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Araştırma Makalesi/Research Article

Investigation of Properties of Glass Fiber and Rubber Filled PA6 Polymer

Elif TÜRKMEN[1], Salih Hakan YETGİN[2*], Mustafa GÜLESEN[3]

Abstract- **In this study, the effects of glass fiber and rubber were investigated on the mechanical, thermal and tribological properties of PA polymer. Mechanical and physical properties of PA6 polymers were determined by tensile and hardness tests, and thermal properties by DSC analysis. Tribological properties were determined using a pin-on-disc device. Wear tests were carried out at a sliding speed of 0.5m/s and 1.0m/s, and a load of 20-40N. As a result, the glass fiber added to the PA6 polymer increased the tensile strength by 33% while the rubber addition decreased by 18%. Addition of glass fiber and rubber reduced the crystallization rate. The wear rate increased with increasing sliding speed, while the wear rate decreased with applied load. Coefficient of friction increased with increase load and sliding speed.**

Keywords- **Specific wear rate, Friction, Mechanical Properties, PA6**

I. INTRODUCTION

Polyamide (PA) is the most widely used type of semi-crystalline polymer among engineering plastics due to its high strength/weight ratio, corrosion resistance, resistance to UV and gamma rays, and relatively simple and economical production processes as compared to conventional materials. However, polyamides have certain disadvantages such as limited mechanical properties, high moisture absorption, low dimensional stability, low heat distortion temperature, poor impact strength at low temperature and easy flammability [1-4]. For this reason, the properties of the pure polyamides can be improved by using different additives. In general, the additives in the form of particles or fibers are glass fiber, wollastonite, carbon fiber and aramid fiber [5, 6]. While glass fibers develop tensile strength and rigidity, TiO_2 contributes to the increase in the amount of crystal. Filler such as MoS_2, graphite, PTFE and silicone oil affect mechanical properties such as strength and impact resistance while reducing friction and wear properties [4, 7]. On the other hand, glass fibers are the most preferred type of filler because of low cost, easy supply and ease of production.

There are a lot of studies in the literature on the mechanical and tribological properties of polymer composites using filler such as carbon, glass and aramid fiber. Stokes et. al. [8] investigated the mechanical properties of glass fiber reinforced PA6 composites produced by injection molding. Zhaobin et. al. [9] studied the mechanical and tribological properties of glass fiber filled 70% PA66/30%PPS blends. The mechanical properties of 20% and 30 glass fiber reinforced composites increased significantly compared to the PA66/PPS blend. The friction coefficient of 20% glass fiber content was 0.35, which was reduced by 47% when compared with the unreinforced mixture. When the wear rates of glass fiber reinforced PA6/PPS composites are examined, it has been determined that the increasing amount of glass fiber reduces the wear rates. Palabiyik and Bsahadur [10] have determined the mechanical strength and tribological properties of PA6 and high density polyethylene (HDPE) blends as well as the increase in tensile strength due to the addition of glass fibers and increasing amounts in the study. As a result of the tribological tests, it was determined that low friction coefficient and high wear resistance were obtained in the mixture of 40% PA6 and 60% HDPE, and it was determined that the PTFE content of 10% reduces the coefficient of friction and wear resistance at the maximum rate. Li et. al., [11] has investigated the tribological properties of polytetrafluoroethylene (PTFE) and ultra high molecular weight polyethylene (UHMWPE) filled 15% glass fiber/PA6 polymer. As a result, the PTFE filler increased the tribological properties at a load of 40N and a sliding speed of 200rpm while the UHMWPE deteriorated the friction and wear properties. The wear rate is increased when the coefficient of friction decreases with increasing speed and load.

