Erodent Size Effect on the Erosion of Polyphenylene Sulfide Composite

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The effect of erodent particle size on solid particle erosion of randomly oriented short glass fiber and mineral particle reinforced polyphenylene sulfide (PPS) was investigated. To examine the effect of erodent size on the erosion resistance of the PPS composite, aluminum oxide particles at three different sizes, namely, 300–425 µm, 150–212 µm, and 45–75 µm, were used. The erosion tests were performed at six different contact angles of 15°, 30°, 45°, 60°, 75°, and 90°, respectively. The results showed a strong relationship between the erodent particle size and erosion rates of PPS composite. Maximum erosion rate for the erodent particles with sizes of 45–75 µm and 150–212 µm occurred at contact angle of 30°, on the other hand maximum erosion rate for particles having 300–425 µm size occurred between 45° and 60°. The morphologies of eroded surfaces were characterized by the scanning electron microscopy (SEM). Possible erosion mechanisms were discussed. POLYM. COMPOS., 31:985–994, 2010. © 2009 Society of Plastics Engineers

INTRODUCTION

Erosive wear is a process of progressive removal of material from a target surface due to repeated impact of solid particles [1]. Solid particle erosion leads to negative effects such as wear of components, surface roughening, surface degradation, macroscopic scooping appearance, and reduction in the functional life of the structure. Hence, solid particle erosion has been considered as a serious problem, as it is responsible for many failures in engineering applications [2]. Polymer composite materials are finding increased application under conditions in which they may be subjected to solid particle erosion at applications such as pipeline carrying, helicopter rotor blades, pump impeller blades, high-speed vehicles, and aircraft operating in desert environments [3]. Erosion resistance of polymer composites, which are used in many applications, has become an important material property, particularly in the selection of alternative materials [4]. Hence, it becomes imperative to study erosive wear behavior of polymeric engineering materials in various operating conditions [5]. However, it has been observed that the polymer composite materials present a rather poor erosion resistance compared with metallic materials [6]. It is also known that erosive wear of polymer composites is usually higher than that of the unreinforced polymer matrix [3, 7, 8].

The influence of parameters such as concentration, impact speed, impact angle, size, and shapes of the particles on erosion rate is very strong, and any changes in them can significantly affect the rate of material loss [9]. The erosive wear behavior of polymer composite systems as a function of fiber [2, 10], particle [11, 12] and fabric content [13, 14], fiber and filler type [2, 8], fiber orientation [3, 7, 10], fiber length [10, 15], impingement angle [2, 3, 5, 7, 8, 10, 11], impact velocity [3, 11], and erodent mass flow [5] has been studied previously. In erosive wear experiments, only one type of erodent particle of similar size has been used to evaluate the erosive wear behavior of polymer composites. A literature survey showed that detailed investigation on effect of erodent particle size in solid particle erosion behavior of polymer composites has not been reported. In most practical situations, polymer composites can be subjected to erosive wear with different sizes of the same erodent. To obtain the desired material characteristics for a particular application, it is important to know how the composite wear performance changes with the different size of the same erodent particle. Polymers and their composites that have been studied include epoxy [7, 8, 15], polyamide [5], polyurethane (PUR) [12] polyetheretherketone (PEEK) [3, 16], polypropylene [10], polyetherimide (PEI) [2, 13, 14, 17], and polyphenylenesulfide (PPS) [16, 18].

One of the dilemmas in the field of solid particle erosion is the correlation between the particle size and the erosion rate. It is generally accepted that dimensionless erosion rate of ductile metals is independent of particle size beyond a critical particle size, but the erosion rate decreases sharply with decreasing particle size and may even become zero at some nonzero threshold particle size, of the order of 1–2 µm [19]. The particle size effect in erosion has been discussed in the technical literature for a
couple of years. The particle size effect is commonly taken as the change in erosion rate associated with changes in the size of erodent particles when nominally the same test conditions are used [20]. Experimental studies made for determining the particle size effect were generally realized by slurry erosion tests using slurries of different erodent particle sizes.

