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The Effect of PA6 Content on the Mechanical and Tribological Properties of PA6 Reinforced PTFE Composites

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Polytetrafluoroethylene (PTFE)/PA6 blends of different compositions, where PTFE acts as the polymer matrix and PA6 as the dispersed phase, were produced in a corotating twin-screw extruder. The effects of PA6 content on mechanical and tribological properties of the composites were investigated. The worn surface morphologies of neat PTFE and its composites were examined by scanning electron microscopy (SEM) and the wear mechanisms were discussed. The presence of PA6 particles dispersed in the PTFE continuous phase exhibited superior tribological characteristics to unfilled PTFE. The optimum value of wear reduction was obtained when the content of PA6 is 30 vol.%.

Keywords composition, tribological properties, worn

1. Introduction

Fillers, in the form of particulates and fibers, are often added to polymeric materials to improve their stiffness and strength. This second phase filler material will influence the mechanical properties and tribological properties of the composite material (Ref 1). Polytetrafluoroethylene (PTFE) possesses some extraordinary characteristics such as very low friction coefficient, good stability at high temperature, and chemical stability (Ref 2). However, its application has been greatly limited due to its poor mechanical properties and low resistance to creep. In order to obtain better friction and wear properties, PTFE is usually reinforced and modified by other reinforcements (Ref 3, 4). PA6-reinforced polymeric materials are widely used as structural materials in many engineering applications. Because they offer several advantages, such as ease of processing, the possibility of obtaining complex shapes, higher strength/density ratio, and recycling, PA6-reinforced thermoplastics are of great commercial and scientific interest (Ref 5).

Under controlled testing, a given phase shows a specific wear mode and wear rate, which is determined by its individual properties. Consequently, when various phases are combined to form a multiphase material, it is expected that the overall performance will be a function of the respective contribution of each phase (Ref 6-9). Nevertheless, the influence of the structure of composites on abrasive wear is a complex function of the properties and interactions of the matrix, the reinforcing constituent, and the interface between them, and experimentally it is found that fillers can either enhance or degrade the wear resistance of polymeric composites (Ref 10-12).

In this study, we aimed to prepare PA6/PTFE blends with different contents of PA6 by twin-screw extrusion. The purpose of this article is to clarify the tribological behavior of PA6-reinforced PTFE composites sliding against CGr15 ball under dry sliding condition, so as to provide some practical guidance for the use of these kinds of composites under dry sliding condition. The effects of filler content on the mechanical and tribological properties were also comparatively discussed, and the wear mechanisms of the composites were discussed based on the SEM examination of the worn surfaces.

2. Experimental

2.1 Materials and Specimens

The reinforcement was Polyamide-6 supplied by YueYang Juli Engineering Plastic Co. Hunan with the following specified properties: tensile strength, 85 MPa; flexural strength, 115 MPa; density, 1150 kg/m^3. PTFE powder supplied by xstar company with a grit size about 30.0 μm was used as matrix resin of the composites.

2.2 Preparation Process

The 0, 10, 20, 30, and 40 vol.% PA6-containing blends were prepared by the twin-screw extruder. The extrudate was chopped into small pellets. The produced PA6/PTFE pellets were vacuum dried further at 80 °C for 12 h. The twin-screw extruder was operated at the same processing conditions as those used during the blend preparation. The specimens for the mechanical characterization experiments were molded by using an injection-molding machine. The injection molding technique is shown in Table 1.

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Table 1 The injection molding technique

Charging barrel, °C						
Discharge jet	Leading portion	Intermediate section	Posterior segment	Mold temperature, °C	Injection pressure, MPa	Molding cyclic, s
365	360	355	340	120-150	150-200	20-50

2.3 Tensile Tests

The PA6/PTFE composites were cut into narrow-waisted dumbbell-shaped specimens in accordance with the Chinese standard GB/T1040-1992. The Erichsen tests were carried out on a computer-controlled Universal Testing Machine (made in China) at room temperature. The beam rate was 5 mm/min. For a more accurate determination of the material parameters and consideration of the possible scatter in the experimental data, the measurements were made at five constant loads for five specimens in tension. The obtained quantities were then averaged. Fractured surfaces were coated with gold to provide conductive surfaces.

