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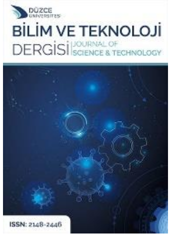

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Research paper

Improvement of Mechanical and Tribological Properties of PC/ABS Composite Parts Manufactured with 3D FDM Technology by Cryogenic Treatment

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ABSTRACT

In this article, the effects of cryogenic treatment on mechanical and tribological properties of products made of PC/ABS composite material used in 3D FDM printing technology were investigated. Three different load test samples were produced for hardness, tensile strength, impact strength and friction coefficient in accordance with the relevant st andards. The production parameters of all the experimental samples produced at room temperature were kept constant and the subsequent cryogenic treatment was focused on. These samples were subjected to cryogenic treatment with liquid nitrogen at different holding times and -180°C. In order to see the effects of cryogenic treatment, mechanical property tests were carried out and also images were taken from the surfaces that were broken in the tensile test with Scanning Electron Microscope (SEM) and the microstructure was examined. Within the limits of this study, the hardness values of all products produced from cryogenically treated PC/ABS composite materials increased compared to those that were not treated. The highest hardness increase was in the 24 CT coded PC/ABS samples with an increase of 22.37%. An increase was observed in the tensile strength values of all samples compared to the untreated samples. However, the highest increase in tensile strength values was in the 18 CT coded samples with an increase of 8.35%. A decrease in impact strength was observed in all samples. However, samples with code 18 CT showed the highest decrease with a rate of 33.38%. In the wear tests performed under three different loads (5 N, 10 N and 20 N), an improvement was observed in the friction coefficients of all samples compared to untreated samples. When the microstructure (SEM) images of the material were compared, it was seen that there were differences in the matrix structure. The increase in the hardness values as a result of the process was explained as the molecular chain arrangement in the microstructure of the samples becoming more regular and turning into a stable structure. It was evaluated that these structural changes had a positive effect on the mechanical properties of PC/ABS composite materials. This research constitutes a pioneering study reporting the tribological and mechanical performance of parts manufactured from PC/ABS composites, a preferred material in 3D FDM printing technology, under cryogenic conditions.

Keywords: *3D FDM, PC/ABS, Mechanical Properties, Friction Coefficient, Cryogenic Treatment*

I. INTRODUCTION

Additive manufacturing (AM) is defined as a non-traditional manufacturing technology. It is also known as three-dimensional (3D) printing or rapid prototyping (Saroia et al., 2020; Yap et al., 2021; Amza et al.. 2023; Yap et al., 2019). It is seen that 3D printing has been used as a production technology for about half a

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century along with its development process. In the last two decades, its use has increased significantly worldwide due to many factors such as speed and cost (Karakoc & Uzun, 2023). This technology can be defined as the production of parts by depositing materials in layers using the data of a 3D solid model created with computer-aided design (CAD) programs. 3D printing technology is rapidly developing and its reliability is increasing with scientific studies. Unlike traditional production technologies, AM is economical in many ways, such as using less material during shaping (Saroia et al., 2020; Yap et al., 2021; Amza et al.. 2023; Yap et al., 2019; Karakoc & Uzun, 2023; Koçar et al., 2024; Gebel & Ermurat, 2021; Garzon-Hernandez et al., 2020). In the latest stage of 3D printing, it has become a highly preferred production technology for rapid prototyping and end-user products. Today, AM technology can offer serious solutions in a wide range of sectors from the automotive industry to the defense industry. In this technology, printing techniques have been developed according to the materials from which the parts are produced. It is understood that one of the most widely used is fused deposition modeling (FDM). FDM 3D printing technique is especially preferred in the production of parts with complex geometries (Rouf et al., 2022; Gaweł et al., 2023; Dizon et al., 2018; Yılmaz et al., 2024; Dey & Yodo, 2019). Thanks to the solutions it offers, the FDM method has become the most widely commercialized 3D printing technology. This technology is especially preferred in parts made of polymer and composite materials. The FDM 3D printing technique is the process of obtaining a prototype or end-user product by adding melted filaments layer by layer (Konta et al., 2017; Salifu et al., 2022; Shahrubudin et al., 2019).

In this process; plastics, amorphous polymers, semi-crystalline polymers, thermosets, their derivatives and many composite materials are used. These are known by many trade names such as ABS, ASA, PC/ABS, PEI, PEEK (Bourell et al., 2017). Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) is an engineering thermoplastic developed by blending PC (polycarbonate) and ABS (Acrylonitrile Butadiene Styrene). It is a unique combination of the heat resistance of PC and the high impact resistance of ABS. PC/ABS composite has advanced properties such as improved impact resistance, dimensional stability and clarity. It is frequently used in engineering applications due to its unique mechanical properties. It is typically preferred in 3D FDM printing applications where advanced properties such as improved impact resistance, dimensional stability and clarity are required. PC/ABS composite is more expensive than PC and ABS (Yap et al., 2021; Bourell et al., 2017; Kannan & Ramamoorthy, 2020; Valino et al., 2019; Engler et al., 2022).

