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Tensile and wear behavior of 3D printed ABS and PC/ABS: An experimental study

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Abstract **–** 3D (three-dimensional) printing technology stands out as an innovative manufacturing method with its unique and revolutionary nature, setting it apart from traditional production methods. In this technology, the ability to shape materials without generating chips and the absence of the need for molding are just a few factors supporting its increasing use in the manufacturing industry. The software, equipment, and materials used in 3D printing technology are rapidly advancing, enabling the cost-effective and swift production of more durable and long-lasting components. In this study, the mechanical and tribological properties of ABS (Acrylonitrile Butadiene Styrene), one of the most commonly used materials in 3D printing technology, were comparatively examined with PC/ABS, a polymer alloy obtained by blending ABS with PC (Polycarbonate). Tensile tests conducted on standard specimens fabricated through 3D printing revealed that the tensile strength of PC/ABS is approximately 112% higher than that of ABS. To investigate the tribological properties of the materials and examine the effects of layer thickness and surface conditions, adhesive wear tests were conducted on samples 3D printed onto different build plates with varying layer thicknesses. According to the results of the wear test, PC/ABS demonstrated superior wear performance to ABS under all test conditions.

Keywords – 3D Printing, Tensile Properties, Dry Sliding, Polymer Blend, Charecterization.

I. INTRODUCTION

Additive Manufacturing (AM) revolutionizes traditional production by enabling the layer-by-layer construction of intricate structures. Fused Deposition Modeling (FDM), a widely embraced AM method, garners popularity, especially among individual users, due to its utilization of affordable polymer-based materials and straightforward equipment requirements [1–3].

Fused Deposition Modeling (FDM) stands out as an accessible and budget-friendly manufacturing solution, attracting attention for its user-friendly characteristics. Its versatility in creating intricate designs using a range of polymer materials, from affordable and eco-friendly options like PLA to advanced engineering materials like PEEK and PEI, distinguishes it from other AM methods. Notably, FDM simplifies the manufacturing process compared to resin-based AM techniques, offering a straightforward and convenient choice for users. Therefore, FDM has captured the attention of researchers due to its potential for development. Emphasizing the enhancement of the technique involves not only improving software and equipment but also advancing materials [4,5].

In this study, the mechanical and tribological properties of the widely used 3D printing filament, ABS, were examined and compared with a next-generation filament material, PC/ABS alloy. For this purpose, uniaxial tensile tests have been conducted, and wear tests have been applied to samples with different surface/manufacturing parameters to investigate the effect of layer thickness and surface roughness on wear behavior.

II. MATERIAL AND METHOD

The samples examined in this research were manufactured on a CREALITY brand (CR-M4 model) 3D printer with the printing parameters specified in Table 1. Manufacturing process was carried out using 1.75 mm diameter black PC/ABS (Polycarbonate/Acrylonitrile Butadiene) and ABS filaments produced by BASF-Ultrafuse company. Before the manufacturing process, the filament materials were dried according to the procedure specified in the manufacturer's datasheet. STL files were created using Ultimaker Cura software version 5.6.0 with default settings for all parameters except those listed in Table 1.

Table 1. Fabrication parameters

Printing Speed (mm/s)	**Layer Height (mm)**	**Infill Density (%)**	**Printing Temperature (ºC)**	**Build Plate Temperature (ºC)**	**Build Plate Material**	**Surface Pattern**	**Orientation**
60	0.1, 0.2, 0.3	100	270	99	PEI coated & smooth spring steel	Lines	XYZ

Tensile test specimens were manufactured with a layer thickness of 2 mm according to the dimensions specified by ISO 527-2 (Type 1A). Tests were carried out at room temperature at a constant deformation rate of 2 mm/min. From the stress-strain curves obtained from these tests, the characteristic mechanical properties of tensile strength at yield (σ_y), tensile modulus (E) and elongation at break (ε) were obtained by calculating the average values for 3 repetitions.

For the wear tests performed according to the parameters listed in Table 2, a pin-on-disk test device from Nanovea was used. Adhesive wear tests were conducted on the different surfaces of test specimens measuring 18x18x2.2 mm^3 with 8 mm corner radii. Optical microscope images of these samples are given in Figure 1. While coding the samples, the first letter of the word “Top” was used for the surface on the nozzle side, the word “Bottom” for the surface in contact with the build plate, the word “Rough” for the PEI coated spring steel plate, and the first letter of the word smooth for the uncoated surface of the spring steel plate. For example, the expression ABS_B_R refers to the sample printed with ABS filament on a PEI-coated plate. By measuring the traces shown in the figure, the trace width (D) values were found, the wear volumes (V) were calculated by substituting them in Equation 1, and the wear rate values were calculated by using Equation 2 [6,7].

