Experimental Study of the Mechanical Properties of 3D Printed PolyJet Test Specimens

MIGLENA PANEVA[1], PETER PANEV[1], NIKOLA KUZMANOV[2]
[1]Institute of Information and Communication Technologies,
Bulgarian Academy of Sciences,
Acad. G. Bonchev str., Block 2, 1113, Sofia,
BULGARIA

[2]Department of Mechanics,
Technical University,
8, St. Kliment Ohridski Blvd., 1764, Sofia,
BULGARIA

Abstract: - Additive manufacturing has become an essential production technology for rapid prototyping and low-volume manufacturing of functional engineering components. Among the available additive manufacturing processes, PolyJet technology offers high dimensional accuracy, good surface quality, and the ability to fabricate complex geometries using engineering photopolymer materials. This study experimentally evaluates the mechanical behaviour of Digital ABS Plus specimens manufactured by PolyJet technology using an Objet260 Connex3 3D printer. Tensile tests were performed in accordance with BDS EN ISO 527-2:2012, while Charpy impact tests were conducted in accordance with ISO 179-1:2010. The influence of manufacturer-recommended thermal treatment on tensile properties was investigated, and the effect of three different printing orientations on impact strength was analysed. In addition to the experimental investigation, a statistical assessment of the measured data is introduced to evaluate the repeatability and reliability of the obtained results. Average values, standard deviations, variances and relative measurement errors are considered for the experimental series. The results show that thermal treatment produces a moderate increase in tensile strength without substantially changing the elastic modulus, whereas printing orientation has a pronounced influence on impact strength due to the anisotropic layered structure produced by the PolyJet process. The study provides engineering data for selecting suitable printing orientations and post-processing conditions when manufacturing functional Digital ABS Plus components.

Key-Words: - Additive manufacturing, PolyJet technology, Digital ABS Plus, Tensile strength, Charpy impact strength, Thermal treatment, Mechanical properties, Statistical analysis.

Received: March 6, 2026. Revised: April 18, 2026. Accepted: May 11, 2026. Published: September 17, 2026.

1 Introduction

Additive manufacturing (AM) has evolved from a rapid prototyping approach into a manufacturing route capable of producing functional engineering components, [1]. Continuous improvements in printing accuracy, material performance and process reliability have enabled AM technologies to be applied in automotive, aerospace, medical and industrial engineering applications, [2].

Among the available AM processes, PolyJet technology is notable for its high dimensional accuracy, smooth surface finish and ability to produce complex geometries from photopolymer materials. The process is based on the layer-by-layer deposition of liquid photopolymer droplets, which are subsequently cured by ultraviolet radiation, [3].

Digital ABS Plus is an engineering photopolymer developed for functional prototypes and components requiring relatively high stiffness, tensile strength and impact resistance. However, as with other additively manufactured polymers, its mechanical behaviour depends not only on the nominal material properties but also on the printing strategy, part orientation, layer arrangement and post-processing procedure, [4].

Previous investigations [5] have shown that build orientation significantly influences the mechanical response of PolyJet materials. Differences in interlayer adhesion and the direction of crack propagation may lead to measurable changes in tensile behaviour, impact strength and fracture stability. Therefore, orientation-dependent testing remains important for reliable engineering design.

Recent developments in PolyJet and multi-material jetting technologies have further demonstrated that mechanical performance is governed by both material composition and the internal structure generated during printing, [6], [7], [8]. Voxel-scale material distribution, curing conditions and support removal procedures may affect the final behaviour of printed components, [9].

Thermal treatment is another important post-processing stage for 3D printing materials. Manufacturer-recommended thermal treatment may promote additional polymer network stabilisation and residual stress relaxation. Nevertheless, the quantitative effect of this treatment on tensile strength, elastic modulus and strain at tensile strength requires experimental verification.

Impact strength is a critical property for polymer components subjected to dynamic or impulse loading. Charpy impact testing provides a practical method for evaluating the ability of a specimen to absorb fracture energy. In additively manufactured polymers, this property is especially sensitive to the orientation of the printed layers relative to the impact direction.

The analysis of tensile strength and impact strength allows for a better understanding of the behaviour of materials and the possibilities for their use in real-life engineering applications, [10].

