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Yüksek Hızlı 3B Yazıcıda Basılmış PLA, PETG ve ABS Numunelerin Mekanik Özellikleri

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ABS, PLA, PETG.

ÖZET

Malzemenin katmanlar halinde biriktirilmesi ile yeni bileşenlerin oluşturulmasında en popüler yöntemlerden biri olan 3B baskı başta havacılık ve tıp olmak üzere birçok alanda geniş bir ürün yelpazesi için kullanılmaktadır. 3B baskı özellikle termoplastik malzemelere odaklanmakta ve fonksiyonel dereceli ürünler kolaylıkla üretilebilmektedir. 3B baskıda kullanılan üretim parametreleri, basılan ürünlerin mekanik özelliklerini önemli ölçüde etkileyecek şekilde değişiklik gösterir. Bu çalışmada, PLA, PETG ve ABS numuneleri, ASTM standartlarına uygun olarak yüksek hızlı bir 3D yazıcı kullanılarak basılmıştır. Üretilen numunelerin malzeme özelliklerini belirlemek amacıyla çekme, sertlik, yüzey pürüzlülüğü ve su emilimi testleri yapılmıştır. Sonuçlar, en çok tercih edilen termoplastik malzemelerin (PLA, PETG ve ABS) karşılaştırmalı bir analizini sunmakta ve yüksek hızlı baskı için bir üretim kılavuzu görevi görmektedir. PETG numuneleri için maksimum gerilme 51,3 MPa olarak bulunurken, PLA için bu değer 48 MPa ve ABS numuneleri için 42,8 MPa olmuştur. Ayrıca, PETG numunesinin üst yüzeyinin ortalama sertliği 76 Shore A ile en yüksek olarak belirlenmiş, PLA ve ABS numuneleri için ise sırasıyla 69 Shore A ve 63 Shore A değerleri gözlemlenmiştir. Son olarak, işlem görmemiş haliyle en pürüzlü yüzey 9,441 Ra ile ABS numunelerinde elde edilmiştir ve zımparalama işlemleri ile yüzey kalitesinde önemli iyileşmeler gözlemlenmiştir.

Mechanical Properties of PLA, PETG, and ABS Samples Printed on a High-Speed 3D Printer

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ABSTRACT

3D printing, one of the most popular methods for creating new components through the deposition of material in layers, is used across a wide range of products, particularly in the aerospace and medical fields. 3D printing focuses especially on thermoplastic materials, allowing for the easy production of functionally graded products. The manufacturing parameters used in 3D printing vary, significantly affecting the mechanical properties of the printed items. In this study, PLA, PETG and ABS samples were printed using a high-speed 3D printer in accordance with ASTM standards. Tensile, hardness, surface roughness and water absorption tests were performed to determine the material properties of the produced samples. The results provide a comparative analysis of the most preferred thermoplastic materials (PLA, PETG and ABS) and serve as a production guide for high-speed printing. The maximum stress for PETG specimens was found to be 51.3 MPa, while for PLA it was 48 MPa and for ABS specimens 42.8 MPa. In addition, the average hardness of the top surface of the PETG sample was found to be the highest with 76 Shore A, while 69 Shore A and 63 Shore A values were observed for PLA and ABS samples, respectively. Finally, the roughest surface in the untreated state was obtained in ABS samples with 9.441 Ra and significant improvements in surface quality were observed with sanding processes.

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INTRODUCTION

Three-dimensional printing is an innovative manufacturing method that enables the rapid and cost-effective creation of complex parts by adding layers. [1]. This technology begins with the creation of a digital model using computer-aided design (CAD) software. This digital model is then transferred to a 3D printer, enabling the production of 3D objects using different materials. This method is frequently preferred in various fields such as automotive, aerospace, and biomedical [2] for purposes such as prototyping, customized products, and R&D [3].

Despite providing many benefits, 3D printing also comes with some disadvantages. Firstly, in certain industrial applications, the production processes can be longer compared to traditional manufacturing methods. Considering the time and material required for the production of large parts, the cost of 3D printing can increase. Additionally, the surface roughness of parts produced by 3D printing is generally high, which can lead to undesirable results in certain applications. Material options are sometimes limited, and suitable options may not be available for specific applications. Lastly, the efficiency of 3D printing for mass production is lower compared to traditional manufacturing methods [4].