Table 2. Pin-on disc test parameters

Disc Speed (rpm)	**Force (N)**	**Sliding distance (m)**	**Friction radius, R (mm)**	**Ball radius (mm)**	**Ball material**
250	20	50	6	3	Hardened Steel

$$V = \frac{\pi \times R \times D^3}{6 \times r} \quad (1)$$

$$k = \frac{V}{L \times X} \quad (2)$$

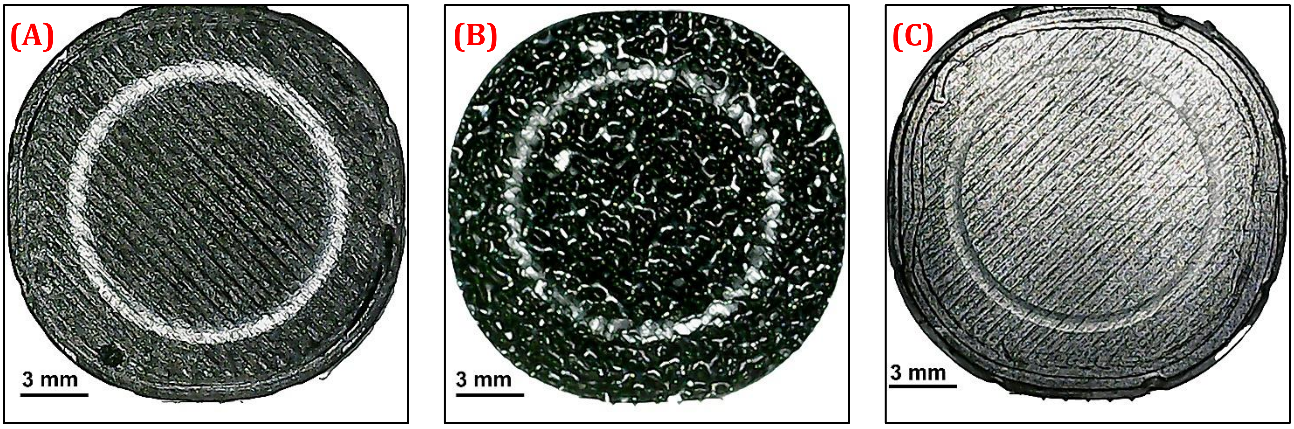

Figure 1. Optical microscope images of samples with different surface patterns; a) Top surface, b) Bottom surface rough, c)Bottom surface smooth

III. RESULTS

Tensile test results of samples manufactured in Type 1A dimensions from ABS and PC/ABS materials via 3D printing are shown in Figure 2. The characteristic mechanical properties obtained from the curves in the figure are listed in Table 3.