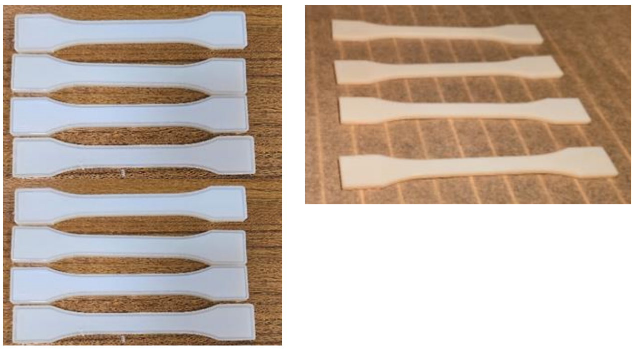
The objective of this study is to experimentally investigate and statistically assess the mechanical performance of Digital ABS Plus specimens produced by PolyJet technology. Tensile tests were performed before and after manufacturer-recommended thermal treatment, while Charpy impact tests were conducted for three printing orientations. The manuscript introduces statistical descriptors and uncertainty indicators to evaluate the repeatability and reliability of the obtained experimental results.

2 Materials and Methods

2.1 Tensile Strength Testing

The tensile tests at room temperature were performed with a Zwick 1474 tensile testing machine, which has been modernised and restored by the team of the Mechanics Department at Technical University, Sofia. The tensile specimens were designed and manufactured according to BDS EN ISO 527-2:2012, [11]. The investigated material is Digital ABS Plus, a two-component PolyJet photopolymer intended for functional prototypes and engineering applications requiring relatively high stiffness and strength. The material consists of the liquid resins RGD515S (base component) and RGD531 (curing component).

Eight tensile specimens were manufactured using an Objet260 Connex3 PolyJet printer. The printing parameters were set through GrabCAD software and oriented in the x-y direction with a minimum distance between them Figure 1a). A Matte finish and a layer thickness of 30 micrometres were used. The Matte coating means that the entire part will be covered with a supporting material, which helps its uniform hardening. The support material SUP705B was removed using a Water Jet system, after which the specimens were left on a flat surface for 24 h before testing. Four specimens were tested in the as-printed condition, while four specimens were subjected to manufacturer-recommended thermal treatment of Procedure A. The thermal treatment was carried out in a programmable oven, starting from room temperature with a heating rate of 1 °C/min and reaching a maximum temperature of 80°C over a total process duration of 400 min, Figure 1b).



a) b)

Fig. 1: PolyJet-printed tensile specimens: a) specimens covered with support material (matte finish); b) specimens subjected to thermal treatment.
Source: created by the authors.

2.2 Charpy Impact Testing

Charpy impact testing was performed to evaluate the ability of the PolyJet-printed specimens to absorb energy under dynamic loading. The tests were conducted according to ISO 179-1:2010 for hard thermoplastic specimens, [12]. In Figure 2, a schematic representation of the testing process, consisting of a support, a lever, a pendulum, a bending knife, and a test specimen support, is shown. The unnotched specimens had dimensions of 80 × 10 × 4 mm and were supported over a span of

62 mm. During testing, the pendulum hammer strikes the specimen, and the absorbed fracture energy is determined from the difference between the initial and final energy states of the pendulum.

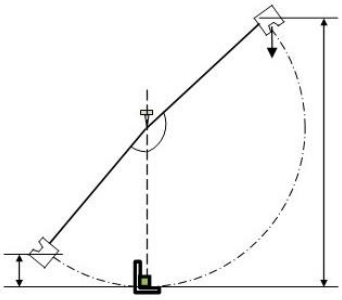


Fig. 2: Schematic representation of the Charpy impact strength test
Source: created by the authors.

The notch reduces the cross-section and acts as a stress concentrator, and it is proposed for metals. However, in the present study, unnotched specimens were used according to the selected testing configuration, [13], [14], [15].

The fracture energy of the specimen can be expressed as:

$$E_c = m.g\,(H_1 - H_2),\ J \qquad (1)$$

where m is the mass of the pendulum, g is the gravitational acceleration, and H_1 and H_2 are the initial and final heights of the pendulum before and after fracture of the specimen.

When the pendulum heights cannot be measured directly, the absorbed energy may be determined from the initial and final angular positions of the pendulum, denoted as α and β, respectively.

