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Investigation Of Tribological Properties of Amorphous Thermoplastic Samples With Different Filling Densities Produced By An Additive Manufacturing Method

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ABSTRACT

ASA (Acrylonitrile Styrene Acrylate) filament is widely used in outdoor applications thanks to its superior properties. It is exposed to wear due to the environments in which it is used. In this study, the tribological properties of the samples produced at different infill densities (30%, 60%, and 90%) were investigated. Samples were produced using the fused filament fabrication method prior to experiments. Friction tests were carried out on a pin-on disc test device. The friction coefficient, wear rates, hardness, and diameter values of the samples were measured. According to the results obtained, it was understood that there was little change in the tribological properties of the samples according to the infill densities. In addition, 90% infill density samples present higher hardness values and lower wear rates compared to other samples. The study also shows that the fused filament fabrication method is a suitable technique to produce samples from the strong ASA polymer.

Eklemeli İmalat Yöntemiyle Üretilen Farklı Dolgu Yoğunluklarına Sahip Amorf Termoplastik Numunelerin Tribolojik Özelliklerinin İncelenmesi

ÖZ

ASA (Akrilonitril Stiren Akrilat) filament üstün özellikleri sayesinde dış mekân uygulamalarında yaygın olarak kullanılmaktadır. Kullanıldığı ortamlardan dolayı aşınmaya maruz kalmaktadır. Bu çalışmada, farklı dolgu yoğunluklarında (%30, %60 ve %90) üretilen numunelerin tribolojik özellikleri araştırılmıştır. Deneylerden önce kaynaşmış filament üretim yöntemi kullanılarak numuneler üretilmiştir. Sürtünme testleri, pin-on disk test cihazında gerçekleştirilmiştir. Numunelerin sürtünme katsayısı, aşınma oranları, sertlik ve çap değerleri ölçülmüştür. Elde edilen sonuçlara göre, dolgu yoğunluklarına bağlı olarak numunelerin tribolojik özelliklerinde çok az değişiklik olduğu anlaşılmıştır. Ayrıca, %90 dolgu yoğunluklu numuneler, diğer numunelere kıyasla daha yüksek sertlik değerleri ve daha düşük aşınma oranları göstermektedir. Çalışma ayrıca, kaynaşmış filament üretim yönteminin, güçlü ASA polimerinden numune üretmek için uygun bir teknik olduğunu göstermektedir.

Anahtar Kelimeler: Akrilonitril bütadien stiren, Aşınma oranı, Sertlik, Pin-on disk, Eklemeli İmalat

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1. Introduction

Additive manufacturing (AM) is a technology that enables the creation of objects layer by layer and generates complicated parts. Different and complicated designs of the components can be produced using this technology with specific fabrication techniques in an economic and versatile way. The fabrication of prototypes can also be made easily in a few hours instead of weeks with AM techniques. By means of these features, additive manufacturing systems have gained more attraction by academia and industry in recent years. Based on American Society for Testing and Materials (ASTM) AM technologies can be categorized as fused material extrusion, binder and material jetting, powder bed fusion, directed energy deposition , sheet lamination, and VAT polymerization [1]. Fused deposition material is one of the most used techniques by many professional and non-professional users due to its accessibility and cost-effectiveness. Briefly, in this method, polymers are melted and sent through the nozzle to fabricate components according to a specific pattern based on layer by layer approach. Several polymers such as poly-caprolactone [2], [3], polyethylene glycol [4], [5], polylactic acid [6], [7], polycarbonate [8], [9], acrylonitrile butadiene styrene [1], [10], [11], acrylonitrile styrene acrylate [1], [12], [13], and a combination of polymers and different materials [14]–[16] can be used with AM technologies to produce prototypes and real products.

Acrylonitrile styrene acrylate (ASA) is a thermoplastic polymer that has strong weather resistance, mechanical properties, UV irradiation, moisture, heat, and cracking. It has been widely used in prototyping production with fused deposition modeling printers, additionally, it has also a broad usage in the automotive industry due to its lightness and strongest [17].