Although the mechanical properties of polymer products produced with AM technology are low, they are preferred due to advantages such as being produced in small quantities and in a short time. Due to this preference, it is seen that many studies have been carried out in order to increase the mechanical properties of the parts. It is seen that there are studies such as production criteria of filament materials, 3D printing criteria, new composite material studies, effects of thermal conditions and surface treatments (Bourell et al., 2017; Moghanizadeh & Ashrafizadeh, 2021; Sözen & Neşer, 2022; Zerankeshi et al., 2022; Pandelidi et al., 2021; Liu et al., 2022; Bakar et al., 2022; Evlen et al., 2019; Jayswal & Adanur, 2022; Karabıyık & Apak, 2021). However, there is no sufficient research in the literature on the effects of cryogenic treatment (Altinsoy & Arslan, 2024; Arslan, 2020a; Arslan, 2020b), which is known to increase the mechanical properties of many different materials, on parts produced with 3D printing. Cryogenic treatment is an irreversible process as it affects the entire structure of the materials. This process slows down the atomic movement of the polymer materials and creates a pure, homogeneous and dense microstructure. Thus, the mechanical and physical properties of the polymers increase. Each engineering plastic has different properties. Due to the cheap and fast production of complex parts that are very difficult to produce with traditional methods, increasing the mechanical properties of polymer products produced with AM technology has become important. Cryogenic processing is promising in this respect (Stan et al., 2019; Bartolomé et al., 2017; Ni et al., 2018; Weiss et al., 2015; Veer et al., 2023; Cruz et al., 2015; Çiçek et al., 2012). This process is, in summary, the process of holding parts at temperatures as low as −80°C to −196°C for certain periods of time. Cryogenic processing is usually carried out with liquid nitrogen because it is economical (Altinsoy & Arslan, 2024; Arslan, 2020a; Arslan, 2020b; Stan et al., 2019; Bartolomé et al., 2017; Ni et al., 2018; Weiss et al., 2015; Veer et al., 2023; Cruz et al., 2015; Çiçek et al., 2012).

Arslan (2020b), investigated the effects of cryogenic treatment on the wear of AISI D2 punches and the effects of punch wear on the hole edge geometry of hot forged AISI 1040 steel ball joint parts. In addition to conventional heat treatment, some of the punches were subjected to cryogenic treatment at −145 °C. It was reported that the wear of D2 tool steel punches was reduced by the application of cryogenic treatment at the end of industrial punching applications. Many studies have been reported in the literature, such as this study, showing that the application of cryogenic treatment to many tool steels after conventional heat treatment leads to a decrease in the amount of retained austenite in their microstructures, improves their mechanical properties and increases their wear resistance (Arslan, 2020a; Arslan, 2020b; Gupta et al., 2025; Das et al., 2009; Podgornik et al., 2009; Arslan et al., 2016). The primary goal of cryogenic processing is to increase mechanical properties such as hardness and wear resistance. However, exposure to thermal shock can cause warping and deterioration in materials. This is one of the most significant disadvantages of cryogenic processing (Veer et al., 2023; Cruz et al., 2015; Çiçek et al., 2012; Gupta et al., 2025; Das et al., 2009; Podgornik et al., 2009; Arslan et al., 2016). Altinsoy and Arslan (2024), investigated the effects of cryogenic treatment on the mechanical and structural properties of polyoxymethylene copolymer (POM-C) materials. They applied cryogenic treatment to the prepared samples at -175°C for different holding times and then applied mechanical strength tests to these samples at room temperature and also performed analyses to understand the changes in the microstructure. They reported that there was no significant improvement in tensile strength after cryogenic treatment in POM-C material, but there was an increase in hardness and impact strength. Pande et al. (2012), applied cryogenic treatment to PTFE and polyamide polymers at different temperatures and different holding times. They investigated the effects of holding times and temperatures on mechanical test results during this process. They reported that there was no significant increase in tensile strength after the treatments, but the friction coefficient and mass loss decreased in all samples subjected to cryogenic treatment in wear tests. Wang et al. (2016), conducted tribological experiments on polyimide, polytetrafluoroethylene and polyetheretherketone polymers at cryogenic temperatures. They reported that the hardness of the polymers increased at cryogenic temperatures, which led to a decrease in the contact area between friction pairs. Therefore, the friction coefficients at cryogenic temperatures decreased. Furthermore, they reported that the wear rates of the three polymers decreased at cold temperatures due to the limited molecular mobility and migration. In the literature, it is seen that at least three different time studies have been conducted to understand the retention times during which cryogenic treatment is effective on different materials such as tool steels and polymers (Arslan, 2020a; Arslan, 2020b; Stan et al., 2019; Bartolomé et al., 2017; Ni et al., 2018; Weiss et al., 2015; Veer et al., 2023; Cruz et al., 2015; Çiçek et al., 2012; Gupta et al., 2025; Das et al., 2009; Podgornik et al., 2009; Arslan et al., 2016; Pande et al., 2012; Wang et al., 2016). When products manufactured with 3D FDM printing technology are operated under cryogenic conditions, the research on the mechanical properties of the parts and how they are affected by various process parameters is quite limited and insufficient in the literatüre (Stan et al., 2019; Bartolomé et al., 2017; Ni et al., 2018; Weiss et al., 2015; Veer et al., 2023; Cruz et al., 2015; Çiçek et al., 2012). However, studies conducted at room temperatures have been reported. Today, AM technology is becoming quite widespread due to the practical and economical solutions it offers. Therefore, in order to understand the performance of products used at different temperatures, it is necessary to further investigate the effects of cryogenic conditions on these products, which are lacking in the literature.

This research is focused on the effects of cryogenic temperatures on the mechanical and tribological properties of parts manufactured from PC/ABS composites, which are preferred in 3D FDM printing technology due to their desired properties such as impact resistance and dimensional stability. Because there are no studies in the literature reporting the tribological and mechanical performances of these parts operated under cryogenic conditions. In this study, samples were produced from PC/ABS composite materials using 3D FDM printing method for hardness, tensile strength, impact strength and friction coefficient tests. These samples were subjected to cryogenic treatment at -180°C for different holding times of 6, 12, 18 and 24 hours. In order to see the effects of the cryogenic treatment, samples were also subjected to wear tests with three different loads for hardness, tensile strength and impact strength. In addition, images were taken from each sample with Scanning Electron Microscope (SEM) for microstructure analysis and the effects of this process were investigated.