In this case, the fracture energy is calculated as:

$$E_c = m.g.l\,(\cos\beta - \cos\alpha),\ J \qquad (2)$$

where l is the length of the pendulum arm.

The Charpy impact strength a_{cU} was calculated by normalising the absorbed fracture energy to the cross-sectional area of the specimen:

$$a_{cU} = E_c / (h.b) \times 10^3,\ kJ/m^2 \qquad (3)$$

where h is the specimen height, in millimetres, and b is the width of the test specimen, in millimetres.

In the Charpy pendulum hammer used in this study, Ec was read directly from the instrument scale in kg·cm and then converted to joules using 1 kg·cm = 0.0980665 J. The specimens were placed horizontally on their 4 mm side, as shown in Figure 3. The calculations of impact strength were performed according to Eq. (3).

The Charpy specimens were fabricated using the same PolyJet printer, material and support removal procedure as the tensile specimens. Three printing orientations were investigated, shown in Figure 4: Orientation 1 (On Edge), printed horizontally along the x-axis and lying on the 4 mm side; Orientation 2 (Flat), rotated 90° along the y-axis and lying on the 10 mm side; and Orientation 3 (Upright), printed vertically along the x-z axis. Five specimens were manufactured and tested for each orientation. The obtained impact strength values were averaged and subsequently used for statistical evaluation.

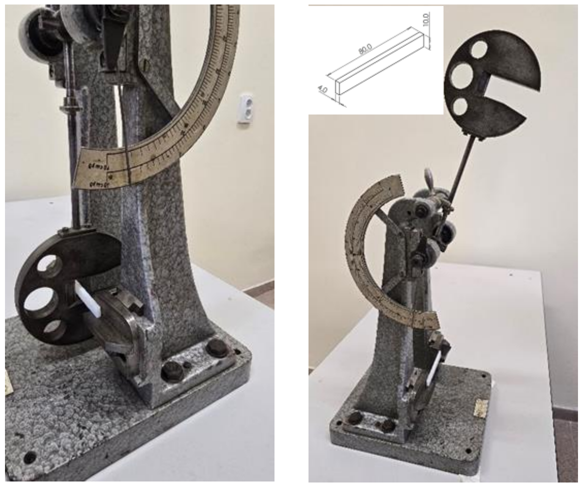


Fig. 3: Positioning of the Charpy impact test specimen.
Source: created by the authors.

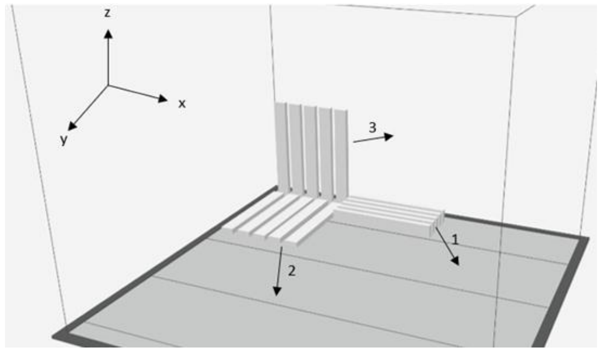


Fig. 4: CAD model showing the three printing orientations of the Charpy impact specimens in GrabCAD.
Source: created by the authors.

3 Experimental Results and Discussions

3.1 Tensile Strength

Tensile tests were performed on 8 test specimens obtained by 3D printing from Digital ABS Plus material using PolyJet technology. Four were marked as "ABS plus", and four were thermally treated according to procedure A, marked as "ABS plus after thermal treatment". The tensile tests were carried out according to the BDS EN ISO 527-1 standard. During the tests, the force, elongation measured by the extensometer, and displacement of the movable grip of the machine were continuously recorded. The obtained results were used to construct the stress-strain curves of the studied polymer materials. From the constructed stress-strain curves, the tensile strength σ_m and the modulus of elasticity E, as well as the strain at tensile strength ε_m, were determined. In Figure 5, the tensile testing machine with a mounted test specimen and extensometer is shown.

Fig. 5: Tensile testing machine.
Source: created by the authors.

In Table 1 and Table 2, the data for the modulus of elasticity E, the tensile strength σ_m, and the strain reached at the tensile strength ε_m for the two studied materials are presented. Their average values have also been calculated.

Table 1. Experimental study of tensile strength of photopolymer Digital ABS plus.

