Abrasive wear of glass fibre reinforced polysulfone composites

A P Harsha & U S Tewari*
Industrial Tribology, Machine Dynamics and Maintenance Engineering Centre
Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India

Received 30 August 2001; accepted 14 March 2002

Abrasive wear behaviour of polysulfone (PSU), an amorphous, brittle and high temperature engineering thermoplastic material, and its composites were investigated by using pin-on-disc machine against silicon carbide (SiC) abrasive paper under multipass conditions. Abrasive wear studies were conducted under various testing conditions such as sliding distance, load, velocity, and abrasive grit size. It was observed that neat PSU showing better wear performance than glass fibre reinforced PSU in most of the experimental conditions. These results may be attributed to the reinforcement, greatly reducing ultimate elongation to fracture, which in turn is key factor in abrasive wear performance. Worn sample surfaces were studied with Scanning Electron Microscopy (SEM).

Abrasive wear, as defined by ASTM¹, is due to hard particles or hard protuberances that are forced against and move along solid surface. Abrasive wear of engineering and agricultural machine components caused by abrasive particles is a major industrial problem. Polymers and their composites are being used for a number of mechanical components such as gears, cams, brakes, clutches, bearing, bushings and seals, etc.² Also, polymers and their composites are extensively used in highly abrasive situations³. Polysulfone and their composites are used in a variety of mechanical and automotive applications because of their excellent property profile. However, tribological properties are not intrinsic material properties and strongly depend on the system in which the material functions⁴.

A number of studies on polymers and their composites subjected to abrasive wear have been reported⁵-¹³ in literature. Cirino et al.⁴,

* For correspondence.

one type of plastics and reported polyurethane having better abrasion resistance over other materials. Navin Chand et al.¹⁰ reported on three-body abrasive wear behaviour of short E-glass fibre reinforced polyester composites. Liu et al.¹¹ studied the wear resistance of ultrahigh molecular weight polyethylene (UHMWPE) with and without quartz particles as reinforcement under three-body abrasion conditions. Cenna et al.¹²,¹³ investigated abrasive wear characteristics of polymer matrix composites reinforced with particles of UHMWPE. From the literature survey, it becomes evident that no work has been carried out on abrasive wear of polysulfone and their composites. Thus, the objective of the present investigations is to study the abrasive wear performance of polysulfone and their composites and to evaluate the effect of different amounts of short glass fibre reinforcement on the abrasive wear resistance of polysulfone matrix.

Experimental

Materials

Polysulfone and its various composites reinforced with short glass fibres (Table 1) were supplied by BASF, Germany, in the form of square plaque. From the plaque, samples of square size, 10x10 mm² were cut for abrasive wear studies. Water-proof silicon carbide (SiC) abrasive papers of various grit sizes (150, 220, 280, 320, 400, 600, 800) were selected as abrading counterface for polymeric samples. All samples were selected from the same lot to avoid variations in the manufacturing process.
Abrasive wear studies

Abrasive wear studies under multipass conditions were carried out on a pin-on-disc machine shown in Fig. 1. Abrasive paper was fixed on the rotating disc and polymer pin is fixed in the holder. Polymer pin (10x10x3.2 mm³) was abraded against the waterproof 1200 grit size (~ 5μm) silicon carbide (SiC) abrasive paper for uniform contact. The tests were carried out at various sliding distance (50-1200 m), load (2-10 N), sliding velocity (0.36-1.8 m/s) and abrasive grit size (800-150). SEM of SiC abrasive paper of 400 grit size, before wear test is shown in Fig. 2, which is being used as counterface for different tests. In all the tests, wear was measured by loss in weight, which was then converted to wear volume using density data. Before and after wear testing, pins were cleaned with brush to remove wear debris. The specific wear rate (K₀) was calculated from:

\[ K₀ = \frac{V}{Ld} \text{[m }^3 \text{Nm}^{-1}] \]