II. MATERIAL AND METHOD

In this study, commercial PC/ABS filaments commercialized by 7 Hills Filament were used. Some properties of the filaments are given in Table 1. The test parts were produced using a Teira 3D Brand Model 3D printer with a 0.4 mm nozzle diameter using the FDM printing method, as seen in Figure 1. The technical and printing specifications of the 3D printing machine are shown in Table 2.

Table 1. Properties of PC/ABS filament materials (by the filament supplier).

PC/ABS	Units	Value	Standard
Hardness	Rockwell R	114	ASTM D785
Specific gravity	g cm^{-3}	1,13	ASTM D792
Tensile Strength	MPa	34,7	ASTM D638

Table 1 (cont.). Properties of PC/ABS filament materials (by the filament supplier).

Elongation at break	%	4,3	ASTM D638
Izod Impact, Notched	J/cm	1,23	ASTM D256
Melting point	°C	230-280	ISO 294
Filament diameter	mm	1,75	
Filament color		Ivory	

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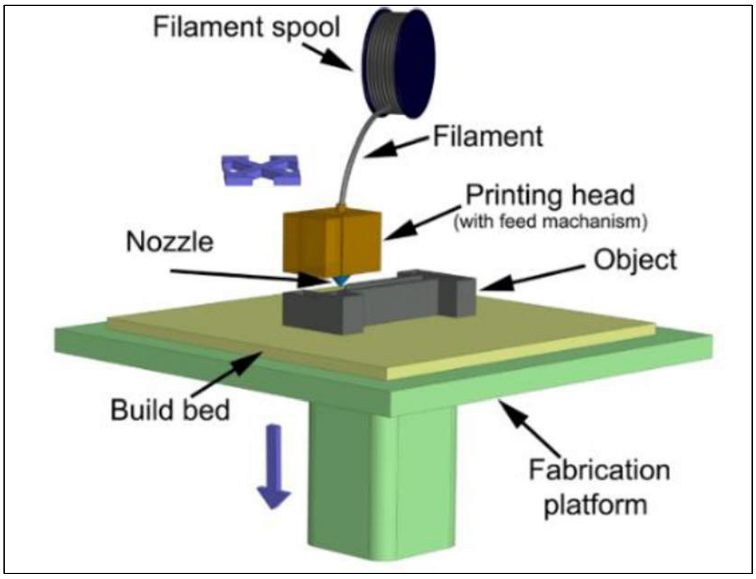

Figure 1. FDM printing system (Saroia et al., 2020).

Table 2. Teira 3D brand model workbench features and printing parameters.

Printing Method	FDM
Print Size (mm)	220 × 220 × 250
Machine Size (mm)	440 × 410 × 465
Filament Diameter (mm)	1.75
Filament Type	ASA,PLA
Nozzle Diameter (mm)	0,4
Nozzle Temperature (°C)	240
Bed Temperature (°C)	80
Printing Speed (mm/min)	3000
CAD Program	Solidworks
Error	±0,1
Filling Structure	Honeycomb
Filling Ratio (%)	25
Layer Thickness (mm)	0,20

The samples were produced using the Solidworks CAD program and the FDM 3D printing technique in accordance with the dimensions in the standards and the parameters in Table 2. The production parameters of the samples were kept constant for all materials. Since the parts produced in honeycomb pattern have high mechanical properties and provide ultra-low weight, they are recommended for use in space conditions at low temperatures (Veer et al., 2023). Honeycomb pattern was preferred due to these features. During printing, the printer environment conditions were isolated with glass protectors.

After the test samples were produced from PC/ABS composite materials in accordance with the relevant standards using the 3D FDM printing method, they were divided into five groups to cover each test group and coded as in Table 3. After all the samples produced at room temperature were separated into groups, they were cooled from room temperature to -180°C with a cooling rate of approximately ~5°C/min in cryogenic process ovens as seen in Figure 2. Since there was no direct contact with liquid nitrogen, no thermal shock was experienced in the samples. When the desired cooling temperature was reached, the 6 CT code group, which was cooled for 6 hours, was removed from the cabin. The other groups were kept at -180°C for 12, 18 and 24 hours, respectively, and then removed from the oven. After the applied process, the samples that came to room temperature were tested and the effects of the cryogenic process were investigated.

Table 3. Experimental groups and codes.

Group	Code
No treatment	Room temperature
6 hours cryogenic treatment at -180°C	6 CT
12 hours cryogenic treatment at -180°C	12 CT
18 hours cryogenic treatment at -180°C	18 CT
24 hours cryogenic treatment at -180°C	24 CT

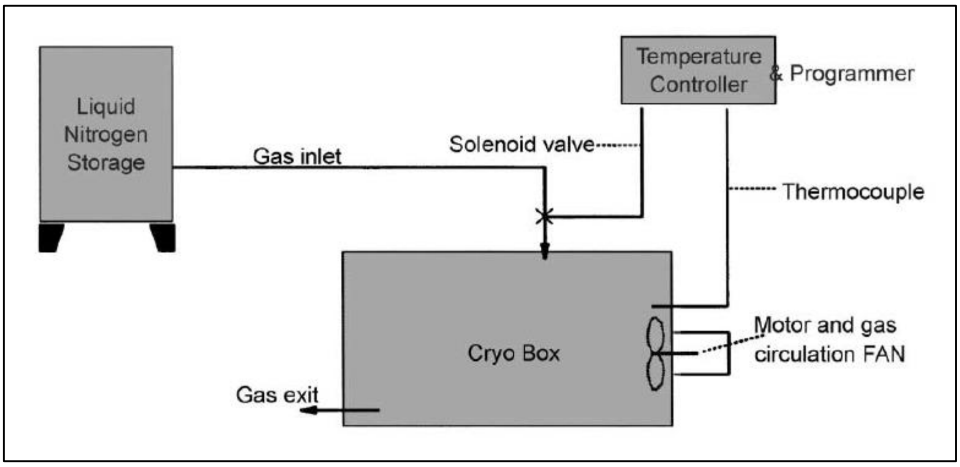

Figure 2. A cryogenic system (Arslan, 2020b).

