

Research on Impact Resistance Using Free-Falling Dart Drop Testing of 3D-Printed Parts Made of ABS and PETG According to ASTM D1709 [†]

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Abstract

The paper investigates impact resistance of 3D-printed ABS and PETG specimens with a falling dart drop. Twenty-five specimens of each material were manufactured in accordance with the ASTM D1709 standard, as well as twenty-five specimens of notched ABS. The test data is processed when 10 cracked and 10 uncracked specimens are available. Dart drop tests are typical for specimens that are manufactured in the shape of films. The purpose of the test is to perform an impact from a certain height with a controlled velocity of the falling dart drop.

Keywords: 3D printing; impact resistance; free-falling dart; mechanical properties

1. Introduction

3D printing is a basic technology for rapid prototyping [1]. The application of the technology is increasingly used in mechanical engineering, aerospace engineering, medical applications, etc. [2]. 3D printing is a preferred technology because of the following advantages—the ability to create parts with complex geometry, the lack of technological waste, and energy efficiency. The most commonly used 3D printing technologies are FDM, SLA, and SLS [3].

The most commonly used materials for 3D printing are PLA and ABS [4]. In addition, other polymers are also used with specific requirements for impact resistance, rigidity, chemical resistance, etc. [5].

Impact resistance is classified as a dynamic test method in which the destruction of the sample occurs at high speed [6]. The method can be used on a wide range of materials—metals, plastics, rubbers, etc. [7]. The test is a transfer of energy created by a falling wedge or hammer to the test sample, which leads to its destruction. Impact resistance is equal to the work performed to break the sample divided by the impact cross-section. There is no dependence on the size of the test pieces, which are determined by different standards.

The following conditions are important for impact resistance testing:



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- Dimensions of specimen;
- Presence of notches, curvatures;
- Test temperature;
- Mass of the falling dart drop/hammer;
- Height of fall of dart drop/hammer;
- Geometry of dart drop/hammer.

In impact resistance testing, specimens with different notches are used in order to create a stress concentrator. Keyhole-, U- and V-type notches are standardized, with keyhole and U being most often used for brittle materials such as cast iron [8]. The most commonly used methods for impact resistance testing are the Izod method, the Charpy method, and the free-falling dart test. The Charpy and Izod methods contain usage of pendulum hammers, and the falling method contains usage of different heads [9]. The load is selected depending on the material and testing conditions in order to guarantee the destruction of the test specimens. Impact resistance tests are extremely important for parts that are subjected to impact loads. In practice, parts obtained by 3D printing are often used as machine elements and structural parts, which determines the importance of testing the impact resistance of parts obtained by this technology [10].

2. Materials and Methods

For this study, filament materials of PETG (polyethylene terephthalate glycol) and ABS were selected [11]. The choice was due to the fact that both materials have applications in mechanical engineering parts. PETG has excellent properties for 3D printing, is easy to mold, and has excellent chemical resistance and strength [12]. Its high temperature resistance and lack of pigmentation make it suitable for printing various body parts. The other selected filament is ABS, which is distinguished by heat resistance, good dimensional accuracy and hardness [13]. ABS has a very wide range of applications—as pipes, fittings, and keyboard keys—in the refrigeration industry, automotive industry, etc. [14]. For our study, we will use a Flashforge Adventurer 5M Pro 3D printer from Zhejiang Flashforge 3D Technology Co., Ltd., Jinhua, Zhejiang Province, China.

The 3D printer works using material deposition technology and has the following characteristics:

- X-axis travel—220 mm;
- Y-axis travel—220 mm;
- Z-axis travel—220 mm;
- Nozzle opening—0.4 mm;
- Maximum extruder temperature—270 °C;
- Maximum bed temperature—110 °C;
- Maximum printing speed—600 mm/s.

The used 3D-printing parameters used for the test specimens Figure 1 are:

- Materials—PETG and ABS;
- Print speed—200 mm/s;
- Extruder temperature—235 °C;
- Bed temperature—60 °C;
- Layer height—0.2 mm;
- Infill—100%.