There are many kinds of research investigating the mechanical [12], [18], [19], thermal, microstructure [18], and recycling properties [20], [21] of ASA polymer in the literature, however, there are a few studies about the tribological investigation of this polymer. Large 3D printed parts was also produced with ASA polymer using large format additive manufacturing process [12]. The parts were produced from neat ASA and carbon fiber-filled ASA polymer to investigate mechanical, thermal and rheological properties in this study. The printability of both materials was achieved with the large format additive system, as a result of the study, thermal conductivity and mechanical properties of carbon fiber loaded ASA increases while the melting flow rate decreases [12]. Guessasma et al. investigated the effect of the microstructure of 3D printed parts with ASA on the mechanical characteristics [18]. They focused on the printing temperature of the polymer to understand its effects on mechanical and thermal performance and specify the optimum printing temperature. In this study samples were produced between 220 °C to 255 °C, result of this, they stated that 250 °C was found as the optimum printing temperature for ASA, while if the temperature is below 240 °C printability problems occur [18]. McFarland and Antunes used ASA polymer to understand suitability as a candidate for hybrid rocket fuel grain in their study, the fused filament fabrication methodology was used to produce 3d printing rocket fuel grain [22]. In this study, ASA, acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), polypropylene, nylon, polylactic acid (PLA), and AL (PLA with aluminum particles) were used to produce samples. The regression rate was investigated after small burning test. Based on these experiments, they stated that acrylonitrile styrene acrylate and nylon had the highest regression rate comparing the other polymers [22]. Tribological performance of ASA polymer parts was investigated in the following studies [16], [23]. Martinez et al. has focused on manufacturing processes effects on the tribological and mechanical characteristic of ASA polymer. Wear rate and coefficient of friction values were examined using a pin-on-disc apparatus. They stated that as a result, wear effects on the samples seemed to be less on printed parts with higher layer thickness in this study [23].

Even many studies on mechanical and physical investigations of ASA polymer in the literature there is a lack of studies about the tribological investigation of this polymer. In order to understand wear and friction performance of ASA polymer produced with fused filament fabrication requires more studies. Therefore, this study will be a preliminary study of the tribological properties of ASA polymer.

2. Material and Method

The In this study, ASA (Acrylonitrile Styrene Acrylate) filament with a diameter of 1.75 mm and a density of 1.04 g/mm^3 was used. Material properties can be found in Table 1. It is a material that is widely used thanks to its anti-static properties, resistant to impacts and abrasion, high UV resistance and water-resistant structure. Due to these properties, this filament was preferred in the experiments. ASA (Acrylonitrile Styrene Acrylate) was purchased from Flashforge, it has a white color, print temperature between 240-260°C with a 100°C bed temperature.

Table 1. Material properties used in the study (From Manufacturer)

Material Type	Amorphous thermoplastic (ASA)
Material Density	1.1 g/cm^3
Material Form and Color	Filament - White
Filament Diameter	1.75 mm
Glass Transition Temperature	105 °C
Printing Temperature	240 - 260 °C
Bed Temperature	Around 100 °C
Thermal Conductivity	0.18 W/ m-K

Teira 3D Plastix 250, Turkey brand 3D printer was used in the production of the samples. The 3D printer is given in Figure 1. In the printing process, the table temperature is 105 °C, the nozzle temperature is 255 °C, the infill angle is 45°, the layer height is 0.2 mm, and the number of walls is 1. The samples were produced in a rectangular pattern, cylindrical shape of 10 mm diameter and 20 mm length at 30%, 60% and 90% infill densities. Thus, the effect of the infill density on the tribological properties of the samples was investigated. In order to determine the effect of the infill densities on the measurement accuracy, the diameter values were measured with the help of a micrometer and the hardness values were measured with the Durameter brand Shore D test device immediately after the samples were produced. The hardness device was calibrated using the calibration block of the device before the measurement. 5 measurements were made and the average values were taken. Printing and test parameters were given in Table 2.

