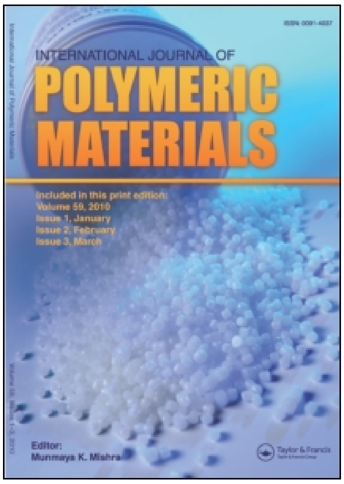

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Tribological Performance of POM, PTFE and PSU Composites Used in Electrical Engineering Applications

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In this experimental study, the tribological performance of polysulfone, poly-tetra-fluoro-ethylene, poly-oxy-methylene composites sliding against a poly-phenylene-sulfide polymer composite was studied. Tribological experiments were run under dry ambient conditions and at sliding speeds of 0.5–1.5 m/s under nominal load values of 20–40 N. Results for tested materials showed for the range of applied load and sliding speed values of this investigation that the friction coefficient and the wear rate are much more sensitive to the change in sliding speed rather than to the change in applied load values. The wear mechanism is mainly an adhesive process, but includes some abrasive process as well.

Keywords composite, friction, GFR, polymer, wear

INTRODUCTION

In engineering applications with two materials sliding against each other, there is the problem of friction and wear. In the case of polymers the friction between polymers can be attributed to two main mechanisms, deformation and adhesion. In this case, the deformation mechanism involves

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complete dissipation of energy in the contact area, while the adhesion component is responsible for the friction of polymer and is a result of breaking weak bonding forces between polymer chains in the bulk of the material [1,2]. Some polymer and polymer composites such as PSU, POM, and PTFE, find a wide range of applications in electrical engineering fields. Polysulfone is a high cost, rigid, amorphous material with low moisture absorption. Reinforcement improves its toughness and further enhances its dimensional stability. In addition, polysulfones are characterized by high strength, very high surface temperature limits, low creep, good electrical characteristics, transparency, self-extinguishing ability, and resistance to greases and chemicals. PTFE is a high-performance engineering plastic which is widely used in industry due to its properties of self-lubrication, low friction coefficient, high temperature stability and chemical resistance. In fact PTFE exhibits poor wear and abrasion resistance, leading to early failure and leakage problems in the machine parts. To enhance its wear resistance, various suitable fillers are added to PTFE. Generally, reinforcements such as glass fibers, carbon fibers and solid lubricants are added internally or incorporated into the PTFE. Filler influence on the tribological behavior of polymers has been investigated by many scholars [3–7]. They reported that the coefficient of friction can, generally, be reduced and the wear resistance improved when the polymers are reinforced with glass, carbon, armed fibers, organic particulates and alumina nanoparticles. Tribological behavior of the materials is also influenced by material surface conditions. The relationship between the wear rate and the surface condition of the counter surface is more complex than the friction. Research in this field reveals that the wear of POM and POM/PTFE blends raises with the increase in roughness, while the wear of glass-reinforced POM is insensitive to surface roughness [8–11]. Furthermore, the tribological behavior of polymers is also affected by environmental and operating conditions and by the type, size, amount, shape and orientation of the fibers [12]. There have been numerous investigations exploring the influence of test conditions and environment on the friction and wear behavior of polymers. Santner et al. [13], Brentnall et al. [14] and Clerico [9] observed that the friction coefficient of polymers rubbing against metals decreases with the increase in applied load value while Stuart [15] and Yamaguchi [10] showed that its value increases with the increase in load. Wang et al. studied the tribological performance of POM and POM composite filled with ZrO_2 nanoparticles. Their results show that ZrO_2 can be used as an untifrizer of wear resistance [16–18]. Finally, the tribological behavior of polymers is also influenced by material combinations. Yamaguchi [10], Hooke et al. [19] and Lawrence et al. [20] reported that the friction coefficient can, generally, be reduced and the wear resistance increased by selecting the right material combinations.

