

Mechanical and Tribological Properties of PA66/PPS Blend. III. Reinforced with GF

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ABSTRACT: Based on previous work, 70 vol % PA66/30 vol % PPS blend was selected as a matrix, and the PA66/PPS blend reinforced with different content of glass fiber (GF) was prepared in this study. The mechanical properties of PA66/PPS/GF composites were studied, and the tribological behaviors were tested on block-on-ring sliding wear tester. The results showed that 20–30 vol % GF greatly increases the mechanical properties of PA66/PPS blend. When GF content is 20 vol %, the friction coefficient of composite is the lowest (0.35), which is decreased by 47% in comparison with the unfilled blend. The wear volume of the GF-reinforced PA66/PPS blend composite decreases with the increase of GF content. However, the wear-resistance is not apparently improved by the addition of GF in the experimental range for comparison with unfilled PA66/PPS blend. The worn surface and the transfer film on the coun-

terface were examined by scanning electron microscopy (SEM). The observations revealed that the friction coefficient of composite depends on the formation and development of a transfer film. The wear mechanism involves polymer matrix wear and fiber wear. The former consists of melting wear and plastic deformation of the matrix, while the latter includes fiber sliding wear, cracking, rupturing, and pulverizing. The contributions of the matrix wear and the fiber wear determine the ultimate wear volume of PA66/PPS/GF composite. In addition, the abrasive action caused by the ruptured glass fiber is also a very important factor. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 102: 523–529, 2006

Key words: polyamide66 (PA66)/polyphenylene sulfide (PPS) blend; glass fiber; composite; friction; wear; surface

INTRODUCTION

Polymeric materials have been replacing metallic materials used as friction and wear parts for many years. It is often found that, however, the unmodified homopolymer could not satisfy the demands arising from the situations where a combination of good mechanical and tribological properties is required. Polymer blending is a fascinating method for polymer modification because it has simple processing and unfolds unlimited possibilities of producing materials with variable properties. Some researchers studied the tribological properties of polymer blends and pointed out that the friction and wear properties varied continuously with the compositions for most polymer blends and the optimal properties were obtained at a certain composition, although some data reported were conflicting.^{1–8} Unfortunately, the studies on the

tribological properties of polymer blends are very limited.

The addition of fillers, including internal lubricants, inorganic powders, and reinforcing fibers, is another important and effective method for improving tribological properties of polymers.^{9–14} Among them, a great attention was given to the fibrous fillers because of its combination of wear-resistance with excellent mechanical properties of resultant polymer composites. To the best of our knowledge, however, the existing studies are focused on the tribological properties of fiber-filled homopolymers, a very few publications dealing with the polymer blend composites reinforced with fibers can be searched out.

On the basis of this current status of studies on the polymer tribology, in earlier works,^{15–17} the authors selected PA66, PPS, and HDPE as matrices, systematically studied the tribological properties of PA66/PPS and PA66/HDPE blends. It was found that the friction and wear of polymer blend are governed by the component having lower and higher melting (softening) point, respectively; the thermal control of friction regime is applicable to the blend under severe conditions. The addition of PTFE greatly decreased the friction coefficient and wear volume of PA66/PPS blend, but impaired the mechanical properties.¹⁸ To evaluate the possibility of further improving the tribological

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TABLE I
Data of the Materials Used in This Study

Material	Form	Trademark	Manufacturer	Density (g/cm ³)	Melting point (°C)
PA66	Pellet	Zytel® 101L NC010	Du Pont Co. Ltd.	1.14	262
PPS	Powder	Ryton® P-4	Chevron Phillips Chem. Co.	1.35	285
GF	Fiber	–	DanYang Glass Fiber Product Factory	2.50	>1,000

properties of PA66/PPS blend and elucidate the friction and wear mechanisms of fiber-reinforced polymer blend composite, in the present work, the authors studied the mechanical and tribological properties of PA66/PPS/glass fiber (GF) composite and discussed the friction and wear mechanisms through SEM analysis.

EXPERIMENTAL

Materials

The data of PA66 pellets, PPS powders, and glass fibers (GF) used in this study are listed in Table I. The average diameter of PPS powders is in the range of 30–50 μm ; the median particle size is 25 μm . GF was treated with coupling agent (silicon alkyl), length: 3 ± 0.5 mm, diameter of single fiber: 13 ± 2 μm .