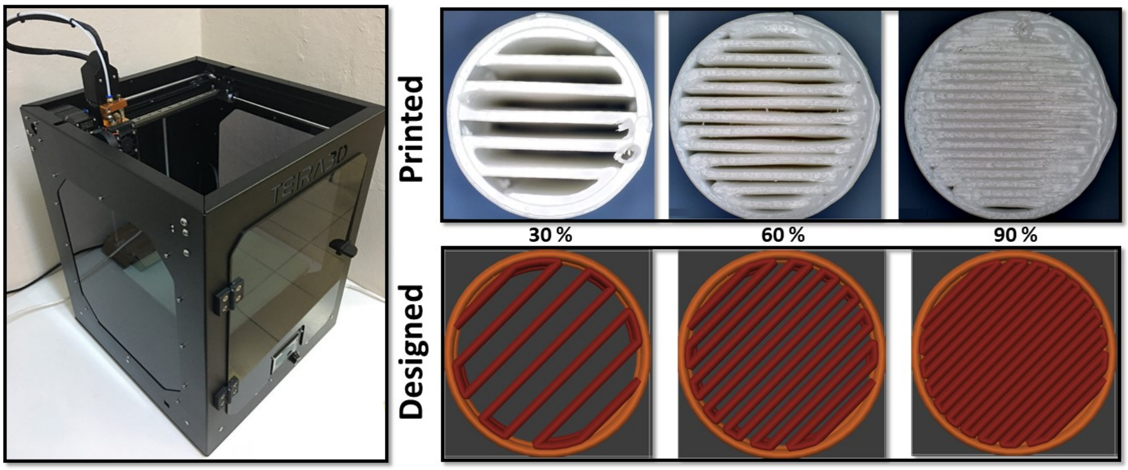

Figure 1. Teira 3D Plastix250 brand printer and test samples used in the experiments

Friction tests were carried out in Turkyus brand pin-on disc test device according to ASTM G99-17 standard. The pin on disc test device was calibrated before the experiments according to the instruction in the user manual. Pin-on disc test was performed at room temperature (20°C) with rotation speed = 600 rpm, track diameter = 40 mm, speed = 1257 mm/s, distance = 1507920 mm, force = 12 N. In the friction tests, 1.2379 steel disc with 60 HRC hardness was used. Radwag PS 360/C/2 brand balance with 0.001 gr precision was used to determine the weight losses after the wear tests. The weighing device is placed on a stable surface with the help of scales. The device was reset before the measurements. A microscope (Dino Lite AM7915MZT) was used to take images of the worn surface of the samples. Scale settings were calibrated using the image processing software of the microscope. The wear rate was calculated according to Equation 1.

$$\text{Wear rate (spesific)} = \frac{\textit{Wear volume loss}}{\text{Sliding distance X Aplied load X Density}} \quad (1)$$

Table 2: Printing and wear test parameters

Printing Parameters	
Nozzle / Bed Temperature	255 °C / 105 °C
Infill Angle / Printing Pattern	45° / Rectangular
Layer Height / Wall Number	0.2 mm / 1
Infill Density	30% / 60% / 90%
Dimensions (Height & Diameter)	Cylinder (20 mm / 10 mm)
Pin-on-disc Test Parameters	
Standard Number	ASTM G99-17
Test Temperature	20 °C
Rotation Speed	600 rpm
Track Diameter	40 mm
Speed	1257 mm/s
Distance	1507920 mm
Load	12 N
Disc type and hardness	1.2379 steel disc / 60 HRC

3. Results and Discussion

The tribological properties of the samples produced at 30%, 60% and 90% infill densities using ASA filaments were investigated. Thanks to the study, it is aimed to use the least material without compromising its tribological properties. The results obtained from the study were evaluated. The hardness, diameter value and wear rate results of the samples are given in Figure 2.

The hardness values of the samples with 30%, 60% and 90% infill densities were measured at 96.6, 94.8 and 98.4 Shore D, respectively (Figure 2a). It is seen that the samples with 90% infill density have the highest hardness value. The lowest hardness value was reached in the samples with 60% infill density. Despite having the same patterns, the change in the infill density affects the hardness of the samples. The difference in hardness values can be attributed to the cooling rate caused by the changing sample mass and the density of the patterns. The diameter values of the samples with 30%, 60% and 90% infill densities, measured immediately after manufacturing, were measured as 9.66, 9.53 and 9.71 mm, respectively (Figure 2b). There is a parallelism between the hardness values of the samples and the diameter values. The hardness differed according to the filling ratios. The hardest samples were observed in samples with 90% fill rate. At the same time, the samples closest to the target diameter value of 10 mm are the samples with 90% fill rate. The highest diameter deviation value was determined in the samples with the lowest hardness and 60% fill rate. This proves that the samples differ according to the amount of material and pattern density. The wear rate values of the samples are given in Figure 2c. The least wear rate was obtained in samples with 90% infill density. As the infill densities increased, a decrease in the wear rates of the samples was obtained.