[2*]Sorumlu yazar iletişim: hakan.yetgin@dpu.edu.tr
[1,3]İletişim: trkmnelf.7557@hotmail.com , mustafa.gulesen@dpu.edu.tr
[2,3]İmalat Mühendisliği Bölümü, Simav Teknoloji Fakültesi, Dumlupınar Üniversitesi, SİMAV-KÜTAHYA*

At the same time, 15% glass fiber added to PA6 polymer increased wear resistance while reducing friction of coefficient. Bahadur and Polyneni [12] studied the effects of glass fibers on the wear and friction behavior of PA11 polymers, and determined that weight loss is reduced due to the increased amount of glass fiber. Duxin et al. [13] have investigated the mechanical and tribological properties of polytetrafluoroethylene (PTFE), graphite and very high molecular weight polyethylene (UHMWPE) filled glass fiber/PA6 polymer composites. In 5% PTFE filled sample, the friction coefficient decreased to the maximum value. The PTFE/UHMWPE filled sample is described as the ideal material for improving the friction and wear properties due to low friction coefficient and wear rate. The glass fiber added to the PA6 polymer increased the wear rate while reduced the friction coefficient. Unal and Mimaroglu [14] studied the friction and wear performance of 15% graphite and 4% wax added PA6 polymers, the friction coefficient increased with increasing load and sliding speed while the wear rate was significantly affected by the sliding speed. The lowest wear rate was obtained in the PA6 polymer composite sample with 4% wax addition and the highest wear rate was obtained in the PA6 polymer. Gordon and Kukureka [15] have investigated the tribological properties of aramid fibers added to the PA46 polymer at rates of 6, 12 and 15%. The friction coefficient of 15% aramid fiber filled PA46 polymer is lower while the wear rate is increased at high speed and load ratios. Yi-Lan et al. [16] investigated the effects of additives such as talc and glass fiber and solid lubricants such as graphite and very high density polyethylene (HDPE) on PA6 polymer. As a result of the study, the glass fiber additive reduced the coefficient of friction and wear of the PA6 polymer.

In this study, mechanical, thermal and tribological properties of PA6 polymer and 30% glass fiber filled PA6 and 30% glass fiber/rubber filled PA6 polymer composites were investigated. Tensile tests were carried out to determine the mechanical properties. DSC analysis was performed to determine the thermal properties. Friction and wear tests were carried out at 1040 steel discs under dry conditions, with different load (20-40N) and sliding speed (0.5-1.0 m/s).

II. EXPERIMENTAL STUDIES

Polyamide 6 polymer, 30% glass fiber reinforced PA6 (PA6+30% GF) and 30% glass fiber+rubber filled PA6 (PA6+30%GF+rubber) polymer composites were obtained from Aydın Plastik (Turkey). The specimens for mechanical and tribological tests were produced using the injection-molding machine. The injection heater temperatures are set at 220-250^{o}C. The mold temperature was fixed at 30°C. Polyamide 6 polymers and composites were dried at 80 ^{o}C for 4 hours before injection molding process. Tensile tests were carried out on a Zwick Roell Z-100 machine in accordance with ASTM D638 standard, at room temperature and at speed of 10 mm/min. Notched isod impact tests were carried out in accordance with TS 1005 standard. Impact tests were carried out at room temperature using 4x10x80mm specimens manufactured by injection molding method with Zwick / Roell HIT 5-5P impact tester. Thermal properties such as melt temperature, melt enthalpy and crystallinity of PA6, PA6+30%GF, PA6+30%GF/rubber polymer composites were determined with Thermo Scientific EK90C/SII Exstar 6000 at 30-300^{o}C temperature and nitrogen environment. Wear tests were carried out on a pin-on-disc wear test configuration at room temperature under dry conditions. The cylindrical pin flat ended specimens of size 6mm in diameter and 40mm length were tested against 1040 steel disc. Figure 1 represents a schematic diagram of the pin-on-disc were test configuration that was designed and used for this work. Before each tribological test disk and pin surfaces were cleaned with acetone and dried. Table 1 gives the test conditions such as density, working ambient temperature, applied load and sliding speed for the materials used in this study.

Figure 1. Schematic representation of the pin-on-disc test configuration.