The materials used in this method vary widely based on the needs of the printing process, the intended use of the final product, and the desired properties. Various types of materials, including plastics, metal alloys, ceramics, biological materials, and hybrid materials [5], can be used in 3D printing. Plastics are generally the most commonly used type of material and can be divided into many subcategories with different properties; these include thermoplastics, thermosets, elastomers, and biodegradable plastics [6].

Among the most used polymer materials in 3D printing are PLA, PETG, and ABS. These materials have a wide range of applications in various industrial and personal uses and are frequently preferred by the 3D printing community [7].

Polylactic acid (PLA) is a thermoplastic monomer typically derived from organic, renewable sources such as sugarcane or corn starch. PLA is considered an environmentally friendly option as it is biodegradable and sourced from renewable resources. Some of its many advantages include ease of production, recyclability, biocompatibility, and minimal or no carcinogenic effects. PLA is frequently used in both food and medical applications. The absence of smoke or unpleasant odors during printing, along with its ease of sanding, painting, or other finishing processes, increases its preference for 3D printing [8].

PETG (Polyethylene Terephthalate Glycol) is a thermoplastic material widely used in various fields such as 3D printing, packaging, and medical devices. Its advantages include high impact resistance and flexibility, low shrinkage tendency, chemical resistance, and ease of processing. PETG also offers high transparency and glossy surface quality, making it aesthetically appealing. Its recyclability is an environmental benefit. However, it also has disadvantages. PETG tends to soften at high temperatures, which can limit its performance in certain applications. Additionally, it can be more expensive compared to some other thermoplastics. Adhesion issues and moisture absorption capacity can also be drawbacks for some users [9].

ABS (Acrylonitrile Butadiene Styrene) is a widely used thermoplastic favored in various fields such as automotive parts, toys (e.g., LEGO), electronic housing, and 3D printing. Its advantages include high impact resistance, rigidity, durability, good heat resistance, and excellent processability. ABS has good flow properties, allowing to produce complex shapes, and it can be painted and coated, making it suitable for various aesthetic applications. Additionally, it is relatively cost-effective and available in a wide range of colors. However, ABS also has disadvantages. It can emit an unpleasant odor during production and typically requires high temperatures during 3D printing, which can lead to warping issues. Moreover, it has low resistance to UV radiation and environmental stress cracking, making it less ideal for outdoor applications. Furthermore, recycling ABS is more challenging compared to some other plastics, and it can have a more significant negative environmental impact [10].

Many researchers are conducting studies to optimize the printing process parameters used in the production of 3D parts. A detailed analysis of the mechanical properties of 3D printed parts helps manufacturers predict the mechanical behaviour of the printed part; this demonstrates the necessity of effectively adjusting process parameters to obtain parts of desired quality [2].

This study examined the hardness, surface roughness, tensile strength, and water absorption properties of ABS, PETG, and PLA 3D printing samples. The tensile properties of the samples were evaluated using ASTM D638 standard, while water absorption properties were tested by conditioning in pure water at 25%, 50%, 75%, and 100% saturation levels followed by mass measurements. Surface roughness analysis was conducted by abrading the samples with three different sandpapers (220, 400, and 800 grit) and then measuring with the Surface Roughness Tester TR200 device. Hardness tests were performed using the Shore D version of the Shore NOVOTEST TS-A device, suitable for thermoplastic materials and compliant with ASTM D2240 standard.

MATERIALS AND METHODS

Supply of 3D Printer and Materials

The 3D printer used in the study is shown in Figure 1.

Figure 1
Creality brand 3D printer (while printing tensile specimens with PLA filament material)

After conducting the research, PETG filament was purchased from Elas 3D, PLA filament from Microzey, and ABS filament from Porimo. All filaments have a diameter of 1.75 mm and are in 1 kg spools. The specifications provided by the companies for the purchased filaments are detailed in Table 1.