Polymer	Test specimen №	E, GPa	σ_m, MPa	ε_m, %
ABS plus	1	2.28	54.4	5.05
	2	2.21	55.7	4.94
	3	2.26	54.5	4.98
	4	2.26	52.7	4.97
	Average	2.25	54.33	4.99

Source: created by the authors.

Table 2. Experimental studies of tensile strength of photopolymer Digital ABS plus after thermal treatment.

Polymer	Test specimen №	E, GPa	σm, MPa	ε_m, %
ABS plus after thermal treatment	1	2.06	57.1	5.25
	2	2.24	57	5.13
	3	2.32	54.8	4.94
	4	2.28	59.2	5.66
	Average	2.23	57.03	5.25

Source: created by the authors.

In Figure 6, one strain curve for materials "ABS plus" and "ABS plus materials after thermal treatment" is shown.

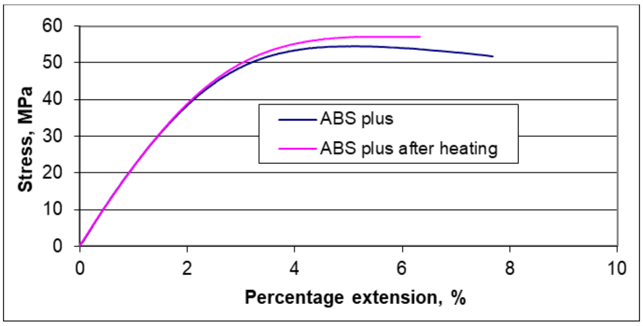


Fig. 6: Stress- strain curves of "ABS plus" and "ABS plus materials after thermal treatment" materials.
Source: created by the authors.

From the tensile tests conducted on test specimens made of ABS plus (without thermal treatment), the following mechanical properties were determined: tensile strength – 54.33 MPa, elastic modulus – 2.25 GPa, strain at tensile strength 4.99 %.

The average values of the mechanical properties after the applied thermal treatment are: tensile strength – 57.03 MPa, elastic modulus – 2.23 GPa and strain at tensile strength 5.25%. The tensile strength according to Technical Specifications is between 55-60 MPa [16]; these data are confirmed by the experimental results of this study. Significant differences are observed in the elongation. In [16], they indicate an elongation at break of 25-40 %, and the maximum measured strain at tensile strength in the present tensile test data is 5.66 %; this value should not be interpreted as elongation at break. For comparison, the tensile strength of standard ABS for injection moulding is usually in the range of 35- 50 MPa, which is slightly lower than that of 3D printed using PolyJet technology. This means that parts manufactured using conventional techniques will have lower tensile strength than those manufactured using PolyJet technology.

3.2 Charpy Impact Strength

A total of 15 test specimens were 3D printed and tested for impact strength, 5 for each printing orientation.

The impact strength test is performed by releasing the mechanism holding the pendulum hammer. After the impact from the knife integrated in the hammer (Figure 2), the test specimen is broken into two parts, and the absorbed energy E_c is determined from the scale of the device. The data from all tests are presented in Table 3 (Appendix) both in kg.cm and converted to J, after which the measured values are averaged.

For Orientation 1, the average fracture energy is 0.433 J, for Orientation 2 - 0.214 J, and for Orientation 3 - 0.085 J. From the obtained average values, the specific absorbed energy (Charpy impact strength) a_{cU} in kJ/m^2 is calculated, and the results are presented in Table 4.

Table 4. Data with calculations of impact strength and relative error of the studies.

	Orientation 1	Orientation 2	Orientation 3
Average Ec , J	0.433	0.214	0.085
a_{cU}, kJ/m^2	10.82	5.35	2.13
Relative error	6.46%	14.45%	17.05%

Source: created by the authors.

The results show the best repeatability for Orientation 1 (≈ 6.5 %), Average scatter for Orientation 2 (≈ 14.5 %) and the largest scatter for Orientation 3 (≈17 %). This shows a clear influence of orientation on the stability of the results, which is typical in impact tests of polymers and 3D printed parts.

The impact strength value for Orientation 1 is 10.82 kJ/m^2, which is the highest measured. For Orientation 2, the result is 5.35 kJ/m^2, which is 50.5 % lower than the result for Orientation 1. For Orientation 3, the values are the lowest, respectively, with a value of 2.13 kJ/m^2 or 80.2 % lower than that for Orientation 1. The impact resistance data from Table 4 are presented graphically in Figure 7.