Table 1. Polymer materials used in wear and friction tests and test conditions

Materials	Density (g/cm^3)	Ambient temperature (^oC)	Sliding distance (m)	Sliding speed (m/s)	Applied load (N)
PA6	1.12			0.5	20
PA6+30%GF	1.28	21±2	1000	1.0	30
PA6+30%GF/Rubber	1.32				40

III. EXPERIMENTAL RESULT

Figure 2 shows the tensile strength and modulus values of the 30% glass fiber and 30% glass fiber/rubber filled PA6 polymer. The tensile strength of PA6 polymer of 55.6 MPa was obtained by adding 30% of glass fiber to 74 MPa. The addition of glass fibers increased the tensile strength by 33%. The rubber added to the PA6+30%GF composite sample reduced the tensile strength by 18%. The modulus of elasticity significantly increased the 30% glass fiber composite added to the PA6 polymer. The modulus of elasticity of the PA6 polymer of 2809 MPa reached 5145 MPa with an increase of 83%. It is believed that the increase in the modulus of elasticity of PA6 may be due to prevent of the deformation and the movement of the polymer matrix by the addition of more rigid glass fiber instead of PA6. The rubber added to the PA6+30%GF polymer caused the reduction of the modulus and the modulus of elasticity was determined to be 4370 MPa. The modulus of elasticity of the PA6+30GF/rubber polymer composite increased by 55% when compared to that of the PA6 polymer. The modulus of the PP polymer was 1.9 MPa, while the modulus of elasticity was 2.4 GPa with addition of wood fiber to PP. EPDM and SEBS elastomers added PP/wood fiber composite to improve impact strength reduced the elastic modulus to 1.9 GPa of composite [17].

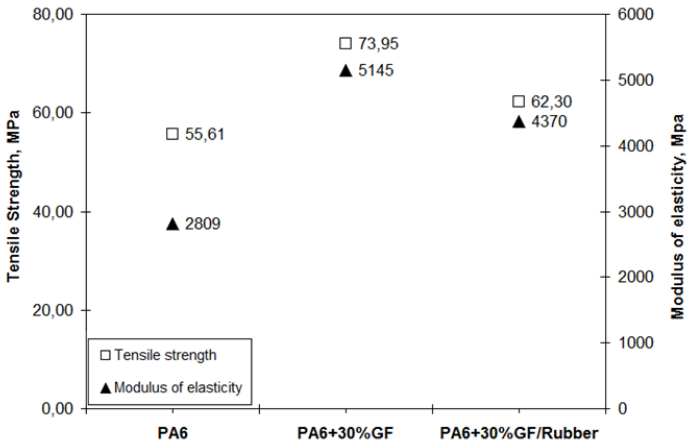


Figure 2. Tensile strength and modulus values of PA6 and PA6 composites

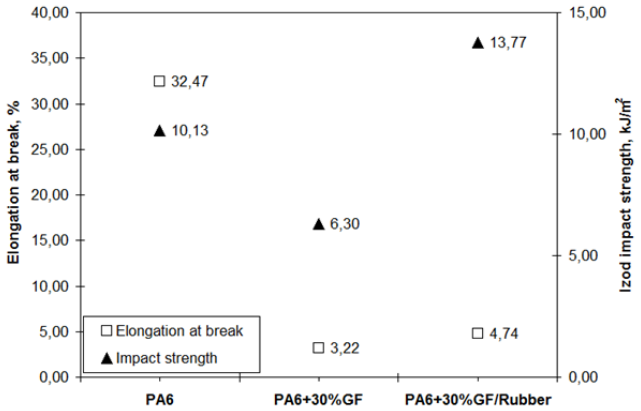
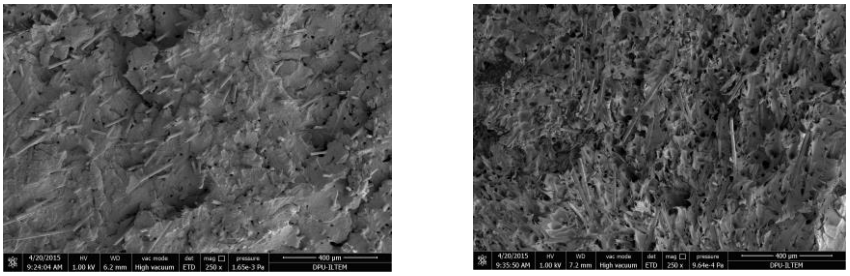


Figure 3. Elongation at break and impact strength values of composites PA6 and PA6

