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Friction and Wear Properties of Glass Fiber Reinforced Polyphenylene Sulfide Composites

Mehmet İskender ÖZSOY*, Levent ESATOĞLU

Abstract

The aim of this study is the experimental investigate of wear and friction properties of polyphenylene sulfide polymer (PPS) and 20%, 30% and 40% by weight glass fiber reinforced polyphenylene sulfide composites. Tribological tests were done by pin-on-disc test configuration. The disc material is AISI 1040 steel. 50, 100, 200 N normal loads and 1, 2, 3 m/s speeds were applied to the test specimens. Adding fiber decreased the friction values and specific wear rates. Furthermore, increasing load decreased the friction coefficient but increased the specific wear rate, although increasing sliding speed increased both friction and specific wear rate.

Keywords: Friction, wear, polyphenylene sulfide, glass fiber

1. INTRODUCTION

Polymer materials have been used widely in engineering applications. In use generally, polymers have been reinforced with various fibers. Fibers improved the tribological performance of the materials and gained the high wear resistance [1-9]. Mens et al. [1], investigated the tribological properties of different polymer materials and concluded that the increasing load increased the wear amount but decreased the friction coefficient. Yilmaz et al. [2], studied the pomza powder/carbon fiber hybrid composites and stated that the reinforcement and fillers enhanced the wear properties of PPS. Sumer et al. [3], studied the 30 wt% glass fiber (GF) reinforced PEEK composite and concluded that the increasing load increased the friction coefficient and wear. Friedrich et al. [4], studied PTFE with glass fiber composites. They found that adding glass fiber enhanced the wear properties of PTFE polymer. Tewari et al. [5], studied the polyetherimidin with glass fiber composites. They stated that increasing wt % glass fiber ratios decreased the friction coefficient. They also showed that increasing load decreased the friction coefficient. Yousif et al. [6], studied the polyester composites with glass fiber mat. They investigated the wear surfaces and observed the cracks in the matrix, breakage in glass fibers at the major load. Reinicke et al. [7],

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studied different fiber reinforced thermoplastic materials. They used the glass fiber as a reinforcement material in the PA46, PP, PPS and PEI polymers. Cai et al. [8], tested the PEI composites reinforcing with glass and carbon fiber. They stated that both increasing fiber ratios and increasing load decreased the friction coefficient. Voss et al. [9], studied the glass and carbon fiber-PEEK composites. They showed that adding fiber into the matrix enhanced the wear resistance of polymer.

Polyphenlyne Sulfide (PPS) polymer has a widespread usage area such as automotive, electrical and electronical. It has high heat, chemical resistance and high mechanical properties. Its melting point is 285 °C. These properties make the PPS an alternative of thermosets and metals [10]. Researchers have been using different reinforcements in the PPS polymer to gain the wear resistance [11-15]. Guo et al. [11], studied the molybdenum concentrate and PTFE filled PPS composites. They stated that thickening of transfer film layer on the disc decreased the friction. Uniform location of transfer film layer and less detachment of materials from the surface, ensured the increasing of wear resistance. Jiang et al. [12], studied the carbon fiber reinforced sub micro TiO₂ filled PPS composites. For this composite increasing sliding speed increased the friction coefficient, but increasing carbon fiber ratios improved the tribological behaviour. Lhymn et al. [13], studied the fiber reinforced PPS composites. They stated that increasing of glass and carbon fiber ratios, decreased the wear amount. Unal et al. [14], studied the glass fiber reinforced PPS composites. They found that increasing speed worsen the tribological behavior, while increasing load increased the wear and decreased the friction. Besnea et al. [15], tested the 40 wt % glass fiber + PPS and 10 wt % PTFE+ 20 wt % carbon fiber reinforced PPS composites.

In the light of these literatures it is seen that the studies for PPS polymer composites have been being rarely and more detailed studies are needed such as different fiber ratios, influence of load and speed parameters. The aim of this study is to experimental investigate of friction and wear behavior of chopped glass fiber reinforced polyphenylene sulfide composites with glass fiber reinforcements in 20%, 30% and 40% weight ratios. Tests were carried 50, 100, 200 N normal loads and 1, 2, 3 m/s sliding speed values at room temperatures. In these tests, the counterface disc material is AISI 1040 steel used.