In [17], test specimens made of ABS and ABS-plus using Fused Deposition Modelling (FDM) technology were tested using the Charpy method. The results were compared with the studies conducted in this paper. For a test specimen without a notch, a thickness of 0.25 mm, and a 0° orientation angle, values of approximately 17 kJ/m^2 were obtained for ABS material and 15.5 kJ/m^2 for ABS Plus material. The results are significantly higher than the results obtained in the present study.

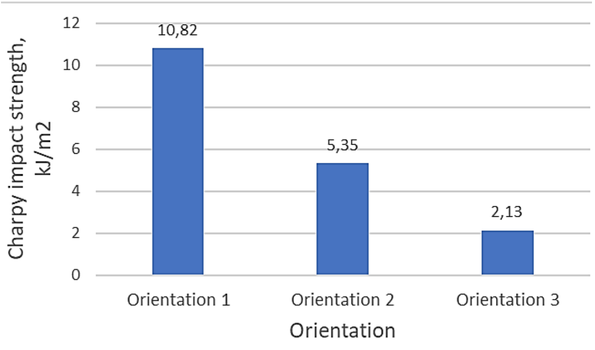


Fig. 7: Impact toughness in the three orientations of 3D printing.
Source: created by the authors.

A comparison was also made with Polylactic Acid (PLA) material, with the test specimens again obtained using FDM technology, [18]. The authors also studied three printing orientations: Upright, On edge and Flat. The values are 1.01 kJ/m^2, 2.28 kJ/m^2 and 2.65 kJ/m^2, respectively. Here again, a decrease in the values is observed for the Upright orientation compared to the on-edge orientation. This reinforces the view that the orientation of the part is of particular importance for its impact strength.

3.3 Mathematical and Statistical Analysis

To address the variability inherent to mechanical testing of additively manufactured polymers, the experimental results were subjected to a mathematical and statistical evaluation. The experimental results were additionally processed using descriptive statistics, confidence intervals, uncertainty estimation and one-way analysis of variance (ANOVA). Only the experimentally measured values from the tensile and Charpy tests were used in the calculations.

3.3.1 Statistical Evaluation of Tensile Properties

The arithmetic mean, standard deviation, variance and coefficient of variation were calculated using the following expressions:

$$\bar{x} = (1/n)\, \Sigma\, x_i \quad (4)$$

$$s = \sqrt{\Sigma(xi - \bar{x})^2/(n-1)]} \quad (5)$$

$$s^2 = \Sigma(x_i - \bar{x})^2 \,/\, (n-1) \quad (6)$$

$$CV = (s \,/\, \bar{x}) \times 100\% \quad (7)$$

where x_i is an individual measured value, n is the number of specimens, $\bar{x}$ is the mean value, and s is the sample standard deviation; CV is the coefficient of variation. For tensile testing, n = 4, while for the Charpy impact test, n = 5 for each orientation.

For small sample sizes, the 95% confidence interval was calculated using Student's t-distribution:

$$CI95 = \bar{x} \pm t0.975, n{-}1 \cdot s / \sqrt{n} \quad (8)$$

The standard uncertainty and expanded uncertainty were estimated according to:

$$u = s / \sqrt{n} \quad (9)$$

$$U = k \cdot u, \quad k = 2 \quad (10)$$

The effect of thermal treatment was quantified using:

$$\eta = [(X_{HT} - X_{AP}) / XAP] \times 100\% \quad (11)$$

where X_{AP} and X_{HT} are the mean values before and after thermal treatment, respectively.

In the present study, the expanded uncertainty was calculated using a coverage factor k = 2, which is commonly used for approximate 95% coverage in engineering measurements. The use of these statistical descriptors provides a quantitative framework for evaluating the reliability of the experimental results and directly addresses the need for stronger analytical interpretation of the measured data.

Using Eq. (11), the mean tensile strength increased from 54.33 MPa to 57.03 MPa after thermal treatment, corresponding to an improvement of 4.97%, see Table 5. The elastic modulus changed by only -1.22%, indicating that the applied treatment did not substantially modify stiffness. The strain at tensile strength increased by 5.22%, which is consistent with a moderate improvement in the deformation capacity of the treated specimens.