Sample preparation

In prior work,¹⁵ the authors found that 70 vol % PA66/30 vol % PPS blend with better mechanical properties exhibits lower friction coefficient and the highest wear resistance. Therefore, the same blend system was selected as a matrix blending with different content of glass fiber (5–30 vol %) to study the mechanical and tribological properties of PA66/PPS/GF composites.

To obtain a sufficient homogeneity, two-step processing method was employed to prepare sample. In the first step, the PPS powders and glass fibers were dispersed in water, vigorously stirred, filtered, and then dried under reduced pressure at 100°C for 24 h to remove residual water. The received PPS/GF mixtures were then preblended using a HAAKE PTW16/25D corotating twin-screw extruder. The diameter of the die is 3 mm. The temperatures from the feed zone to the die of the extruder were 265, 275, 285, 295, and 285°C, respectively. The screw speed was set at 70 rpm. The extrudate was obtained in the form of a cylindrical rod that was quenched in cold water and then pelletized.

In the second step, PA66 pellets were blended with extruded PPS/GF pellets using the same extruder and followed the same procedure. Before compounding, PA66 and preblended PPS/GF pellets were dried at 100°C in vacuum oven for 24 h.

The specimens for mechanical and tribological tests were injection molded from the blended materials using a SZ-20 reciprocating screw injection-molding machine equipped with a standard test mold. The temperatures maintained in the two zones of the barrel were 280 °C and 300°C, and in the mold 25°C. After polishing with abrasive and metallographic abrasive paper, the topographies of the sample surfaces to be tested for tribological properties are shown in Figure 1. It can be seen that the fibrous fillers oriented slightly along with the injection molding direction resulting from the shear force of the melting flow.

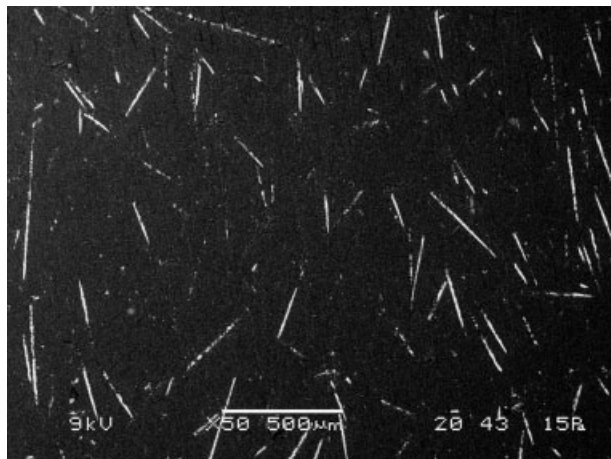
Measurements of mechanical and tribological properties

The tests of tensile strength, flexural strength, impact strength, and Rockwell hardness (HRM) were carried out according to GB/T 16,421–1996, GB/T 16,419–1996, GB/T 16,420–1996, and GB/T 9342–88, respectively, and the error of the data is within 5%.

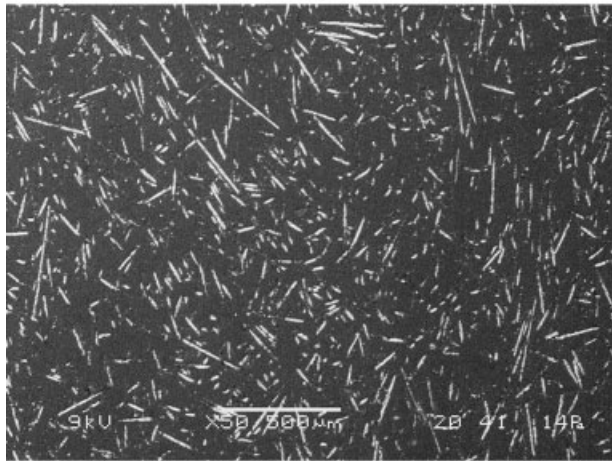
The friction and wear tests were conducted on an M-200 friction and wear tester according to GB 3960–83 standard test method under ambient conditions (temperature: 20 ± 3 °C, humidity: 50 ± 10 %). Block-on-ring contact configuration was employed, as shown in Figure 2. The normal load was 196 N, sliding speed was 0.42 m/s, surface roughness of polymer block and steel ring was R_a 0.17–0.23 μm and R_a 0.09–0.11 μm , respectively. The test durations ranged from 0 to 130 min and the values of friction torque were noted after 10 min and later at intervals of 20 min. The friction coefficient of sample was derived from the friction force torque, and the wear volume was calculated from the following formula¹⁹:

