THE INVESTIGATION OF AISI 52100 STEEL BALL ON ALUMINA FILLED EPOXY MATERIAL SURFACE FOR DETERMINING TRIBOLOGICAL PROPERTIES

A. AKINCI a, S. SEN a, S. YILMAZ a and U. SEN a

a Sakarya University, Dept. of Metallurgy and Materials Engineering, Esentepe Campus, 54187, Sakarya, Turkey, akinci@sakarya.edu.tr

Abstract

The wear behavior of epoxy matrix composites filled with alumina particles is discussed in this paper. The tribological performance of pure epoxy and epoxy+5-20wt% alumina composites were studied under the dry sliding conditions. Wear tests were carried out with AISI 52100 ball on the configuration of rotating epoxy matrix composite disk. Test conditions were atmospheric conditions under the loads of 5N, 10N and 15N and at the sliding speeds of 0.3 m/s. The wear test results showed that the alumina particles could improve the wear resistance of the epoxy matrix. This makes it possible to develop novel type of epoxy-based composite with improved wear resistance for various applications. It was found that the increase in the filler content seemed to be more effective in the improvement of the wear resistance of the composites. The wear rates of the epoxy composite are changing between 5.727x10-5 mm3/m and 6.022x10-4 mm3/m, depending on the alumina additive percentage and applied load. Increase in load value caused to increase in friction coefficient and wear rate.

Keywords: epoxy, alumina, wear, ball-on-disc.

1. INTRODUCTION

High performance polymer composite materials are used increasingly for engineering applications under hard working conditions. The materials must provide unique mechanical and tribological properties combined with a low specific weight and a high resistance to degradation in order to ensure safety and economic efficiency [1]. Epoxy resin has been widely used in coatings, supporting materials for printed circuit boards, and resin matrix for advanced composites, and so on. Under these hard working conditions, epoxy resin must provide unique mechanical and tribological properties in order to ensure safety. But in general, epoxy resin is not an ideal material used in sliding wear applications due to its three-dimensional network structure compared with thermoplastics. Recently many attempts were made to develop epoxy resin composites modified by micro and nano fillers to improve the tribological performance of the matrix [2,3]. Epoxy alone has a high friction coefficient in most applications, as well as poor wear resistance compared to epoxy containing composites. Many hard particulates made of ceramic or metal particles have been tried as the fillers to modify the epoxy resin–matrix composites for that purpose by several researchers [4,5]. Their results show that the addition of various ceramic particles into the epoxy matrix enhances the tribological properties of the composites. The use of such hard particles increases the dry sliding friction coefficient and abrades the counterface. Fillers have been added to reduce both friction coefficient and wear rate. Studies with epoxy and
micron-scale or nano-scale fillers by Xian et al. [6], Friedrich et al. [7], and Zhang et al. [8] show an effective in the reduction in the wear rate of a polymeric material, and the coefficient of friction with increased filler [3]. Good mechanical strength and hardness, as well as thermal and chemical resistance, favor the application of epoxy resins as commercially used engineering materials. In order to improve the friction and wear behavior of an epoxy material, one of the traditional concepts is to reduce its adhesion to the counterpart material and to enhance its hardness, stiffness and compressive strength. This can be achieved quite successfully by using special fillers [7,9]. Epoxies are commonly modified by the inclusion of inorganic-particulate fillers, such as silica and alumina and mica or talc. Fillers are added to epoxy resins to improve fracture toughness and electrical or heat transfer properties and to increase resin stiffness, flame retardants, and wear resistance, and to reduce the coefficient of thermal expansion and thermal resistance. The resulting composite specimens have applications as automobile parts, dental restoratives and and electronic packaging/underfill for circuit cards, and. Many variables (e.g. resin crosslink density, particle type, size, size distribution, and filler loading) can affect the composite’s thermal, electrical, mechanical and fracture properties [10,11].

