CHAPTER 6

ABRASIVE WEAR BEHAVIOR OF UNFILLED AND SILANE-TREATED SILICON CARBIDE (SiC) PARTICLES FILLED CARBON FABRIC REINFORCED EPOXY MATRIX HYBRID COMPOSITES

6.1 INTRODUCTION

With the initiation of new advanced materials, the use of polymer matrix composites is becoming more common. Its superior distinctive qualities such as high specific strength and modulus, excellent fracture toughness and fatigue properties, and good corrosion, thermal and electrical resistance properties enhance its effective utilization in the end applications. The bi-directional fabric type of composites has been gaining popularity in the recent years because of their balanced properties in the fiber plane as well as their ease of handling during fabrication. These materials are subject to abrasive wear in many applications. This chapter deals with the two-body and three-body abrasive wear behavior of bi-directional carbon fabric reinforced epoxy hybrid composites and the influence of different weight percentage of silane-treated SiC filler reinforcement on composites. The wear mechanisms involved in the abrasive wear have been detailed in this current study.

6.2 TWO-BODY ABRASIVE WEAR BEHAVIOR

The effects of various parameters such as abrading distance and applied load on two-body abrasive wear behavior of unfilled and
silane-treated SiC particulates filled bi-directional carbon fabric reinforced epoxy matrix hybrid composites are discussed in the following sections.

6.2.1 Results and Discussions

6.2.1.1 Abrasive wear volume

The difference in abrasive wear volume of unfilled and silane-treated SiC filled C-E composites was abraded on 150 and 320 grit abrasive paper at applied loads of 10 and 20 N against the abrading distance as shown in Figures 6.1 (a)-(b) and 6.2 (a)-(b) respectively. The wear volume loss was found to increase with the abrading distance/load and also it was found to depend on the girt size of the abrasive paper, for the both of unfilled and silane-treated SiC filled C-E composites. From the Figures 6.1 (a)-(b), the lowest wear volume can be found in 10SiC-C-E composite and highest wear volume occurred in unfilled C-E composite. The wear volume loss of unfilled C-E was $0.1253 \times 10^3 \text{ mm}^3$ for 75 m distance and it increased to $0.1623 \times 10^3 \text{ mm}^3$ for 225 m abrading distance for a load of 10 N (Figure 6.1(a)).

The wear volume of 5 SiC-C-E composite noticed was $0.1082 \times 10^3 \text{ mm}^3$ for 75 m distance and $0.1350 \times 10^3 \text{ mm}^3$ for 225 m distance. In the case of 10 SiC-C-E composite, the wear volume was $0.0936 \times 10^3 \text{ mm}^3$ (minimum) and $0.1092 \times 10^3 \text{ mm}^3$ (maximum). From Figure 6.1 (a), it can be observed that 10 SiC-C-E showed a lower wear loss than the 5 SiC-C-E and unfilled C-E. The minimum wear volume loss ($0.0936 \times 10^3 \text{ mm}^3$) and maximum wear volume loss ($0.1623 \times 10^3 \text{ mm}^3$) was observed in the case of 10 SiC-C-E and unfilled C-E respectively. It can be seen that the addition of the silane-treated SiC filler particles with the C-E composites reduces wear volume rate and enhances wear resistance.
Figure 6.1  Wear volume loss of unfilled C-E and silane-treated SiC filled C-E composites against the abrading distances at (a) 10 N load, 150 grit SiC abrasive paper and (b) 20 N load, 150 grit SiC abrasive paper
Figure 6.2  Wear volume loss of unfilled C-E and silane-treated SiC filled C-E composites against the abrading distances at (a) 10 N load, 320 grit SiC abrasive paper and (b) 20 N load, 320 grit SiC abrasive paper
When load on the samples increased from 10 to 20 N the wear volume loss was also found to increase. Figure 6.1 (b) showed the wear volume loss of unfilled and silane-treated SiC filled C-E at 20 N load. The wear volume loss was $0.1047 \times 10^3 \text{ mm}^3$ for 10 SiC-C-E composite; it was found to be lower than the other two composites. Lower wear loss has occurred for a load of 10 N because of epoxy resin surface was removed by abrasion and micro fracture of carbon fibers by abrasion particles, wear debris did not adhere to the abrasive paper. When an applied load was increased from 10 to 20 N, severe abrasion takes place due to the penetration of many abrasion particles in to epoxy matrix consequently. The carbon fibers fractured which were spread on the counterface. The higher crushing action of these carbon fibers further increased wear damage on the specimen surface. Therefore, the wear volume loss of composites was found to increase at higher loads than the lower loads. However, the wear performance of 10SiC-C-E composite showed a higher wear resistance for all loads. The incorporation of filler particles on polymer composites strongly influences its abrasive wear performance (Bijwe et al 2002, Rajesh et al 2002). Most polymer composites show an improvement in abrasive wear performance after the incorporation of filler/fiber materials (Tewari and Bijwe 1993, Suresha et al 2009).