$$V = B \left[\frac{\pi r^2}{180} \arcsin \left(\frac{b}{2r} \right) - \frac{b}{2} \sqrt{r^2 - \frac{b^2}{4}} \right] \quad (1)$$

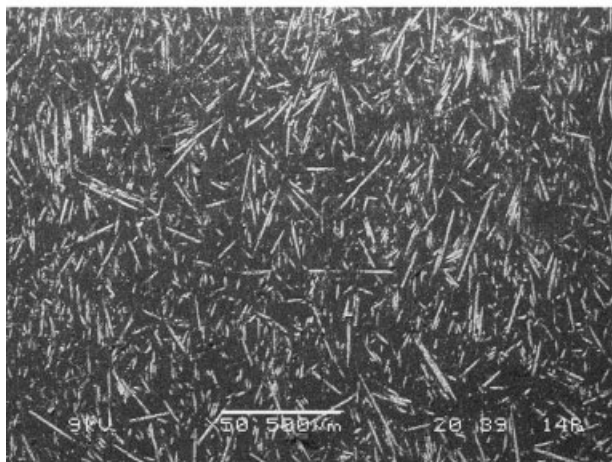
where V is the wear volume (mm^3); B the width of the specimen (mm); r the radius of the steel ring (mm); and b the width of the wear scar (mm) (measured by measuring microscope). In this work, three replicates of friction and wear tests were carried out. Experimental details can be referred to Ref.15.



(a)



(b)



(c)

Figure 1 SEM micrographs of sample surfaces of PA66/PPS blends reinforced with different content of GF. Arrow indicates injection molding direction. (a) 5 vol % GF; (b) 20 vol % GF; (c) 30 vol % GF.

Surface analysis

The worn surface of the sample and the steel ring surface (transfer film) were observed by scanning elec-

tron microscopy (SEM, JSM-5600LV). The polymer block was sputter-coated with a gold palladium alloy before viewing under the microscope.

RESULTS AND DISCUSSIONS

Mechanical properties

The mechanical properties of PA66/PPS blend filled with different content of GF are given in Figure 3. From this figure, it can be seen that the loading of GF greatly increased the tensile strength, flexural strength, and hardness of PA66/PPS blend, which can be attributed to the high strength and hardness of the glass fibers. However, because of the lower toughness, the addition of GF decreased the impact strength of the blend. When GF content changed from 20 to 30 vol %, the effect of GF on the mechanical properties became inapparent, the increase percentage of tensile strength and hardness is less than 2%, and the flexural and impact strength decreased to a certain extent, indicating that the compatibility between the polymer matrix and the GF became poor when the GF content is exceeding. In the experimental range, the best mechanical properties were obtained with the composite with 20–30 vol % GF.

Friction and wear

The friction coefficient and wear volume of GF-reinforced PA66/PPS blend are presented in Figure 4. This figure shows that, as the GF content increases, the friction coefficient of sample gradually decreases and reaches minimum (0.35) at 20 vol % of GF. Further increasing GF concentration (30 vol %) leads to the rise of friction coefficient to 0.49. For wear property, a general trend that the wear volume of composite decreases with the increase of GF content can be seen, although it seems that the addition of GF does not improve the wear resistance of unfilled PA66/PPS blend. When GF is 30 vol %, the minimum wear volume (6.04 mm^3) is reached.