2.4 Friction and Wear Tests

Friction and wear tests were done using a ball-on-block reciprocating UMT-2MT tribometer at room temperature with a relative humidity of 30-45%. The specimens were polished using a 400 grit SiC paper and cleaned ultrasonically with acetone and dried before testing. The reciprocating friction stroke was 5 mm, and tests were conducted at a normal spring-driven load. Five tests were conducted under each test condition, and the average values of measured friction coefficient and wear volume were used for further analysis.

3. Results and Discussion

3.1 Tensile Properties

The tensile properties of PA6/PTFE blend with different contents are detailed in Fig. 1. It is obvious that the tensile properties of pure PTFE were inferior to PA6/PTFE. After adding PA6, the mechanical properties were greatly improved. With the increase of the content of PA6, the tensile properties of PA6/PTFE blends increased. When the composition ratio of PA6 is larger than 40 vol.%, the tensile bending strength decreased greatly. Hence, there is an optimum PA6 content for compatibilization effect in this experiment; when the composition ratio of PA6/PTFE blend is 30 vol.%, the blend has the optimal tensile properties.

3.2 Friction and Wear Properties

The variations of friction coefficient of neat PTFE and PA6/PTFE composite are shown in Fig. 2 and 3. It is seen in Fig. 2 that the friction coefficients of all the filled PTFE composites and neat PTFE increase as the load increases from 6 N to 15 N under the same reciprocating sliding frequency 4 HZ. The friction coefficient decreases as the reciprocating sliding frequency increases from 1 HZ to 12 HZ under the same load 9 N (Fig. 3). The composite exhibits better friction behavior since the reinforcing of PA6 can reduce effectively the adhesion force and the plow. Moreover, 30 vol.% PA6/PTFE composite

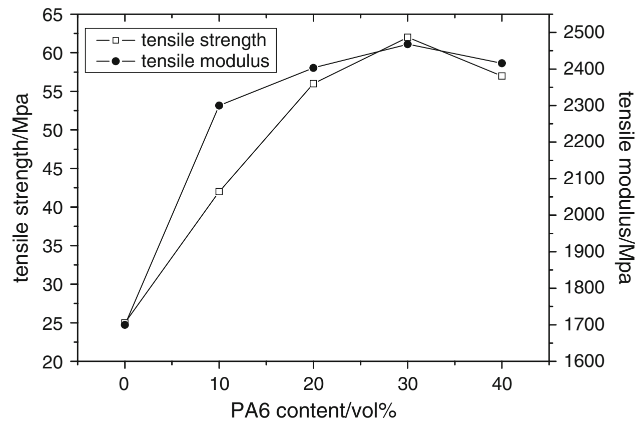

Fig. 1 The tensile properties of PA6/PTFE composites

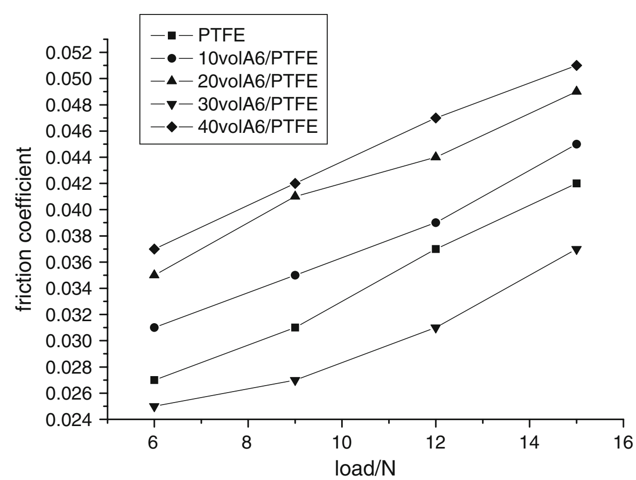

Fig. 2 Variations of friction coefficient with load (reciprocating sliding frequency: 4 Hz)

exhibits the lowest friction coefficient. The addition of the PA6 strengthened the combination of the interface between the reinforcements and the PTFE matrix and increased the elastic modulus of the PTFE composites. As a hard phase in the soft polymer matrix, PA6 can reduce the true contact area with the counterbody under certain load. As a result, it exhibits an important influence on reducing the plow and the adhesion between the relative sliding parts. Filled with a lower content of PA6, the composite exhibits higher friction coefficient compared with pure PTFE, and so the higher friction coefficients in these cases appear to be derived from the activation of fracture in the interface of reinforcing PA6 and PTFE matrix as interfacial energy dissipation mechanism during the sliding process. While for PTFE composite filled with higher PA6 content, the lower coefficients of the friction compared with pure PTFE may result from the smooth role played by PA6.

