Three-body abrasive wear behaviour of polyaryletherketone composites

A.P. Harsha\textsuperscript{a}, U.S. Tewari\textsuperscript{a*}, B. Venkatraman\textsuperscript{b}

\textsuperscript{a} Industrial Tribology Machine Dynamics and Maintenance Engineering Centre, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India
\textsuperscript{b} Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500058, India

Received 6 June 2002; accepted 5 February 2003

Abstract

An experimental investigation was carried out to study the effect of reinforcement fibres, solid lubricants, mass of abrasives and load in three-body abrasive wear situations on various polyaryletherketone (PAEK) matrix. Three-body abrasive wear studies were carried out using a rubber wheel abrasion test (RWAT) rig. In the present investigation, angular silica sand particles of size ranging between 150 and 300 μm were used as dry and loose abrasives. The ketone/ether ratios among the selected PAEKs have shown significant influence on three-body abrasive wear behaviour at higher load. It was observed that fibre reinforcement is detrimental to the abrasive wear resistance of neat PAEK matrix. A combination of fibre and particulate filler is more detrimental to abrasive wear performance. Efforts were made to correlate the abrasive wear performance of the composites with appropriate mechanical properties. The Ratner-Lancaster plot showed a linear correlation. Scanning electron microscopy was used to observe the worn surfaces and to understand the mechanisms involved in the removal of the material.

Keywords: Three-body abrasive wear; Polyaryletherketone; Composites; Scanning electron microscopy

1. Introduction

With advent of new advanced materials, the use of reinforced polymer composites is becoming more common. These materials are subjected to abrasive wear in many applications [1]. Abrasive wear can be defined as where hard asperities on one surface move across a softer surface under load, penetrate and removes material from the softer surface, leaving grooves [2]. Abrasive wear can be classified as two-body or three-body. Two-body abrasive wear occurs when a rough surface or fixed abrasive particles slide across a surface to remove material; three-body abrasive wear, where the particles are loose and may move relative to one another, and possibly rotate, during sliding across the wearing surface. Most of the abrasive wear problems which arise in engineering and agricultural machine components involve three-body wear, while two-body abrasion occurs primarily in material removal operations. Three-body abrasion is often of considerable practical importance but appears to have received much less attention than a two-body problem. The data regarding three-body abrasive wear investigations of polymer composites are limited. Very little has been reported on the effect of filler or fibre reinforcement on three-body abrasive wear performance of polymer composites [3-6]. Hence, a fundamental and comprehensive understanding of the three-body abrasive wear behaviour of these composites is required.

In recent years, much research has been devoted to exploring the potential advantage of thermoplastic matrix for composite materials. One such matrix is polyaryletherketones (PAEKs), which show exceptional properties due to its semicrystalline character and molecular rigidity of its repeating units. PAEKs such as polyetheretherketone (PEEK), polyetherketone (PEK), polyetherketoneketone (PEKK) have similar crystal structures but differ in ketone content (Table 1). Several investigations on the abrasive wear behaviour of PEEK and their composites reinforced with fibres and fillers have been carried out [7-11]. Cirino et al. [7,8] reported the sliding as well as the abrasive wear behaviour of continuous glass, carbon and aramid fibre reinforced PEEK. Lhymn et al. [9] investigated the abrasive wear of short carbon fibre reinforced PEEK. Voss and Friedrich [10] studied the sliding and abrasive wear behaviour of short glass and carbon fibre reinforced PEEK composites at room temperature. Briscoe et al. [11] reported abrasive wear behaviour of PEEK-filled PTFE and PTFE-filled PEEK. Incorporation of PEEK in PTFE reduced the wear rate of
Table 1: Chemical structures and ketone/ether linkage ratios of polyaryletherketones investigated in the present study

<table>
<thead>
<tr>
<th>Structure</th>
<th>Name</th>
<th>Ketone (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[O=O]_2</td>
<td>PEEK</td>
<td>33</td>
</tr>
<tr>
<td>[O=O]</td>
<td>PEK</td>
<td>50</td>
</tr>
<tr>
<td>[O=O]_2</td>
<td>PEKK</td>
<td>67</td>
</tr>
</tbody>
</table>

PTFE while wear rate increased in the PTFE-filled PEEK [11]. Harsha and Tewari [12] investigated the two-body abrasive wear behaviour of various short fibre reinforced polyaryletherketone composites. The above investigations were concentrated on two-body abrasion studies of PAEKs and their composites against abrasive papers. In view of the above, the objective of present investigation to study the effect of chemical structure and ketone/ether linkage ratios on the three-body abrasive wear behaviour of polyaryletherketones. Another aim was to study the effect of different types of short fibres and filler reinforcements, on the three-body abrasive wear resistance of PAEKs having different mechanical properties.