2. MATERIALS AND EXPERIMENTAL WORK

In this study, the materials used were PPS polymer and chopped glass fiber reinforcements. Mechanical and physical properties of PPS and chopped glass fiber were given in Table 1. Specimens were prepared using an extruder. Firstly, the composite materials were produced in granular form in an extruder which temperature ranges from 210 °C to 240 °C. Then the test specimens were obtained as cylindrical forms with a 5 mm diameter and 40 mm length by an injection mold. The molding temperature varied from 200 °C to 240 °C. Tests were done with pin-on-disc test configuration. ASTM G99 test standard was used in wear tests. Experimental and schematic images of the wear test rigs were given in Figure 1a and 1b respectively.
Figure 1b Schematic representation of the wear test rig [16]

Table 1
Mechanical and physical properties of PPS [17] and chopped glass fiber [18]

| Properties                  | PPS   | Chopped GF |
|-----------------------------|-------|------------|
| Tensile strength (MPa)      | 80    | 520        |
| Elongation at break (%)     | 10    | 4.8        |
| Elasticity modulus (GPa)    | 2.9   | 75         |
| Thermal conductivity (W/m.K)| 0.2   | 1.35       |

Before and after each test, pin specimens and AISI 4140 counterface steel disc with surface roughness (Ra) is 0.29 μm were cleaned with alcohol. Friction force was calculated with a load cell sensor and datas were transferred to the computer. A software calculated the friction forces according to equation (1).

\[ \mu = \frac{F_F}{F_N} \]  

where \( F_F \) is the frictional force and \( F_N \) is the normal load. Wear amount was obtained by weight differences which obtained before and after the tests. Applied loads were 50, 100, 200 N and sliding speeds were 1, 2, 3 m/s. Tests were repeated three times at room temperature conditions. At the end of the tests, the specific wear rates were calculated, compared and evaluated. Eq. (2) gives the specific wear rate.

\[ \text{Wear rate} = \frac{\text{Wear loss}}{\text{Density}\times\text{Load}\times\text{Sliding distance}} \quad [mm^3/Nm] \]  

3. RESULTS AND DISCUSSIONS

Figure 2 shows the friction coefficient and sliding distance relationship of pure PPS and PPS composites at 2m/s sliding speed and 50N applied load conditions. It is clear from this figure that PPS polymer showed a small increasing trend up to 1200 m travelling distance and then showed a sharp decreasing behavior and then it continued a steady state behavior. There are some weavings on the PPS line. It is thought that polymer pin could be melt during the rubbing process and detachment particles could make a roughness effect. 20 wt% glass fiber reinforced PPS composites have more waving behavior than the other reinforced composites. Increasing fiber ratio showed more steady state trend and adding of glass fiber decreased the friction coefficient. PPS polymer showed the maximum friction value and 40 wt% glass fiber PPS composite showed the minimum friction with very little weaving trend.

Figures 3 and 4 show the friction coefficients of PPS polymer and glass fiber reinforced PPS composites with load and speed, respectively. In the Figure 3 that, adding fiber decreased the friction coefficient and increasing load decreased the friction. Similar situation is seen in the literature [5, 8, 12, and 14]. It is thought that increasing load could shear the surface asperities between pin and disc and it made the pin surface smooth. Therefore, the friction coefficients were decreased. Sarkar et al. [19], explained that as a result of increasing load, it could be a transfer film because of heat generation of rubbing process, thus the friction coefficient decreases because of the increasing load. In the Figure 4, increasing sliding speed caused an increase of friction coefficient. Similar behavior was observed in the
It is thought that increasing speed could increase the surface temperature and it could melt and deform the pin surfaces. This could cause the roughness of pin surfaces. And increasing roughness could increase the friction coefficient. It is seen that in the figures 3 and 4, increasing fiber ratio decreased the friction coefficients of PPS polymer. It is thought that adding fiber could decrease the adhesion forces between pin and disc. Also, fibers could decrease the shear forces and thus it could ensure the decreasing of friction forces. Thus, the movement of rotating disc against the pin could be easily. It is seen that in the figures, 40 wt% glass fiber PPS composites have the lowest friction coefficient all the load and velocity conditions.