Table 5. Statistical summary of the tensile test results.

Property	**As-printed mean ± SD**	**Treated mean ± SD**	**Effect, %**
Elastic modulus E, GPa	2.25 ± 0.030	2.23 ± 0.115	-1.22
Tensile strength σ_m, MPa	54.33 ± 1.234	57.02 ± 1.797	4.97
Stain, ε_m,, %	4.99 ± 0.047	5.25 ± 0.305	5.22

Source: created by the authors.

The 95% confidence interval was estimated according to Eq. (8). The confidence intervals show that the scatter is higher after thermal treatment, especially for the strain values, but the overall trend in tensile strength remains positive Table 6.

Table 6. Coefficients of variation and 95% confidence intervals for the tensile results.

Property	**As-printed CV / CI95**	**Treated CV / CI95**
Elastic modulus E, GPa	1.33% / 2.20–2.30	5.16% / 2.04–2.41
Tensile strength σ_m, MPa	2.27% / 52.36–56.29	3.15% / 54.17–59.88
Stain, ε_m,, %	0.93% / 4.91–5.06	5.81% / 4.76–5.73

Source: created by the authors.

Figure 8 compares the standard-deviation error bars of the tensile strength before and after thermal treatment.

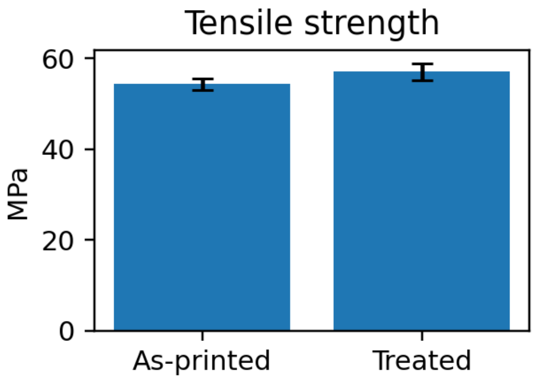


Fig. 8: Tensile strength before and after thermal treatment with standard deviation bars.

Source: created by the authors.

3.3.2 Statistical Evaluation of Charpy Impact Strength

The statistical descriptors for the three printing orientations are presented in Table 7. The results confirm a pronounced orientation effect. Orientation 1 gives the highest mean impact strength, 10.81 kJ/m², and the lowest relative scatter, CV = 2.71%. Orientation 2 gives 5.34 kJ/m², while Orientation 3 gives only 2.13 kJ/m² and the highest scatter. This indicates that the direction of crack propagation relative to the printed layers is a dominant factor in impact loading.

Table 7. Statistical evaluation of Charpy impact strength.

Orientation	**Mean a_{cU} ± SD**	**CV, %**	**CI95, kJ/m²**
Orient. 1	10.81 ± 0.293	2.71	10.45–11.18
Orient. 2	5.34 ± 0.778	14.56	4.38–6.31
Orient. 3	2.13 ± 0.364	17.05	1.68–2.58

Source: created by the authors.

In Figure 9, the Charpy impact strength for the three printing orientations with standard deviation bars is presented.

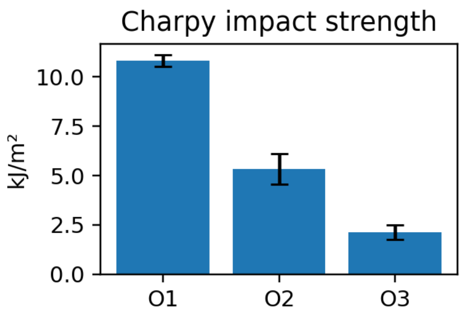


Fig. 9: Charpy impact strength for the three printing orientations with standard deviation bars.
Source: created by the authors.

A normalised orientation efficiency factor was used to quantify the loss of impact performance relative to the best orientation:

$$K_o = a_{cU}/a_{cU,max} \qquad (12)$$

Calculations are made with Eq. (12) and presented in Table 8. The standard and expanded uncertainties were also calculated. The orientation factor is equal to 1.000 for Orientation 1, 0.494 for Orientation 2 and 0.197 for Orientation 3. Therefore, Orientation 2 retains approximately 49% of the impact performance of Orientation 1, whereas Orientation 3 retains only about 20%.

Table 8. Orientation factor and expanded uncertainty for Charpy impact strength.