Twenty-five samples shown were printed from a colorless PETG material, as well as fifty from ABS, of which twenty-five had notches to investigate the impact resistance of the material. The study will expand an accumulate experimental data on the strength of this material and its application in various printed parts. The samples were printed with the

same printing parameters outlined above. The test sample was designed according to the available impact resistance test stand, namely with a diameter of 158 mm and a thickness of 1.6 mm for PETG and 1.2 mm for ABS. Approximately 36.5 g of filament is used in one test sample. Impact resistance test samples are often made with artificial notches—most often with a U and B shape in order to localize stress concentrators [15]. In plastic products, a U notch is used most often [16]. The notches were made only on the ABS samples. The notch was made by milling the samples. The diameter of the notch is F2 in the middle of the sample. The notch is standardized for plastic products. The notched samples were installed on the stand so that the notches were on the upper side. Before the test, the pneumatic system of the stand was checked; the location of the impact with the falling wedge was also checked by marking the central mark. Slippage during fastening is critical for the reliability of the results. The dimensions of the samples are shown in Figure 2.

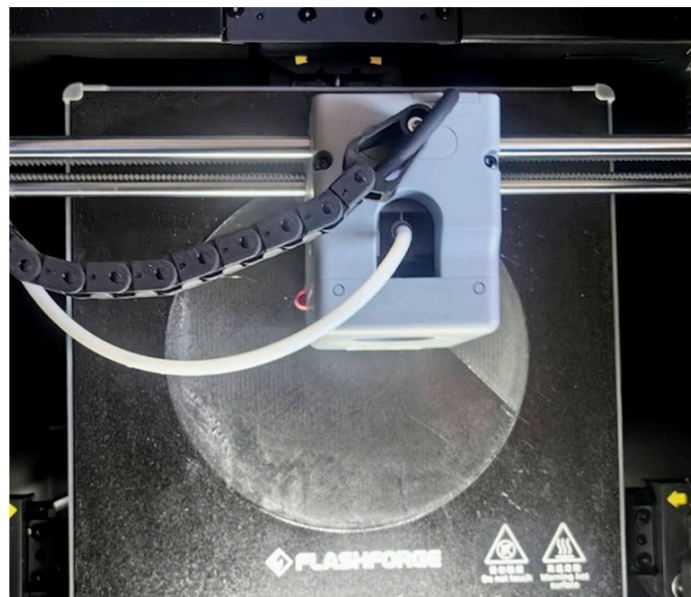


Figure 1. Process of printing a specimen from PETG.

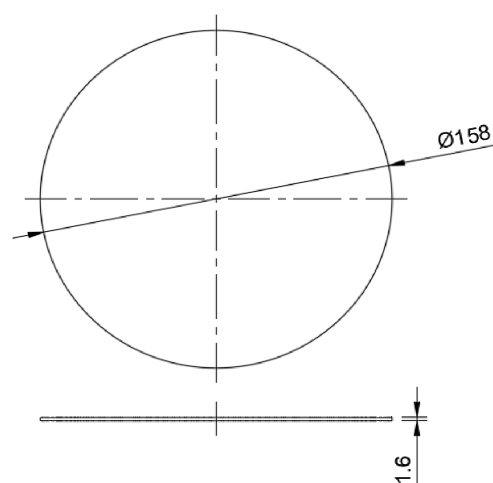


Figure 2. Specimen dimensions.

For testing purposes, a calibrated impact resistance using a free-falling dart drop machine according to ASTM 1709 Method A was used, as shown in Figure 3.

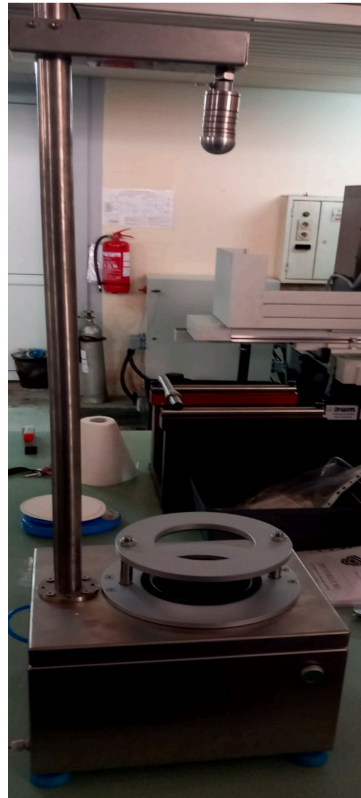


Figure 3. Free-falling dart drop stand.