where V is the volume loss in cubic meters, L is the load in Newton and d is the sliding distance in meters.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test method</th>
<th>Unit</th>
<th>PSU</th>
<th>PSU+20% GF</th>
<th>PSU+30% GF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g cm⁻³]</td>
<td>ISO 1183</td>
<td>g cm⁻³</td>
<td>1.24</td>
<td>1.4</td>
<td>1.49</td>
</tr>
<tr>
<td>Tensile Strength [MPa]</td>
<td>ISO 527-2</td>
<td>MPa</td>
<td>80</td>
<td>115</td>
<td>125</td>
</tr>
<tr>
<td>Tensile Modulus of elasticity [MPa]</td>
<td>ISO 527-2</td>
<td>MPa</td>
<td>2600</td>
<td>7000</td>
<td>9900</td>
</tr>
<tr>
<td>Tensile Elongation [%]</td>
<td>ISO 527-2</td>
<td>%</td>
<td>8</td>
<td>2.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Izod Impact Strength [kJm⁻²]</td>
<td>ISO 180/B</td>
<td>KJm⁻²</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Hardness</td>
<td>ISO 209-1</td>
<td>MPa</td>
<td>147</td>
<td>190</td>
<td>202</td>
</tr>
<tr>
<td>Sc</td>
<td></td>
<td>MPa</td>
<td>640</td>
<td>276</td>
<td>225</td>
</tr>
</tbody>
</table>

Fig. 1 — Schematic diagram of the pin-on-disc machine

Fig. 2 — Scanning electron micrograph of the SiC abrasive paper (400 grit size) before wear test

Fig. 3 — Wear volume as a function of sliding distance [v = 0.36 m/s, L = 6 N, counterface, SiC abrasive paper of 400 grit size]

Fig. 4 — Wear volume and specific wear rate [K₀] as a function of load [v = 0.36 m/s, sliding distance = 500 m, counterface, SiC abrasive paper of 400 grit size]
SEM studies
Worn polymer pins and abrasive paper surface were made to conduct by gold sputtering and were observed using scanning electron microscope [Philips 515].

Results and Discussion
Wear studies under various test conditions are given in Figs 3-6. Scanning electron micrographs of worn surfaces are shown in Figs 7-9.

Fig. 3 shows the wear volume as a function of abrading distance. It is seen that non-linear increase in wear volume as the abrading distance is increased. Initially, the increase in wear volume was rapid, subsequently wear volume stabilises to an almost constant value. During repeated sliding of polymer pin surface over circular wear track on abrasive paper, circular path tends to become clogged with wear debris and transfer films, which progressively reduces abrasive capacity and hence wear volume is stabilised to almost constant value. This saturation effect occurred after a sliding distance of 400 m. The decrease in the abrading efficiency of the counterface occurs due to fracture of/or pull out of abrasive grains due to presence of hard glass fibres and transfer of wear debris of polymer on counterface. The wear debris collects in the crevices or depressions on the paper leading to clogging effect. Hence, after a certain number of traverses, abrasion of materials reduces and reaches to equilibrium conditions. It was observed that neat PSU shows better abrasive wear resistance as compared to glass fibre reinforced PSU composites. This is in agreement with reported results which suggest that transfer films from polymers with high elongation are beneficial and

![Fig. 5 — Specific wear rate \( K_v \) as a function of sliding velocity \( L = 6 \) N, sliding distance = 500 m, counter face, SiC abrasive paper of 400 grit size](image1)

![Fig. 6 — Specific wear rate \( K_v \) as a function of abrasive grit size \( L = 6 \) N, \( v = 0.36 \) m/s, sliding distance = 500 m](image2)

![Fig. 7 — Scanning electron micrograph of neat PSU abraded at \( v = 0.36 \) m/s, \( L = 6 \) N, (a) 800 grit size (b) 150 grit size](image3)
reduce wear rate, whereas less ductility is detrimental and increases wear.

The effect of load on wear volume and specific wear rate of polysulfone and its composites are shown in Fig. 4. For all the materials, it was observed that wear volume increases and specific wear rate decreases with increase in load. Also, it is seen that the wear performance of neat PSU deteriorates due to the inclusion of glass fibres. The ranking order of materials in terms of decreasing abrasion resistance is given by PSU+20% GF > PSU +30% GF > PSU. Friedrich has reported that the wear rate of thermoplastics will not improve by adding short fibres if the wear mechanism is highly abrasive in nature. However, in case of polyetherimide (PEI) composites, 30% short glass fibre reinforcement enhanced the wear resistance of PEI.

The primary reason of adding fillers or reinforcing fibres to polymers is to improve their mechanical properties, but their effect on wear is not invariably beneficial. According to Lancaster, the most important factor that controls the abrasive wear behaviour of composites is the product of ultimate tensile strength ($S$) and ultimate elongation ($e$). Reinforcement to polymer matrix increases ultimate tensile strength ($S$), usually decreasing the ultimate elongation to break and hence the product $Se$, for the composites is smaller than that of unreinforced polymer. Thus, reinforcement frequently increases abrasive wear rate of polymer. In the present study also, the product $Se$ was maximum for neat PSU, which showed its high abrasive wear resistance as compared to its composites.