2. Experimental details

2.1. Materials

Three types of neat resins of polyaryletherketones having different chemical structure and ketone/ether linkage ratios investigated in the present study are given in Table 1. Details of mechanical properties of various PAEKs and their composites are given in Table 2. Initial surface roughness (arithmetic mean average, \( R_a \)) of all the specimens were also measured and given in Table 2. Test specimens were cut from the same injection moulded plaque in order to avoid variation of surface roughness.

2.2. Abrasive wear studies

Three-body abrasive wear studies of polyaryletherketones and their composites were studied on a dry sand/rubber wheel abrasion test (RWAT) rig as shown in Fig. 1. It was felt that this test produced the closest simulation of the real tribosystem. The abrasives are introduced between the test specimen and rotating wheel composed of chlorobutyl rubber tyre. The test specimen is pressed against rotating wheel at a specified force by means of lever arm while a controlled flow of grit abrades the test surface. The rotation of the wheel is such that its contact face moves in the direction of sand flow. The pivot axis of the lever arm lies within a plane, which is approximately tangent to the rubber wheel surface, and normal to the horizontal diameter along which the load is applied. The experimental conditions are summarised in Table 3. The abrasive wear studies were carried out at two different loads (5 and 12 N). It has been reported in the literature that the unfilled and short fibre reinforced polymer composites were used in abrasive applications [13]. It is also reported in the literature that the unfilled polymer/composites were suitable to operate up to \( PV \) (product of limit bearing pressure and sliding speed) limit of < 15 MPa m/s and velocity up to 5 m/s under abrasive wear situations. The present loading conditions were chosen, because the objective and interest was to study the abrasive wear resistance of PAEKs and their composites at low \( PV \) values (<0.075-0.2 MPa m/s). In the present study, silica sand (\( \rho \approx 2000 \text{ kg/m}^3 \); Knoop hardness 880 [14]) was used as abrasives. The scanning electron micrograph of the silica sand is shown in Fig. 2. Weight loss measurements were made at a regular test intervals (each time interval comprises of 60 s), using an analytical balance having accuracy count of 1 x 10^-5 g. The specimen holder was designed to ensure that samples are removed and replaced during each test such that wear scar was always at the same location. Wear volume \((AV)\), wear rate \((w)\) and specific wear rate \((K)\) were calculated from the following equations:

\[
AV = \frac{\Delta m}{\rho} \quad (\text{mm}^3) \quad (1)
\]

\[
w = \frac{AV}{M_s} \quad (\text{m}^3 / \text{g}) \quad (2)
\]

\[
K = \frac{AV}{Ldpi} \quad (\text{1}/(\text{N m})) \quad (3)
\]
Table 2
Mechanical properties of PEEK, PEK and PEKK composites