The height of the dart drop is the standardized 0.66 m for ABS and 0.260 m for PETG, with the tip having a diameter of 38.1 mm and a hemispherical head. This method is suitable for testing films with a mass of 50 g or less, which is why it is preferred for testing. Missile weight and incremental weights are calibrated for the purpose of the accuracy of the test. The atmospheric conditions for temperature and humidity mentioned in the standard are observed. The dart is positioned vertically above the specimen, with no slippages greater than 0.1 mm detected during the tests.

The notches were made using an engraving router (Figure 4), with a 4 mm ball nose cutter at a depth of 0.8 mm, representing half of the total thickness of the test specimen (Figure 5).

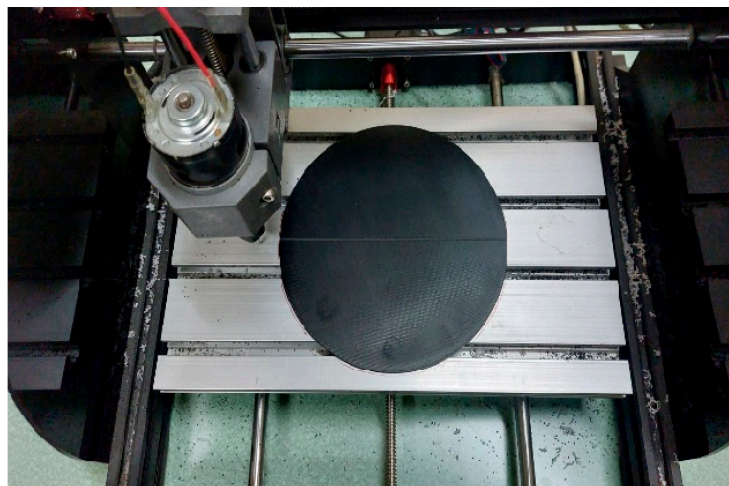


Figure 4. Experimental setup.

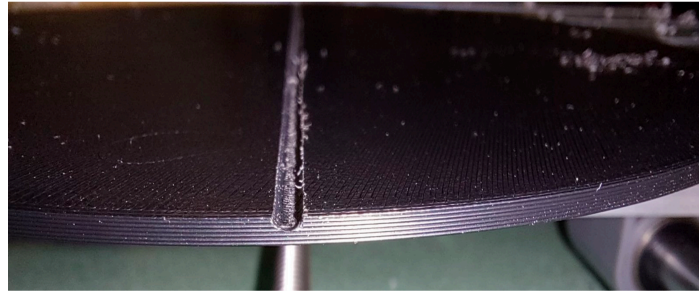


Figure 5. Notched ABS sample.

The results are presented in a table according to the standard, and it is necessary to have 10 broken and 10 unbroken test specimens (Table 1). According to the theoretical data, a weight is selected with which to start the test, and in case of successful breakage, the weight is reduced; if unsuccessful, it is increased by one step. The signs X are used for a broken specimen and O for an unsuccessfully broken specimen. After the end of the test, the impact failure weight is calculated.

Table 1. Test results of impact resistance, featuring notched ABS samples.

Missile Weight [g]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
120								O						O		O		O		
130	O						X		O				X		X		X		O	
140		O		O		X				O		X								X
150			X		X						X									

3. Results

After the tests are completed, failure rates are calculated according to the different missile weights (Table 2).

Table 2. Missile weight and % of failures of notched ABS samples.

Missile Weight, g	% Failure
130	57
140	50
150	100
Σ	207

Failure weight is calculated in several alternative ways according to the standard with similar results, the difference in them being within the statistical error. In this article, the formula used according to the standard ASTM S1709 [16] is:

$$WF = WL - [\Delta W (S/100 - 1/2)] \quad (1)$$

where

WF—impact failure weight, g;

DW—uniform weight increment used, g;

WL—the lowest missile weight at which 100% failure occurs, g.