Fig. 5 shows influence of sliding velocity on specific wear rate for PSU and its composites.

Fig. 8—Scanning electron micrograph of glass fibre reinforced PSU abraded at $v = 0.36$ m/s, under a load of (a) 10 N (b) 6 N

Fig. 9—Scanning electron micrograph of neat PSU abraded at $L=6$ N, (a) $v=1.83$ m/s (b) $v=0.36$ m/s
Specific wear rate increases with increasing sliding velocity for neat PSU and its composites. During sliding, the normal and tangential loads are transmitted through contact points by ploughing actions. During repeated sliding, the hard abrasive particle penetrated into the soft polymer matrix resulting in increase in wear rate of PSU and its composites. Because of severe cutting and ploughing action by abrasive particles, the soft PSU matrix shows excessive wear rate with increase in sliding velocity. In case of composites debonded glass fibres modifies counterface by transfer films, and trapped debris further influences in increasing wear. However neat PSU shows high wear rate as compared to its composites.

Fig. 6 shows variation of specific wear rate as a function of abrasive grit size. With increase in size of abrading particles, wear rate increased slowly and steadily for neat PSU and its composites. As reported by Vaziri et al., the wear of polymers/composites against abrasive papers is proportional to ploughing component of friction and depends on the physical properties of polymer. The size effect is extensively observed in case of metals. As the abrasive grit diameter is increased, the wear rate increases rapidly until a critical size is reached; it then becomes independent of grit diameter or increases slightly. The size effect phenomenon is observed in polymer and its composites to limited extent. In the present study no "size effect" was observed as reported in case of metals and few polymers. The specific wear rate increases slowly with increase in abrasive grit size and at 150 grit size specific wear rate increases rapidly. It occurs as the attack of very rough abrasive paper, the individual abrasive grains penetrate deeply into the surface of polymer, subsequently removing material from the surface by extensive microplothing process. During this process, large amount of plastic deformation takes place. At lower grit size, very soon wear track tends to become clogged with wear debris and transfer films and hence reduces abrasive capacity. This result in lower specific wear rate ($K_w$) for all the materials. Performance ranking of material certainly depends upon abrading particle size. The ranking of material was magnified at higher abrasive grit size (150). For lower abrasive grit size (800), marginal difference in performance ranking of material was observed. Overall, specific wear rates varied from 0.25 to 0.4 x $10^{-11}$ m$^3$/Nm for lower abrasive grit size and for higher abrasive grit size varied from 2.0 to 4.2x$10^{-11}$ m$^3$/Nm.

Neat PSU proved to be the most wear resistant against all the abrasive grit sizes.

**SEM studies** — Worn surfaces were viewed using SEM in order to determine the predominant wear mechanisms. Figs 7a and 7b show worn surface of neat polysulfone abraded by 800 and 150 grit size respectively. The micrograph (Fig. 7a) depicts furrows due to microplothing of asperties in to the softer polymer matrix in the direction of abrasion is visible. The matrix is heavily damaged (as shown in Fig. 7b) by ploughing and cutting action due to increase in grit size. In the extreme conditions (grit size 150, Fig. 7b), cutting dominates ploughing action and complete polymer surface shows chunky wear debris.

Figs 8a and 8b show the surfaces of glass fibre reinforced PSU pins abraded under different loading conditions. As a result of comparatively higher load (10 N, Fig. 8a) the polymer matrix and fibre is damaged more severely than that in the low load conditions (6 N, Fig. 8b). In both cases, matrix phase covering the fibre was completely removed. It is seen that the fibre failure process is characterised by fibre breaking and fibre removal, due to ploughing and cutting action. It was also observed that fibre breaking occurs owing to the formation of cracks perpendicular to their length (Fig. 8b). Figs 9a and 9b show worn surfaces of neat PSU pins abraded at different sliding velocity. In micograph (Fig. 9b), furrows in the abrading direction due to microcutting and microplothing action are visible ($v=0.36$ m/s). The matrix is severely damaged by ploughing and cutting action by abrasive particles (Fig. 9a). This is caused by of severe abrasion at higher sliding velocity (1.83 m/s), depth of furrows are greater as compared to lower sliding velocity (Fig. 9b).

**Conclusions**

Abrasive wear studies polysulfone and its composites in the dry conditions showed that their wear resistance deteriorated because of fibre reinforcement. With an increase in glass fibre percentage, elongation to break decreased, which is a controlling factor for abrasive wear performance. Load, sliding velocity and abrading particle size were observed as important influencing parameters in abrasive wear studies.

**References**