In this study, the tribological behavior of several polymer composites used in the electrical engineering field is evaluated. These composites are PSU + 20%GFR, PTFE + 20%GFR and POM + 20%GFR composites. The counterface material was PPS + 30%GFR. The main aim of this study is to point out among tested materials the composite with the best tribological performance under different test conditions. For this aim the tribological tests were carried out at room temperature, under 20 N, 30 N and 40 N load values and at 0.5–1.5 m/s sliding speed values. Finally, their friction and wear rate values were evaluated and compared.

EXPERIMENTAL

Friction and Wear Tests

Wear tests were carried out using a pin-on-disc wear test rig at room temperature under dry conditions. Cylindrical pin specimens of size 6 mm diameter and 50 mm length of POM, PTFE and PSU polymers and polymer composites were tested against a 30% glass fiber-reinforced poly-phenylene-sulfide polymer composite disc. The average surface roughness of the polymer composite disc was 20 μm Ra. Figure 1 represents a schematic diagram of the pin-on-disc wear test rig home designed and used in this work. As shown in this figure, the rig consists of a stainless steel table which is mounted on a turntable, a variable speed motor which provides the unidirectional motion to the turntable, hence to the disc sample, and a pin sample holder which is rigidly attached to a pivoted loading arm. This loading arm is supported in

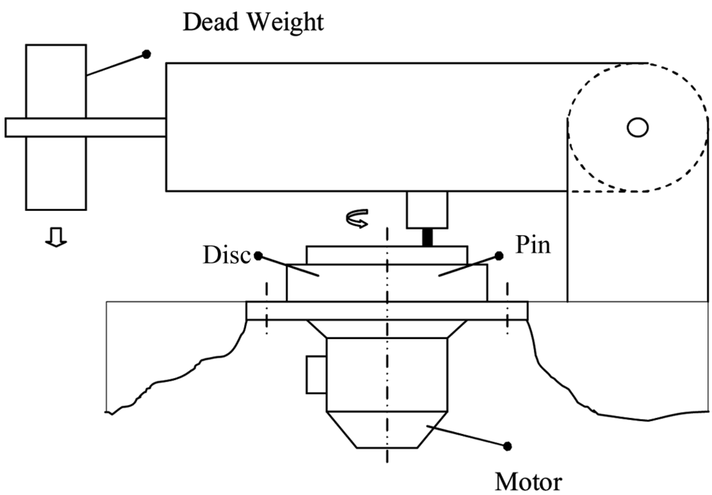

Figure 1: Schematic diagram of wear test rig.

Table 1: Materials and the specific test conditions.

Materials	Test temperature (°C)	Load (N)	Sliding speed (ms^{-1})	Humidity (%)
PSU	21 ± 2	20 30 40	0.5	32
PSU + 20%GFR	18 ± 1	20 30 40	0.5	30
PTFE	21 ± 2	20 30 40	0.5	32
PTFE + 20%GFR	23 ± 1	20 30 40	0.5 1.0 1.5	33
POM	23 ± 1	20 30 40	0.5	34
POM + 20%GFR	21 ± 2	20 30 40	0.5	30

bearing arrangements to allow loads to be applied to the specimen. During the test, friction force was measured by a load cell. The average of 100 readings per second for the friction force readings was taken. The materials and test conditions of the experimental tests are given in Table 1. Sliding wear data reported here is the average of at least three runs. The average mass loss was used to calculate the specific wear rate (K_0) as shown below.

$$K_0 = \Delta m / L \cdot F \cdot \rho \; (m^3 \, N^{-1} \, m^{-1})$$

where Δm is average mass loss in kilograms, L is sliding distance in meters, F is the applied load in (N) and ρ is density of the materials in $kg \cdot m^{-3}$.