According to the particular DW used, at which 100% failure occurred, and S denotes the sum of the percentages of breaks at each missile weight (from a weight corresponding to no failures up to and including WL),

$$WF = WL - [\Delta W (S/100 - 1/2)] \quad (2)$$

$$WF = 150 - [10 (207/100 - 1/2)] \quad (3)$$

$$WF = 150 - 15.7 \quad (4)$$

$$WF = 134.3 \text{ g} \quad (5)$$

The results of ABS without notches are shown in Table 3.

Table 3. Test results of ABS samples without notches.

Missile Weight [g]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
120		O				O				O				O		O				
130	X		O		X		O		X		O		X		X		X		X	O
140				X				X				X						X		

Similarly presented are the percentage of the failures according to the missile weight (Table 4).

$$WF = WL - [DW (S/100 - 1/2)] \quad (6)$$

$$WF = 140 - [10 (164/100 - 1/2)] \quad (7)$$

$$WF = 140 - 11.4 \quad (8)$$

$$WF = 138.6 \text{ g} \quad (9)$$

Table 4. Missile weight and % of failures of ABS samples without notches.

Missile Weight, g	% Failure
130	64
140	100
Σ	164

The PETG results are presented in Tables 5 and 6. The requirements for 10 destroyed and undestroyed specimens are met.

$$WF = WL - [DW (S/100 - 1/2)] \quad (10)$$

$$WF = 100 - [10 (160/100 - 1/2)] \quad (11)$$

$$WF = 100 - 11 \quad (12)$$

$$WF = 89 \text{ g} \quad (13)$$

Table 5. Test results impact resistance of PETG samples.

Missile Weight [g]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
80	O				O		O				O		O		O				O	
90		O		X		X		O		X		X		X		O		X		O
100			X						X								X			

Table 6. Missile weight and % of failures of PETG samples.

Missile Weight, g	% Failure
90	60
100	100
Σ	160

4. Discussion

The experimental results show a very small range, which validates them. The results cannot be compared with values obtained from other standard methods, different shapes of the specimens, as well as different geometry of the falling dart drop (Figure 6). The test results of the ABS specimens show a notch effect with low sensitivity, which is due to the geometry of the hemispherical head of the dart drop in relation to the width and depth of the notch [17]. No notched specimen failed from a crack initiated by the artificial stress concentrator. All notched ABS specimens failed from a crack initiated near the notch and propagated through the notch [18] (Figure 7). The main conclusion from the in-depth analysis is that the combination of a blunt hemispherical dart and a relatively thick (for a film test), yet still thin, notch leads to a situation where the loading geometry bypasses the stress concentrator. The ductility of ABS and the anisotropy of the 3D-printed structure further reinforce this effect.

**Figure 6.** All the tested samples.**Figure 7.** The crack of a notched sample.

5. Conclusions

The following conclusions can be drawn from the study:

- Impact weight failure was calculated for ABS (with and without notch) and PETG test specimens.
- The number and geometry of the specimens was in accordance with the requirements of the standard.
- The results of ABS show a notch effect with little sensitivity to notches in the falling dart drop test.
- The experimental results can be used in the strength design of impact resistance at similar thicknesses.
- The cracks of the failed specimens are near the notch.
- There is no single specimen that failed due to crack propagation initiated from the notch.
- No critical deviations were observed during the test that would affect the experimental results.
- The specimens had no visible defects that would affect testing.
- Due to the specificity of the impact resistance test, data from specimens with other geometries and dimensions, as well as with different thicknesses, cannot be used, which makes such studies applicable in engineering practices.
- The selected materials are increasingly used in mechanical engineering and the automotive industry, which necessitates the testing of their mechanical properties