Table 1
Properties of materials used in 3D printing

Print Specifications	PLA	PETG	ABS
Extrusion Temperature (°C)	190-230	230-250	220-260
Bed Platform Temperature (°C)	25-80	60-80	80-110
Density (g/cm³)	1.24	1.32	1.04
Recycling	Yes	Yes	Yes
Biodegradability	Yes	No	No
Smoke Toxicity	Low	Low	Medium

Additionally, 5 liters of distilled water and three different types of sandpaper (220, 400, and 800 grit) were purchased for use in the tests.

Production of 3D Parts

As part of the project, sample sizes were determined in accordance with relevant ASTM standards or literature. The geometry of the samples was modeled using SolidWorks and saved in STL format. Subsequently, the models were simulated for 3D printing and necessary parameters were adjusted using Creality Print software (Figure 2).

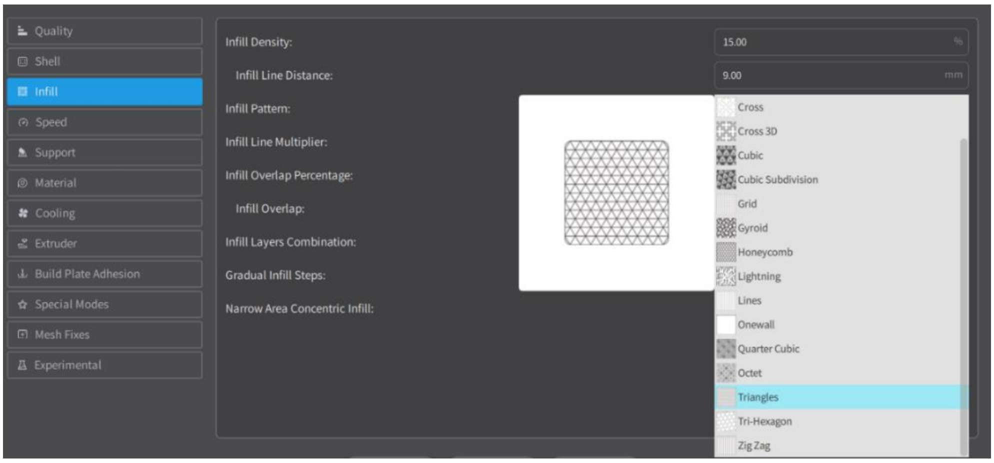

Figure 2
Interface used when setting printing parameters with Creality Print software

The basic parameters used for printing the parts are provided in Table 2.

Table 2
Basic printing parameters of 3D parts

Process Parameters	PLA	PETG	ABS
Layer Thickness (mm)	0,2	0.2	0.2
Initial Layer Thickness (mm)	0.2	0.2	0.2
Number of Wall Lines	2	2	2
Number of Upper and Lower Lines	4	4	4
Raster Angle	45°/-45°	45°/-45°	45°/-45°
Filling Pattern	Triangles	Triangles	Triangles
Filling Speed (mm/s)	300	300	300
Printing Temperature (°C)	230	250	260
Nozzle Diameter (mm)	0.4	0.4	0.4
Room Temperature (°C)	25±1	25±1	25±1
Relative Humidity (%RH)	50±5	50±5	50±5

Tensile Test

The samples designed in SolidWorks program for determining tensile strength in accordance with ASTM D638 standard geometry are shown in Figure 3.

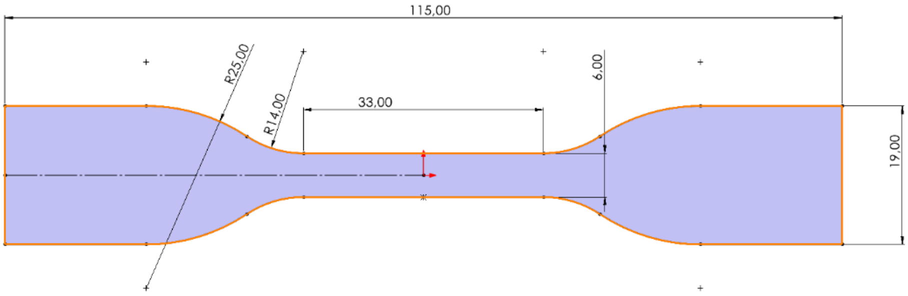

Figure 3
Geometry of specimens used in tensile tests

The tensile specimens designed in SolidWorks were saved in STL format, edited using Creality Print software, and transferred to the printer (Figure 4).