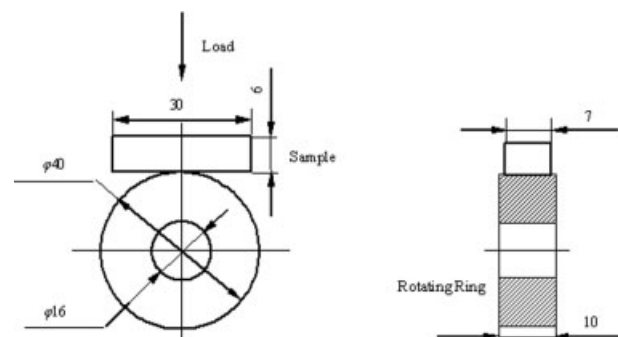


Figure 2 Contact scheme of the frictional pairs (in mm).

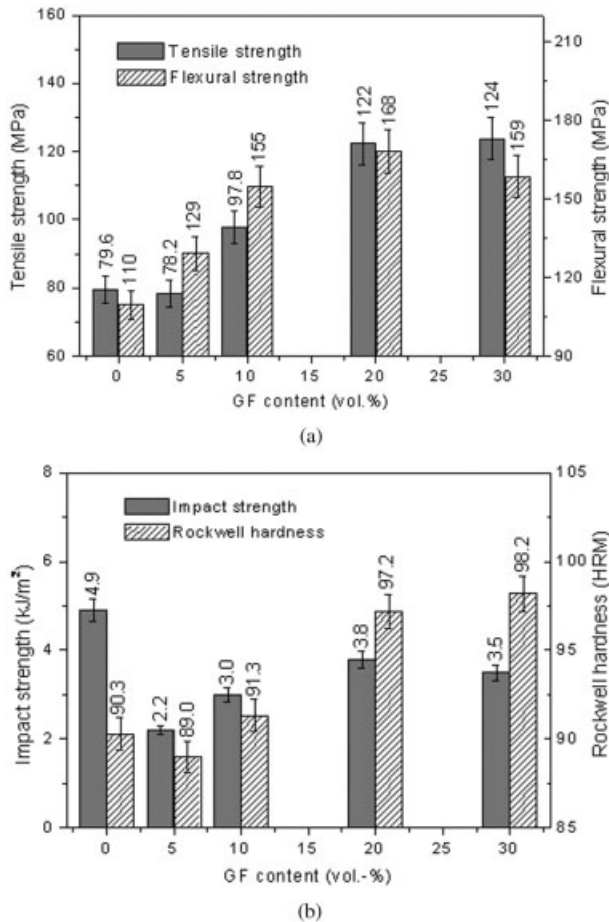


Figure 3 Mechanical properties of PA66/PPS/GF composite. (a) Tensile and flexural strength; (b) impact strength and hardness.

Surface analysis

To ascertain the friction and wear mechanisms of PA66/PPS blend reinforced with glass fiber, the worn surface and the transfer film formed by the samples on the steel surface during sliding were observed using SEM, and the micrographs are given in Figures 5–7.

Figure 5(a) shows that some deeper furrows with various width presented at the worn surface of PA66/PPS/5 vol % GF composite. At higher magnification, a melting of PA66/PPS matrix can be observed [right-hand, Fig. 5(a)] because of the accumulation of frictional heat during sliding. When GF content is lower, the composite formed a belt-like and nonuniform transfer film [Fig. 5(b)] parallel to the sliding direction, which is similar with the unfilled PA66/PPS blend.¹⁵ However, apparently different phenomenon for the composite is that, a lot of GF embedded in the dark transfer film, which is surrounded by the melted blend matrix, and the length is less than 50 μm . This length is much shorter than that of unrubbed sample [Fig. 1(a)], indicating that the glass fiber was fractured during sliding under the frictional shear and normal load.

The SEM micrographs shown in Figure 6 are the typical features of the worn surface and the transfer film formed by PA66/PPS/20 vol % GF composite. Comparing with PA66/PPS/5 vol % GF composite [Fig. 5(a)], one can observe that the fraction of exposed GF at frictional surface of the sample is much more and no clear furrows at the worn surface is detected. The SEM investigation of the worn surface at higher magnification shows some of detailed features characterizing the wear of the composite [right-hand, Fig. 6(a)]. The wear of the composite can be divided into two aspects: polymer matrix wear and glass fiber wear. The polymer matrix wear is indicated by the letter (A). The fiber wear includes fiber sliding wear (B), fiber cracking (C), and fiber fracturing (D). In addition, fiber/matrix debonding at interface is also a nonnegligible wear mechanism (E). The arrow indicates that the pulverized fibers resulting from the fiber wear filled in the grooves formed by the separation of fiber from matrix during sliding.