Silane-treated SiC filled C-E composites exhibit a lower wear loss which can be attributed to the presence of silane-treated SiC particles on the counter surface, which act as a transfer layer and also as an efficient barrier to prevent large scale fragmentation of epoxy. Silane-treated SiC hard ceramic filler particles provide the enhanced hardness and excellent wear resistance to silane-treated SiC filled C-E composites. Figure 6.2 (a)-(b) show the two-body wear volume loss of unfilled and silane-treated SiC filled C-E composites and at loads of 10 and 20 N under the 320 grit size paper. Increase of grit size of an abrasive paper reduces the wear loss. The inherent better mechanical and self lubricating properties of carbon fibers and silane-treated
SiC ceramic particles in epoxy medium provides the better fiber-matrix adhesion against the two-body abrasion may be the reason for improved wear resistance. The results obtained also showed the same trend as in the previous case.

6.2.1.2 Specific wear rate

The variations in the specific wear rate of unfilled and silane-treated SiC filled C-E composites worn on different abrasive grit papers (150 and 320 grit size papers) with the loads of 10 and 20 N against abrading distance are shown in Figure 6.3 (a)-(b) and 6.4 (a)-(b) respectively. It can be seen that the specific wear rate decreases with an increase in abrading distance and grit size of the abrasive paper under multi pass condition. The specific wear rate decreases significantly with an increase in abrading distance when the emery paper is of 150 grit size, as shown in Figure 6.3 (a)-(b). The higher specific wear rate was noticed for unfilled C-E composite when compared to 5 and 10 wt. % silane-treated SiC filled C-E composites as shown in Figures 6.3 and 6.4. In the initial stage, the wear track is not completely attained and with an increase in abrading distance, a consistent contact was established. The addition of silane-treated SiC particles in the epoxy medium enhances the interfacial bonding between the carbon fibers and the epoxy resin. When the sample slides against the abrasive paper, the contact surface of the sample is removed by abrasive wear. Further, the carbon fiber in epoxy with silane-treated SiC particles gets crushed and produces the wear debris. The thin transfer layer is formed on the counter surface of abrasive paper by crushed carbon fiber and epoxy, powdered silane-treated SiC particles reduces the wear rate. The high specific strength and self-lubricating properties of the carbon fiber, hardness of the silane-treated silicon carbide particles both in the epoxy medium were the effective barriers of abrasion and enhance the wear resistance of the silane-treated SiC filled C-E composites when compared to the unfilled one.
Figure 6.3 Specific wear rate of unfilled C-E and silane-treated SiC filled C-E composites against the abrading distances at (a) 10 N load, 150 grit SiC abrasive paper and (b) 20 N load, 150 grit SiC abrasive paper
Figure 6.4 Specific wear rate of unfilled C-E and silane-treated SiC filled C-E composites against the abrading distances at (a) 10 N load, 320 grit SiC abrasive paper and (b) 20 N load, 320 grit SiC abrasive paper.
The variations in the specific wear rate of composites worn on 320 grit abrasive papers and at loads of 10 and 20 N are shown in Figure 6.4 (a)-(b) respectively. In the beginning, the C-E sample showed the higher wear rate. This is suddenly decreased in consecutive intervals followed by slow and steady decrease at subsequent intervals. But in the case of silane-treated SiC filled C-E composites, specific wear rate gradually decreases with an increase in abrading distance against both the 150 grit and 320 grit SiC abrasive papers. This wear behavior can be attributed to the fact that complete wear track could not be attained initially. The main role of reinforcing materials with the polymers is to improve their mechanical properties and to also influence the wear rate. In common, the reinforcement of fillers/fibers with polymers enhances the tensile properties of the composite and also decreases the percentage of elongation. Also in the present study, the addition of silane-treated SiC particles with the C-E composites was found to enhance the interfacial bonding between the carbon fiber and epoxy matrix leading to minimum wear volume and reduced specific wear rate.