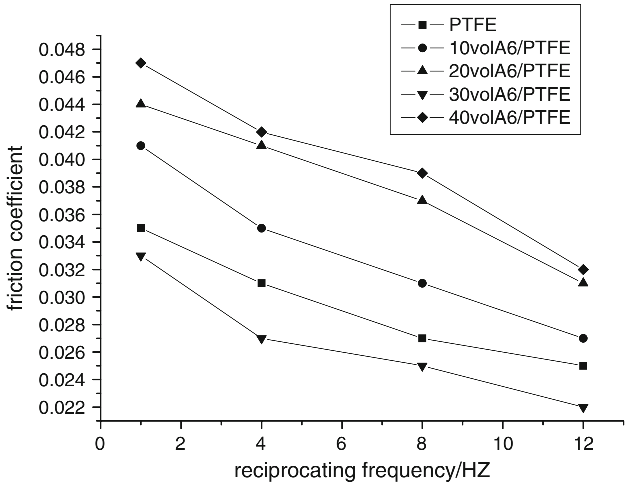

Fig. 3 Variations of friction coefficient with reciprocating sliding frequency (load: 9 N)

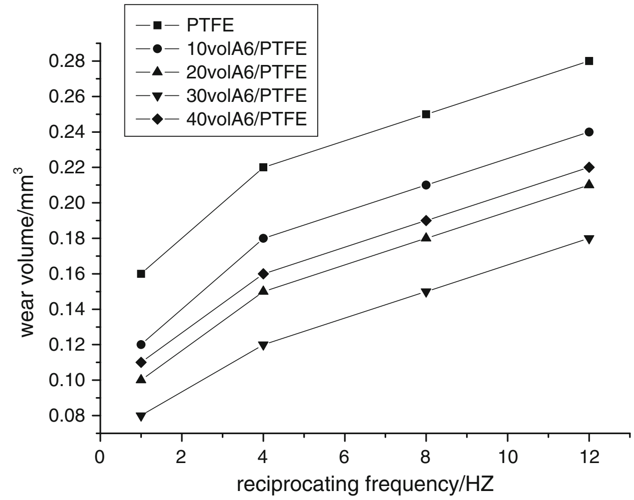

Fig. 5 Variations of volumetric wear with reciprocating sliding frequency (load: 9 N)

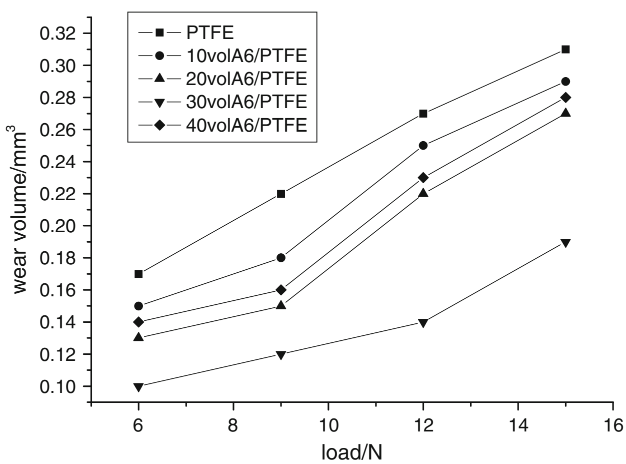

Fig. 4 Variations of volumetric wear with load (reciprocating sliding frequency: 4 HZ)

