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Influence of Load and Speed on Sliding Tribology of Silica-Polyamide Composites against AISI 4140 Steel

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The wear behavior of polyamide (PA6) matrix composites filled with silica particles is discussed in this paper. The tribological characteristics of pure PA6 and 5, 10, 30 wt% silica (SiO_2) filled PA6 composites were comparatively evaluated under dry sliding conditions. Wear tests were carried out at room temperature under the loads of 5, 10, and 20 N and at the sliding speeds of 0.5, 1.0, and 1.5 m/s. The wear test results showed that the silica particles could improve the wear resistance and the friction coefficient of the PA6 matrix even though the content of the fillers was 5–30% by weight. The friction coefficient of the PA6 was getting decreased from 0.420 to 0.213 with an increase in silica content, depending on applied loads and sliding speeds. The results showed that the wear rates of pure PA6 and silica filled PA6 composites increase with increase in loads. The wear rate of the PA6 decreased from 4.2×10^{-6} mm^3/m to 6.0×10^{-7} mm^3/m with an increase in silica content depending on applied loads. This makes it possible to develop novel type of polyamide-based composite with improved wear resistance for various applications.

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1. Introduction

The chemical properties of polyamide (PA) depend mainly on the typical reactions of the amide groups [1]. Pure PA sliding against metal surfaces does not perform well. However, PA is an excellent low-friction and wear resistant material if used in the form of plastic composite sliding against metal surfaces. This can be observed from the few studies that are available in the literature on PA [2–7].

Several studies have shown that if pure PA is used in sliding, the transfer film is weak and patchy. This kind of transfer film can be easily removed from the counterface due to the dynamic actions of sliding. Interfacial temperature also plays its role in making the transfer layer soft and weak. With certain types of fillers in PA, it has been found that the composite makes a very thin but adherent transfer layer. This transfer layer protects the bulk of the polymer from further wear. Common fillers with advantageous effects on the wear resistance of PA are glass fiber [8], CuS, CuO, CuF_2 [9], and PTFE [10]. Antifriction bearing and oil-lubricated driving gear were made from a PA [11]. Shanmuganathan et al. investigated the effect of silicate concentration on the evolution of morphology in PA6 [12]. Inorganic particles are added to polymers in the expectation of obtaining unique physical and mechanical properties [13, 14]. Inorganic particles have been widely used in recent years as fillers in polymers to improve their hardness and tribological performance [15].

In this study, test materials have been prepared as series of filled PA6 materials with silica filler (5, 10, 30 wt%) to study the tribological effect of the filler content. The aim of this work was to study the effect of the silica on the wear and friction behavior of PA6.

2. Experimental

Three different weight percentages of silica (1–10 μm, between 5 and 30 wt%) were introduced to PA6 to investigate the wear relationships between the PA6 and silica combinations. The polymer matrix material that was used in this study is a commercial grade PA6 Arkema Polymer Industry, USA. Silica obtained from Sigma-Aldrich Chemie GmbH was used in the polymer matrix composites. For tests, the samples were manufactured in the form of a pin whose dimension is 6 mm in diameter and 60 mm in length. For production of silica filled polymers, an injection apparatus was used with four different heating stages of 240, 255, 260, 265 °C. Injection and molding pressure were chosen as 4 MPa and 8 MPa, respectively. The mold temperature was fixed at 15 °C and the pressure was applied for 3 composites. The friction and wear tests were realized using a pin-on-disk arrangement with the standards of ASTM G 99 and ASTM G 115 against the hardened AISI 4140 steel (65 HRc). Wear tests parameters are given in Table in Ref. [16]. The hardness tests were performed on Instron S1 Durotech, digital shore D scale hardness tester using the standard of ASTM D 2240.

3. Results and discussion

Figure 1a–c presents the variety of coefficient of friction and wear rate values of pure PA6 and silica filled

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polyamide composites according to silica content under the loads of 5, 10, and 20 N at the sliding speeds of 0.5, 1.0, and 1.5 m/s, respectively.