RESULTS AND DISCUSSION

Figures 2 and 3 show the variation of friction coefficients of pure PSU, PTFE and POM polymers and their composites with variation in applied load values. Apart from PSU and its composite, all the tested materials' coefficient of friction values have not shown much sensitivity to the change in applied load. In the case of PSU, there is an increase in the coefficient of friction values for the increase in applied load value. Furthermore the presence of the filler GFR results in a 40% decrease in the coefficient of friction and to less sensitivity of friction to the change in applied load. This could be because PSU has an amorphous microstructure while POM and PTFE have a crystalline structure. Furthermore it is known that polymer materials show viscoelastic behavior

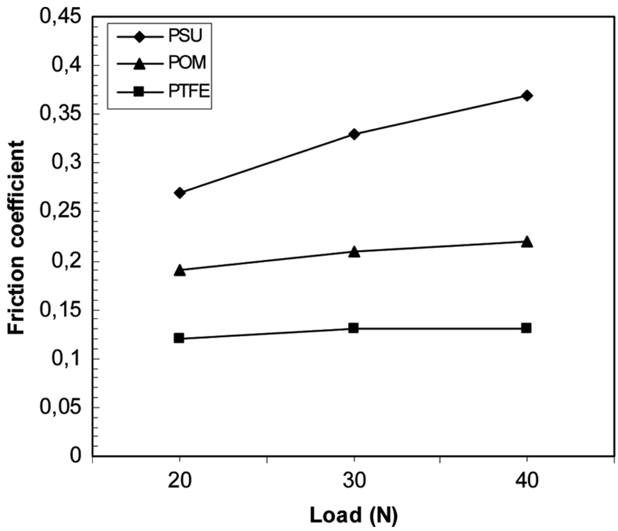

Figure 2: The relationship between friction coefficient and applied load values for pure polysulfone, pure polyoxymethylene and pure polytetrafluoroethylene engineering polymers.

under load, therefore, the variation of friction coefficient with load follows the equation

$$\mu = \mathrm{k}\ \mathrm{N}^{(\mathrm{n}-1)}\ [24]$$

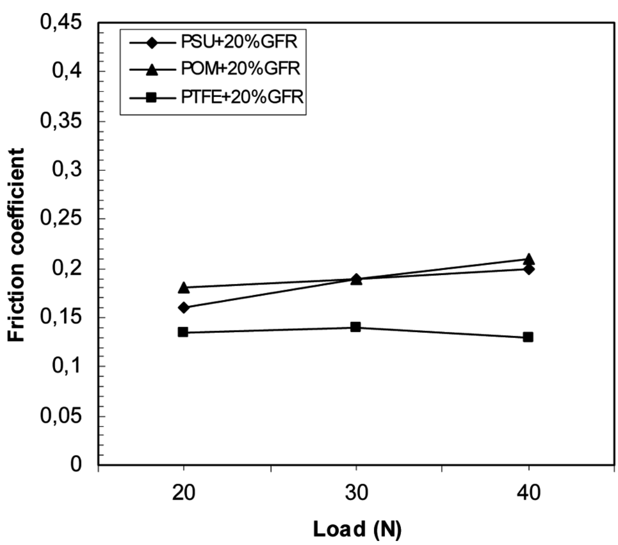

Figure 3: The relationship between friction coefficient and applied load values for 20% glass fiber-reinforced polysulfone, 20% glass fiber-reinforced polyoxymethylene and 20% glass fiber-reinforced polytetrafluoroethylene composites.

where μ is the coefficient of friction, N is the load, k constant and n is also a constant, its value $2/3 < n < 1$. According to this equation, the coefficient of friction decreases with the increase in load, but when the applied load increases to the limit load values of the polymer, the friction and wear will increase due to the critical surface energy of the polymer. Moreover, this is because the frictional heat raised the temperature of the friction surfaces, which lead to the relaxation of polymer molecule chains. On the other hand the insensitivity of the PTFE friction process to the change in applied load is attributed to its high softening temperature, which lead to less influence of frictional heat, hence to less relaxation of polymer molecules. In this study the lowest friction coefficient value is for PTFE + 20%GFR composite with an average value of 0.12.