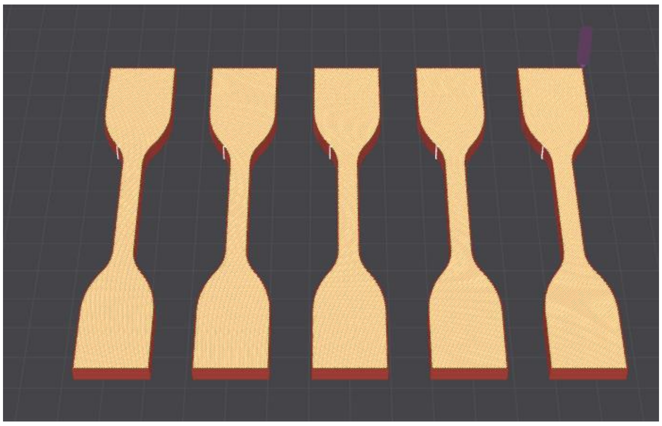

Figure 4
Preparation of tensile samples for printing in Creality Print software

The produced samples (Figure 5) were tested using the Shimadzu Tensile Testing Machine located in the Mechanical Laboratory of Necmettin Erbakan University, Department of Mechanical Engineering.

Figure 5
Tensile samples produced by 3D printer (yellow colour ABS filament material, black colour PETG filament material)

Hardness Test

To determine the hardness of the materials, the Shore Durometer NOVOTEST TS-A device was used (Figure 6). This testing device is typically used to measure the hardness of elastomers, rubber, plastics, and other soft materials. It operates using the Shore A scale, which measures how much deformation a material undergoes under a specified pressure applied to its surface [11].

Figure 6
a) Shore Durometer NOVOTEST TS-A hardness tester, b) zeroing the load scale

Surface Rouhgness

To enhance the aesthetic appearance of 3D parts, various surface treatments such as sanding, filling, painting, or chemical processes are employed. Therefore, the response of filament materials to sanding is crucial. In this project, samples made from three different materials (PLA, PETG, and ABS) were sanded at three different grades (220, 400, and 800 grit) to investigate surface quality. The sanding process progressed stepwise to higher grits; for example, 220 and 400 grit sanding were performed before using 800 grit sandpaper. Sanding was conducted in a wet environment and continued in one direction until the marks underneath disappeared (Figure 7).

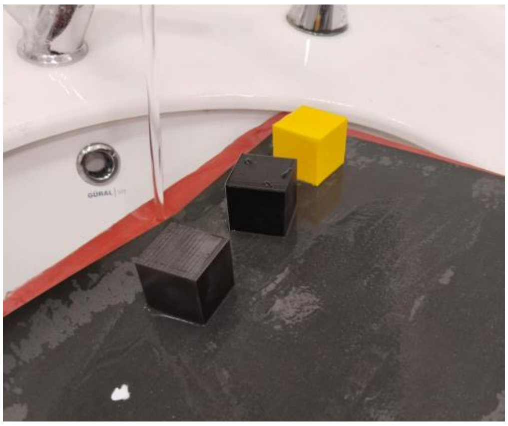

Figure 7
Gradual sanding of the samples in aqueous medium

The Surface Roughness Tester TR200 was used to determine the surface roughness of the samples (Figure 8). Surface roughness was measured in two different angular directions, 0° and 90°, and expressed as the arithmetic average value known as Ra.

Figure 8
Surface roughness tester TR200

Water Absorption Behaviour

As part of the study, cubic parts measuring 3x3x3 cm were produced at 25%, 50%, 75%, and 100% infill densities using three different filament materials (PLA, PETG, and ABS) (Figure 9).

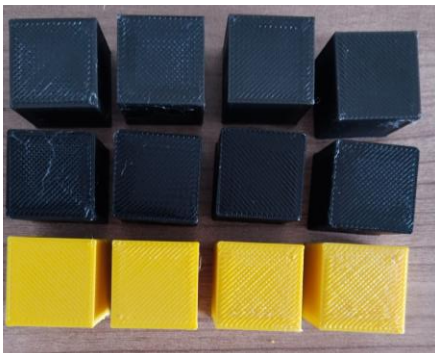

Figure 9
PETG (top), PLA (middle) and ABS (bottom) filament material specimens of different fillings produced to determine water absorption behavior

These parts were fully immersed in distilled water and regular daily mass measurements were taken (Figure 10).