The manufactured abrasion test, hardness test, Charpy notched impact test and tensile test samples are shown in Figure 3.

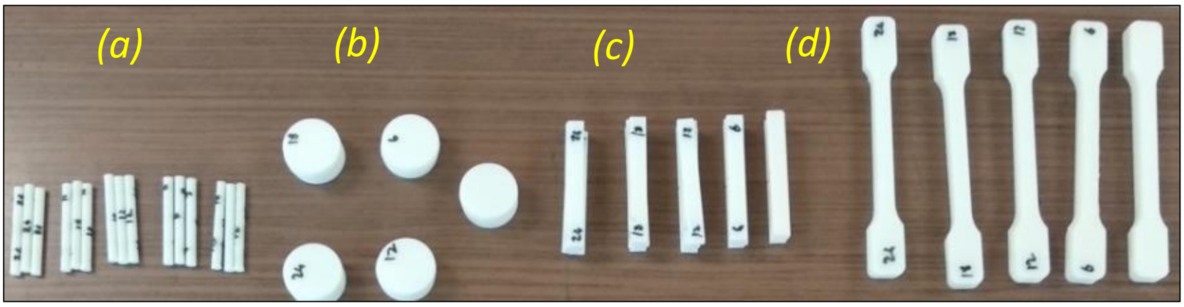

Figure 3. (a) Abrasion test, (b) Hardness test, (c) Charpy notched impact test, (d) Tensile test samples.

The hardness test was carried out using the Shore D Hardness Tester TIME TH-210 brand model according to ASTM D2240 standards. For the Shore D hardness test, the samples in Figure 3.(b) were produced with a thickness of 6 mm and a diameter of 35 mm. Nine measurements were taken from each sample with a minimum interval of 6 mm and the average was recorded.

Tensile strength test samples were produced in accordance with ASTM D638 type 3 standards, as seen in Figure 3.(d), with the dimensions in Figure 4. A total of 30 tensile tests were performed, 6 from each process group. Tensile tests were performed using a UTS brand testing machine at a speed of 50 mm/min (Figure 5).

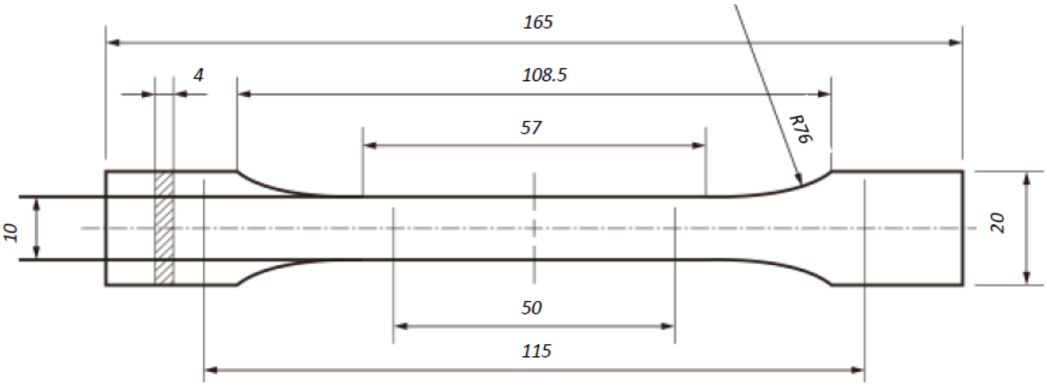

Figure 4. Tensile test sample dimensions.

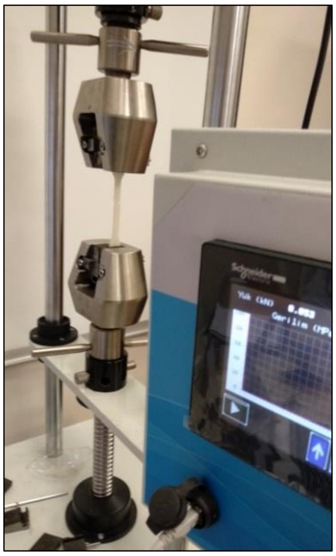
Figure 5. Tensile strength test.

Notched impact test specimens were produced according to ASTM D256 standard, 10 for each test group, totaling 50 specimens (Figure 3.c). Impact test was applied 10 times for each group and a total of 50 experiments were performed. The impact resistance of the specimens was measured with the pendulum type Izod impact test TIME JB-W300 device (Figure 7). After the experiments, the average of the results was recorded and evaluated. The fracture energy value of the specimens is reached with the Charpy notched impact test. The fracture energy value was found using Eq.1, and the impact strength values were found using Eq.2.

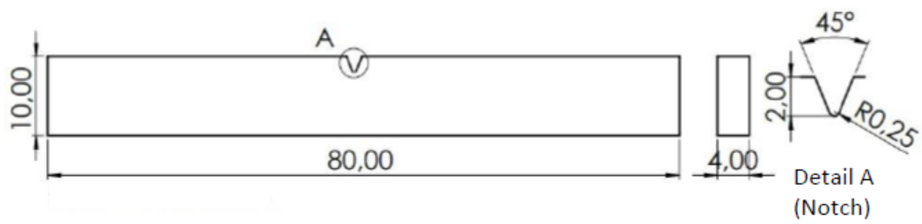

Figure 6. Charpy impact test specimen dimensions and notch type.

$$Fracture\ Energy = GL(Cos\beta - Cos\alpha) \quad (1)$$

$$Impact\ Strength = \frac{Fracture\ Energy\ (J)}{Cross\ Section\ Area\ (mm^2)} \quad (2)$$

G=m.g, G=hammer weight, m=hammer mass, g=gravity acceleration (9.81 m/s^2), L=pendulum length, β=rise angle, α=fall angle indicates.