<table>
<thead>
<tr>
<th>Material Designation</th>
<th>Filler (wt.%)</th>
<th>Density ASTMD 792 (g/cm$^3$)</th>
<th>Tensile strength ASTMD 638 (S; MPa)</th>
<th>Tensile modulus ASTMD 638 (MPa)</th>
<th>Tensile elongation at break ASTMD 638 (%)</th>
<th>Flexural strength ASTMD 790 (MPa)</th>
<th>Flexural modulus ASTMD 790 (GPa)</th>
<th>Izod impact strength ASTM 256 (kJ/m$^2$)</th>
<th>Hardness ASTM L</th>
<th>Surface roughness (Ra; µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEK</td>
<td></td>
<td>1.32</td>
<td>101</td>
<td>3600</td>
<td>40</td>
<td>170</td>
<td>4.0</td>
<td>6.4</td>
<td>122 97</td>
<td>115 0.170</td>
</tr>
<tr>
<td>B</td>
<td>Glass fibre (20)</td>
<td>1.42</td>
<td>120</td>
<td>6800</td>
<td>5.81</td>
<td>199</td>
<td>6.7</td>
<td>7.5</td>
<td>119 97</td>
<td>115 0.304</td>
</tr>
<tr>
<td>C</td>
<td>Glass fibre (30)</td>
<td>1.49</td>
<td>144</td>
<td>9700</td>
<td>4.24</td>
<td>220</td>
<td>8.2</td>
<td>10</td>
<td>125 105</td>
<td>115 0.304</td>
</tr>
<tr>
<td>D</td>
<td>Carbon fibre (30)</td>
<td>1.44</td>
<td>224</td>
<td>13000</td>
<td>2.6</td>
<td>350</td>
<td>20</td>
<td>9.0</td>
<td>125 104</td>
<td>115 1.24</td>
</tr>
<tr>
<td>E</td>
<td>Carbon fibre (10), PTFE (10), graphite (10)</td>
<td>1.48</td>
<td>148</td>
<td>-</td>
<td>2.5</td>
<td>210</td>
<td>8.1</td>
<td>6.3</td>
<td>127 95</td>
<td>113 0.450</td>
</tr>
<tr>
<td>PEK</td>
<td></td>
<td>1.30</td>
<td>120</td>
<td>4000</td>
<td>20</td>
<td>183</td>
<td>5.12</td>
<td>7.0</td>
<td>124 105</td>
<td>112 0.240</td>
</tr>
<tr>
<td>G</td>
<td>Glass fibre (10)</td>
<td>1.38</td>
<td>140</td>
<td>7000</td>
<td>6.03</td>
<td>265</td>
<td>7.9</td>
<td>7.0</td>
<td>126 107</td>
<td>111 0.198</td>
</tr>
<tr>
<td>H</td>
<td>Glass fibre (20)</td>
<td>1.44</td>
<td>155</td>
<td>10500</td>
<td>4.14</td>
<td>250</td>
<td>9.9</td>
<td>7.0</td>
<td>126 109</td>
<td>115 0.283</td>
</tr>
<tr>
<td>I</td>
<td>Glass fibre (30)</td>
<td>1.53</td>
<td>165</td>
<td>12500</td>
<td>3.88</td>
<td>350</td>
<td>15.5</td>
<td>7.0</td>
<td>110 110</td>
<td>115 0.268</td>
</tr>
<tr>
<td>PEKK</td>
<td></td>
<td>1.31</td>
<td>141</td>
<td>4416</td>
<td>12</td>
<td>194</td>
<td>4.55</td>
<td>-</td>
<td>110 110</td>
<td>115 0.342</td>
</tr>
</tbody>
</table>

*Victrex Plc., USA, supplied PEEK, PEK and their composites.

*Infinite Polymer System II, USA, supplied PEKK.
Table 3
Test conditions used in the present study

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>5 and 12 N</td>
</tr>
<tr>
<td>Rotational speed of rubber wheel</td>
<td>200 ± 10 rpm (v = 2.4 m/s)</td>
</tr>
<tr>
<td>Diameter of rubber wheel</td>
<td>228.6 mm</td>
</tr>
<tr>
<td>Abrasive particles</td>
<td>Silica sand, angular, 150-300 mm</td>
</tr>
<tr>
<td>Sand flow rate</td>
<td>250 ± 5 g/min</td>
</tr>
<tr>
<td>Size of the specimen</td>
<td>76 mm x 25 mm x (5-12) mm</td>
</tr>
<tr>
<td>Total test duration</td>
<td>10 min</td>
</tr>
</tbody>
</table>

where $A_m$ is the mass loss in grams, $\rho$ the density of the test material in g/cm$^3$, $M_a$ the mass of abrasive in grams, $A_F$ the volume loss in m$^3$, $L$ the load in Newton and $d$ the sliding distance in meters. Since the quantity of abrasive interacting with the material surface is considered to be an important factor in determining the rate of material removal, the change in wear volume was plotted as a function of abrasive mass rather than exposure time.

2.3. Scanning electron microscopy (SEM) studies

Morphologies of the wear scar were examined by using scanning electron microscopy (S 360, Cambridge). Before taking micrographs, the samples were coated with thin layer of gold by sputtering.

3. Results and discussion

Figs. 3 and 4 show the wear volume as a function of mass of abrasive for polyaryletherketones and their composites at different loads. Fig. 5 shows wear rate ($w_r$) as a function of mass of abrasive for all the composites at different loads. Fig. 6 is histogram showing specific wear rate ($K_o$) of polyaryletherketones and their composites at different loads. Fig. 7 shows schematic representation of failure modes in short fibre reinforced composites under three-body abrasion.