Figures 4 and 5 illustrate the variation of the specific wear rate of tested polymers with applied load values. It is clear from Figures 4 and 5 that apart from PTFE and its composite, the specific wear rate for pure polymers and their composites increases with the increase in applied load value. Furthermore, adding GFR to PTFE results in a 90% lower wear rate levels while causing an increase in the POM wear rate. In the case of PTFE, the addition of GFR leads to improvement in mechanical properties and interlaminar shear strength, which results in lower wear rate values. The lowest wear rate is for PTFE + 20% glass fiber with a value of $8.3 \times 10^{-15}\,m^2/N$ while the wear rate values for both PSU + 20%GFR and POM + 20%GFR composites are in the order of $10^{-14}\,m^2/N$. The wear rate values for pure PTFE, pure PSU

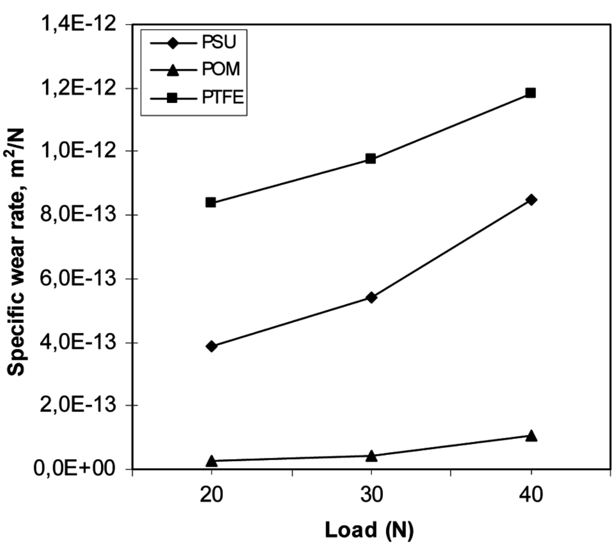

Figure 4: The relationship between specific wear rate and applied load values for pure polysulfone, pure polyoxymethylene and pure polytetrafluoroethylene engineering polymers.

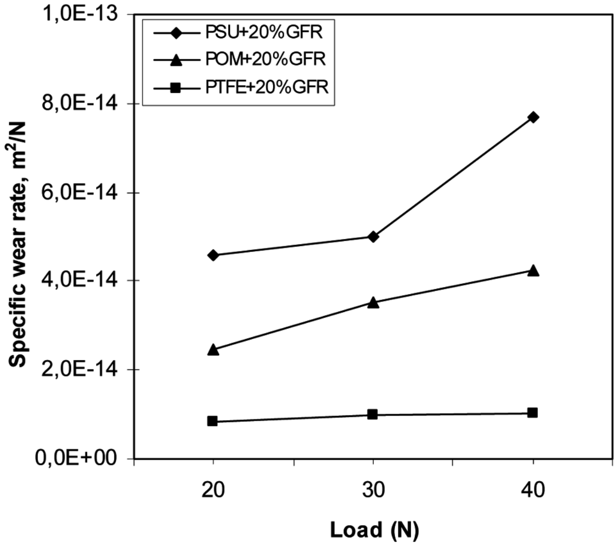

Figure 5: The relationship between specific wear rate and applied load values for 20% glass fiber-reinforced polysulfone, 20% glass fiber-reinforced polyoxymethylene and 20% glass fiber-reinforced polytetrafluoroethylene composites.

and POM are in the order of $10^{-13}\,m^2/N$. As a result of this investigation among tested polymer composites, PTFE + 20%GFR composite showed the lowest friction and wear rate values. For this composite material the effect