Figure 7. Charpy impact tester.

Wear samples were produced according to ASTM G99 standard with a diameter of 6 mm and a length of 55 mm. A total of 45 pieces were produced, three for each experimental group and each load (Figure 3.a). Wear tests were carried out under dry conditions, at room temperature and using the pin-disc wear system. AISI 4140 steel with a hardness of 56 HRc was used as the abrasive disc. The pin-disc wear device used in this study is given in Figure 8. Before the wear test, the surfaces of the pin materials were first sanded with 1000 grit sandpaper and then with 1500 grit sandpaper. Wear tests were applied to the samples at 5 N, 10 N and 20 N loads, at a constant speed of 126 rpm from a distance of 500 m. After each test, the abrasive surface was sanded with 1000 grit sandpaper and the surface was prepared for the next test. The friction coefficient was recorded for all samples.

Figure 8. Pin-disc wear tester.

The samples divided into groups were evaluated by taking microstructure images with 70X and 600X magnifications with the help of FEI Quanta FEG 250 brand scanning electron microscope (SEM) (Figure 9).

Figure 9. Scanning electron microscope (SEM).

III. RESULTS AND DISCUSSIONS

A. Hardness Test

It is known from previous studies that the mechanical properties of polymer products produced with AM technology are lower than those produced with conventional methods (Sözen & Neşer, 2022; Zerankeshi et al., 2022; Bakar et al., 2022; Evlen et al., 2019; Jayswal & Adanur, 2022; Karabıyık & Apak, 2021). In many studies, it has been reported that the hardness of polymers increases after cryogenic treatment (Altinsoy & Arslan, 2024). When the hardness test results in this study are examined, it is clearly seen that the hardness of the samples increases as the holding time at cryogenic temperature increases. The hardness values of all samples shown in Figure 10 have increased. However, the hardness value of PC/ABS samples with 18 CT code increased by 22.37% compared to the samples at room temperature and reached the highest values.

Stan et al. (2019), reported that PETG retained its mechanical properties at -40°C, but the mechanical properties of PETG at -196°C were lower than those at -40°C. Ni et al. (2018), produced test samples from PC, ABS and PP polymer materials with rapid prototyping machines. They applied cryogenic treatment to the samples at -190°C for 8 hours. They reported that the hardness of cryogenically treated PC, ABS and PP samples increased by 27.6%, 10.8% and 20.3%, respectively.

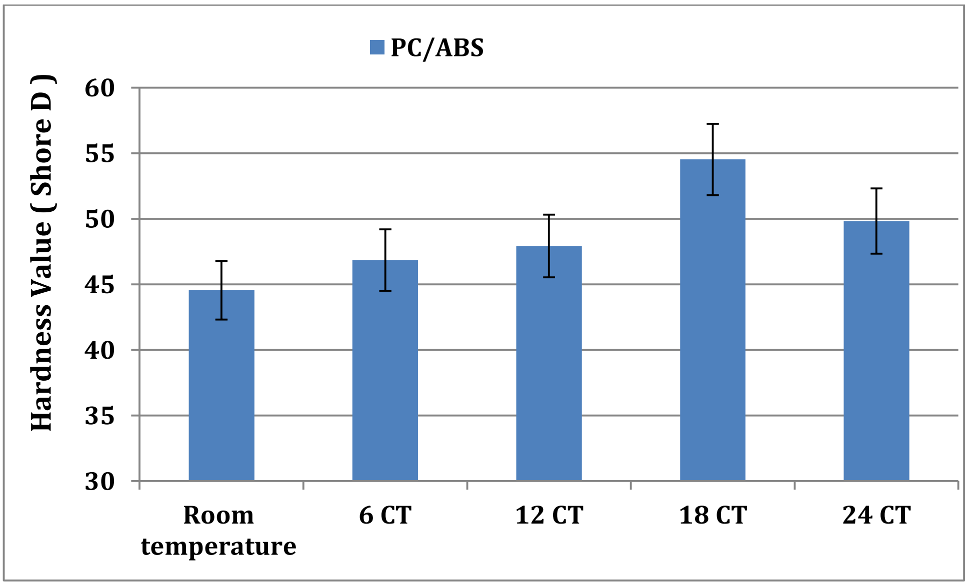

Figure 10. Shore D hardness results.

They based this increase on the fact that cryogenic treatment makes the molecular chain of the material more regular and increases its stability. According to very limited literature information on cryogenic treatment, it has been reported that there is an increase in the hardness of polymer products produced with AM technology. In the results of this study, the hardness values of all PC/ABS composite materials increased after cryogenic treatment. Limited literature information supports the results of this study.

B. Tensile Strength Test

The results of the tests performed on samples produced from PC/ABS materials using the 3D FDM printing method after cryogenic treatment are given in Figure 11. The highest increase in tensile strength value compared to samples at room temperature was in samples with code 18 CT with 8.35%.