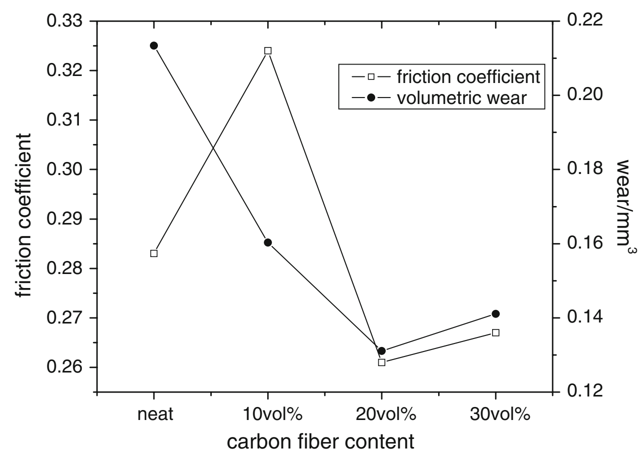

Fig. 6 Influence of carbon content on tribological property of CF/PA6 composites

Figure 4 shows the volumetric wear of unfilled PTFE, and of the PA6/PTFE composite as a function of the load applied. In general, the volumetric wear for unfilled and all the filled PTFE composites increased with increasing applied load, but they exhibit different relationships between volumetric wear and load. It can be seen from Fig. 4 that the addition of PA6 can improve the wear resistance of the PTFE composites, and 30 vol.% PA6-reinforced PTFE composite exhibits the lowest volumetric wear. The unfilled PTFE composite showed, in general, the highest volumetric wear of all the specimens tested under the same sliding condition. In addition, the high percentage (40 vol.%) of fillers in composite degraded the wear resistance of the PA6/PTFE because the fillers themselves caused stress concentrations in the matrix.

Figure 5 also shows clearly that in most test conditions, 30 vol.% PA6-reinforced PTFE composite exhibits the lowest volumetric wear, while neat PTFE shows the highest. The increase of reciprocating sliding frequency provokes evident varieties of volumetric wear.

Some frictional work was required to drag or to dig the PA6 off the matrix since the PA6 were limited by the PTFE matrix. These help to reduce material adhesion to the disc surface and bulk temperature of the wear surface. Hence, the addition of some certain PA6 can improve the wear resistance of the PTFE composites. As the wear-reducing mechanism of reinforcement, the PA6 can support a great portion of the applied load to reduce the direct interaction between polymer and counterface. However, when the PA6 content was over a certain concentration, the wear resistance was, in turn, reduced because the PA6 would get easily cracked or even dragged due to the lower continuity of the PTFE matrix and poor harmonization of deformation of the reinforcements with the matrix under the alternative interaction of the asperities of the counterface during sliding. Moreover, stress concentration easily occurs at the interface due to inhomogeneous plastic deformation between reinforcement and matrix and provides preferential sites for stress concentration. The composite that contained a higher reinforcement fraction may produce more abrasion debris, which contributes negatively to the wear resistance. The stress concentration sites increased with the PA6 content. The tribological properties of PA6 composite with carbon fiber are shown in Fig. 6.

3.3 SEM Studies on Worn Surfaces

The worn surfaces of the neat PTFE and PA6/PTFE composite under the same load and reciprocating sliding frequency are shown in Fig. 7. In the case of unfilled PTFE (Fig. 7a), the peeling of PTFE was observed. The matrix material exhibited very poor wear resistance in wear tests as it was removed. A topography like this is conducive to abrasion of the soft polymer material, and so the volumetric wear would be high.

Large quantities of worn matrix material as seen here were not observed as seen in Fig. 7(b) through (e). As the likelihood of abrasion in this case decreased markedly, wear was also reduced compared to that of the unfilled PTFE. The worn surface of the 10 vol.% PA6/PTFE sample is shown in Fig. 7(b). Microcracks were observed at the surface either at the reinforcement-matrix boundary or at weak spots in the matrix and eventually led to delamination of the matrix