Typical wear scars on the specimens at different loads is shown in Fig. 8. Fig. 9 shows correlation between wear volume and appropriate mechanical properties of PAEKs and their composites. Scanning electron micrographs of worn surfaces are shown in Figs. 10-15. The following important observations were made from the investigations:

1. Among the selected neat polyaryletherketones, the wear resistance was shown to occur in the order PEEK > PEK > PEKK at higher load ($L = 12$ N).
2. Wear volume tends to increase linearly with mass of abrasives and strongly depends upon the applied load for all the composites (Figs. 3 and 4).
3. Wear rates ($w_r$) of the materials were observed to be in the range of $10^{-9}$ m$^3$/g at low load ($L = 5$ N) and at high load ($L = 12$ N) it was in the range of $10^{-10}$ to $10^{-12}$ m$^3$/g (Fig. 5).
4. Polyaryletherketones and their composites surfaces exhibited relatively high initial wear rate, when the surfaces are new, which decreases gradually to an almost constant value (Fig. 5).
5. The fillers such as PTFE and graphite were observed to be detrimental to wear performance (composite E).
6. The carbon fibre reinforced PEEK (composite D) had worst abrasion resistance as compared to glass fibre reinforced PAEK composites.
7. The comparative performance of all the composites abraded at different loads and at sliding speed of 2.4 m/s...
can be seen from the histogram (Fig. 6). The neat PEEK showed the lowest specific wear rate ($K_o$) while composite E exhibited high wear rate.

8. Better correlations between the wear volume and selected mechanical properties emerged from the studies.

The PAEKs such as PEEK, PEK, and PEKK contain different ketone content. It is known that the ketone moiety displays more rigid behaviour than ether moiety [15] and also the chain stiffness are known to increase with an increase in ketone content. The variation of the percentage of ketone groups, affects the microstructure and hence on their mechanical properties. In the present study, the different ketone content among the selected PAEKs have shown significant influence on three-body abrasive wear behaviour especially at higher load (Fig. 3). Figs. 4 and 5 show that excessive wear was exhibited by composite E which contained a combination of three types of fillers, particulate PTFE, graphite and carbon fibres. It is important to note that these composites were used as bearing materials [16]. Thus, having optimised a composite material for sliding wear performance against a smooth steel counterpart does not automatically mean that this particular material will perform sufficiently well enough when sliding in an abrasive wear situation.
Often, an opposite trend may result [17]. The influence of fibre and/or fillers on the abrasive wear resistance of neat polymer is more complex and unpredictable phenomenon [18].

From the literature survey it is evident that very little work has been reported on three-body abrasion studies of polymers and their composites (3-6). Budinski [3] investigated the abrasion resistance of 21 types of plastic and reported that polyurethane had better abrasion resistance over the other materials. Also, it is reported that, the hard reinforced and filled engineering plastics had relatively poor abrasion resistance to silica sand (215-300 μm). Cenna et al. [5,6] studied abrasion resistance of three types of vinyl ester resin systems, i.e. unreinforced, reinforced with glass fibres and reinforced with particles of ultra-high molecular weight polyethylene (UHMWPE). They reported that UHMWPE reinforcement enhanced the wear resistance against both coal (0.5-7 mm) and mineral ignimbrite (2-5 mm) abrasives. With coal as the abrasive, it was found that glass fibre reinforcement reduced the wear rate, whereas in the case of harder ignimbrite, fibre reinforcement increased wear rate. However, the above studies were conducted using an open linear sliding abrasive wear tester. Chand et al. [4] studied a low stress abrasive wear behaviour of short E-glass fibre reinforced polyester composites with and without filler by using rubber wheel abrasion test apparatus. They used angular silica sand particles as abrasive of size ranging from 100 to 200 and 200 to 300 (μm). They reported that, higher weight fraction of glass fibres (45%) in the composites improves the abrasive wear resistance as compared to the composite containing less glass fibres (40%). However, they have not compared abrasive wear rate of composites with neat polyester.

In the present study, the abrasive wear resistance of polyaryletherketones did not improve by fibre reinforcement.

The severity of abrasive wear depends upon the abrasive particles, size, shape, and hardness, the magnitude of the stress imposed by the particle, and the frequency of contact.
Fibre reinforcement to any matrix will modify the wear behaviour of the composite and there is a broad agreement with related studies reported in the literature. Cirino et al. [8] reported the wear resistance of composites with respect to fibre configurations and sliding direction. They found that the wear rate was strongly dominated by wear mechanisms associated with the fibres rather than those associated with matrix. Fig. 7 shows a schematic representation of failure modes in short fibre reinforced composites under three-body abrasion. In the present study short fibre reinforced composites were used. Sliding of rubber wheel took place in the direction of plate thickness. Fibres are randomly oriented which is almost parallel to the sliding surface. Typical wear scars on the specimens are shown in Fig. 8. In the initial stage of abrasion, a minimum number of abrasive particles are in contact with rubber.