Figure 3 shows the elongation at break and isod impact strength values of the PA6 and PA6 polymer composites. 30% glass fiber added to the PA6 polymer reduced the elongation at break by approximately 907% relative to the PA6 polymer. This reduction in the elongation at break is due to the limitation of the glass fiber's movement of the macromolecular chains of the polymer, the limitation of polymer deformation and thus the material becoming more brittle (Figure 4-a). The rubber added to the PA6+30GF polymer composite sample increased the elongation at break by 32%. The increase in the elongation at break is due to the high ductility of the rubber particles. As seen in Figure 4-b, the fracture mechanism of the PA6+30GF/Rubber polymer composite sample has been changed from brittle to ductile behavior. When the isod impact strength values were examined, the impact strength of PA6 polymer was 10.13 kJ/m^2 and decreased by 60.8% with the addition of 30% glass fiber and was obtained as 6.30 kJ/m^2. The glass fiber matrix added to the PA6 polymer reduces the flexibility of the matrix, making it more rigid. PA6+30GF/rubber polymer increased the impact strength by 35.8%.



a) PA6+30%GF b) PA6+30%GF/Rubber

Figure 4. SEM images taken from fracture surfaces

DSC thermograms of PA6 and PA6 composites are given in Figure 5. As can be seen, the glass fibers and rubber filled PA6 polymers have 220-222 °C of melt temperatures. The melt enthalpy (ΔHm) value of the PA6 polymer was 91.03 J/s, which decreased to 51.44 and 42.33 J/g. As shown in Table 2, the crystallization rate of the PA6 polymer was 47.6%, while that of the PA6+30GF and PA6+30GF/rubber polymer composites was 31.6% and 29.5%, respectively.

Table 2. Melting temperature, melting enthalpy and % crystallinity of samples according to endothermic DSC results

Materials	Melting temperature (°C) T_m	Melting enthalpy, (J/g) ΔH_m	% crystallinity X_c
PA6	220.1	91.03	47.6
PA6+30GF	221.9	51.44	31.6
PA6+30GF/Kauçuk	221.9	42.33	29.5

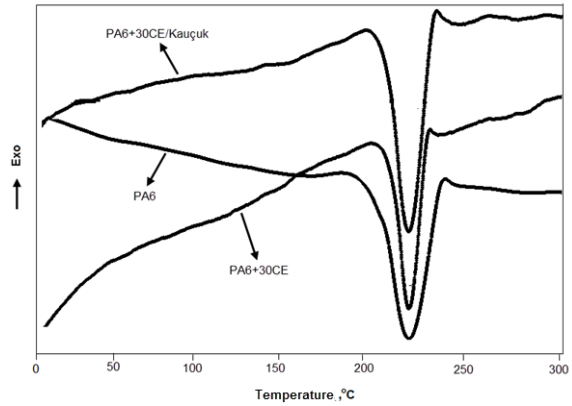


Figure 5. DSC thermogram of PA6 and composites

Figure 6 shows the relationship between coefficient friction and sliding distance of PA6 polymer and PA6 composites under at a sliding speed of 1.0 m/s and load of 30N. As can be seen, the change in the coefficient of friction of all three polymer materials occurred in two stages as initial and steady state conditions. The friction coefficient reached a steady-state period after about 350 m of sliding distance. For the PA6 polymer, the initial coefficient of friction is lower than steady state of period. Glass fiber and rubber additives added to the PA6 polymer significantly reduce the friction coefficient. The coefficient of friction for the PA6 polymer was 0.48, while for the 30% glass fiber filled PA6 polymer was 0.43 obtained. In the case of PA6+30GF/rubber

polymer, the coefficient of friction was obtained as 0.39 at steady-state stage. Friedrich et. al. [18] reported that the carbon fiber reinforced polyetheretherketone (PEEK) polymer plays an important role in the transfer of load with transfer film on the steel disc surface. These layers, which are composed of worn fibers and matrix fragments, reduce contact pressure and surface stresses by reducing the contact between polymer and disc surface. At the same time, due to the reduced thermal conductivity of the transfer film layer, the contact temperature of the polymer and disk surface increases, reaching the melting temperature of the matrix material. Hanmin et. al. [19] and Lancaster [20] have also suggested that fibers support a large portion of the applied load to reduce the direct interaction between polymer and metal.