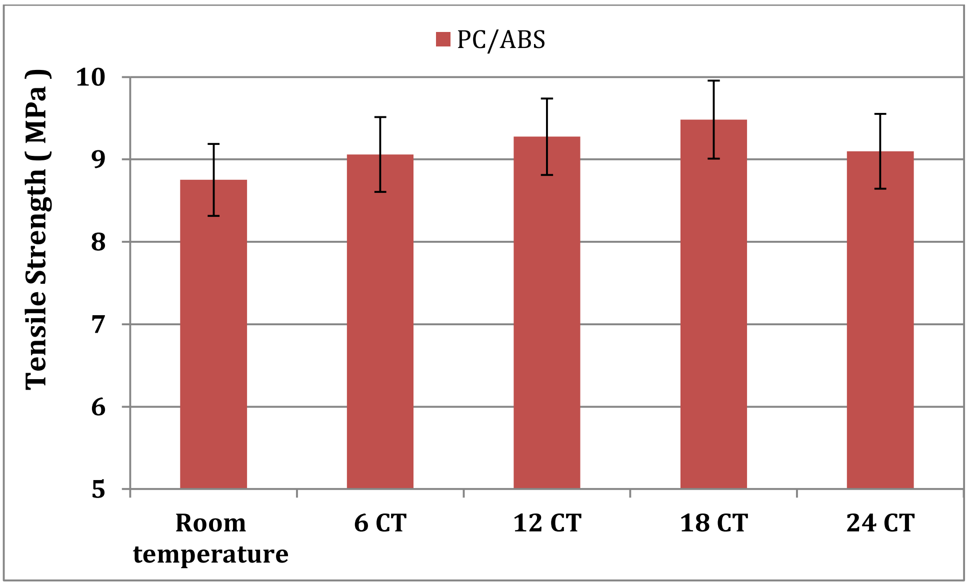

Figure 11. Tensile strength results.

Stan et al. (2019), suggested that honeycomb patterns should be produced for use at very low temperatures due to their high mechanical properties. They also reported that mechanical properties were affected by the production pattern and printing orientation angles in cryogenic conditions and that further research was needed. Cruz et al. (2015), produced tensile samples from Nylon-12 and ULTEM materials by FDM method. They produced tensile samples from Duraform EX, Duraform HST, Duraform PA, carbon-glass reinforced nylon-12 and nylon-11 materials by SLS method. They carried out their experiments in liquid nitrogen immersion apparatus according to ASTM D638. In general, they reported that tensile strength increased by 35.8% to 175% at 77 K in samples produced by SLS method, while modulus increased by 29.4% to 228% compared to room temperature. They also reported that the ultimate tensile stress values at 77 K were affected by the sample pressure direction. As a result of their studies, they reported that plastics produced with 3D printing technologies can be used in cryogenic environments, but more studies such as fatigue should be done for critical applications. Gupta et al. (2025), reported that cryogenic treatment significantly improved the tensile strength and ductility of 3D-printed PLA samples. In their study, they reported that exposing PLA samples to cryogenic temperature (10 K) using a cryogenic cooler resulted in a 35% increase in tensile strength within 5 hours, with the greatest improvement occurring within the first hour. They concluded that cryogenic treatment increased the strength and ductility of the PLA sample through increased crystallinity and better molecular alignment. In this study, the tensile strength values of all PC/ABS composite materials increased under cryogenic conditions.

C. Notched İmpact Test

The impact strengths obtained from the notched Charpy impact tests performed on the samples produced with the 3D FDM printing method after cryogenic treatment are given in Figure 12. A decrease in impact strengths was observed compared to the samples at room temperatures. The 24 CT coded PC/ABS samples also decreased by 10.74% compared to the room temperature samples. However, the 18 CT coded PC/ABS samples showed the greatest decrease in impact strength, decreasing by 33.38% compared to the room temperature samples. This decrease was attributed to the increase in the hardness values of the 18 CT coded PC/ABS samples compared to the room temperature samples. It has long been known that increasing the hardness values of materials causes a decrease in their toughness values. Impact tests of samples produced with the 3D FDM printing method at room temperature are found in the literature, but no results have been found regarding impact strength in limited studies conducted in cryogenic conditions. It is thought that the results of this study will guide subsequent studies at cryogenic temperatures.

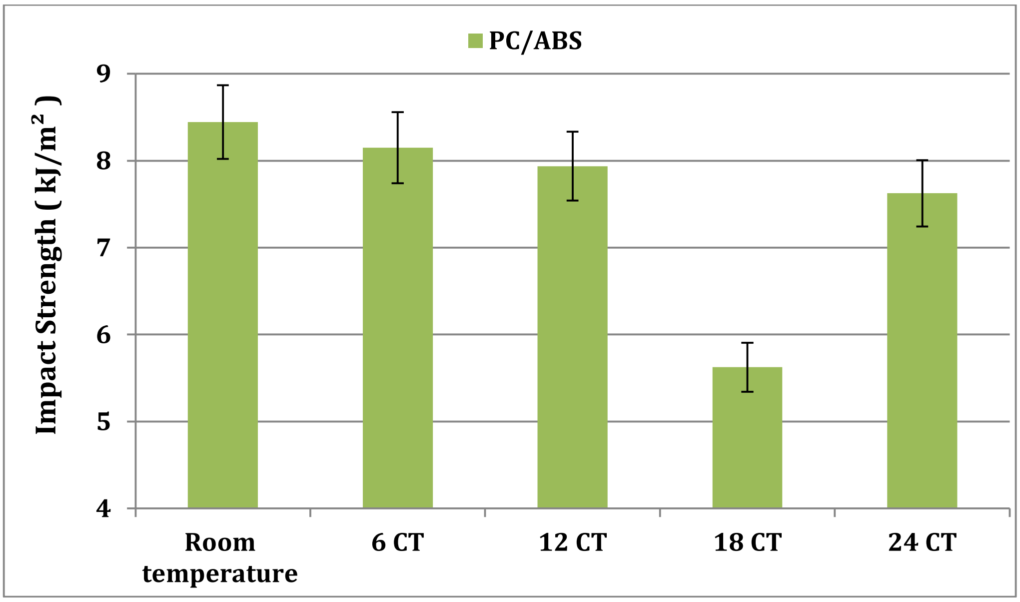

Figure 12. Charpy impact test results.