During the rubbing process, adhesive bonds occurred at the polymer metal contact surfaces and adhesion transfer of polymer material to counterface occurred by molecular and electrostatics forces [20]. Contact region is subjected to shear forces during the rubbing and the forces which effect the contact asperities defined by $F_T = \tau_s A_r$ equation. $A_r$ is the contact area, $\tau_s$ is the shear stress and $F_T$ is the shear force which cuts the adhesive joints at the interface [21, 22]. Polymer – metal adhesion is greater than composite materials. So the $F_T$ tangential forces which necessary to shear the junction points are higher and friction forces are higher than reinforced materials. Adding fiber decreased the adhesion bonds between the contact surfaces and ensured the composites slide easily on the disc so the tangential friction forces decreased as it is seen in the Figures 2-4.

Figures 5 and 6 show the specific wear rates of PPS polymer and glass fiber reinforced PPS composites with load and speed, respectively. In the Figure 5, it is shown that increasing load increased the wear rates of PPS and glass fiber PPS composites. These results are agreement with the literature [1,3,14]. Increasing fiber ratios strengthened and made the polymer surface harder and so fibers decreased the deformations on the polymer surface and amount of detachment particles decreased. Thus the wear rates of composites decreased. It is seen in Figure 5 that specific wear rate of 40 wt% PPS composite is higher than that of 30 wt% PPS composite at 200N load condition. It is stated in the literature, glass fibers were broken at the high loads [6, 23]. It is thought that it could be a fiber breakage in the PPS polymer at high fiber ratios and higher load. It is seen in the Figure 5 that increasing normal load caused an increase of wear amount and increase of specific wear rate, according to the formula given by equation (2).

Figure 6 shows increasing speed increased the wear rate. This is in a good agreement with the literature [14,19,24,25]. PPS polymer showed the highest wear rate, while 40 wt% reinforced PPS composite showed the minimum specific wear rate. In the literature, increasing speed increased the contact surface heat [19]. It is thought that increasing speed could cause the increasing of surface temperature of pin specimens due to the frictional heating and it could be result of melting the pin contact surfaces and it could increase the
wear amount. Furthermore, the work which performed by friction force is given by equation (3) at below,

\[ Q(t) = \mu(t)Wv \]  

(3)

where the \( Q(t) \) is the work which generated by friction force by over time, \( \mu \) is the friction coefficient, \( W \) is the load and \( v \) is the speed [26]. It is clear in this formula, load and speed are effective on the friction force. Increasing sliding speed increased surface temperature and it caused a high adhesion between the contact surfaces [14,19,24]. High adhesion caused an increase of friction force, thus, increasing friction forces increased the wear rates as it is seen in Figures 4 and 5.

Figure 5 shows the scanning electron microscopy (SEM) images of disc and pin worn surfaces at 1m/s speed and 100 N applied load value. In Figure 7a, PPS polymer caused the transfer film on the disc surface and is not regular on the disc surface. It caused the waving in friction coefficient values as it is seen in the Figure 1 (friction coefficient vs. sliding distance diagram). In Figure 7b (PPS polymer), micro ploughing lines are more than composite materials. Applied load and sliding speed were caused the softening of PPS contact surface. Besides the shear forces which applied by the disc caused the detachment of particles. In Figures 7c-d-e, it is seen that fibers were broken towards the sliding direction by protecting matrix to the shearing failure. Existing of overlapping layers because of fiber breakage on the material surfaces show the plastic deformation and material losses. Also, 40 wt% ratio of fiber content caused the increase in wear rate at the higher load. It is thought that polymer matrix does not sufficient to bond the fibers at the higher fiber ratios. Some researchers concluded that higher load caused the breakage of the fibers [23, 27]. Wear debris adhered to disc and it makes an abrasive effect on the pin contact surface. Hence, PPS polymer and glass fiber reinforced PPS composites were subjected to adhesive and abrasive wear mechanisms and deformations were seen on the pin surfaces.

Figure 5 Specific wear rates of materials with load at 1 m/s speed

Figure 6 Specific wear rates of materials with speed at 100N load
4. CONCLUSIONS

In this study, the following conclusions are reached:

Increasing load from 50N to 200N, decreased the friction values of PPS and glass fiber reinforced PPS composites.

Increasing speed increased the friction value of PPS and glass fiber-PPS composites.

Friction coefficients of glass fiber-PPS composites decreased with increasing fiber ratio.

Increasing sliding speed and load increased the wear rate. Adding glass fiber ratio decreased the wear rates of PPS composites. PPS polymer showed the maximum increment of wear rate with increment of speed and load.

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