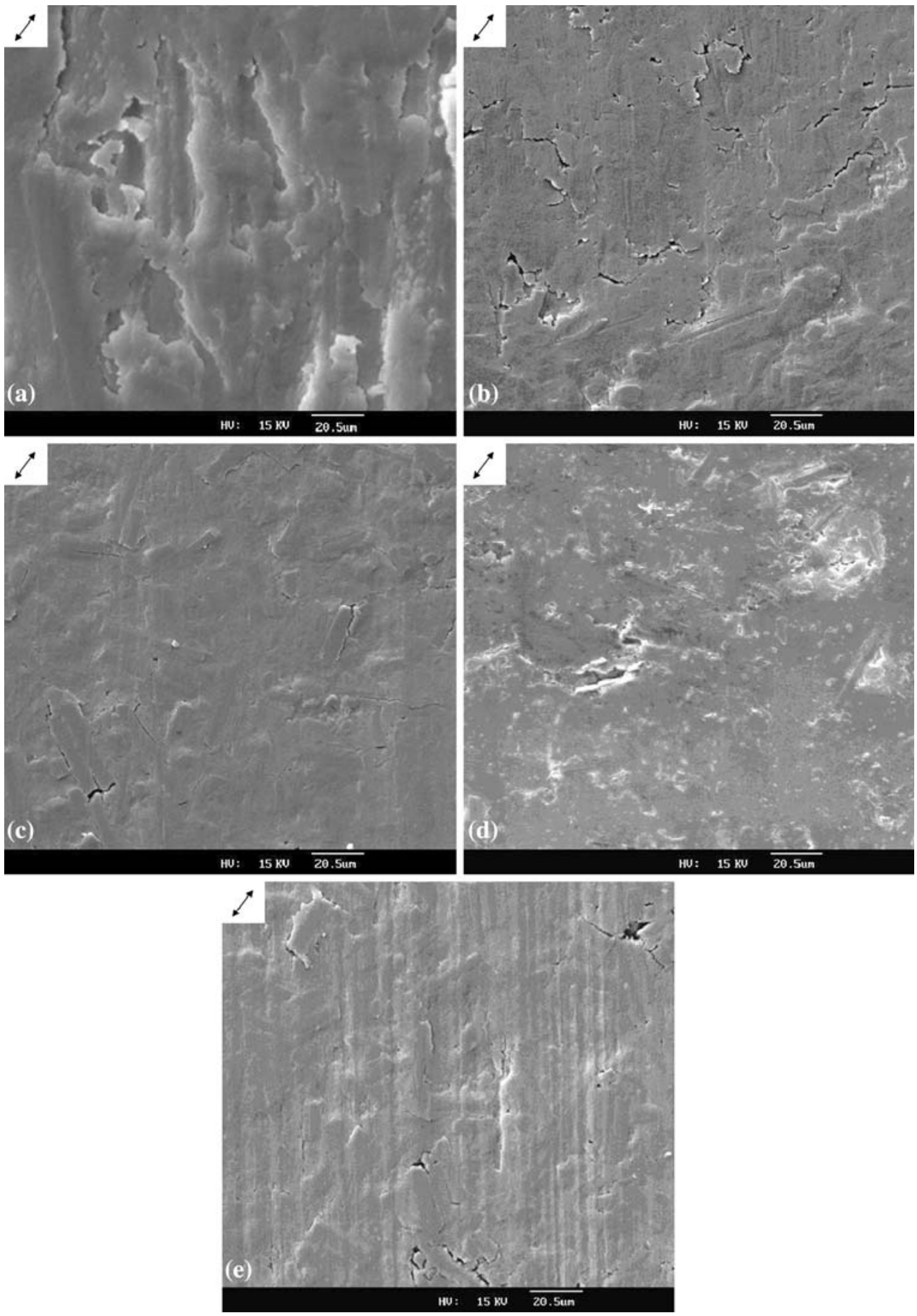

Fig. 7 SEM morphologies of the worn surface of neat PTFE and PA6/PTFE composites at a load of 9 N and a reciprocating sliding frequency of 4 HZ: (a) neat PTFE; (b) 10 vol.% PA6/PTFE composite; (c) 20 vol.% PA6/PTFE composite; (d) 30 vol.% PA6/PTFE composite; and (e) 40 vol.% PA6/PTFE composite

material. Low content of PA6 can not support the load from the counter body sufficiently. This means that the matrix far away from the PA6 has the same wear mechanism as that with neat PTFE.

Figure 7(e) shows some cracks in the matrix, normal to the sliding direction, which formed after neighboring fillers had been detached. This would give rise to a high volume loss of matrix. Microcracking and subsequent spalling of material is an important wear mode for high content-filled polymeric materials. Probably, a crack follows the reinforcement-matrix interface and passes between the reinforcements at their closest distance. The crack propagates under the original surface matrix layer and causes fragments of the matrix to be broken off. The driving force for the crack comes from the friction forces being applied on the matrix surface. Figure 7(d) also shows that reinforcements were fractured into fragments and many small filler particles were detached from the matrix material leaving cavities in the matrix. These cavities were themselves sites of stress concentrations and resulted in more cracks in the matrix and a higher volumetric wear.

4. Conclusions

1. The incorporation of PA6 into PTFE improved the tensile properties of PA6/PTFE blends. Moreover, the friction and wear properties of the materials were improved with the addition of PA6 reinforcement. The optimum PA6 content was obtained at 30 vol.%.
2. The friction coefficient of neat PTFE and PA6/PTFE composites increased with the increase of the load and decreased with the increase of the sliding frequency whereas the volumetric wear of neat PTFE and PA6/PTFE composites increased with the increase of load and reciprocating sliding frequency.
3. The plastic deformation is the primary wear mechanism for the neat PTFE under dry sliding. When incorporated with PA6, the plastic deformation was greatly reduced.

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