Stack and Peña [21] have examined the effects of particle size on the erosion behavior of metal matrix composite-based coatings. It was determined that erodent size has a significant effect on the transitions between the wastage regimes for such materials. They defined the wastage regimes according to thickness loss per hour ($L_t$) as low ($L_t < 0.3$ $\mu$m$^{-1}$), medium ($0.5$ $\mu$m$^{-1} < L_t < 0.3$ $\mu$m$^{-1}$), and high ($L_t < 0.3$ $\mu$m$^{-1}$). Gandhi and Borse [1] observed that a reduction of approximately 40–50% in the wear is possible by addition of finer particles 25 wt% of bigger particles. Clark and Hartwich [20] have explained that the nature of a particle size effect on the rate of erosion of materials can only be understood if the effect of the change of particle size on the slurry flow and particle impact conditions is known quantitatively. In addition, erosive wear behaviors of bismaleimide (BMI) polymer and graphite fiber-reinforced BMI polymer composite were tested using angular alumina oxide erodent particles having various sizes such as 42, 63, 130, 143, and 390 $\mu$m [3].

PPS composites are being used as a coating and structural material in various engineering applications, which is subject to solid particle erosion. Therefore, the resistance to particle erosion of the PPS composites has an important parameter that should be taken into account [18]. A literature survey showed that the effect of erodent particle sizes on erosive wear behavior of random-oriented glass fiber and calcium carbonate (CaCO$_3$) filled hybrid PPS composites has not been reported previously.

The objective of the present investigation is to study the effect of erodent particle size on solid particle erosion characteristics of random oriented glass fiber and calcium carbonate particulate reinforced hybrid PPS composite under low particle speed experimental conditions.

### Experimental Details

#### Material

PPS composite used in this study was kindly supplied from Ticona-Germany as injection-molded 80 $\times$ 80 mm plates with a thickness of 2 mm. PPS matrix was reinforced by random-oriented short glass fiber (40 wt%) and CaCO$_3$ mineral particulate (25 wt%) (total: 65 wt%). The commercial name of the material was 6165A4. From these molded plaques, test samples of approximately of 15 mm $\times$ 80 mm $\times$ 2 mm in dimensions were cut using a diamond cutter. Table 1 summarizes the physical properties of the short glass fiber/mineral particle-reinforced PPS composite [22].

#### Erosive Wear Studies

A schematic illustration of the low-speed solid particle erosion rig used in the present study is shown in Fig. 1. Electric motor drives the system and the speed control unit enables us to adjust desired travel speed of sample holder in the chamber. Composite specimen was mounted in the sample holder. Upper end of the sample was 40 mm beneath the upper sand surface. Composite samples were mounted on the sample holder which could be rotated around the vertical axis. As seen in Fig. 2, composite sample follows the circular path into the chamber which has a radius of $r$. It is possible to adjust the travel speed by means of changes in $r$ values in the chamber. Maximum available travel speed can be achieved as 1.57 m/s in this chamber. The contact angle varies between the 0° and 90° with the increments of 15°. Angle of contact is enabled to be set in the desired angle. Contact angle of the specimen, $\alpha$ is 90° (Fig. 3). Contact

### Table 1. Properties of the short glass fiber/mineral particle reinforced PPS composite.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass transition temp.</td>
<td>110 °C</td>
</tr>
<tr>
<td>Melting temp.</td>
<td>280 °C</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>130 Mpa</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>19,000 Mpa</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>18,000 Mpa</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>210 Mpa</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>230 Mpa</td>
</tr>
<tr>
<td>Compressive modulus</td>
<td>18,500 Mpa</td>
</tr>
<tr>
<td>Impact strength (Charpy)</td>
<td>20 kJ/m$^2$</td>
</tr>
<tr>
<td>Rockwell hardness (M)</td>
<td>100</td>
</tr>
<tr>
<td>Density (g/cm$^3$)</td>
<td>1.95</td>
</tr>
</tbody>
</table>

![Fig. 1. Schematic illustration of erosion test rig.](image-url)
angle is a very important parameter, which affects the erosive wear behavior of the samples remarkably.

Test rig includes a chamber which is filled with erodent particles. In the present study, sharp and angular brown fused aluminum oxide (Al₂O₃) was used as erodent. In erosive wear experiments, aluminum oxide, silica sand, and silicon carbide can be used. Hardness of brown fused aluminum oxide is higher than that of silica sand, but its hardness is lower than that of silicon carbide. Besides, its density is higher than that of silica sand but lower than that of silicon carbide. Namely, aluminum oxide depicts an intermediate property between silica sand and silicon carbide. So, aluminum oxide was preferred as an erodent particle in this study. To examine the effect of erodent size on the erosion resistance of the PPS composite, angular aluminum oxide eroding particles of three different sizes namely, 300–425 μm, 150–212 μm, and 45–75 μm were used. Figure 4 shows the micrographs of the erodonts.