Orientation	**Ko**	**Decrease, %**	**U, kJ/m²**
Orient. 1	1.000	0.0	0.262
Orient. 2	0.494	50.6	0.696
Orient. 3	0.197	80.3	0.325

Source: created by the authors.

The degree of anisotropy was additionally expressed by the anisotropy coefficient:

$$A = a_{cU,max}/a_{cU,min} \qquad (13)$$

The anisotropy coefficient obtained from the experimental data is A = 5.07, which means that the most favourable orientation provides approximately five times higher impact strength than the least favourable one.

The expanded uncertainty is lowest for Orientation 1 and increases for the less favourable orientations, confirming the lower repeatability of impact behaviour when the layer arrangement promotes crack propagation.

A one-way ANOVA was applied to the Charpy impact strength results in order to evaluate the statistical significance of the orientation effect. The obtained result was $F = 350.74$, $p = 2.26e\text{-}11$, calculated according Eq. (14)

$$H0: \mu 1 = \mu 2 = \mu 3, \qquad (14)$$

H1: at least one μ_i is different

This confirms that the observed differences are not only experimental scatter but reflect a real orientation-dependent mechanical response of the PolyJet-printed material.

4 Conclusion

An experimental and statistical investigation of PolyJet-printed Digital ABS Plus specimens was performed before and after thermal treatment. The results demonstrate that thermal treatment improves the average tensile strength by approximately 5% without significantly affecting the elastic modulus, whereas the strain at tensile strength shows a moderate increase. Statistical descriptors, confidence intervals and ANOVA confirmed the reliability of the experimental observations. Build orientation exhibited a substantially stronger influence on impact behaviour than thermal treatment, with Orientation 1 providing the highest impact resistance and Orientation 3 the lowest. The one-way ANOVA confirms that the influence of printing orientation is statistically significant ($p < 0.05$), supporting the engineering recommendation that Orientation 1 should be preferred for dynamically loaded components. The results provide practical guidance for the design and manufacture of functional PolyJet Digital ABS Plus components subjected to static and impact loading.

References:

[1] Kent, N. & Jolivet, L. & O'Neill, P. & Brabazon, D., An evaluation of components manufactured from a range of materials, fabricated using PolyJet technology, *Advances in Materials and Processing Technologies*,

2017, 3, 1-12, doi: 10.1080/2374068X.2017.1330856.

[2] Das SC, Ranganathan R, N. M, Effect of build orientation on the strength and cost of PolyJet 3D printed parts, *Rapid Prototyping Journal*, 2018, Vol. 24 No. 5 pp. 832–839, https://doi.org/10.1108/RPJ-08-2016-0137.

[3] Wu C., Do T.T., Tran P., Mechanical Properties of PolyJet 3D-Printed Composites Inspired by Space-Filling Peano Curve, *Polymers (Basel)*, 2021 Oct 13, 13(20):3516. doi: 10.3390/polym13203516. PMID: 34685275; PMCID: PMC8538836.,

[4] Aitor, C. & Morer, P. and Matey, L., PolyJet technology for product prototyping: Tensile strength and surface roughness properties. *Journal of Engineering Manufacture*, 2014, Volume 228, Issue 12, https://doi.org/10.1177/0954405413518515.

[5] Bellamkonda P. N., Dwivedy M., Influence of printing orientation on properties of 3D-printed parts produced by polymer jetting technology, *Journal of Elastomers & Plastics*, 2025, 57(4), pp.407-429, doi: 10.1177/00952443251317089.

[6] Soni, Y., Rothweiler, P., Erdman, A. G., Mechanical Characterization and Feasibility Analysis of PolyJet™ Materials in Tissue-Mimicking Applications.Machines 2025, 13, 234. https://doi.org/10.3390/machines13030234.

[7] Majca-Nowak N., Pyrzanowski P., The Analysis of Mechanical Properties and Geometric Accuracy in Specimens Printed in Material Jetting Technolog, *Materials (Basel)*, 2023 Apr 11, 16(8):3014. doi: 10.3390/ma16083014. PMID: 37109851; PMCID: PMC10146525.

[8] Kęsy A., and Kotliński J., Mechanical properties of parts produced by using polymer jetting technology, *Archives of Civil and Mechanical Engineering*, 2010, volume10, pp. 3750, https://doi.org/10.1016/S1644-9665(12)60135-6.