The average friction coefficients of the ASA samples obtained with the pin-on test device are given in Figure 3. The friction coefficient of the samples with 30% infill density is at the lowest level. Changes in the average friction coefficient values were observed with the change of infill densities. However, it is seen that there is no direct proportionality between the increase in the occupancy rate and the friction coefficient. This can be explained by the fact that friction behavior is a complex phenomenon. The friction coefficient was the highest in the samples with 60% filler density. Fluctuations in the friction coefficient were detected in the first period of the friction test, during the break-in phase. It has been determined that the friction coefficient of the 90% filler density samples with the highest infill density is more stable after the familiarization phase, that is, after the 400 s test period. This can be explained by a greater change in the contact area with particles deposited and adhering between the patterns during testing, when the infill density is low. There may not always be a linear relationship between the filling density and the coefficient of friction. The changes that occur on the surfaces during friction affect the friction coefficient. Some researchers have observed this in their studies. Zhang et al. [24] evaluated the friction coefficients of 25, 50, 75 and 100 fill density PLA samples. They reached the lowest coefficient of friction in samples with 50% filler density. This is due to the friction process on the surface of the sample with 50 percent filler density. Friction particles uniformly fill the irregular shape of the three-dimensional printing original surface. With this filler, it ensures that the surface smoothness reaches the best condition. They stated that this reduces the friction coefficient on the contact surface of the two friction pairs.