The properties of erodent used in the present study and the experimental parameters were carried out are listed in Table 2. In addition, the chemical composition of aluminum oxide erodent is given in Table 3.
The same test procedure was employed for each sample. The erosion tests were conducted at contact angles by changing the orientation of the sample with respect to the erodent particles. The samples were mounted on sample holder at six different contact angles as 15°, 30°, 45°, 60°, 75°, and 90° as illustrated in Fig. 3. Wear rates of the samples were determined using weight loss. The samples were cleaned in acetone, dried in oven at 22°C for 2 h, and weighed to an accuracy of 0.1 mg using an electronic balance before the wear test. After wear testing, erodent particles that were adhered to surface of sample were removed by air blasting. Before samples were weighed at the end of certain period of erosion test to determine the weight loss, they were cleaned in acetone and dried in oven at 22°C for 2 h so that they were freed of all erodent particles or other foreign substance such as dust, dirt, etc. Great care was given to ensure clean surface before and after the wear tests. All erosion tests were performed at room temperature. Five tests were performed on each sample and an average value calculated. In erosive wear experiments, samples were separately subjected to erosive wear in the test rig at certain contact angles for 1, 3, 5, and 7 h. Since each sample was not successively subjected to erosive wear, weight loss of each sample, which was obtained at the end of certain period, was directly considered as cumulative wear rate of that sample. Erodent particles were replaced after certain periods in consideration of the fact that their abrasive capability reduces due to the interaction among themselves.

### RESULTS AND DISCUSSION

The cumulative wear rates obtained after erosive wear experiments using aluminum oxide particles having different particle sizes are seen in Fig. 5. Erosive wear rates

![Figure 5](https://via.placeholder.com/150)

**TABLE 2.** Properties of erodonts used and test parameters.

<table>
<thead>
<tr>
<th>Erodent</th>
<th>Brown fused aluminum oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erodent size (μm)</td>
<td>300-425, 150-212, 45-75</td>
</tr>
<tr>
<td>Erodent shape</td>
<td>Angular</td>
</tr>
<tr>
<td>Hardness (GPa)</td>
<td>21</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>3.77</td>
</tr>
<tr>
<td>Contact angle (°)</td>
<td>15, 30, 45, 60, 75, 90</td>
</tr>
<tr>
<td>Shaft revolution (rpm)</td>
<td>120</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>1.57</td>
</tr>
<tr>
<td>Test period for each sample (h)</td>
<td>1, 3, 5, 7</td>
</tr>
<tr>
<td>Test temperature</td>
<td>Room temperature</td>
</tr>
</tbody>
</table>

![Figure 5](https://via.placeholder.com/150)

**TABLE 3.** Chemical composition of erodent used in erosion tests.

<table>
<thead>
<tr>
<th>Erodent</th>
<th>Chemical composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown fused</td>
<td>Al₂O₃: 96%, TiO₂: 2.5%, SiO₂: 0.8%, Fe₂O₃: 0.15%, CaO: 0.21%, MgO: 0.21%</td>
</tr>
</tbody>
</table>

![Figure 5](https://via.placeholder.com/150)

**FIG. 5.** Cumulative wear rates of samples as a function of erodent sizes. (a) 45–75 μm, (b) 150–212 μm, (c) 300–425 μm.
show a strong dependence with contact angles for all particle sizes. It was observed that cumulative wear rates increase proportionally with erosion time for each contact angles. It has been reported that ductile polymers and some elastomers show an initial incubation period with mass gain before steady-state erosion rate was established under constant erosion conditions [7, 23, 24]. However, in the present study, an initial mass gain and incubation period were not observed for the PPS composite under the experimental condition chosen. As seen in Fig. 5, there was not an incubation period for all impingement angles (from 15° to 90°) and there was a linear proportion between erosion rate and erosion time. This indicates that repeatable steady state wear mode has reached during the experiments. In Fig. 5c, unlike Fig. 5a and b, maximum erosion rates were reached at contact angles of 45° and 60°, and increase in wear rate was observed after erosion time of 3 h.