6.2.1.3 Worn surface morphology

To understand the two-body wear mechanism, scanning electron photomicrographs of worn surfaces of unfilled and silane-treated SiC filled C-E composite samples are shown in Figures 6.5 (a)-(b) to 6.8(a)-(b). Abrasion of samples leads to removal of material from the sample surfaces due to the action of some mechanisms. The degree of complexity of abrasion process was found to be more and no one mechanism can be taken as completely contributing to the entire wear loss. In general, the abrasive wear process involves four different mechanisms namely microploughing, microcutting, microfatigue and microcracking.
Figure 6.5 SEM pictures of worn surfaces of unfilled C-E composites abraded against 150 grit abrasive paper (a) 75 m and (b) 225 m

Figure 6.5(a)-(b) show the worn surfaces of unfilled C-E samples abraded with 150 grit SiC paper at a load of 20 N and abrading distance 75 m and 225 m respectively. Due to ploughing and cutting action of the sharp abrasive particles, the deep furrows in the abrading direction are seen on the surface and it is indicated in the Figure 6.5(a). In this figure fiber pullout, fiber damage and displacement can be noticed. At higher abrading distance, SEM photomicrograph Figure 6.5 (b) shows the severe damage to the fibers and the matrix. This severe abrasion on sample exhibits the stepped appearance (marked by black arrow) and exposure of the carbon fibers which leads to debonding between the matrix with fibers. So, the surface topography of both Figure 6.5 (a) and (b) indicate more fiber pulverization, more fiber breakage and less fiber-matrix debonding.
Figure 6.6 SEM pictures of worn surfaces of unfilled C-E composites abraded against 320 grit abrasive paper (a) 75 m and (b) 225 m

The contribution of the fibers and the matrix to the wear behavior varies with the grit size of the abrasive paper. Figure 6.6 (a)-(b) shows the worn surfaces of unfilled C-E samples abraded with 320 grit SiC paper at a load of 20N and abrading distances 75 m and 225 m respectively. Figure 6.6(a) and (b) show fibers pullouts and deep furrows in the abrading direction owing to the ploughing of fibers by the action of sharp abrasive particles, as seen on the surface. At higher abrading distance, the surface of the unfilled C-E sample (Figure 6.6 (b)) shows less fiber fracture, and in some regions cracks and voids [marked by box] were noticed. This can be attributed to the finer abrasive particles getting crushed as the abrading distance increases and abrasive particles become ineffective. The worsening of the fiber-matrix adhesion due to repetitive mechanical stress and debonding of fibers from the matrix is also indicated in the SEM picture.
Figure 6.7  SEM pictures of worn surfaces of silane-treated SiC filled C-E composites abraded against 150 grit abrasive paper (a) 75 m and (b) 225 m

Figure 6.7 (a) - (b) show the worn surfaces of silane-treated SiC filled C-E samples abraded with 150 grit SiC paper at a load of 20 N and abrading distances 75 m and 225 m respectively. The incorporation of silane-treated SiC filler particles with the C-E composite increases its wear resistance. It is evident by less fiber pullout, matrix damage and debonding of fibers noticed in the Figure 6.7 (a) and (b). Under the same test conditions, the wear loss of silane-treated SiC filled C-E composite was significantly reduced when compared to the unfilled C-E composite. This can be attributed to the interfacial bonding strength between the high strength carbon fibers and epoxy matrix which was enhanced by the hard silane-treated SiC particles.
Figure 6.8  SEM pictures of worn surfaces of silane-treated SiC filled C-E hybrid composites abraded against 325 grit abrasive paper (a) 75 m and (b) 225 m