A very interesting phenomenon was observed for the steel ring surface, as shown in Figure 6(b). A uniform and continuous transfer film was formed, in which pulverized and ruptured fibers with length of about 20 μm oriented parallel to the sliding direction were embedded.

From Figure 6 we cannot find any matrix melting traces such as shown in Figure 5, this could be attributed in part to the improvement of heat-resistance of composite upon addition of relatively higher fiber volume fraction.²⁰ The supporting normal load provided by the GF during sliding is another important factor, which will be discussed in the next section.

The SEM micrographs of the worn surface and the transfer film formed by PA66/PPS/30 vol % GF composite are given in Figure 7. The worn surface is almost completely covered by exposed GF and a great amount of pulverized fibers can be observed at higher magnification [Fig. 7(a)]. However, except for the

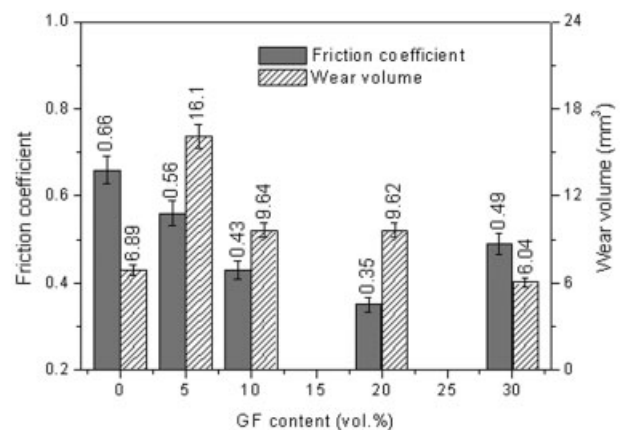


Figure 4 Variation in friction coefficient and wear volume of PA66/PPS/GF composite with GF content.