Figure 10
Weighing the samples by keeping them in pure water

Thus, the aim was to determine both the water absorption levels of the samples based on infill density and filament material, as well as any dimensional changes that may occur over time.

RESULTS

The results of the study conducted in the project were analyzed in four parts: tensile test analyses, hardness test analyses, surface roughness analyses, and water absorption behavior analyses.

Tensile Test Analyses

The samples were tested using the Shimadzu Tensile Testing Machine according to ASTM D638 standard, at a crosshead speed of 5 mm/min, at 23°C room temperature, and with 5 repetitions. The data obtained from the tests were analyzed using Excel software and shown in Figure 11. Upon examining the graph, it is observed that in terms of the slope in the elastic region, PLA filament material has the highest modulus of elasticity, while PETG material has the lowest modulus. Additionally, the area under the curves represents the energy required to fracture the material, indicating its toughness. In this context, PETG material exhibits the highest toughness, whereas PLA material shows the lowest toughness.

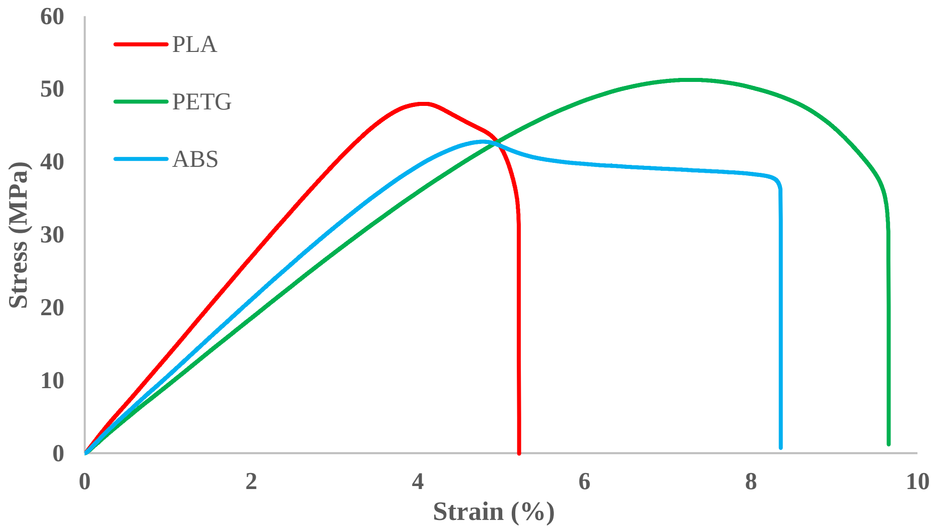

Figure 11
Stress strain graph

The equations used in the calculations are as follows:

$\sigma = F / A$ …………………………. (Equation 1)

Here, σ represents the stress value; F denotes the tensile force obtained by the testing machine. A represents the cross-sectional area ($4x6=24mm^2$) of the tensile specimen.

$\varepsilon = (\Delta L / L0).100$…………………..... (Equation 2)

Here, ε represents the percentage elongation (% strain), ΔL denotes the amount of elongation that occurred, and L0 represents the initial gauge length.

$E = \sigma / \varepsilon$ …………………………... (Equation 3)

Here, E represents the slope of the linear region of the stress-strain diagram, which is the elastic modulus.

$\int_0^{\varepsilon_k} \sigma . d\varepsilon$ …………………………… (Equation 4)

The value obtained from Equation 4 represents the area under the stress-strain curve, indicating the toughness of the specimen. The results of the calculations and analyses are comprehensively presented in Table 3.

Table 3
Mechanical properties of specimens

Mechanical Properties	PLA	PETG	ABS
Elastic Modulus (MPa)	1346.4±20	905.6±10	1030.0±15
Max. Stress (MPa)	48.0±2	51.3±2	42.8±1
Max. Strain (%)	5.22±0.1	9.65±0.1	8.36±0.1
Toughness (kJ/m³)	159.2±5	334.4±8	256.7±7

When examining Table 3, the maximum tensile strength is achieved in PETG samples up to 51.3 MPa, while PLA and ABS samples yielded 48 MPa and 42.8 MPa, respectively. Additionally, the elastic modulus, an important parameter in material characterization, was highest in PLA samples at 1346.4 MPa, followed by PETG at 905.6 MPa and ABS at 1030 MPa.