In literature, materials are broadly classified as ductile or brittle, based on the dependence of their erosion rate with impingement angle. The behavior of ductile materials is characterized by maximum erosion at low impingement angles (15°–30°). Brittle materials, on the other hand, show maximum erosion under normal impingement angle (90°). Reinforced composites, unlike the above two categories, have been shown to exhibit a semi ductile behavior with maximum erosion occurring in the range of 45°–60° [2, 7, 24, 25]. However, the above classification is not absolute as the erosion behavior of materials strongly depends upon the experimental conditions and composition of target materials [2]. In the present study, typical brittle glass fibers were used as reinforcement in PPS matrix, so erosion mainly dominated by microcracking due to the impact of solid particles. The glass fibers that fracture during the erosion removed from the matrix immediately after being exposed to an eroded surface and have an effect on increasing the erosion rate. The erosion of fiber is mainly caused by damage mechanisms as microcracking or plastic deformation due to the impact of aluminum oxide erodent particles. Such damage is supposed to increase with the increase of kinetic energy loss. According to Hutchings et al. [26], kinetic energy loss is maximum at an impingement angle of 90°, where erosion rates are maximum for brittle materials. In the present study also, the peak erosion rate occurs around an impingement angle of 30° and 60° due to the semibrittle nature of PPS composite.

Wear rates obtained by erosive wear experiments are given in Fig. 6. The effect of particle size on erosive wear rates of the materials is illustrated in Fig. 6a, b, and c after erosion time of 1, 3, and 5 hours, respectively. For different sized erodent particles (45–75 μm and 150–212 μm), maximum wear rates were achieved at contact angle of 30°. On the other hand, for bigger particles having a size of 300–425 μm, the maximum wear rates were achieved at contact angle between 45° and 60° (Fig. 6d). This is one of the most important results of this study, which indicates that the particle size affects the erosive wear characteristics of the material. At higher contact angles, higher than 45°, the PPS composite behaves like a brittle material against the bigger particles compared to smaller particles. Up to erosion time of 3 h there was a reasonable increase in wear rates were observed. The increments in wear rates show close tendency with increment in particle sizes. Bigger particles result in higher wear rates. After the erosion time of 5 and 7 h, remarkable increase in wear rates of the material is observed for the particles having size of 300–425 μm.

The morphology of the eroded sample at contact angle of 15° for 7 h by the aluminum oxide particles in smallest size (45–75 μm) is illustrated in Fig. 7. As seen in Fig. 7, there were not any fractured fibers observed at the surface of the material. Since the contact angle of 15° is quite close to horizontal direction, generally abrasive wear mechanisms are dominant. Because of the small vertical (perpendicular to surface) components of the particle velocity, the impact of the particle upon the material surface is very limited. Under this consideration particle erosion occurred as matrix erosion due to particle-material surface interaction following detachment of the fibers from their original places which are not supported enough.

When we consider the kinetic energy as $E_k = \frac{1}{2} m V^2$, the correlation between mass and kinetic energy is clear. Not surprisingly, small sized particles (like 45–75 μm) would have lower kinetic energies. Because of the low impact of erodent particle, the CaCO$_3$ reinforced polymeric matrix was subjected to more intensive microploughing and microcutting wear mechanism. As seen in Fig. 7, there is very limited pulled out and fractured fiber (indicated by white arrow) observed on material surface after particle erosion. Also interaction between the fibers and small-sized particles result in very clean fiber surfaces after particle erosion.

Figure 8a illustrates the wear morphology after erosion time of 7 hours at contact angle of 30°. The particle size is the same as in Fig. 7 as 45–75 μm. The peak angle is 30°, where the maximum erosion rate was achieved for given particle size. Effects of the particles (vertical to material surface) are higher compared to 15°, which result in higher matrix erosion (as already seen in Fig. 6) among the fibers and insufficiently supported fibers show a higher tendency to be broken. There were higher number of broken fiber fragments (indicated by white arrows in Fig. 8a) found on material surface compared with material surface eroded at contact angle of 15° in Fig. 7.

Effect of smaller particles on erosive wear morphology of composite material can be seen in Fig. 8b. Small-sized particles would erode the matrix among the fibers easier. This why very smooth wear morphology was achieved. Both matrix and fiber surfaces are very smooth and clean. As seen in Fig. 8b, although the smaller gap between the fibers with several micron width, the matrix among the fibers was eroded uniformly. It should be noted that the erodent particles colliding each other or fractured into
smaller pieces as a result of colliding target material. As a result, they have smaller sizes when compared with their original sizes, which enable them to penetrate smaller gaps between the fibers and clean the fiber surface remarkably.