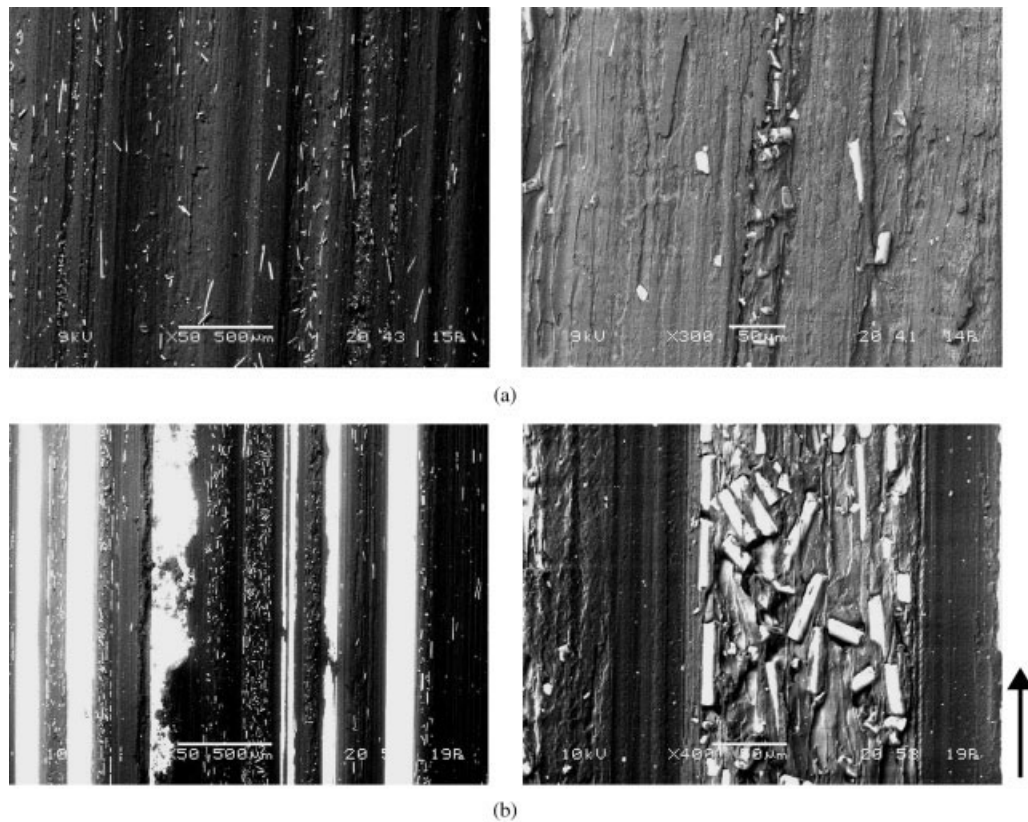


Figure 5 SEM micrographs of the worn surface and the transfer film formed by PA66/PPS/5 vol % GF composite. Arrow indicates sliding direction. (a) Worn surface; (b) transfer film.

worn fibers, no ruptured single fibers such as shown in Figures 5 and 6 are present at the frictional surface. Another difference is given by the SEM micrographs of the counterface [Fig. 7(b)]. From this figure, it can be seen that the PA66/PPS blend filled with 30 vol % GF does not form a transfer film, the scratch action between the counterpart and GF during sliding leads to the formation of scratch texture on the counterface parallel to the sliding direction.

DISCUSSIONS

Although some studies focused on the wear-resistance of fiber-filled homopolymers,^{13,14} a very little attention has been given to the friction and wear properties and mechanisms of polymer blend reinforced with fibrous fillers. In this study, the authors studied the friction and wear of GF-filled PA66/PPS blend composite, and some interesting results were obtained.

It is now well-known that the friction and wear behaviors of a polymer sliding against a metal are strongly influenced by its ability to form a transfer film on the counterface.^{21–23} A thin, uniform, and continuous transfer film is favorable for reducing friction coefficient. It was found in this study that the transfer film also plays a very important role in affecting the friction behavior of fiber-reinforced polymer blend

composite. Comparing the SEM micrographs of the transfer films formed by PA66/PPS blends reinforced with different content of GF (Figs. 5–7), we can see that the ability of sample to form a transfer film on a metal closely related to the GF concentration. When GF content is lower (5 vol %), composite formed a belt-like and discontinuous transfer film. As GF content increases, the ability of sample to form a transfer film became stranger, and the PA66/PPS blend with 20 vol % GF forms a uniform and continuous transfer film on the counterface. However, excessive GF content (30 vol %) has an adverse effect on the formation of a transfer film; no transferred layer was observed at the counterface. The variation in friction coefficient with GF content shows the trend of decrease at the beginning and increase later, which corresponds to the changes of topographies of the transfer films. At 20 vol % of GF concentration, sample reaches minimum friction coefficient (0.35), which is decreased by 47% compared with unfilled PA66/PPS blend. During sliding, the transfer film decreases the adhesion between polymer and metal, impairs the plowing action of metal asperities at counterface over the soft polymer surface. On the other hand, once the transfer film is formed, subsequent interaction occurs between the polymer and a layer of similar material. As the polymer is a self-lubricant material,^{22–24} so that the friction coeffi-