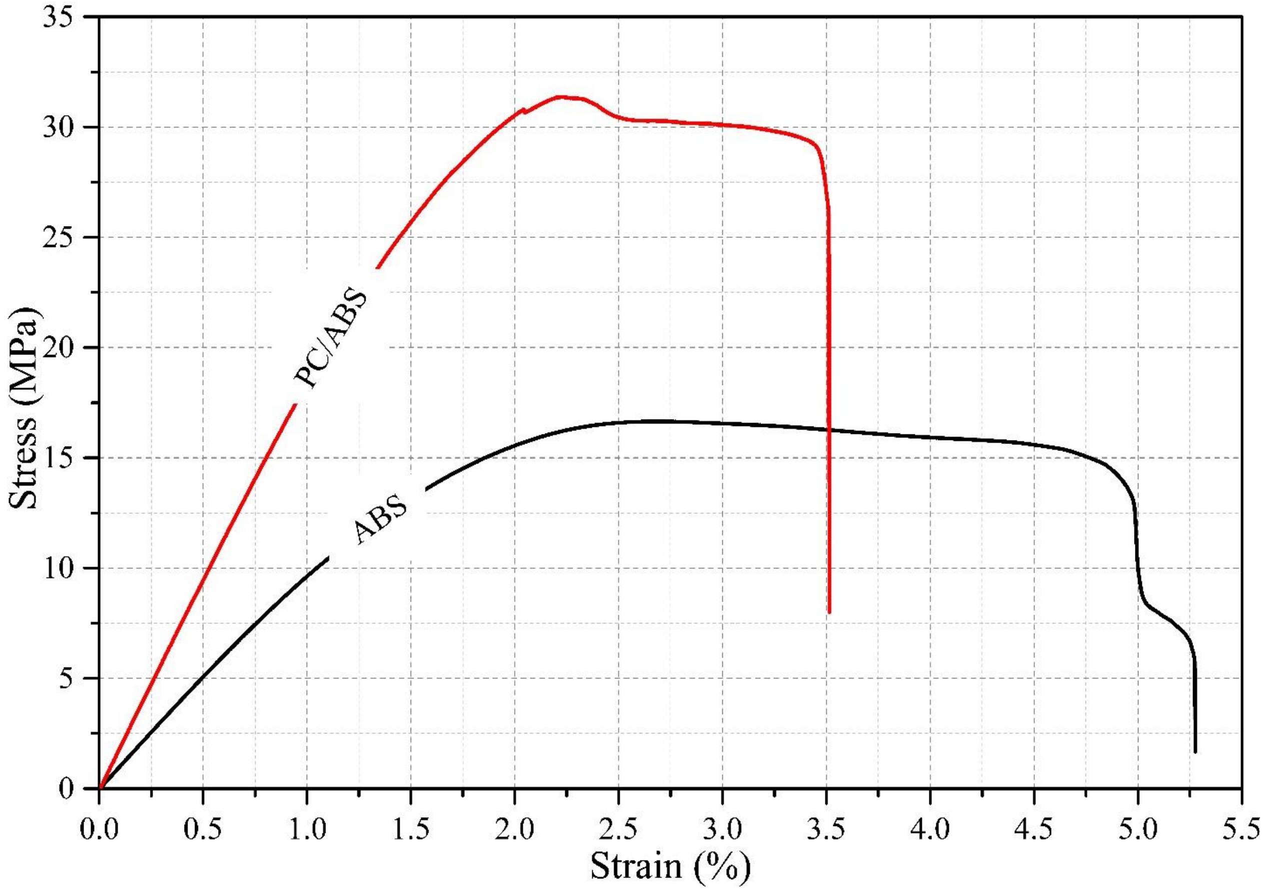

Figure 2. 3D printed materials' representative curves for uniaxial tensile test behaviors

Table 3. The findings of uniaxial tensile testing

	ABS	PC/ABS
σ (MPa)	16.7 ±1.3	35.5 ±4.3
E (GPa)	10.0 ±2.0	17.3 ±0.9
ε (%)	5.3 ±0.3	4.2 ±0.8

The wear rate values obtained from dry friction tests of different surfaces of ABS and PC/ABS based samples are given in Figure 3 and listed in Table 4.