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References

1. Ma, J. The application of 3D printing in mechanical manufacturing. *Appl. Comput. Eng.* **2025**, *117*, 44–50. [\[CrossRef\]](#)
2. Xu, Y. Types and applications of 3D printing. *Highlights Sci. Eng. Technol.* **2024**, *119*, 697–702. [\[CrossRef\]](#)
3. Jaiswal, N.; Akhtar, J. Additive manufacturing (3D printing). In *Comprehensive Materials Processing*; Hashmi, M.S.J., Ed.; Elsevier: Amsterdam, The Netherlands, 2024.
4. Pérez, D.; Zumba, E.; Mazón, H.; Llamuca, J. Elasticity and plasticity of PLA, PETG, ABS polymers for printing automotive parts. *Espirales Rev. Multidiscip. Investig.* **2024**, *8*, 51–66. [\[CrossRef\]](#)
5. Wajima, T.; Yamashita, K. Recovery of carbon fiber from carbon fiber reinforced plastics using alkali molten hydroxide. *Sci. Rep.* **2025**, *15*, 590. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Wu, Y.; Guo, Y.; Yi, S.; Lv, Z.; Fan, Z. Impact resistance of aluminum foam composites with filler and coating materials. *Polymers* **2024**, *16*, 3286. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Zhang, Z.; Lu, R.; Zhang, H.; Bai, L.; Sun, Y. Research progress on the impact resistance of basalt fiber-reinforced polymer composites. *J. Phys. Conf. Ser.* **2024**, *2891*, 082017. [\[CrossRef\]](#)

8. Xu, X.; Wang, T.; Sun, Q.; Wang, B.; Ge, Y.; Lang, J.; Yan, Y. The effect of notch and molecular weight on the impact fracture behavior of polycarbonate. *Polymers* **2024**, *16*, 1072. [[CrossRef](#)] [[PubMed](#)]
9. De Freitas, L.F.; Duarte Lopes, F.P.; Cosme, G.; Simonassi, N. Study of tensile strength and Izod impact on epoxy matrix composites reinforced with jute fabric. In Proceedings of the 77th ABM Annual Congress—International, São Paulo, Brazil, 3–5 September 2024.
10. Dębski, M.; Magniszewski, M.; Bernaczek, J.; Przeszłowski, Ł.; Gontarz, M.; Kielbicki, M. Influence of torsion on the structure of machine elements made of polymeric materials by 3D printing. *Polimery* **2021**, *66*, 298–304. [[CrossRef](#)]
11. Mirasadi, K.; Rahmatabadi, D.; Ghasemi, I.; Khodaei, M.; Baniassadi, M.; Baghani, M. Investigating the effect of ABS on the mechanical properties, morphology, printability, and 4D printing of PETG-ABS blends. *Macromol. Mater. Eng.* **2024**, *309*, 2400038. [[CrossRef](#)]
12. Hozdić, E.; Hozdić, E. Influence of infill structure shape and density on the mechanical properties of FDM 3D-printed PETG and PETG+CF materials. *Adv. Technol. Mater.* **2024**, *49*, 15–27. [[CrossRef](#)]
13. Khledj, A.; Mohamed, H.M.; Mendas, M.; Zidane, I. Comparative analysis of three polymers: ABS, PMMA, and ABS/15% PMMA bilayer in three-point bending. *Commun. Sci. Technol.* **2024**, *22*, 1–6.
14. Katiyar, P.C.; Singh, B.P.; Chhabra, M.; Kumar, N.; Parle, D. Analysis of tensile strength of thin ABS specimens 3-D printed in various build orientations for turbomachinery applications. *Int. J. Interact. Des. Manuf.* **2025**, *19*, 1869–1881. [[CrossRef](#)]
15. Guo, L.; Huang, H.; Chen, J.; Romanov, K. Axial behavior of square CFST with local corrosion simulated by artificial notch. *J. Constr. Steel Res.* **2020**, *174*, 106314. [[CrossRef](#)]
16. ASTM D1709-22; Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method. ASTM International: West Conshohocken, PA, USA, 2022. [[CrossRef](#)]
17. Cicero, S.; Devito, F.; Sánchez, M.; Arrieta, S.; Arroyo, B. Notch effect in acrylonitrile styrene acrylate (ASA) single-edge-notch bending specimens manufactured by fused filament fabrication. *Materials* **2024**, *17*, 5207. [[CrossRef](#)] [[PubMed](#)]
18. Cicero, S.; Martinez-Mata, V.; Alonso-Estébanez, A.; Castañón Jano, L.; Arroyo, B. Analysis of notch effect in 3D-printed ABS fracture specimens containing U-notches. *Materials* **2020**, *13*, 4716. [[CrossRef](#)] [[PubMed](#)]

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