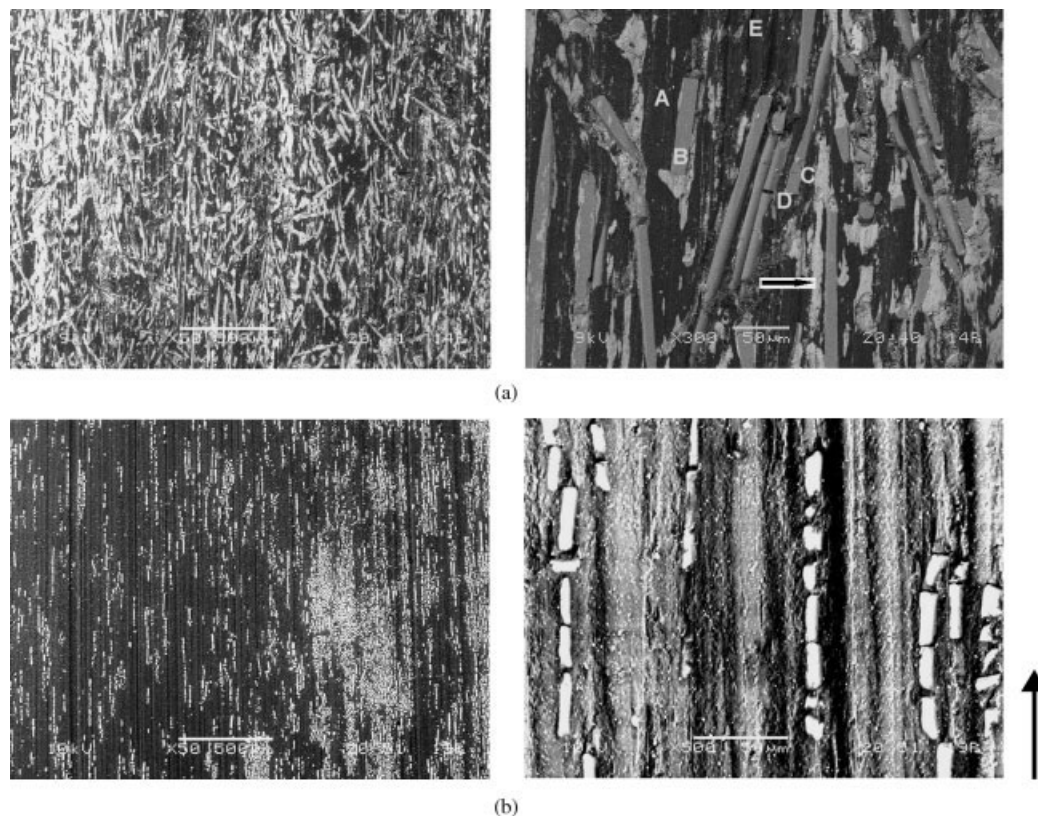


Figure 6 SEM micrographs of the worn surface and the transfer film formed by PA66/PPS/20 vol % GF composite. Arrow indicates sliding direction. (a) Worn surface; (b) transfer film.

cient of PA66/PPS/GF composite is closely related to the formation and development of a transfer film.

The wear of GF-filled PA66/PPS blend consists of two wear modes: polymer matrix wear, which includes matrix melting and matrix plastic deformation; and fiber wear, which involves fiber sliding wear, fiber cracking, fiber rupturing, and fiber pulverizing. The ultimate wear properties of PA66/PPS/GF composite depend on the contributions of these factors.

When GF content is lower (5 vol %), the matrix wear is prominent, and the matrix melting occurs during sliding [Fig. 5(a)]. Under the action of frictional force and normal load, GF ruptured to the length of about 50 μm , which were surrounded by the polymer matrix. These small broken fibers embedded in the transfer film act as abrasives during sliding. The melting wear of the polymer matrix and the abrasive wear of ruptured fibers lead to the highest wear volume of PA66/PPS/5 vol % GF composite (16.1 mm^3).

The contributions of the matrix and the fibers to the wear behavior vary with the increase of GF content. For the PA66/PPS blend containing 20 vol % GF, the melting phenomenon of the polymer matrix can hardly be seen from the SEM micrographs [Fig. 6(a)], the plastic deformation of the exposed matrix surface is the major wear mode. At this composition, the presence of the fibers greatly improves the wear-resis-

tance of sample. First, fiber raises the heat-resistance of PA66/PPS blend and inhibits the development of melting wear.²⁰ Second, fiber exposed at sliding surface supports part of the applied load, which reduces the penetration of the steel asperity tips into the polymer surface, so that the microcutting and/or microplowing actions are impaired.²⁴ Third, the wear of the glass fibers is much lower than that of the polymer matrix under sliding conditions. Therefore, the wear volume of PA66/PPS/20 vol % GF composite is lower than that of unfilled blend and blend containing 5 vol % GF.

Further increasing GF concentration to 30 vol % leads to an even lower wear volume (6.04 mm^3). Figure 7(a) shows that the worn surface of the sample is almost completely covered by GF. In other words, here, the fiber governs the wear behavior of the composite. Because the glass fibers possess higher mechanical properties, superior hardness, and excellent heat-resistance, a better wear resistance is obtained.