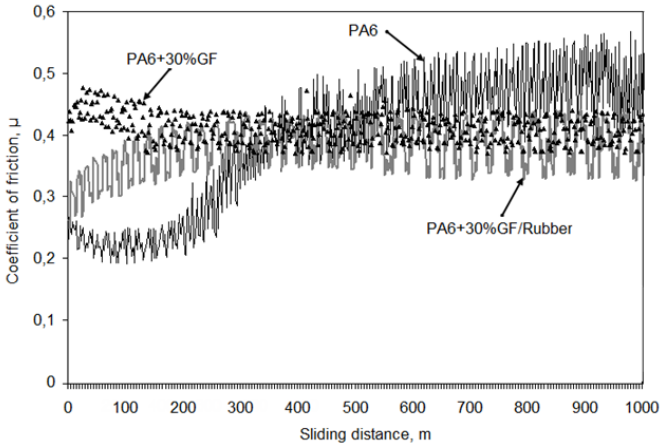


Figure 6. The coefficient of friction-sliding distance of PA6 polymer and PA6 composites (Sliding speed: 1.0 m/s, Applied load: 30 N)

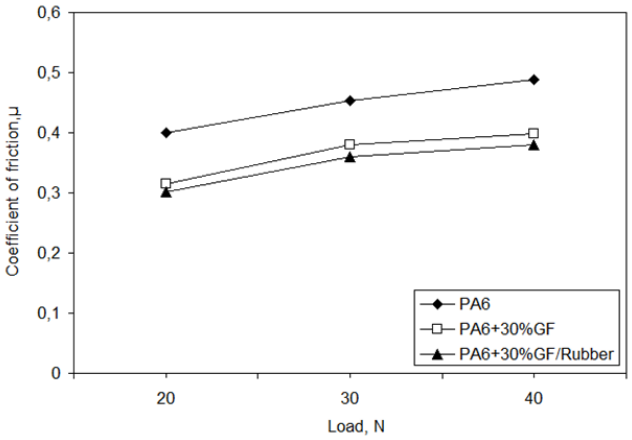


Figure 7. Relation of friction coefficient-applied load for PA6 polymer and PA6 composites

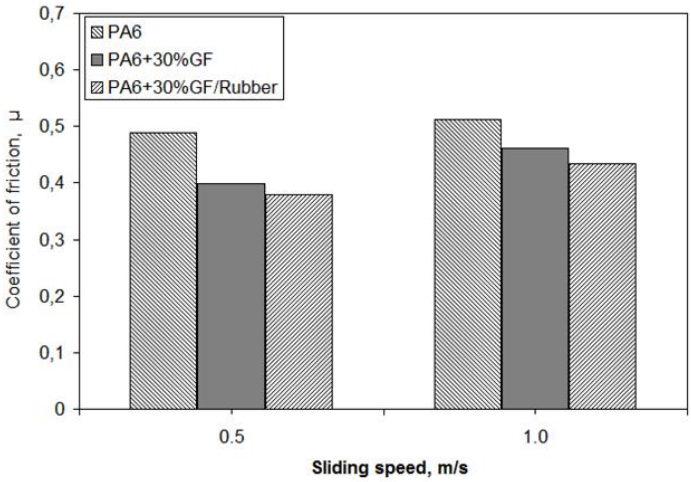


Figure 8. Relation of friction coefficient-sliding speed for PA6 polymer and PA6 composites

Figure 7 shows the variation of the friction coefficients of PA6 polymer and PA6 composites with applied load. It appears that friction coefficients increase with increasing amount of load in all three polymer types. The friction coefficients for PA6, PA6+30% GF and PA6+30GF/Rubber polymers increased by 9%, 24.7% and 26.6%, respectively, when the applied load was increased from 20N to 40N. Under 30N constant load, 30% glass fiber added to PA6 polymer reduced friction coefficient by 11% while rubber added to PA6+30GF polymer reduced friction coefficient by 8.9%. The lowest coefficient of friction in the applied load ranges was obtained in the PA6 + 30GF / Rubber polymer with a load of 20N at 0.301 and the highest coefficient of friction in the PA6 polymer at 0.489 under 40N load. Similar results obtained by Duxin et. al., [13] and Unal and Mimaroglu [14]. Figure 8 shows the variation of the friction coefficients depending on the sliding speed. The friction coefficient increased with the increase of the sliding speed. This increase was 9% for PA6 polymer, 16% for PA6+30GF polymer and 12.6% for PA6+30GF/rubber polymer. The 30% glass fiber added to the PP polymer reduced the friction coefficient by 10.8% while the rubber added to the PA6+30GF polymer reduced the friction coefficient by 6.5%.