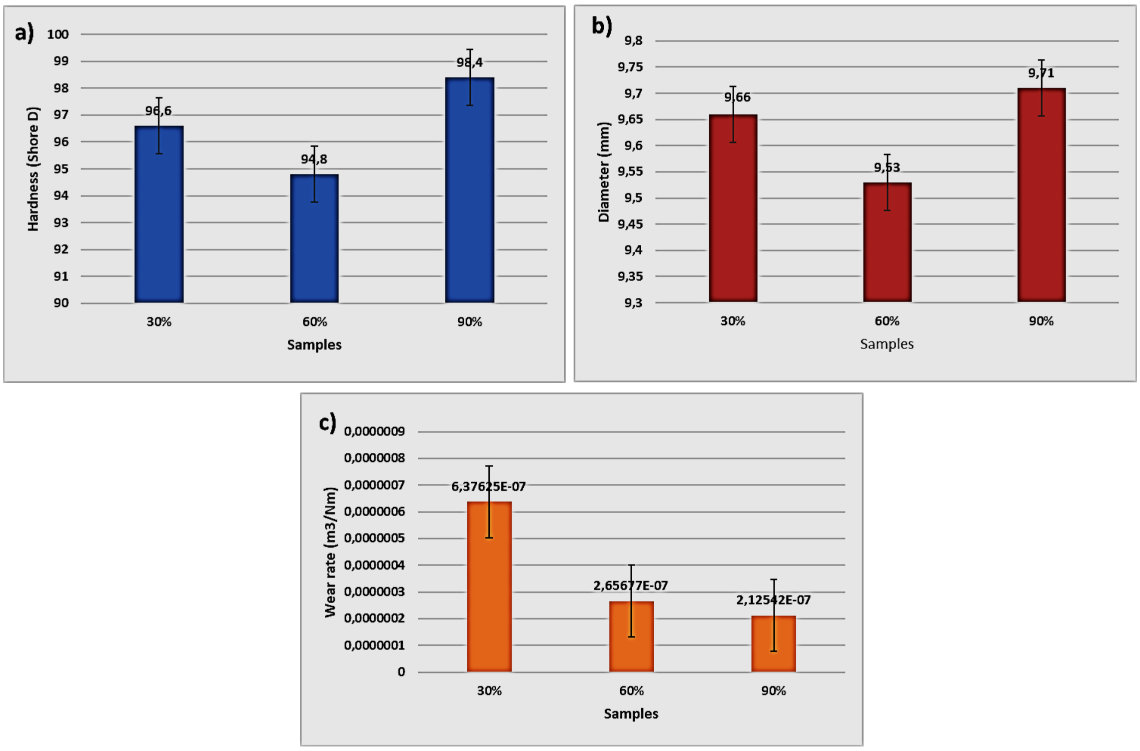

Figure 2. Hardness, Diameter and Wear rates of samples

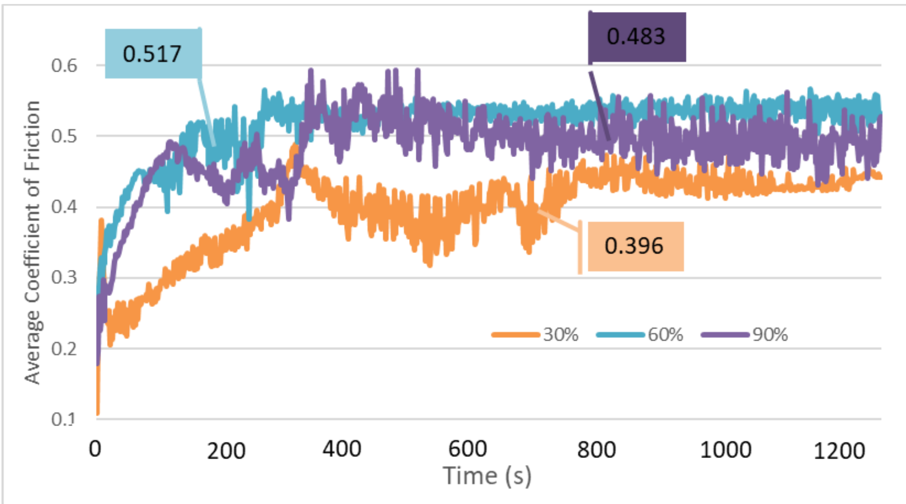

Figure 3. Friction coefficients of samples with 30%, 60% and 90% filler densities

The worn surface images of the samples with 30%, 60% and 90% infill densities are given in Figure 4. As a result of the wear tests, it is seen that there are obvious wear marks on the samples. It is seen that adhesions between patterns are intense in samples with 60% and 90% infill densities. The presence of adhesions and the presence of grooves on the samples indicate that abrasive and adhesion mechanisms are effective. In the sample with 60% filling density, the contact area with the pieces accumulated between the patterns increased, so the wear also increased. This also affected the coefficient of friction. Increasing the contact area and changing the surface quality of the contact surface affect the friction coefficient and wear mechanisms. At 90% infill density, after the friction test, the pattern gaps were filled and a completely flat surface was formed. It can be said that this situation behaved like a 100% filled sample. According to this result, reducing the infill density may be advantageous in some cases in terms of cost. Different infill densities affect the contact area, temperature during wear, friction coefficient and surface wear behavior [6]. The air spaces between the patterns differ according to the patterns. In addition, during the friction test, the filling of the air spaces with the adhered particles causes the contact surface to change and the heat generated to increase. This also affects the wear behavior of the samples.

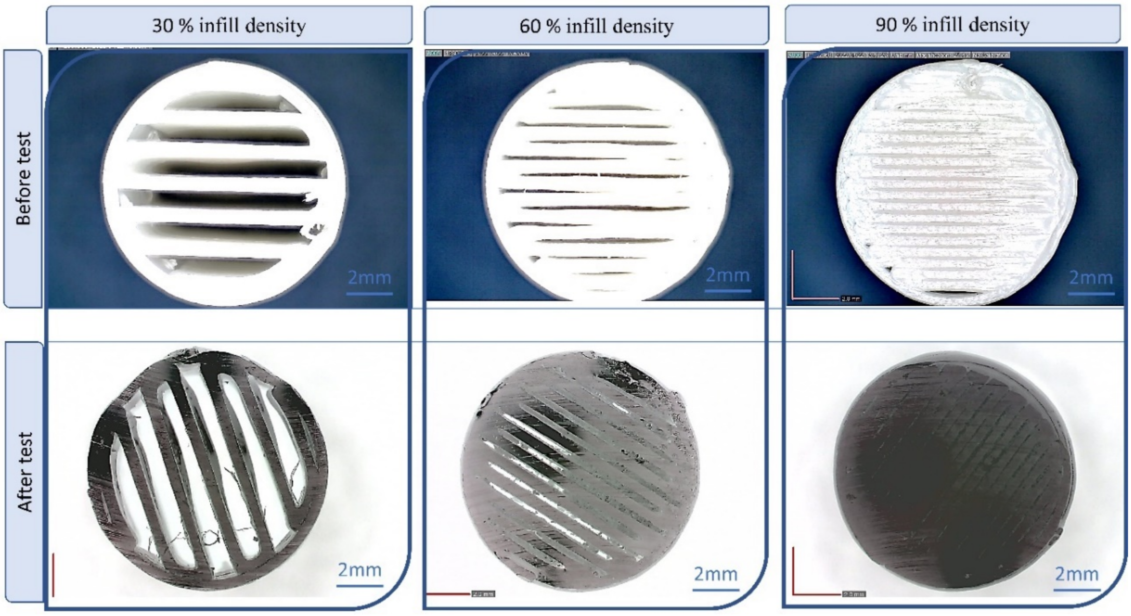

Figure 4. Worn surface images of samples with 30%, 60% and 90% infill densities

Conflict of Interest Statement

The authors declare that there is no conflict of interest

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