Although the wear volume of the PA66/PPS/GF composite decreases with increasing GF content, the loading of GF does not apparently improve the wear resistance of PA66/PPS blend. This can be attributed to the fragility and the poor antifatigue properties of the glass fiber. When sliding against a metal, the ruptured and/or pulverized fibers act as abrasives, which

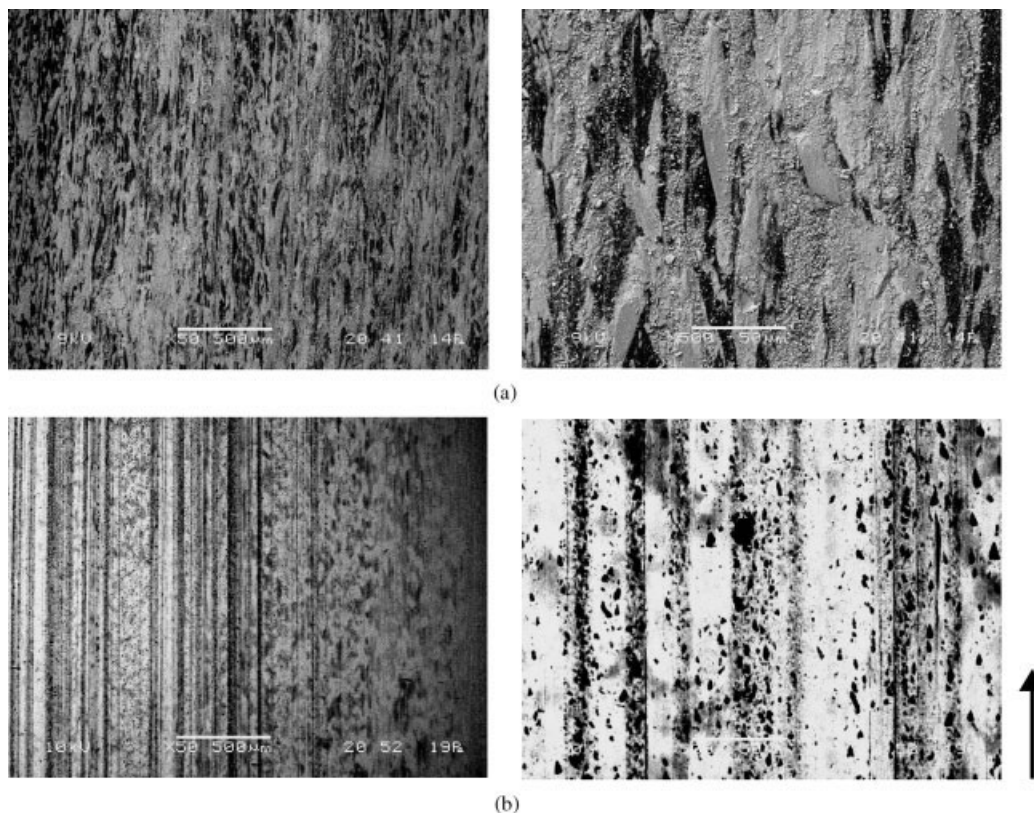


Figure 7 SEM micrographs of the worn surface and the transfer film formed by PA66/PPS/30 vol % GF composite. Arrow indicates sliding direction. (a) Worn surface; (b) transfer film.

leads to the occurrence of abrasive wear and give a negative effect on the wear properties of composite.

CONCLUSIONS

The addition of 20–30 vol % glass fiber greatly increases the mechanical properties of PA66/PPS blend. The lowest friction coefficient (0.35) is obtained for the PA66/PPS blend containing 20 vol % GF. The formation and development of a transfer film on the counterface during sliding govern the friction coefficient of fiber-reinforced PA66/PPS blend. The wear volume of PA66/PPS/GF composite depends on the contributions of polymer matrix wear (melting wear and plastic deformation) and fiber wear (fiber sliding wear, fiber cracking, fiber rupturing, and fiber pulverizing).

All the tests and characterizations were conducted at Shanghai R&D Center for Polymeric Materials.

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