The SEM micrograph of the composite eroded by aluminum oxide particles having 150–212 μm size at contact angle of 15° is seen in Fig. 9. It is clearly observed that wear rates are higher at bigger particles (Fig. 6). Higher erosion of polymer matrix among the fibers was observed. Compared to the Fig. 7, higher number of broken fibers fragments were observed on the eroded sample surface. Similar to Fig. 7, fiber surfaces are found very clean as a result of erosion.

In Fig. 10a, wear morphology is illustrated after particle erosion of aluminum oxide with the particle size of 150–212 μm at contact angle of 30°. Note that maximum erosion is achieved at contact angle of 30° for this particle size.

FIG. 6. Wear rates of the samples as a function of contact angle. (a) 1h, (b) 3h, (c) 5h, and (d) 7h erosion times.

FIG. 7. SEM micrograph of composite surface eroded by 45–75 μm Al₂O₃ erodent particles at contact angle of 15° (400× magnification).
Because the impact of the particles is greater compared to smaller particle size (45–75 µm), there are many fractured fibers and small fibre/matrix fragments distributed on the material surface randomly. Due to higher impact energy, the erodent particles can be easily fractured and embedded on polymer matrix of the composite. Embedded aluminum oxide particles (confirmed by EDX analysis) are indicated with arrows both in Fig. 10a and b.

Morphology of the erosion that was achieved at contact angle of 30° for 7 h by the biggest aluminum oxide particles (300–425 µm) is illustrated in Fig. 11a and b. When we compare to previous ones, wear morphology was very different. Note that material gives maximum erosion at contact angle between 45° and 60°. So, 30° should be taken into account as a “small angle” and gives lower erosion rate compared to maximum angle. When we examine the wear morphology, first of all there is a remarkable difference in fiber surface is observed. The

FIG. 8. SEM micrographs of composite surface eroded by 45–75 µm Al₂O₃ erodent particles at contact angle of 30° and magnification (a) 400× and (b) 1500×.

FIG. 9. SEM micrograph of composite surface eroded by 150–212 µm Al₂O₃ erodent particles at contact angle of 15° (400× magnification).

FIG. 10. SEM micrographs of composite surface eroded by 150–212 µm Al₂O₃ erodent particles at contact angle of 30° and magnification (a) 400× and (b) 600×.
surfaces of the fibers are not smooth like the previous ones and they are partially covered by matrix and small fragments. Moreover, rougher matrix surface is observed compared to previous morphologies. Deeper gap formations on the polymer matrix and fractured fibers are observed on the material surface. Also the particle flow direction can be deduced in micrographs (indicated by hatched arrow in Fig. 11a and b). It can be easily observed that the right sides of the fibers (indicated with white arrows in Fig. 11a and b)—located perpendicular to the particle flow direction—exposed to higher particle erosion compared to other side (left side). Since the higher particle erosion occurred at the right sides of the fibers—which are located perpendicular to the particle flow direction—cleaner and smoother boundary surfaces are observed. On the other hand, other sides of the fibers still covered by matrix. One of the main reasons of this morphology is the bigger sizes of the particles. Erodents are not small enough to penetrate or worn the matrix material between the fibers. Fibers, which are located perpendicular to the particle flow direction, behave like a “barrier” and keep the matrix material from particle erosion. During the particle erosion, matrix which located among the fibers does not interact with erodent particles and keeps its location. As a result of particle impingements fibers were fractured and left their places. During this removing process some of the matrix material was eroded with the fibers.

It should be taken into account that the polymeric materials (matrix) have a higher erosion resistance compared to fibers. As known, the reinforcements adversely affected the erosion wear resistance of polymeric matrix which can be attributed to severe damage to the fibers caused by excessive fiber-matrix de-bonding, fiber fracture, microcutting and pulverization by successive impacts of high speed impinging particles. It is quite clear from the literature that erosion rate of polymer and its composites are highly dependent on various combinations of

FIG. 11. SEM micrographs of composite surface eroded by 300–425 μm Al2O3 erodent particles at contact angle of 30° and magnification (a) 400× and (b) 1000×.