Small ceramic particles are known to enhance the mechanical and tribological properties of polymers. Introduced into an epoxy resin, the filler morphology, size, particle amount and the dispersion homogeneity influence extend the composite’s performance. High performance polymer composite materials are used increasingly for engineering applications under hard working conditions. The materials must provide unique mechanical and tribological properties combined with a low specific weight and a high resistance to degradation in order to ensure safety and economic efficiency. It has been shown, that a considerable improvement of the mechanical and tribological properties can already be achieved at very low filler volume content, somewhere in the range of 1–5 vol.% [1] Kumar [12] found that the addition of alumina powder of size <1µm into epoxy increases the sliding wear resistance of the material.

In this study, we examined the tribological properties of micrometer Al₂O₃ particle filled epoxy resin composites. We investigated the differential effects of micrometer Al₂O₃ particles on the tribological behaviors of epoxy composites under identical experimental conditions.

2. EXPERIMENTAL

The polymer matrix material that used in this study is epoxy “(triethlenetetramine bisphenol-A (epichlorhydrin), epoxy resin (≤700), oxinane, mono [C₁₂₋₁₄-alkyloxy] methyl)” supplied by Denmark. Al₂O₃ obtained from Sigma-Aldrich Chemie (USA) was used in the composites. The samples used in the wear test were manufactured in the disk form in the dimensions of 25 mm in diameter and 20 mm in length by applying ultrasonic vibration. The friction and wear tests were realized using ball-on-disk arrangement. AISI 51200 steel ball was used as a counter ball material which has 59 HRC hardness and 1.2 µm average roughness (Ra). Wear tests parameters are given in Table 1.
Table 1. Experimental process parameters of wear tests

<table>
<thead>
<tr>
<th>Parameters (Units)</th>
<th>Experimental Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied load (N)</td>
<td>5, 10, 15</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.3</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>23±2</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>65±1</td>
</tr>
<tr>
<td>Sliding distance (m)</td>
<td>500</td>
</tr>
<tr>
<td>Surface roughness, Ra (µm)</td>
<td>0.20</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Figure 1 presents the variety of coefficient of frictions of pure epoxy, epoxy-5, 10, 15, 20 %wt Al₂O₃ at the sliding speed of 0.3 m/s and under the loads of 5N, 10N and 15N for the composites.

![Graph showing coefficient of friction vs. Al₂O₃ content](image)

**Fig. 1** Variation of coefficient of friction with micro-alumina content under the loads of 5N, 10N and 15N at sliding speed of 0.3 m/s.

As shown from the Figure 1 that increases in the load value for 200% caused to increase of coefficient of friction about 300%, 7.2%, 6%, 12.4% and 12.8% for epoxy, epoxy+5%, 10%, 15% and 20%wt Al₂O₃ included the epoxy composites, respectively. As shown from the figure that the effect of the applied load is much more effective for the pure epoxy than that of the Al₂O₃ filled composites. An increase in the Al₂O₃ content in the polymer composite (15% and 20% Al₂O₃) resulted to increase the friction coefficient twice than the 5% and 10% Al₂O₃ included composites.
In order to predict the coefficient of friction of Al₂O₃ filled epoxy composite, contour-diagram of the coefficient of friction was constructed as a function of the filler content and applied load as shown on Figure 2. The figure can be used for two purposes. One of them is predict the coefficient of friction of the samples depending on filler content and applied load. Another is the construction of the composite for pre-determined friction coefficient. Myshkin et al. [13] explained that friction conditions affect the coefficient of friction of the polymers. Polymers as viscoelastic materials are very sensitive to frictional heating. It is well known that friction is a typical dissipative process in which mechanical energy is converted into heat. The thermal state of friction contact is frequently a decisive factor when evaluating the performance of a friction unit. Romanes et al. [14] explained that the shape and abrasiveness of the wear particles are responsible for the magnitude of the coefficient of friction value.

**Fig. 2** Contour diagram of coefficient of friction of micro-alumina filled epoxy composite depending on applied load and filler content.

The variation of the wear rate of pure epoxy and 5-20%wt. Al₂O₃ filled epoxy based composites with applied load are shown in Figure 3. Samples are tested at 0.3 m/s sliding speeds under dry sliding condition. These values were calculated from volumetric loss data.
Fig. 3 Variation of wear rate with micro-alumina content depending on applied load and filler content.