The differences in tensile properties between PLA, PETG and ABS materials are related to their molecular structure and thermal behaviour. Although PLA offers high tensile strength, it lacks flexibility due to its crystalline structure, which can cause the material to be brittle under stress. PETG is a PET copolymer that combines the stiffness of PLA with improved flexibility and impact resistance. Its molecular structure provides better adhesion between layers during 3D printing, increasing the overall durability of the material. On the other hand, ABS allows more deformation thanks to its more amorphous structure, making it a suitable option for applications subjected to high mechanical stress or impacts [12,13]. The data obtained in this context are consistent with the findings obtained from other studies in the literature [14].

Hardness Test Analyses

The hardness tests were conducted using the Shore Durometer NOVOTEST TS-A device, with repeated tests at 5 different points on each sample. The test samples were at 100% infill, and both the top and side surfaces of the samples were tested. The data obtained from the tests are presented in Table 4.

Table 4
Hardness analysis of the samples (Unit: Shore A - 50 Shore A medium hardness, 30 Shore A softer flexible material, 90 Shore A hard plastic)

PLA- Top	PLA- Side	PETG- Top	PETG- Side	ABS- Top	ABS- Side
72	50	77	66	64	72
68	46	87	52	63	73
68	53	79	56	62	65
67	48	62	64	63	75
70	51	75	61	64	74

When examining Table 4, differences in hardness values between the top and side surfaces of the samples can be observed. The average hardness on the top surface of the PETG sample reaches the highest value at 76 Shore A, whereas for PLA and ABS samples, it is calculated as 69 Shore A and 63 Shore A, respectively. In terms of side surfaces, the highest hardness is obtained in the ABS sample with an average value of 72 Shore A, while for PLA and PETG samples, values of 50 Shore A and 60 Shore A, respectively, are calculated. In light of all this data, it is evident that all examined samples are moderately hard polymer samples, with no significant characteristic differences among the values.

PLA has a more brittle structure compared to other materials, with relatively low tensile strength and impact resistance. Its rigid and crystalline structure can show brittleness without allowing significant deformation and therefore its stiffness is lower. ABS, on the other hand, is known for its high strength and durability as a petroleum-based thermoplastic. It has high impact strength, can withstand higher temperatures and provides higher elongation at break than PLA, making it more resistant to bending and deformation and increasing its stiffness. PETG is a thermoplastic that combines the advantages of PLA and ABS. Offering moderate tensile strength, PETG excels in impact resistance and layer adhesion. Thanks to its ability to withstand deformation without cracking, PETG's stiffness is higher than that of PLA, making it a suitable choice for applications requiring both strength and flexibility [15]. As a result, hardness differences between these materials are due to the unique components and mechanical properties of each material. Furthermore, variable parameters in 3D printing processes can lead to variations in these hardness properties [16].

Surface Roughness Analyses

Surface roughness was measured in two different angular directions, 0° and 90°, using the Surface roughness tester TR200, and expressed as the arithmetic average value of the surface roughness parameter Ra. The obtained data are presented in Table 5.

Table 5
Surface roughness values of the samples (Unit Ra)

	Top Surface	Side Surface (0°)	Side Surface (90°)	220 grid top surface	220 grid side surface	400 grid top surface	400 grid side surface	800 grid top Surface	800 grid side surface
PLA	6.603	0.502	11.207	2.195	1.338	1.623	1.173	1.054	0.654
PETG	6.166	0.645	11.506	1.828	1.323	1.148	1.146	0.687	0.763
ABS	9.441	0.792	11.519	2.865	1.222	2.005	0.995	1.363	0.861

When Table 5 is analysed, it is seen that there are differences in surface roughness depending on the material and printing wool. According to the data, it is seen that the roughest top surface is obtained in ABS specimens with 9.441 Ra in the untreated state. On the side surfaces, the surface roughness varies considerably depending on the printing direction and the material difference does not create a characteristic. In addition, the surface quality is greatly improved with the sanding processes and the values are very close to each other in the last step.