FIG. 12. SEM micrographs of composite surface eroded by 300–425 μm Al2O3 erodent particles at contact angle of 60° and magnification (a) 400× and (b) 650×.
mechanical properties. The primary reason for adding fillers and/or fibers to polymers is to improve the mechanical properties, but the effect on erosion resistance is not invariably beneficial [2, 8, 11, 24]. Fibers have a brittle nature and they are easily eroded by means of fracture. Fractured fibers detached from its original places with some amount of matrix, which is responsible for supporting them in a material. This why, for the brittle fiber reinforced polymer composites, the main parameter is the contact angle and the kinetic energy of the erodents. If the erodents hits the material with appropriate angle having enough impact energy to fracture the fibers, it is possible to get higher erosion rate. Compared to other sizes the particles having a dimensions of 300–425 \( \mu m \) have a highest ability to fracture fibers which result in highest wear rates.

At higher contact angles, particles have a higher impact, which is more capable of fiber fracture in brittle manner. Fig. 12 illustrates the wear morphology at contact angle of 60° for given particle size. The contact angle of 60° results in highest wear rates. The biggest erodent particles having 300–425 \( \mu m \) sizes at contact angle of 60° have the highest kinetic energies caused maximum wear rate in this study. At this contact angle, due to the effects of the particles, fibers tends to broken easily. Also detachments of the broken fibers are easier. Wear morphology of the matrix is rougher compared to the other smaller particles. It was seen that surfaces of the fibers are not clear and covered with certain amount of matrix.

In Fig. 12, it is possible to see many fractured fibers because of particle impact on material surface. Fibers were fractured into smaller pieces. Also many highly deformed fiber/matrix interfaces are observed. There are many small gap formation on the polymer matrix. Also one of the debonded fiber trace is observed.

**CONCLUSIONS**

Steady state wear behavior was observed for each aluminum oxide erodents having different particle sizes. No incubation period or initial mass gain was observed. Erosive war rates show a strong dependence with contact angles for each particle size. Also particle size affects the erosive wear characteristics of the PPS composite. Maximum erosion rates were observed at contact angle of 30° for the eroding particles with the sizes of 45–75 \( \mu m \) and 150–212 \( \mu m \). On the other hand, maximum erosion rate for particles having 300–425 \( \mu m \) size occurs between 45° and 60°.

Small-sized (45–75 \( \mu m \)) eroding particles have lower kinetic energy, which result in minimum erosive wear rate for all contact angles compared to other bigger particles. At the contact angle of 15°, very smooth surface morphology was observed with a clean fiber surfaces. At the contact angle of 30°, the amount of matrix wear among the fibers and the number of broken fibers were higher compare to contact angle of 15°. It should be noted that the particles having smaller sizes enable to reach into smaller (or narrow) gaps between the fibers. Also this particles are not big enough to fracture the fibers, but they interact with the fiber surface which result in un-broken and clean fiber surface. After erosion of aluminum oxide particles having 150–212 \( \mu m \) sizes at contact angle of 30°, there were many broken fibers distributed on the surface randomly and also many horizontally cracked fibers were remained on their positions. The impact of the particles was greater compared to smaller particle size (45–75 \( \mu m \)), and there were many fractured fibers and small fibre/matrix fragments distributed on the material surface randomly. Due to higher impact energy, the erodent particles can be easily fractured and embedded on polymer matrix of the composite. In case of largest (300–425 \( \mu m \)) eroding particles at 60° contact angle—where the peak erosion rate was achieved—fibers were broken by the impact of eroding particles due to their higher vertical velocity components. Compared with other particle sizes (45–75 and 150–212 \( \mu m \)), fibers were detached from their positions easily, which result in higher erosion rates. Particles having a dimensions of 300–425 \( \mu m \) have a higher ability to fracture fibers, which result in highest wear rates. Also detachment of the broken fibers was easier. Wear morphology of the matrix was rougher compared to the other smaller particles. It was seen that surfaces of the fibers were not clear and covered with certain amount of matrix.

It can be easily observed that one sides of the fibers, which are located perpendicular to the particle flow direction, were exposed to higher particle erosion compared to other sides. The higher particle erosion occurred at the one sides of the fibers result in cleaner and smoother boundary surfaces. On the other hand, other sides of the fibers were still covered by the matrix. One of the main reasons of this morphology based on the bigger particles. Bigger erodents are not small enough to penetrate or worn the matrix located between the fibers. Fibers, which are located perpendicular to the particle flow direction, behave like a “barrier” and keep the matrix material from particle erosion. During the particle erosion, matrix which located among the fibers does not interact with erodent particles and keeps its location.

**REFERENCES**