABS material exhibited a much higher toughness. This printed material is more likely to withstand high levels of impact without fractures, as its results were 75.91% higher in 0.1mm layer thickness and 100% infill, as shown in Figure 6. Lower differences in maximum energy can be noticed for the combinations: H_s=0.10mm, P_u=50%:68.81%; H_s=0.10mm, P_u=75%:69.28%; H_s =0.15mm, P_u=75%:69.64%; H_s=0.15mm, P_u=50%:68.65%. As noted in [32-34], the average values of the mechanical characteristics were different for ABS and PLA. Figure 7 shows that although the tensile strength is higher for PLA, ABS behaves better in terms of absorbed impact energy. The impact energy of a material depends on its composition, microstructure, geometry, temperature, loading rate, and testing method. These factors also affect the deformation and failure behavior of the material under impact loading.

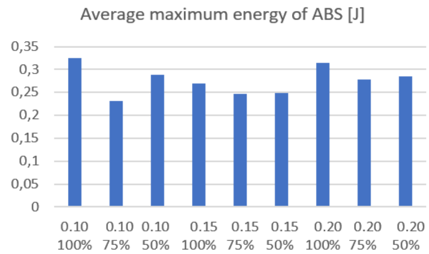

Fig. 5. Range of maximum energy absorbed for ABS samples.

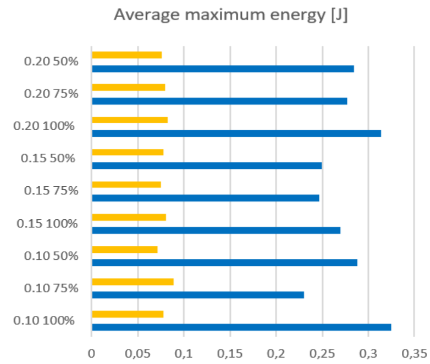

Fig. 6. Comparison of maximum energy absorbed for PLA and ABS.

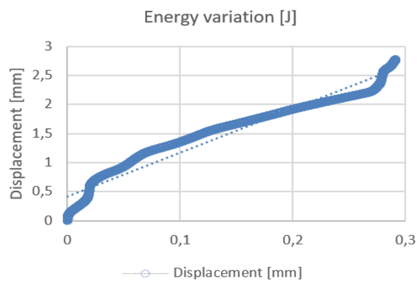

Fig. 7. Variation of impact energy.

IV. CONCLUSIONS

This study investigated the impact resistance testing of the two most common materials used in 3D printing with FDM technology to compare them to help users choose the right material for different practical applications. The PLA material is more brittle in the Charpy test because it absorbs a small amount of energy during testing, while ABS has a ductile behavior because it absorbs a large amount of energy. It is important to note that the maximum Charpy energy for a printed part can be influenced by a variety of factors, including the printing parameters, such as the variation of layer height and infill percentage, part design, and post-processing techniques. PLA has a fragile comportment at the Charpy test because it absorbs a small amount of energy during testing, while ABS behaves as ductile because it absorbs a large amount of energy. Therefore, it's a good idea to test and validate the toughness and impact resistance of 3D-printed parts under actual use conditions.

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