Figure 3 shows that the wear rate for pure epoxy under dry sliding conditions is in the range of $3.84 \times 10^{-4}$ and $6.01 \times 10^{-4}$ mm$^3$/m and the highest wear rate is for pure epoxy under dry sliding conditions with a value of $6.01 \times 10^{-4}$ mm$^3$/m at 0.30 m/s sliding speed and under 15 N loads. The lowest wear rate is $5.09 \times 10^{-5}$ mm$^3$/m for 20% $\text{Al}_2\text{O}_3$ filled epoxy composite at 0.30 m/s sliding speed and under the load of 5N. As shown from the Figure 3 that increase in the load value for a 200% caused to decrease of wear rate about 59%, 303%, 571%, 665% and 682% for pure epoxy and epoxy+5%, 10% 15% and 20%wt $\text{Al}_2\text{O}_3$ included the epoxy composites, respectively.

In order to predict the the wear rate of $\text{Al}_2\text{O}_3$ filled epoxy composites, contour-diagram of the wear rates was realized as a function of filler content and applied load as shown in Figure 4. The figure can be used for two purposes that either predict the wear rates of the samples depending on filler content and applied load or is the construction of the composite for pre-determined wear rate. In general, as shown from Figures 3 and 4, increase $\text{Al}_2\text{O}_3$ filler addition into the epoxy causes to increase in the wear resistance. Among the two fillers employed, alumina filler in glass epoxy composite shows better abrasion resistance under different loads/abrating distances in the study of Suresha et al. [15]. Xin et al. [16] reported that the filling of micrometer $\text{Al}_2\text{O}_3$ particles greatly increased the wear resistance of PPESK under filler volume fractions from 1 to 12.5%.
Fig. 4 Contour diagram of wear rate of micro-alumina filled epoxy composite depending on applied load and micro-alumina content.

Figure 5 (a) and (c) shows the optical micrographs of the worn scars of AISI 52100 steel balls under the loads of 15N and 10N, respectively. Figure 5 (b) and (d) shows the 15% and 20% Al₂O₃ filled epoxy composite at the 0.3m/s sliding speed under the loads of 15N and 10N, respectively. As it can be seen in Figure 5 (a) and (b), the worn surface of AISI 52100 steel balls worn against 15% and 20% Al₂O₃ filled epoxy composites are smooth and including tiny grooves. It is possible to say that, the abrasive particles scratch the surface of the steel ball and polished the steel surface with some tiny abrasive grooves. Figure 5 (b) and (d) show that epoxy composite filled with 5% and 20% Al₂O₃ includes some wrinkles and walls beside the abrasive groves. Wear tracks of the 20% Al₂O₃ filled composite includes much thinner groves but not includes any deformation. It is possible to say that the increase in the filler content caused to sustainable composite structure during the wear test. As known, increase in filler content makes polymer composite harder and resist to tribological applications.
Fig. 5 Optical micrographs of worn surfaces of (a) and (c) AISI 52100 steel ball, (b) 5% and (d) 20% Al$_2$O$_3$ filled epoxy composite, under the load of 15N.

4. CONCLUSIONS

The following conclusions can be drawn from the present study;

Coefficient of friction of epoxy and Al$_2$O$_3$ filled (5%, 10%, 15% and 20% wt.) epoxy composites worn against AISI 52100 steel ball at the sliding speed of 0.3 m/s under the loads of 5N, 10N and 15N showed that the effect of the applied load is much effective for the pure epoxy than that of the Al$_2$O$_3$ filled composites and increase in the Al$_2$O$_3$ content in the polymer composite (15% and 20% Al$_2$O$_3$) resulted to increase the friction coefficient twice than the 5% and 10% Al$_2$O$_3$ included composites. Wear rates of the samples showed that filler content increases caused an increase of wear resistance of the epoxy composites, effectively. While, epoxy and low Al$_2$O$_3$ content epoxy composites includes some wrinkles and walls beside the abrasive groves, higher Al$_2$O$_3$ content Al$_2$O$_3$ includes much thinner groves but not includes any deformation.

REFERENCES