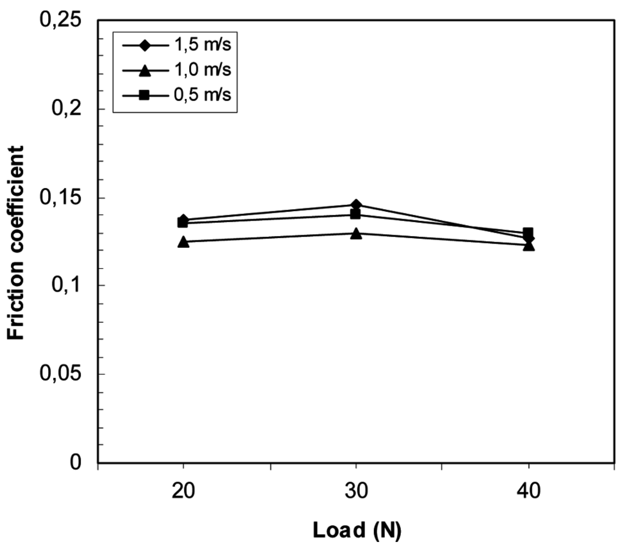

Figure 6: The relationship between coefficient of friction, applied load and sliding speed for 20 wt% glass fiber-reinforced PTFE composite.

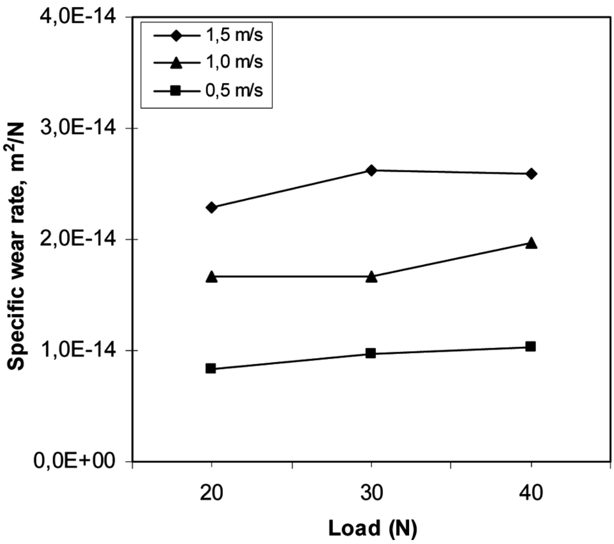

Figure 7: The relationship between specific wear rate, applied load and sliding speed for 20 wt% glass fiber-reinforced PTFE composite.

of sliding velocity on the tribological properties of the material was also further investigated.

Figure 6 presents the variation of the coefficient of friction of PTFE composite with applied load under different sliding speed values. This figure shows the insensitivity of PTFE composite friction coefficient levels to the change in sliding speed and applied load values. Moreover, Figure 7 illustrates the variation of the wear rate for PTFE composite with applied load under different sliding speed values. It is seen from this figure that the specific wear rate of PTFE + 20%GFR composites have shown much sensitivity to the change in sliding speed than the change in applied load values. The specific wear rate for the PTFE + 20%GFR composite showed 170% increase with 100% increase in sliding speed. This could be because as the speed increases, the pressure increases, which leads to broken GFR and the removal of transfer film and to higher wear rates.

Figure 8 presents the optical microscopy of the pin worn surfaces for PSU + 20%GFR, POM + 20%GFR and PTFE + 20%GFR composites. It is clear from this figure that the PSU + 20%GFR and POM + 20%GFR worn surfaces showed the broken GFR fibers which lead to some abrasive wear plus the main adhesive process (see 8(a) and 8(b)). In the case of PFTE, these broken fibers are dipped again in the matrix which weakened the transfer film but kept the whole process as adhesive mechanism (see Figure 8(c)). The microscopy of the pin worn surfaces suggests that the main wear process is adhesive with some abrasive mechanisms as well.