Studies show that the surface roughness of PLA is approximately 7% less than PETG and 50% less than ABS. This smoothness is attributed to its low tendency to deform during printing and excellent layer adhesion [17]. However, it is stated that the surface quality decreases with the increase of the printing speed and PLA samples have the highest decrease among the specified materials [18]. ABS typically results in the roughest surface finish of these materials. Surface roughness is affected by factors such as warping and delamination during high-speed printing. The inherent brittleness of ABS leads to more pronounced layer lines and imperfections compared to PLA and PETG [19].

Water Absorption Analysis of 3D Parts

The samples produced from PLA, PETG and ABS filament materials with 25%, 50%, 75% and 100% filling were kept in pure water and weighed every day. Thus, it was possible to analyses the relationship between the water absorption of the specimens and the material and occupancy. The data obtained as a result of the measurements are given in Table 6.

When examining Table 6, it is observed that the material that absorbs the most water is the PLA filament. Additionally, the mass percentage change increases with the increase in void content and the filling of these voids with water. When comparing the samples with full infill, the changes in the masses of PLA, PETG, and ABS samples after 30 days of conditioning were calculated as 1.04%, 0.3%, and 0.96%, respectively.

PLA has a high-water absorption capacity over time due to its organic structure and hygroscopic properties, which causes the material to show significant changes as it encounters water. PETG, on the other hand, exhibits moderate water absorption and provides better structural integrity than PLA when in contact with moisture. ABS has the lowest water absorption rate of the three materials and is therefore less susceptible to degradation from moisture; however, it can still be affected by high humidity environments [20].

Table 6
Changes in the masses of the samples produced with PLA, PETG and ABS filament material at 4 different filling levels (25%, 50%, 75% and 100%) after standing in water - A:PLA, B:PETG and C:ABS (values in grams)

DAYS	A100	A75	A50	A25	B100	B75	B50	B25	C100	C75	C50	C25
1	9.65	8.01	6.08	4.14	9.94	8.23	6.37	4.58	8.33	7.36	5.93	4.31
2	9.68	8.05	6.09	4.17	9.94	8.23	6.38	4.61	8.35	7.37	5.95	4.32
3	9.69	8.06	6.11	4.29	9.95	8.24	6.39	4.62	8.36	7.39	5.95	4.32
4	9.69	8.08	6.16	4.34	9.95	8.25	6.41	4.68	8.36	7.39	5.95	4.33
5	9.70	8.10	6.21	4.39	9.95	8.26	6.42	4.74	8.37	7.39	5.95	4.33
6	9.70	8.11	6.22	4.39	9.95	8.27	6.43	4.74	8.37	7.39	5.96	4.34
7	9.70	8.12	6.22	4.39	9.95	8.27	6.43	4.74	8.37	7.39	5.96	4.34
8	9.71	8.12	6.22	4.39	9.95	8.27	6.43	4.75	8.38	7.39	5.96	4.34
9	9.72	8.13	6.22	4.39	9.96	8.27	6.43	4.75	8.38	7.40	5.97	4.34
10	9.72	8.13	6.22	4.39	9.96	8.27	6.43	4.75	8.38	7.40	5.97	4.34
11	9.72	8.14	6.22	4.39	9.96	8.27	6.43	4.76	8.38	7.40	5.97	4.34
12	9.72	8.14	6.22	4.39	9.96	8.27	6.43	4.76	8.39	7.40	5.97	4.35
13	9.72	8.14	6.22	4.39	9.96	8.27	6.43	4.76	8.39	7.40	5.97	4.35
14	9.72	8.15	6.22	4.39	9.96	8.27	6.43	4.76	8.39	7.41	5.97	4.35
15	9.73	8.15	6.23	4.39	9.96	8.27	6.43	4.77	8.39	7.41	5.97	4.35
16	9.73	8.15	6.25	4.39	9.96	8.28	6.43	4.78	8.39	7.41	5.97	4.35
17	9.73	8.15	6.25	4.39	9.97	8.28	6.43	4.78	8.39	7.41	5.97	4.35
18	9.73	8.15	6.25	4.39	9.97	8.28	6.43	4.79	8.40	7.41	5.97	4.35
19	9.73	8.15	6.26	4.39	9.97	8.28	6.43	4.79	8.40	7.42	5.97	4.35
20	9.74	8.15	6.26	4.39	9.97	8.28	6.43	4.80	8.40	7.42	5.97	4.35
21	9.74	8.16	6.27	4.39	9.97	8.28	6.43	4.80	8.40	7.42	5.98	4.35
22	9.74	8.16	6.27	4.39	9.97	8.28	6.43	4.80	8.40	7.42	5.98	4.35
23	9.74	8.16	6.28	4.39	9.97	8.28	6.43	4.80	8.40	7.42	5.98	4.35
24	9.74	8.17	6.28	4.39	9.97	8.29	6.43	4.80	8.40	7.42	5.98	4.35
25	9.74	8.17	6.29	4.39	9.97	8.29	6.43	4.80	8.41	7.42	5.98	4.35
26	9.75	8.17	6.29	4.39	9.97	8.29	6.43	4.80	8.41	7.43	5.98	4.35
27	9.75	8.18	6.30	4.39	9.97	8.29	6.43	4.80	8.41	7.43	5.98	4.35
28	9.75	8.18	6.30	4.39	9.97	8.29	6.43	4.80	8.41	7.43	5.98	4.35
29	9.75	8.18	6.31	4.39	9.97	8.29	6.43	4.80	8.41	7.43	5.98	4.35
30	9.75	8.18	6.31	4.39	9.97	8.29	6.43	4.80	8.41	7.43	5.98	4.35
Increase (%)	**1.04**	**2.12**	**3.78**	**6.04**	**0.30**	**0.73**	**0.94**	**4.80**	**0.96**	**0.95**	**0.84**	**0.93**