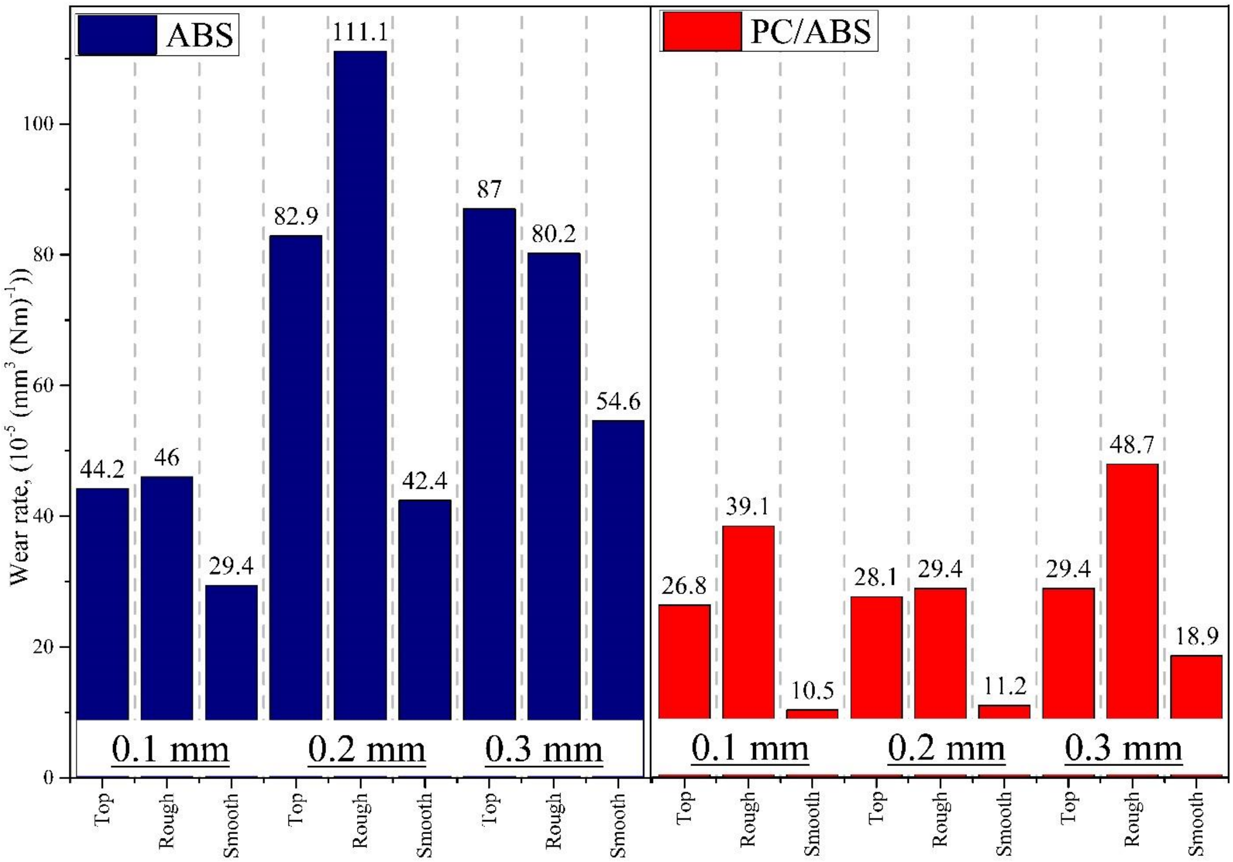

Figure 3. A comparative graph depicting wear rates for various surface types and layer thicknesses

Table 4. The computed wear rates for various layer thicknesses and surface types

	ABS									PC/ABS								
Layer Thickness (mm)	0.1			0.2			0.3			0.1			0.2			0.3		
Surface	Top	Rough	Smooth	Top	Rough	Smooth	Top	Rough	Smooth	Top	Rough	Smooth	Top	Rough	Smooth	Top	Rough	Smooth
Wear Rate x10^{-5} (mm^3/Nm)	44.2	46.0	29.4	82.9	111.1	42.4	87.0	80.2	54.6	26.8	39.1	10.5	28.1	29.4	11.2	29.4	48.7	18.9

IV. DISCUSSION

As observed in the stress-strain diagram depicted in Figure 2, the mechanical responses of PC/ABS and ABS differ. ABS exhibited a more ductile fracture behavior, rupturing with an elongation of approximately 5%. In contrast, PC/ABS displayed a higher modulus and yield strength, experiencing failure at an elongation of around 3.5%. Moreover, the sudden drop in the curve indicates significant yielding in PC/ABS after reaching maximum stress, suggesting that the material is not inherently brittle. Examining the curves in the figure and the data in the table reveals that PC/ABS demonstrated superior mechanical properties despite its inherent brittleness compared to ABS.

The wear rate data in Figure 3 and Table 4 are provided for samples with various surface conditions and layer thicknesses. Upon examining the results, it is evident that ABS exhibits higher wear resistance than PC/ABS across all test parameters.

When the materials are examined individually for different test parameters, it is observed that ABS demonstrates the best wear performance with a layer thickness of 0.1 mm. Additionally, as expected, the lowest wear rate values have been calculated for smooth surfaces at all layer thickness values. An aspect that can be considered as an unexpected result is the worst wear performance exhibited by the sample with a rough surface (ABS_B_R) for a layer thickness value of 0.2 mm. This situation may be attributed to an experimental error, as for a layer thickness of 0.2 mm, ABS exhibited better wear performance on TOP and smooth surfaces.

PC/ABS material's wear test results indicate a consistent pattern, with higher wear rates observed on rough surfaces for all layer thicknesses and lower rates on smooth surfaces. Furthermore, the wear rate for a 0.1 mm layer thickness is lower than that of other thicknesses, aligning with expectations.

V. CONCLUSION

This study focuses on comparing the widely used 3D printing filament, ABS, with the newer generation filament, PC/ABS, highlighting the distinctions and characteristics between the two materials in terms of mechanical and tribological properties under various conditions. For this purpose, 3D printed samples were subjected to comprehensive tensile and wear tests, providing insights into the mechanical and tribological properties of these materials.

According to the tensile test results, PC/ABS demonstrated superior mechanical performance by exhibiting approximately 112% higher yield strength and 74% higher tensile modulus than ABS until the point of rupture.

Wear test results indicated that PC/ABS generally exhibited higher wear resistance compared to ABS across various surface conditions and layer thicknesses. In addition to the material type, the influence of layer thickness and surface condition parameters on the wear rate was demonstrated via calculated wear rate results.

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