Fig. 9. Wear volume as a function of various mechanical properties of PAEKs and their composites at different loads (sliding time = 10min, v = 2.4m/s, hardness M scale is used): (a) (Se)\textsuperscript{1}; (b) (HSe)\textsuperscript{1}; (c) (He)\textsuperscript{1}; (d) 5\textsuperscript{1}; (e) \textsuperscript{1}.
but the effects on wear rate are not invariably beneficial. The primary reasons for adding fillers or reinforcing fibres to polymers is to improve their mechanical properties, usually greatly decreases ultimate elongation to break (e) and hence product Se may become smaller than that of neat polymer. Hence, reinforcement usually leads to deterioration in the abrasive wear resistance. Various theories have been proposed to interpret the abrasive wear performance of the composites. Table 4 provides some of the models proposed by various researchers [20-25] to correlate abrasive wear performance of the polymer/composites. One model that seemed to be quite reasonable was that proposed by Ratner et al. [20], where the rate of material removal was said to be inversely proportional to the product of stress and strain at rupture. In the present studies, Fig. 9 indicates the relationship between wear volume and (Se)−1, (HSe)−1, (Hey)−1, S−1 and e−1. The wear volume versus (Se)−1 and (HSe)−1 showed better correlation indicating all the three factors, i.e. S, e and H (hardness) played a prominent role in controlling the wear behaviour of selected composites rather than the individual one. The wear volume versus (Hey)−1, S−1 and e−1 showed more scatter in the plots as compared to Ratner-Lancaster plot (wear volume versus (Se)−1 and (HSe)−1). In the present study, the product of Se was maximum for neat PEEK, which showed the highest wear resistance. This product is decreased due to inclusion of fibre and/or fillers which results in deterioration of abrasive wear performance. Hence, the fibre/fillers were detrimental to the abrasive wear resistance of ductile polymers because it reduces toughness. The product Se was proved to be a critical factor in abrasive wear resistance of polymer composites.

3.2. Scanning electron microscopy studies

Worn surfaces of materials were examined by SEM to find out predominant wear mechanisms. Abrasive wear occurs generally by three different mechanisms, viz. microploughing, microlcutting and micromicrocracking [26]. Using SEM images, it is possible to identify qualitatively the dominant mechanism that operates and thus, gain an insight into the influence that the reinforcement is having upon the abrasive wear process. The examination of the wear scars indicated that the damage morphologies for all samples were similar, consisting of three zones, a short entrance and exit area and the main central wear zone. A typical wear scar obtained at different loading conditions is shown in Fig. 8. The damage morphologies of neat PEEK matrix are also shown in Fig. 10. At the entrance and exit zone, where the pressure applied to the abrasive is lowest, the damage morphologies were consistent with particle rolling. In the centre of the wear scar, parallel grooves were formed, typical of particle sliding, a result of the higher pressure forcing abrasive into the rubber wheel. Displacement of material had occurred within the grooves, forming shallow ridges similar to ploughing process. The long microcrack may be observed, predominantly in the transverse direction. The transverse microcracks observed on the surface are consistent
Fig. 10. Surface appearance of neat PEEK following 10 min abrasive wear test at a load of 12 N: (a) unworn surface; (b) wear scar at entry zone; (c) center of wear scar; (d) wear scar at exit zone (800x magnification).

Fig. 11. SEM of neat PEEK abraded at different loads of: (a) 5N (750x magnification); (b) 12N (1500x magnification).
Fig. 12. Worn surface of carbon fibre reinforced PEEK composite abraded at load of 12N: (a) 1500x magnification; (b) 3400x magnification.

Fig. 13. Worn surface of composite E (PEEK + 10% carbon fibre + 10% PTFE + 10% graphite) abraded at load of 5N: (a) 200 x magnification; (b) 1500x magnification; (c) 220 x magnification; (d) 1000 x magnification.
with a repeated ploughing mechanism causing surface fatigue. Material is plastically deformed under load through ploughing and with subsequent applications of load, microcracks are created in the transverse direction along the deformed material, which are eventually removed by fracture. The grooves are observed in the wear direction on the surface are formed by microcutting by the abrasive particles.