Figure 6.8 (a)-(b) show the worn surfaces of silane-treated SiC filled C-E samples abraded with 150 grit SiC paper at a load of 20 N and abrading distances 75 m and 225 m respectively. Figure 6.8(a) shows the epoxy matrix with the silane-treated SiC particles withstand and hold the fibers in its own position by its bonding strength as highlighted by the less matrix removal and fiber damage. At maximum abrading distance, smooth surfaces obtained by the fine abrasive particles were noticed. Since, the thin transfer layer formed by the crushed carbon fiber with powdered epoxy matrix withstand its position for more time when it was added with the crushed hard SiC filler particles. Overall the SEM microphotographs of silane-treated SiC filled C-E composites highlight the minimum abrasive wear rate by less fiber pullout and fiber removal by ploughing action, minimum fiber breakage and matrix damage by cutting action and formation of thin transfer film layer on the countersurface. Hence, it can be deduced that the silane-treated SiC filled C-E composite exhibits better wear resistance when compared to the unfilled C-E composite.
6.3 THREE-BODY ABRASIVE WEAR

The influence of various parameters such as abrad ing distance and applied normal load on three-body abrasive wear behavior of bi-directional unfilled and silane-treated SiC filled carbon fabric reinforced epoxy polymer matrix hybrid composites are discussed in the following sections.

6.3.1 Results and Discussions

6.3.1.1 Abrasive wear volume loss

The abrasive wear tests were conducted for the unfilled C–E and silane-treated SiC-filled C–E samples; the wear scratch on samples after the experiments are shown in Figure 6.9.

![Figure 6.9 Typical worn surfaces of unfilled and silane-treated SiC-filled C–E samples](image)

The wear scratch of the samples consists of the three areas, numbered 1 and 3 were entrance and exit zones, respectively, and zone 2 was the central zone. The zones 1 and 3 are subject to lowest pressure by rubber wheel and give the entrance and exit to the running abrasive particles. Zone 2
is subject to the maximum pressure under the rolling rubber wheel. It is also abraded with both the abrasive sand particles and the rubber wheel.

Figure 6.10 Wear volume loss of C-E and silane-treated SiC-filled C–E composites at a load of (a) 25 N and (b) 35 N
The wear experiments were conducted for C–E, 5SiC–C–E and 10SiC–C–E samples as a function of various abrading distances (160, 320 and 480 m) under the loads of 25 and 35 N and the corresponding wear volume loss was plotted in graph as shown in Figure 6.10 (a)-(b), respectively. The wear volume details of C–E and silane-treated SiC filled C–E composites are shown in Table 6.1.

**Table 6.1 Wear volume details of the C-E and silane-treated SiC filled C-E composites**

<table>
<thead>
<tr>
<th>Sample designation</th>
<th>Wear volume ( x 10³ mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load 25 N</td>
</tr>
<tr>
<td></td>
<td>Abrading distance</td>
</tr>
<tr>
<td></td>
<td>160 m</td>
</tr>
<tr>
<td>C-E</td>
<td>0.1967</td>
</tr>
<tr>
<td>5 SiC-C-E</td>
<td>0.1548</td>
</tr>
<tr>
<td>10 SiC-C-E</td>
<td>0.1253</td>
</tr>
</tbody>
</table>