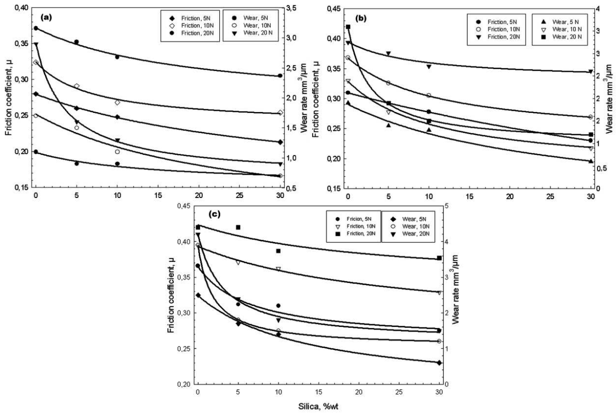

Fig. 1. Variation of coefficient of friction and wear rate values of pure PA6 and silica filled polyamide composites at the sliding speeds of (a) 0.5 m/s, (b) 1.0 m/s, and (c) 1.5 m/s.

Figure 1 reveals that a 300% increase in load value caused the increase in the coefficient of friction of PA6 and the silica filled polyamide composites in the range of 29–164%, 15–100% and 29–150% depending on the silica content for 0.5, 1.0, and 1.5 m/s sliding speeds, respectively. A 200% increase in the sliding speed caused the increase in the coefficient of friction of PA6 and the silica filled polyamide composites in the range of 14–127%, 20–129%, and 38–67% depending on the silica content for 5, 10, and 20 N, respectively. The addition of silica in the PA6 resulted in the decrease of the coefficient of friction in the range of 36–69%, 62–68%, and 64–76% according to applied loads for 0.5, 1.0, and 1.5 m/s sliding speeds, respectively. In general, as shown by the figures and calculated and discussed results, the coefficient of friction of silica filled PA6 decreased with increase in silica content for the all test conditions, and increase in the load value in the wear test caused the increase in coefficient of friction. An increase in the sliding speeds resulted in the decrease of the coefficient of friction tested under the loads of 5 N and 10 N, however, the coefficient of friction has not been affected effectively for the silica filled polyamide composites tested under the loads of 20 N for all the sliding speeds. Unal et al. [17] studied on different polymers and indicated that PA6 presented an average friction coefficient approximately between 0.35 and 0.45. Generally, higher lubricant filler contents are more advantageous to lubrication capability of the polymer matrix materials. Variation of wear rate on contour diagrams of pure PA6 and silica filled polyamide composites were given in Fig. 2.

Figure 2a–c reveals that a 300% increase in load value caused the increase in the wear rate of PA6 and the silica filled polyamide composites in the range of 33–43%, 27–50% and 15–37% depending on the silica content for 0.5,

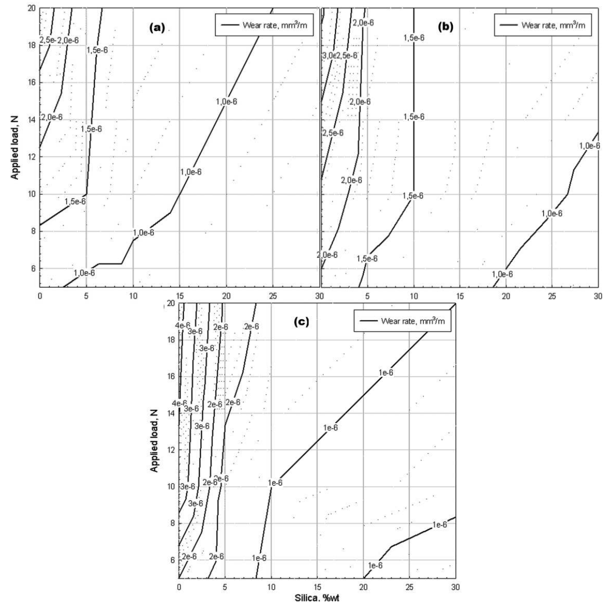

Fig. 2. Variation of wear rate on contour diagrams of pure PA6 and silica filled polyamide composites at the sliding speeds of (a) 0.5 m/s, (b) 1.0 m/s, and (c) 1.5 m/s.