Considering the obtained data, it is understood that the water absorption amounts of the samples are quite limited and negligible. Furthermore, the obtained data are consistent with other studies in the literature. Thus, it was possible to analyses the relationship between the water absorption of the specimens and the material and occupancy [21].

DISCUSSION AND CONCLUSIONS

In this study, samples were produced and experiments were conducted in accordance with ASTM standards to examine the hardness, surface roughness, tensile strength, and water absorption properties of ABS, PETG, and PLA 3D printed samples. The main results are as follows:

- As a result of the tensile tests, the maximum stress was obtained in PETG samples with 51.3 MPa, while it was 48 MPa and 42.8 MPa in PLA and ABS samples, respectively. Additionally, the modulus of elasticity, which is an important parameter in material characteristics, was highest in PLA samples with 1346.4 MPa, and in PETG and ABS samples, it was 905.6 MPa and 1030 MPa, respectively.
- The average hardness on the top surface of the PETG sample was the highest with 76 Shore A, while it was 69 Shore A and 63 Shore A for PLA and ABS samples, respectively. Considering the obtained data, it is understood that all the examined samples are medium-hardness polymer samples.
- Differences in surface roughness were observed depending on the type of material and the printing direction. According to the data, the roughest top surface, in its untreated state, was obtained in ABS samples with 9.441 Ra. For the side surfaces, surface roughness varied significantly depending on the printing direction, and the sanding processes greatly improved the surface quality, bringing the values quite close to each other in the final step.

It was determined that the material absorbing the most water was the PLA filament. Additionally, the mass percentage change increased with the increase in void content and the filling of these voids with water. When comparing the samples with full infill, the changes in the masses of PLA, PETG, and ABS samples after 30 days of conditioning were calculated as 1.04%, 0.3%, and 0.96%, respectively.

Ethical Statement

This study is an original research article designed and developed by the authors.

Ethics Committee Approval

This study does not require any ethics committee approval.

Author Contributions

Research Design (CRediT 1) M.Y. (%75) – M.E. (%25)
Data Collection (CRediT 2) M.Y. (%75) – M.E. (%25)
Research - Data Analysis – Validation (CRediT 3-4-6-11) M.Y. (%75) – M.E. (%25)
Writing the Article (CRediT 12-13) M.Y. (%75) – M.E. (%25)
Revision and Improvement of the Text (CRediT 14) M.Y. (%75) – M.E. (%25)

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals (SDG)

Sustainable Development Goals: 9: Industry, Innovation, and Infrastructure

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