The wear volume loss of all the samples was found to increase with the increase of the loads and the abrading distances. The wear volume of the 10SiC–C–E was $0.1253 \times 10^3$ mm³ for an abrading distance of 160 m and $0.2069 \times 10^3$ mm³ for 480 m under 25 N load. Similarly, the wear loss of the 5 SiC–C–E and C–E was found to increase with the abrading distance and load. The wear resistance of the 10 SiC–C–E composite has an improvement of 19% and 39% when compared to the 5 SiC–C–E and C–E materials, respectively. At lower speed/loads the abrasive particles possess the lower energy than the surface energy of composite, so minimum wear loss was observed. When the speed/ load of the rubber wheel was increased, the
abrasive particles attained more energy than the surface energy of the composites leading to increased wear volume loss. In the silane-treated SiC-filled C–E composites, the reinforcement of the silane-treated SiC particles with the C–E increases the surface energy level of the composites to a maximum. So even at higher loads, the hard SiC particles obstruct the penetration of the abrasive particles of the rubber wheel on silane-treated SiC-filled C–E sample. Results revealed a minimum wear volume loss and the wear resistance of the 5 SiC–C–E and 10 SiC–C–E composites were improved to a percentage of 19% and 39%, respectively, with an increase of silane-treated SiC wt. % in SiC-filled C–E composite.

The effect of SiC filler material on three body abrasive wear behaviour of Glass–Epoxy(G–E) composite using rubber wheel abrasive wear tester were studied by Basavarajappa et al (2010). They reported that the addition of the SiC particles with the G–E composites resists the abrasion and improves the wear resistance to a significant extent. A similar trend can be observed in the present investigation as well. So, the addition of SiC particles with the C–E composites increases the wear resistance of the materials.

6.3.1.2 Specific wear rate

The specific wear rate data as a function of abrading distance at two normal loads of 25 N and 35 N are shown in bar charts of Figure 6.11 (a) -(b), respectively. The specific wear rate data are shown in Table 6.2.
Figure 6.11 Specific wear rate of unfilled and silane-treated SiC-filled C–E composites at a load of (a) 25 N and (b) 35 N
Table 6.2 Specific wear rate of the C-E and SiC filled C-E composites

<table>
<thead>
<tr>
<th>Sample designation</th>
<th>Specific wear rate (x 10^{-11} m^3/Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load 25 N</td>
</tr>
<tr>
<td></td>
<td>Abrading distance</td>
</tr>
<tr>
<td></td>
<td>160 m</td>
</tr>
<tr>
<td>C-E</td>
<td>4.197</td>
</tr>
<tr>
<td>5 SiC-C-E</td>
<td>3.869</td>
</tr>
<tr>
<td>10 SiC-C-E</td>
<td>3.133</td>
</tr>
</tbody>
</table>

When considering the specific wear rate of all C–E with silane-treated SiC samples, the highest specific wear rate of $5.768 \times 10^{-11}$ m$^3$/Nm was observed for the C–E samples and lowest specific wear rate of $2.198 \times 10^{-11}$ m$^3$/Nm for 10 SiC–C–E were obtained. From the bar charts of Figure 6.11 (a) - (b), the specific wear rate decreased gradually with an increase in abrading distance from 160 to 480 m. The range of specific wear rate of C–E samples was from $5.768 \times 10^{-11}$ m$^3$/Nm to $3.286 \times 10^{-11}$ m$^3$/Nm under the higher load 35 N with an increasing abrading distance from 160 to 480 m. Moreover, the variation of specific wear rate of 5 SiC–C–E samples was from $4.988 \times 10^{-11}$ to $2.697 \times 10^{-11}$ m3/Nm under the same test conditions. Similarly, the maximum and minimum specific wear rate of 10 SiC–C–E samples obtained varied from $4.173 \times 10^{-11}$ m$^3$/Nm to $2.198 \times 10^{-11}$ m$^3$/Nm for a load of 35 N. When the percentage of silane-treated SiC particles increased from 5% to 10%, the wear resistance of all C–E samples was found to increase. In the silane-treated SiC-filled C–E, carbon fiber has a higher specific strength and also possesses the self-lubricating property. Also with reinforcement of hard SiC particles in epoxy medium effectively reduces the wear loss and this could be the reason for lower specific wear rate as well.
Suresha et al (2007) reported that the addition of the SiC particulates with the G–E composite materials increases the wear resistance of that material when compared to the plain G–E composite materials. Kumaresan et al (2011) reported that the addition of the silane-treated SiC particles by 10% volume fraction with the C–E composite enhances the wear resistance of the composites under sliding conditions when compared to the plain C–E composite. With reference to the above investigations, same kind of results was observed in the current study in the case of silane-treated SiC-filled polymer composites. So, from the above abrasive test, it can be understood that the combination of carbon fibers with the hard silane-treated SiC particles in epoxy medium strengthened the interface between the reinforcement and matrix materials.