[9] Ulu F., Tomar R.P.S., Mohan R., Processing and mechanical behavior of rigid and flexible material composite systems formed via voxel digital design in polyjet additive manufacturing, *Rapid Prototyping Journal*, 2021, Vol. 27, No. 3, pp. 617–626, https://doi.org/10.1108/RPJ-06-2020-0119.

[10] Pugalendhi A., Ranganathan R., Ganesan S., Impact of process parameters on mechanical behaviour in multi-material jetting, *Materials Today: Proceedings*, Volume 46, Part 19, 2021, pp. 9139-9144, ISSN: 2214-7853, https://doi.org/10.1016/j.matpr.2019.12.106.

[11] Standard BDS EN ISO 527-2:2012; Plastics—Determination of tensile Properties—Part 2: Test Conditions for Molding and Extrusion Plastics, Bulgarian Institute of Standardization: Sofia, Bulgaria, 2025, [Online]. https://bds-bg.org/en/project/show/bds:proj:82856 (Accessed Date: March 15, 2026).

[12] Standard ISO 179-1:2010(E) Plastics — Determination of Charpy impact properties — Part 1: Non-instrumented impact test, International Organization for Standardization, Switzerland, 2026, [Online]. https://www.iso.org/standard/91071.html (Accessed Date: March 15, 2026).

[13] *(text in Bulgarian)* Avdjieva T., Staevski K., Materials Science and Technology of Materials, University of St. Kliment Ohridski, Sofia, 2013. ISBN: 978-954-07-3468-2.

[14] Ramasamy, M. N., Sliva, A., Nag, A., Ma, Q.-P., Hilser, O., Heliova, M., Martynkova, G. S., Brozova, S., and Dizo, J., Characterization of PC-ABS and PETG Multi-Material Laminates Fabricated by MEX Method, *Polymers*, vol. 18, no. 6, Art. no. 763, 2026, doi: 10.3390/polym18060763.

[15] *(text in Bulgarian)* Penchev, T. and Hubenov, Sp., Manual for Exercises in Materials Science, TU- Sofia 2000.

[16] Stratasys, PolyJet™ Materials, [Online]. https://www.stratasys.com/en/materials/materials-catalog/polyjet-materials/digital-abs-plus/ (Accessed Date: March 15, 2026).

[17] Vidakis, N., Petousis, M., Vairis, A. et al., A parametric determination of bending and Charpy's impact strength of ABS and ABS-plus fused deposition modeling specimens. *Prog. Addit. Manuf.*, 4, pp. 323–330 (2019). https://doi.org/10.1007/s40964-019-00092-8.

[18] Gechev T., Tsonev V., Ivanov P., Kralov I. and Nedelchev K., The Influence of Printing Parameters on the Impact Strength of FDM 3D- Printed Polylactic Acid, Eng. Proc., MDPI, 2026, 121, 14, https://doi.org/10.3390/engproc2025121014.

APPENDIX

Table 3. Impact strength test results.

	Orientation 1		Orientation 2		Orientation 3	
	E_c		E_c		E_c	
Measurement	kg.cm	J	kg.cm	J	kg.cm	J
1	4.4	0.432	2.3	0.226	0.8	0.078
2	4.5	0.441	1.65	0.162	0.7	0.069
3	4.55	0.446	2.2	0.216	0.85	0.083
4	4.35	0.427	2.5	0.245	0.9	0.088
5	4.25	0.417	2.25	0.221	1.1	0.108
Average	4.41	0.433	2.18	0.214	0.87	0.085

Source: created by the authors.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Miglena Paneva carried out the tensile strength and impact strength testing methodology.
- Peter Panev has organised and executed the experiments of Section 3.2.
- Nikola Kuzmanov has organised and executed the experiments of Section 3.1. He analysed the obtained results.
- Peter Panev prepares the Tables for the manuscript and created the 3D models.
- Miglena Paneva created the graphical visualization of the obtained results.
- Miglena Paneva and Peter Panev carried out the mathematical and statistical analysis of Section 3.3.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The research was carried out as part of project No. KP-06-M87/4 “Research the wear resistance of machine elements, possibilities for optimising their properties through innovative methods and materials”, financed by the Bulgarian National Science Fund.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.