Figure 9 shows the relationship between the wear rate and the applied load of PA6 polymer and PA6 composites. The wear rate of PA6 polymer decreased with increasing load at 20N to 40N load range. This reduction in wear rate is approximately 35%. It has been determined that the wear rate of PA6 + 30GF polymer is reduced by 27% in the load range of 20N to 40N. The reduction in wear rate of PA6+30GF/Rubber polymer was approximately 33% with a applied load increase in 100%. 30% glass fiber added to PA6 polymer reduced the wear rate by 211%. Similar results were obtained in the study conducted by Bahadur and Polineni [12].

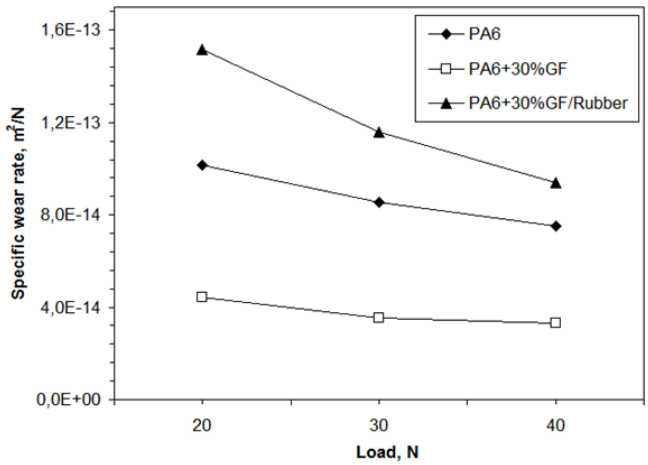


Figure 9. Relation of wear rate-applied load of PA6 polymer and PA6 composites

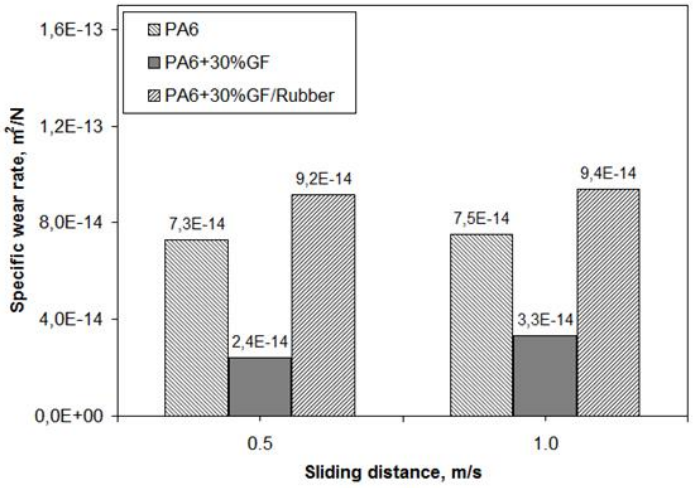


Figure 10. Relation of wear rate-sliding speed of PA6 polymer and PA6 composites

Figure 10 also shows the wear rate results depending on the sliding speed for PA6 polymer, glass fiber and rubber reinforced PA6 polymer composites. In general, the wear rate of PA6 polymer is obtained at 10^{-13} m^2/N, while the wear rate of glass fiber and rubber filled PA6 polymers is 10^{-14} m^2/N. For all three materials, it is seen that the wear rate increases with the increase of the sliding speed. The wear rate of the PA6+30GF polymer composites in the range of 0.5 and 1.0 m/s sliding speed was found to be significantly lower than that of the PA6 polymer. The glass fiber added to the PA6 polymer caused the wear rate of the composite to decrease by 125%. The highest wear rate was observed at 20N load in PA6+30GF/rubber polymer with $1.5x10^{-13}$ m^2/N. The lowest wear rate was obtained at 40N load in PA6+30GF polymer with $3,3x10^{-14}$ m^2/N. Similar results have been obtained previously in literature by Li et. al. [11] and Colak et. al. [21].