Table 6.3  Glass transition temperature and specific wear rate of the composites

<table>
<thead>
<tr>
<th>Sample Designation</th>
<th>Glass transition temperature(T_g) °C</th>
<th>Specific wear rate(K_v) x 10(^{-11}) m(^3)/Nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-E</td>
<td>78</td>
<td>3.286</td>
</tr>
<tr>
<td>5 SiC - C-E</td>
<td>84</td>
<td>2.697</td>
</tr>
<tr>
<td>10 SiC- C-E</td>
<td>153</td>
<td>2.198</td>
</tr>
</tbody>
</table>

The correlation of glass transition temperature of DMA with specific wear rate of abrasive wear tests of the unfilled and silane-treated SiC-filled C–E composites is made and given in Table 6.3. The incorporation of the silane-treated SiC filler with C–E shows the rising trends of glass transition temperature \(T_g\) of composite from 78°C to 153.36°C. On the other hand, an increase of its weight percentage seems to decrease specific wear rate of the composite from \(3.286 \times 10^{-11}\) m\(^3\)/Nm (C–E) to \(2.198 \times 10^{-11}\)
m$^3$/Nm (10 SiC–C–E). Carbon fibers have a high modulus and strength; moreover, silane-treated hard SiC particles reinforced with the carbon fiber and epoxy matrix provide higher stiffness and strength.

The mobility and deformations of the matrix are restricted by the combination of hydrodynamic property of the carbon fiber in viscoelastic medium and the mechanical self-possession of spreading of the silane-treated SiC filler. This could be the reason for increase of the $T_g$ for silane-treated SiC-filled C–E. The abrasive wear resistance of the SiC-filled C–E increases with the silane-treated SiC particulates. From the results of DMA and specific wear rate, it can be observed that the glass transition temperature increases with silane-treated SiC wt%; moreover, the specific wear rate decreases in the silane-treated SiC-filled C–E. This could be the reason behind the concentration of hard silane-treated SiC particles with the carbon fiber. Epoxy matrix prevents the chain movability of the molecular structure and displays higher thermal stability. Moreover, during the abrasion of hard silane-treated SiC particles with the graphitized carbon fibers, it formed complex mechanism to reduce the specific wear rate.

### 6.3.1.3 Worn surface morphology

The predominant wear mechanisms on the worn surfaces of the material samples were obtained by SEM examination. The mechanisms such as microploughing, microcracking and microcutting were the main reasons for abrasive wear on the composites. SEM photomicrographs of abraded surfaces of the samples C–E, 5SiC–C–E and 10SiC–C–E for 25 and 35N loads with abrading distance 480 m are shown in Figures 6.12–6.14 respectively.
Figure 6.12 Photomicrographs of unfilled C–E samples at (a) 25 N load and (b) 35 N load

Figure 6.12 (a) - (b) demonstrates the abraded surfaces for the C–E samples under an abrading distance of 480 m with the loads of 25 N (Figure 6.12 (a)) and 35 N (Figure 6.12 (b)), respectively. During the abrasion, the sharp abrasive particles of the silica sand that made the deep furrows on the sample surfaces (indicated in rectangular box of Figure 6.12 (a)) due to the ploughing action are shown in Figure 6.12 (a) along the abrading direction. In Figure 6.12 (a), the matrix and the fiber were subject to wear and tear, matrix cracking and removal, and fiber breakage. Some fibers were pulled out from the C–E surfaces. The voids were also observed on the surfaces by debonded fibers from the surfaces. The reason for the fiber damage and voids may be the result of surface fatigue and repeated abrasion. For the increased load of 35 N with same 480 m abrading distance of C–E sample, SEM photomicrographs (Figure 6.12 (b)) showed severe damage of the transverse fibers. The abraded region was occupied by more damaged fibers and debris of matrix. Moreover, the arrow mark on Figure 6.12 (b) shows the stepped appearance of the carbon fibers with fiber matrix debonding and damaged portions of fibers. The reason for this severe damage of the matrix with carbon fiber is the poor bonding between the fiber and matrix.
Figure 6.13 Photomicrographs of 5SiC-filled C–E samples at (a) 25 N load and (b) 35 N load