D. Wear Test

Wear tests after cryogenic treatment were performed with 5 N, 10 N and 20 N loads. These tests were performed based on a constant speed of 126 rpm and a distance of 500 m and friction coefficients were evaluated. The friction coefficients obtained with three different loads applied to samples produced from PC/ABS composite materials using the 3D FDM printing method are given in Figure 13. In the wear tests conducted with three different loads, a general decrease in the friction coefficient was observed. In the wear test conducted with a 5 N load, it was observed that the friction coefficient of 24 CT samples decreased by 13.19% compared to room temperature. In tests performed with 10 N load, it was observed that the friction coefficient increased by 1.89% in tests performed with 20 N load, while it decreased by 37.25%. However, the friction coefficients of 18 CT samples decreased by 14.56% under 5 N load, 42.58% under 10 N load and 6.26% under 20 N load, compared to room temperature.

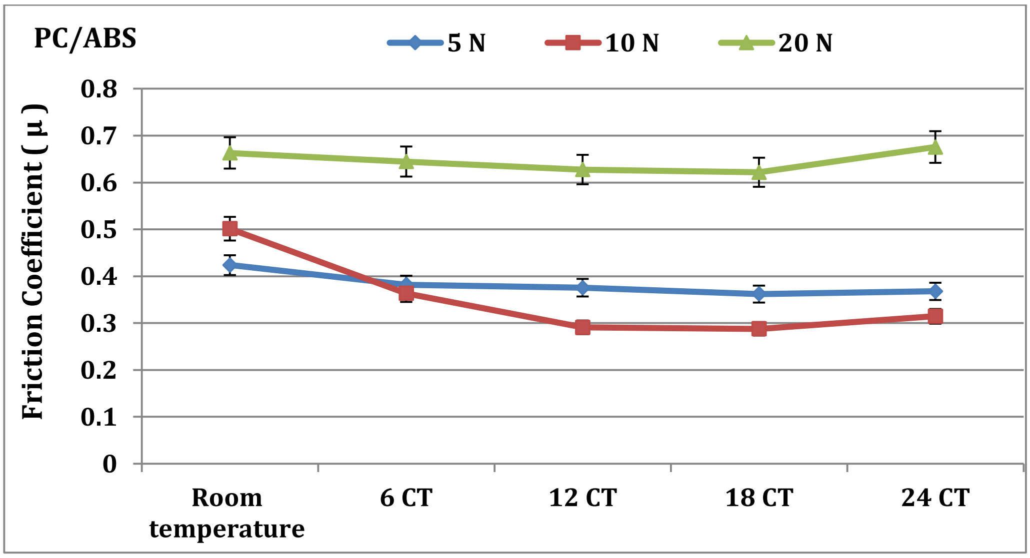

Figure 13. PC/ABS samples wear test friction coefficient results (Load 5 N, 10 N and 20 N).

It is known from studies that cryogenically processed plastics have improved friction coefficients and reduced wear rates (Altinsoy & Arslan, 2024). Ni et al. (2018), reported that cryogenic treatment increased the hardness of polymer material samples and that these materials showed significant improvements in wear tests. They attributed this to the fact that the cryogenic process removes some of the residual stress, makes the molecular chain of the material more regular, and increases stability. Veer et al. (2023), produced samples from TPU material using the FDM method. They applied deep cryogenic treatment to these samples at 77 K for 24 hours. As a result of their study, they reported that the cryogenic treatment increased the wear performance of TPU samples produced with the FDM method, but the surface was rougher. In this study, as in the literature, it was observed that the cryogenic treatment generally improved the friction coefficients of all PC/ABS composite materials according to three different loading results.