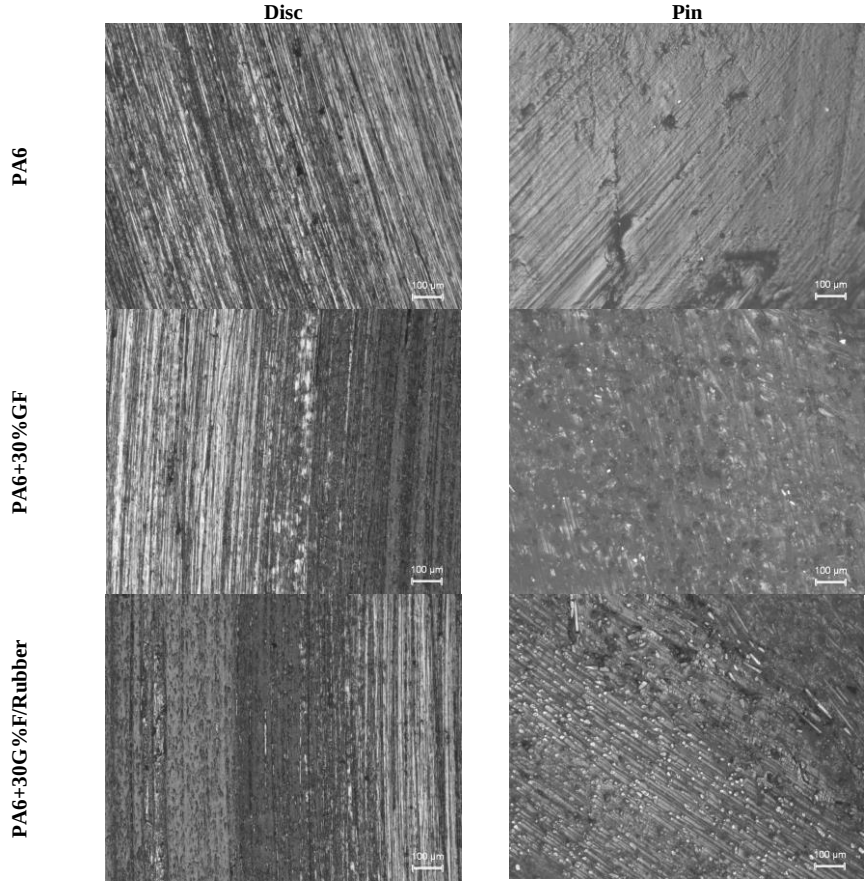


Figure 11. Wear surface images of PA6 and composites

Wear surface images of PA6 and composites are given in Figure 11. As can be seen, a transfer film layer was formed on the surface of the counter disk for of the three polymer types. The transfer film layer became homogenous with the glass fiber and rubber additives added to the PA6 polymer. When the pin surface of the PA6 polymer was examined, characteristic plastic deformation causing high friction and wear, deep wear marks and voids due to deformation of the matrix were observed. At the same time, grooves parallel to the sliding direction were also detected. This indicates that the wear mechanism is adhesion and abrasive wear. Addition of 30% glass fiber to PA6 polymer resulted in less plastic deformation and less wear marks on the surface. The wear mechanism of PA6+30GF polymer is seen as adhesion wear. Yi-Lan et. al. [16] found that the wear surface of 15% glass fiber filled PA6 polymer is softer than the PA6 polymer, the fibers contacting the wear surface carried the applied load and friction and wear properties have improved due to reduced deformation.

IV. RESULTS

The glass fiber added to the PA6 polymer increased the tensile strength by 33%. The rubber additive added to the PA6+30GF composite sample reduced the tensile strength by 18%. The modulus of elasticity of the PA6 polymer of 2809 MPa reached 5145 MPa with an increase of 83%. The 30% glass fiber added to the PA6 polymer reduced the elongation at break by about 907% compared to the PA6 polymer. The rubber additive added to the PA6+30GF polymer composite sample increased the elongation at break by 32%. Glass fiber and rubber additives added to PA6 polymer reduced the crystallization rates. The 30% glass fiber added to the PA6 polymer reduced the friction coefficient by 11% while the rubber added to the PA6+30GF polymer reduced the friction coefficient by 8.9%. The coefficient of friction increased with increasing load and sliding speed. The wear rate decreased with increasing load while decreasing with increasing sliding speed.

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