SEM photomicroscopes, Figure 6.13 (a)-(b), shows the abraded surfaces of the 5SiC–C–E composites under the abrading distance of 480 m with load 25 and 35 N, respectively. From the wear volume data (Figure 6.10 (a) - (b)) and the specific wear rate details of the silane-treated SiC-filled C–E materials (Figure 6.11 (a) - (b)), the addition of silane-treated SiC particles with the C–E reduced the wear rate and increased wear resistance. The less matrix damage and fiber breakage indicated on the abraded surface of the 5 SiC–C–E composite sample of Figure 6.13 (a) supports the above statement. The abraded sand particles and minimum number of damaged fibers were also seen on the surface. The wear debris formed on the surface (indicated by arrow) was also seen. For increased load of 35 N, the surface of the sample was abraded further. The ploughing action results in breakage of fibers and removal of the same from the surface. Fibers displacements (indicated in square box) are shown in Figure 6.13(b). The hard silane-treated SiC particles in the C–E materials produced hard particles with soft regions. Hence the severity and damage of the fibers and matrix of the C–E can be noticed to be minimal. So, the presence of silane-treated SiC particles seems to have reduces the matrix loss. The broken fiber seems to
have led to increased wear resistance. When the wt% of the silane-treated SiC increased with C–E by 10%, the wear resistance of the (10 SiC–C–E) composite also increased when compared to the C–E and 5 SiC–C–E materials, as referred in Figures 6.10 (a)-(b) and 6.11 (a)-(b).

Figure 6.14 Photomicrographs of 10 SiC-filled C–E samples at (a) 25 N load and (b) 35N load

Figure 6.14 (a)-(b) show SEM photomicrographs of the abraded surfaces of 10SiC–C–E sample under the abrading distance of 480 m with load 25 and 35 N, respectively. Lesser matrix damage and fiber cutting were observed on the surface (indicated in box) as shown in Figure 6.14 (a). The spreading silane-treated SiC particles were also mixed with matrix and fiber, which enhanced the bonding between the carbon fiber and epoxy resin matrix. When the load was increased to 35 N, the fibers were removed from the matrix by abrasive particles. Fragmented fibers by microcutting seen on the surface (indicated by arrow) of the sample were observed using SEM (Figure 6.14 (b)). Fiber breakage and debonding of fiber from the matrix of the SiC-filled C–E composites were identified and the wear was very minimum when compared to the C–E composite.
6.4 SUMMARY

The following conclusions are drawn from the two-body and three-body abrasive wear tests.

Two-body abrasive wear behavior:

1. Abrasive wear volume loss seemed to increase with increasing abrading distance and applied loads for all samples.

2. Abrasive wear rate is higher in unfilled C-E composites than SiC filled C-E composites. Silane-treated SiC filled C-E hybrid composite showed better wear resistance under various abrading distances and loads. The addition of silane-treated SiC particles with the C-E composites lowers its specific wear rate than unfilled composites.

3. SEM photomicrographs support the involved mechanisms and highlighted the fiber pullout, fiber damage, and fiber-matrix debonding, exposure of fibers, fiber cracking and removal of broken fibers.

Three-body abrasive wear behavior:

1. Three-body abrasive wear volume loss of the both unfilled and silane-treated SiC-filled C–E hybrid composite samples increased with increasing abrading distance and load.

2. The wear resistance of the silane-treated SiC filled C-E hybrid composites was found to increase with the weight percentage of silane-treated SiC loading when compared to the unfilled C-E composites.
3. The specific wear rate decreases with the increasing of abrading distance and also addition of SiC particles with the C-E composites exhibits decreased trend in specific wear rate.

4. SEM studies of worn surfaces indicated the appearance of damages on composite surfaces such as deep furrows, matrix cracking, fiber breakage, damage of the transverse fibers, fiber matrix debonding and fiber displacement.