Table 4

<table>
<thead>
<tr>
<th>Model</th>
<th>Formula</th>
<th>Parameters</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( W \propto \mu \cdot L \cdot H )</td>
<td>( \mu ), friction coefficient, ( L ), load, ( H ), hardness</td>
<td>Ratner et al. [20]</td>
</tr>
<tr>
<td>2</td>
<td>( W \propto \beta \cdot N \cdot P \cdot d )</td>
<td>( \beta ), abrasive wear factor, ( N ), scratching efficiency factor, ( P ), normal load, ( d ), sliding distance</td>
<td>Yamaguchi [21]</td>
</tr>
<tr>
<td>3</td>
<td>( W \propto \left( F_N \left( 1 + F_N \right) \right)^{1/2} )</td>
<td>( F_N ), normal load, ( F ), friction coefficient</td>
<td>Czichos [22]</td>
</tr>
<tr>
<td>4</td>
<td>( W \propto H \cdot C )</td>
<td>( H ), hardness, ( C ), cohesive energy</td>
<td>Friedrich and Cyffka [23]</td>
</tr>
<tr>
<td>5</td>
<td>( W \propto K \cdot \epsilon \cdot H )</td>
<td>( K ), ploughing contribution to the coefficient of friction, ( \epsilon ), percentage elongation to failure, ( H ), tensile strength</td>
<td>Giltrow [24]</td>
</tr>
<tr>
<td>6</td>
<td>( W \propto C \cdot \epsilon \cdot H )</td>
<td>( C ), cohesive energy, ( \epsilon ), percentage elongation to failure</td>
<td>Vaziri et al. [25]</td>
</tr>
</tbody>
</table>
higher magnification (Fig. 12b). This mechanism is resulted because of the brittle nature of carbon fibres, which fractures due to repeated abrasion by silica sand particles. The interfacial debonding results into more and more naked fibres, which are exposed to the abrasive medium.

Fig. 13 shows the worn surface of composite E, which contained a combination of three types of fillers, particulate PTFE, graphite and carbon fibre. At low magnification (Fig. 13a), the micrograph indicates the severe ploughing, cutting action by silica particles. The wear debris appears as fine fibrils cut from the composite and the nature of surface damage confirms a cutting type of wear mechanism. Since the composite contains PTFE, graphite as fillers, which is more ductile than PEEK, different features on the surface were seen. PTFE, graphite particles in elongated form pulled out from furrows can be seen on the surface. The wear pattern also reveals that there is less rolling of particles and abrasive particles tend to slide rather than roll. Overall, it appears that dominant wear mechanism starts to shift from microfatigue to microploughing/cutting. At higher magnification (Fig. 13b), the formation of deep grooves by ploughing action and microcracks are the characteristic features on the surface. It is also illustrates the flake like pattern on the worn surface. Fig. 13c and d show worn surfaces at lower and higher magnification, respectively. At lower magnification, the network of microcracks and loose wear debris are seen on the surface. At higher magnification significant amount of matrix debris, voids, transverse crack, and filler/matrix debonding are observed.

Fig. 14 shows SEM images of glass fibre reinforced PEKK composites. The low magnification (Fig. 14a) shows some ploughing marks on the surface, matrix damage, exposure of glass fibres. These exposed fibres tend to fracture and their removal from the surface of the composite. The magnified view of worn surface (Fig. 14b) shows fractured fibres and fibre removal and also wear debris as a result of fracture. Fig. 15 shows an abraded surface of glass fibre reinforced PEKK composite. The micrograph indicates long transverse crack and exposure of glass fibre. The micrograph also indicates the matrix damage, deterioration of fibre matrix adhesion due to repetitive mechanical stress. Polverised portion of glass fibre is protruding out from polymer matrix is also visible.

4. Conclusions

Experimental studies of three-body abrasive wear behaviour of polyaryletherketones and their composites at various loads and mass of abrasives reveal the following characteristics:

1. The ketone/ether ratios among the selected PAEKs have shown significant influence on three-body abrasive wear behaviour at higher load (L = 12 N).
2. Abrasive wear rate is higher in composites than the neat matrix at different loads.
3. The abrasive wear rate of composites increases with increase of fibre content. The carbon fibre reinforced PEKK composite had a worst abrasive wear resistance as compared to glass fibre reinforced PAEK composites.
4. The fillers such as PTFE and graphite were observed to be detrimental to wear performance (composite E).
5. Better correlation between the wear volume and selected mechanical properties emerged from the studies.
6. SEM studies of worn surfaces support the involved mechanisms and indicate damage to the matrix, exposure of fibres and removal of the fibre.

References