1.0, and 1.5 m/s sliding speeds, respectively. A 200% increase in the sliding speed caused the increase of wear rate of PA6 and the silica filled polyamide composites in the range of 20–31%, 22–35%, and 13–24% depending on the silica content for 5, 10, and 20 N, respectively. The addition of silica in the PA6 resulted in a decrease of the wear rate in the range of 18–24%, 12–27% and 10–25% according to applied loads for 0.5, 1.0, and 1.5 m/s sliding speeds, respectively.

In general, as shown by the figures and calculated and discussed results, the wear rate of silica filled PA6 decreased with increase in silica content for the all test conditions, and increase in the load value in the wear test caused the increase in wear rate. An increase in the sliding speeds caused the increase of the wear rate tested materials under the loads of 5, 10, and 20 N. In fact, increasing the wear load can increase the wear loss as explained in the Archard composites equation [18, 19]. Increase in silica of the PA6 resulted in the increase of the polymer hardness and pressure strengths of the PA6–silica filled polyamides beside the lubricant behaviors. Shore hardnesses of the pure PA6 and 5, 10, 30 wt% silica filled PA6 composites were measured in this study as 73.58, 74.44, 76.97, and 80.96, respectively.

The optical micrographs of worn pin surfaces of 5, 10, 30 wt% silica filled PA6 at the 1.5 m/s sliding speed under the load of 10 N are given in Fig. 3a–c. As it can be seen in Fig. 3a, the worn surface of the silica filled PA6 includes some micro scratches and some grooves and valleys on the worn surfaces. In addition these, some softened zone, especially low content silica including polyamide

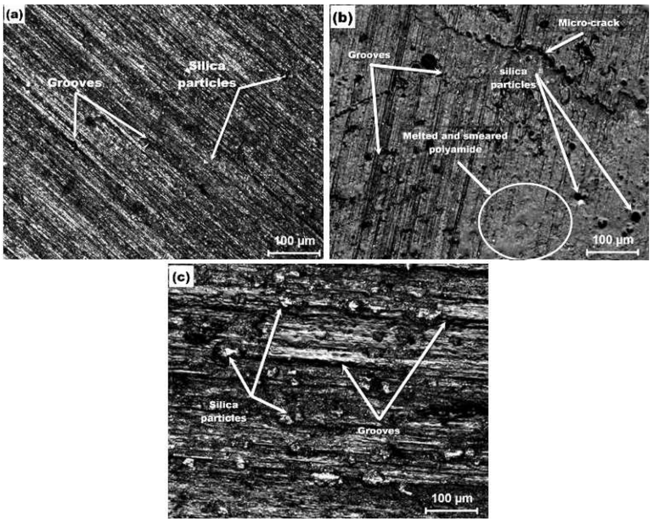

Fig. 3. Optical micrographs of worn surfaces of (a) PA6+5 wt%, and (b) PA6+10 wt% silica, (c) PA6+30 wt% silica at 1.5 m/s sliding speed under 10 N load.

composites, are shown on the wear track. Also, worn surfaces of the polyamide composites are getting roughened with an increase in silica content. It is probable that silica particles may be transferred on the steel counter face while of PA6 matrix smeared on the slick line. These particles might cause the formation of micro scratching effect during the sliding tests, and some parts of the PA6 were softened with sliding effect and smeared the worn surfaces and produced some plastically deformed and so smeared zones.

4. Conclusions

The following conclusions can be drawn from the present study.

Coefficient of friction is changing between 0.420 and 0.213 depending on SiO_2 addition and applied load. The coefficient of friction of silica filled PA6 decreased with increase in silica content for the all test conditions and increase in the sliding speeds and load values resulted in the increase of the coefficient of friction.

The wear rate of the PA6 decreased from 4.2×10^{-6} mm^3/m to 6.0×10^{-7} mm^3/m with an increase in silica content depending on applied loads. Increase in the sliding speeds caused the increase of the wear rate tested materials for all applied loads. Increase in the load value in the wear test caused the increase in wear rate.

PA6 composite filled with 5% SiO_2, 10% SiO_2 and 30% SiO_2 includes some wrinkles, smeared and softened zones beside the abrasive grooves. In addition these, some softened zones are shown especially 10% silica including polyamide composites. Wear tracks of the 30% SiO_2 filled composite shows much roughened surface according to low silica content.

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