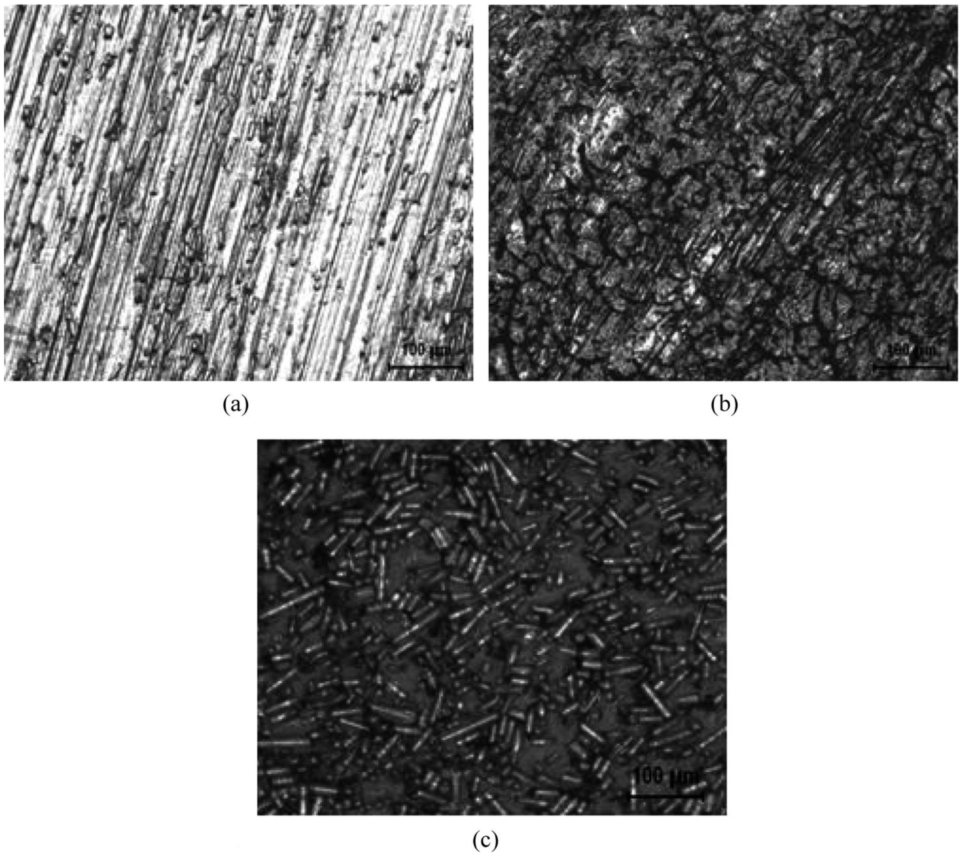

Figure 8: Optical microscopy of polymer composites pin worn surface a) PSU + 20%GFR, b) POM + 20%GFR, and c) PTFE + 20%GFR.

CONCLUSIONS

For the polymers and polymer composites of this investigation, the following conclusions can be drawn:

1. The tribological behavior of polymers and polymer composites of this investigation were ranked as follows for their wear performance: PTFE + 20%GFR followed by POM + 20%GFR and PSU + 20%GFR. Among all materials tested, PTFE + 20%GFR exhibited the best wear performance (wear rate is in the order of $10^{-15}\,m^2/N$) and can be considered as the most recommended tribo-material for electrical engineering applications.

2. The friction coefficient of all tested polymer composites showed insensitivity to the change in applied load values.

3. Pure PTFE is characterized by high wear. The addition of glass fiber to the polymer results to enhancement of its tribological performance.
4. The wear rate of PTFE + 20%GFR is highly influenced by the change in sliding speed.
5. The wear mechanism is mainly adhesive and includes some abrasive process.

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