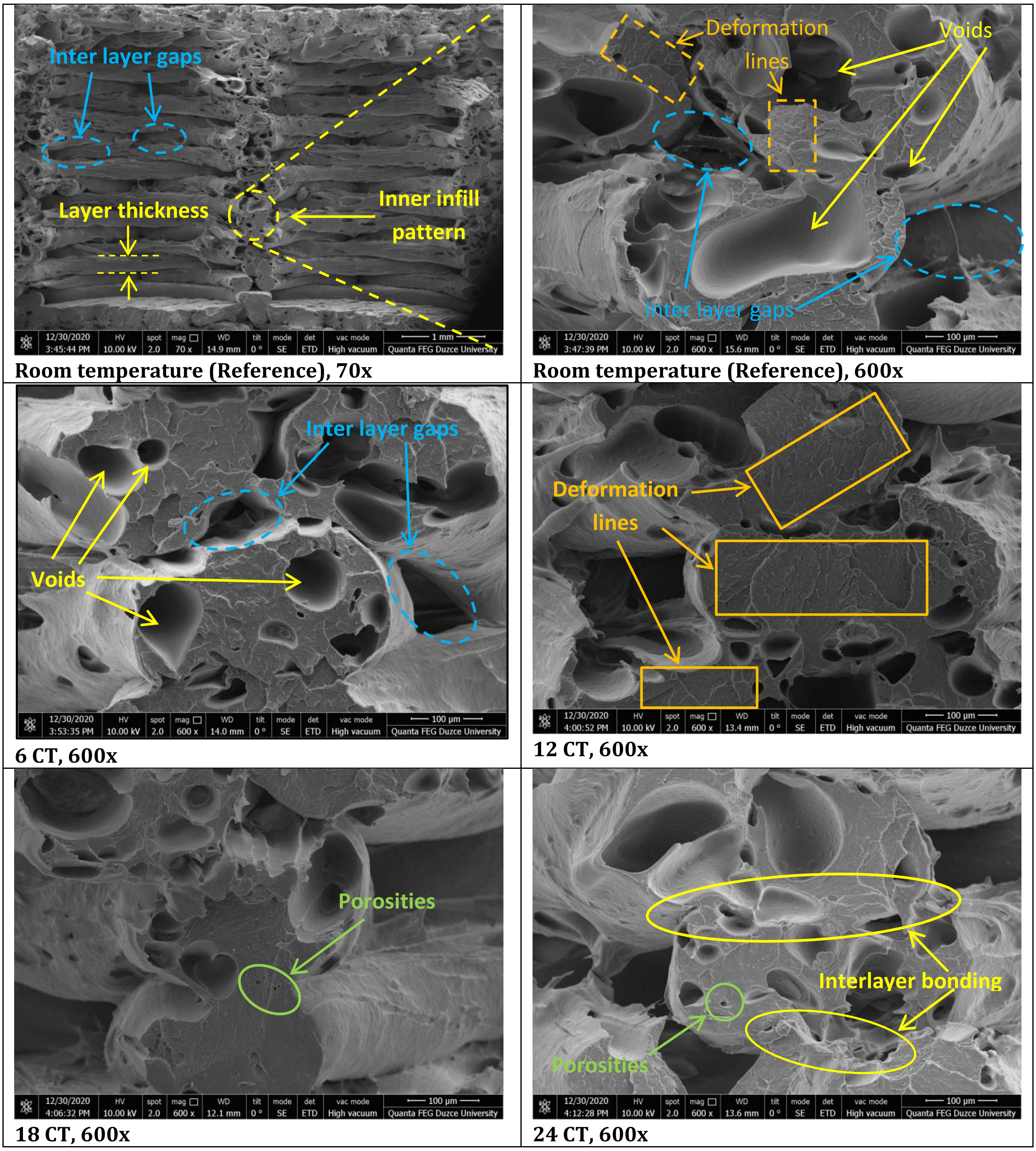

Figure 14. SEM images of PC/ABS samples (70X, 600X).

E. Scanning Electron Microscope (SEM)

As a result of the tensile strength test, SEM images were taken from the fracture areas in the plastic deformation regions of the material. When the microstructure images of the PC/ABS composite material given in Figure 14 were compared, it was observed that there were differences in the matrix structure. In the untreated (room temperature) samples, it was observed that a circular void structure was formed inside the layers and between the layers together with the matrix structure (Bartolomé et al., 2017). This structure was observed to be smaller and more regular in the treated samples (6 CT, 12 CT, 18 CT and 24 CT). It was observed that the irregular molecular chains became more regular and the pore structures decreased with the cryogenic treatment. These structural changes have a good correlation with the tensile test results (Altinsoy & Arslan, 2024; Bartolomé et al., 2017). The increase in hardness values of cryogenic treatment can be explained as the molecular chain arrangement in the microstructure of the materials becoming more regular and turning into a stable structure. After cryogenic treatment, the properties of functional groups weaken, the length of the molecular chain increases, crystallinity increases, the matrix structure becomes more regular and the stability of the material increases (Ni et al., 2018).

It is known from the literature that the parts produced with 3D FDM printing technology have an effect on the microstructure and strength values as a result of changing the production parameters. When the SEM images are examined, it can be said that the cryogenic process densifies the layers and the strength values increase due to the shrinkage that occurs by reducing the pores and voids (Veer et al., 2023). The gaps in the matrix structure affect heat distribution during production and cause residual stresses. Therefore, it is understood that they affect the strength values. If there are large gaps, the deformation of the parts becomes easier (Wang et al., 2016; Bermudo Gamboa et al., 2024; Horasan & Sarac, 2024; Chopra et al., 2021). As can be understood from the images, in PC/ABS composite materials, there are quite a few voids in the samples at room temperature compared to cryogenically treated samples, but the bond between the layers is greater. According to SEM images, in the fracture surfaces where brittle fracture behavior is observed; porosity, voids, interlayer voids and a few lack of adhesion are observed. In the limited similar studies in the literature and in this study, the positive effects of cryogenic treatment on samples produced from PC/ABS composite materials using the 3D FDM printing method were observed with the applied tests. However, in this study, the production parameters of the products produced with 3D FDM printing method were kept constant and the working cost was tried to be optimized. Therefore, in order to improve the mechanical properties of the polymer products produced with AM technology and to understand their performance in cryogenic conditions, a lot of work needs to be done in the future. For example, the literature gap regarding commonly used composite polymers should be filled by considering important factors such as printing speed, printing direction, layer thicknesses, etc. It is thought that the results of this study will make a significant contribution to the effects of cryogenic treatment on products produced with 3D FDM printing method and will be beneficial for researchers and manufacturers.

IV. CONCLUSION

As a result of the experiments conducted on samples produced from PC/ABS composite materials using the 3D FDM printing method, the following results were obtained.

• The hardness value of PC/ABS samples with code 24 CT increased by 11.83% compared to samples at room temperature, while the value of samples with code 18 CT increased by 22.37% and reached the highest values. The tensile strength value of PC/ABS samples with code 24 CT increased by 3.95% compared to samples at room temperature. However, the value of samples with code 18 CT increased by 8.35% and reached the highest values. The impact strength of 24 CT coded PC/ABS samples decreased by 10.74% compared to room temperature samples. However, the value of 18 CT coded samples decreased by 33.38%, showing the greatest decrease.

• In the wear tests performed on PC/ABS samples with three different loads, a general decrease in the coefficient of friction was observed. In the wear test performed with a load of 5 N, it was observed that the coefficient of friction of 24 CT samples decreased by 13.19% compared to room temperature. It was observed that the friction coefficient decreased by 37.25% in tests performed under a 10 N load, and increased by 1.89% in tests performed under a 20 N load. However, the friction coefficients of the 18 CT samples decreased by 14.56% under a 5 N load compared to room temperature. It decreased by 42.58% under 10 N load and decreased by 6.26% under 20 N load. These results provided important information about the role of cryogenic treatment in improving the friction coefficient of PC/ABS.

• When the microstructure (SEM) images of the PC/ABS material were compared, it was observed that there were differences in the matrix structure. It was observed that the irregular molecular chains became more regular and the pore structures decreased with the cryogenic process. The increase in the hardness values of the cryogenic process can be explained as the molecular chain arrangement in the microstructure of the materials becoming more regular and turning into a stable structure. It was evaluated that these structural changes had a positive effect on the mechanical properties of the materials.

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