Properties of Potassium Titanate Whisker Reinforced Polytetrafluoroethylene-Based Friction Materials of Ultrasonic Motors

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ABSTRACT: Ultrasonic motors (USMs) are driven by friction forces between a stator and rotor. So the output properties and life of USMs are strongly related to the properties, such as the mechanical and tribological properties, of the frictional materials. In this study, the effects of the content of potassium titanate whiskers (PTWs) on the mechanical and tribological properties of polytetrafluoroethylene (PTFE)-based friction materials and the performances of the corresponding USMs were studied. The morphology of worn surfaces of PTFE composites were observed with a scanning electron microscope. The experimental results show that the PTWs not only increased the hardness and elastic modulus of the PTFE composites but also increased the friction coefficient and wear resistance of the PTFE composites. On the whole, the PTFE-based friction materials filled with 5 wt % PTWs were the preferable friction materials for USMs.
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Key words: mechanical properties; morphology; polytetrafluoroethylene (PTFE)

INTRODUCTION

Ultrasonic motors (USMs) are a new type of actuator and are driven by ultrasonic vibration and the piezoelectric effect.[1] Compared to electromagnetic motors, they have excellent performance and many excellent features,[2,3] such as a simple construction, quick response, large output torque at low speed, and quiet operation. Because of their excellent properties, USMs show strong vitality and broad market potential. Therefore, USMs are attractive for researchers from different countries.[4–6]

However, sliding loss and wear between the rotor and the stator are inevitable because the rotational velocity of the rotor is almost constant and the vibration velocity of the stator is sinusoidal. Thus, the frictional material used on the sliding surface plays an important role in the characteristics and lifetime of the motor.[1] Because the life of the frictional material is one limitation of USM life, it is necessary to research frictional materials.[7]

Frictional materials play a very important role in USMs because of their influence on the efficiency, speed, torque, and so on[8–10] of the motors. Frictional materials of various kinds, such as chloroprene rubber (CR),[11] carbon-fiber- and polyimide-reinforced polytetrafluoroethylene (PTFE),[12] carbon-fiber-reinforced plastic,[7,10] and glass embedded teflon (GET) and silicon-incorporated-diamond like carbon (Si-DLC) coatings,[1] have been investigated.

In recent years, PTFE has attracted a great deal of attention because it possesses some extraordinary characteristics, including a low friction coefficient, good self-lubrication, good high-temperature stability, and chemical stability.[13] Unfortunately, PTFE exhibits a high wear rate under normal friction conditions, which limits its application fields. Therefore, many kinds of PTFE-based composites have been produced to improve the wear resistance of PTFE. It has been found that some microscale inorganic fillers showed distinct effects on the friction and wear behaviors of PTFE composites.[14–16]

Potassium titanate whiskers (PTWs) have been widely used as promising reinforcement fillers because of their unique properties, including outstanding mechanical performance, hardness, coefficient of thermal expansion, and chemical stability.[17,18] Therefore, the purpose of this work was to investigate the effects of the content of PTWs on the mechanical

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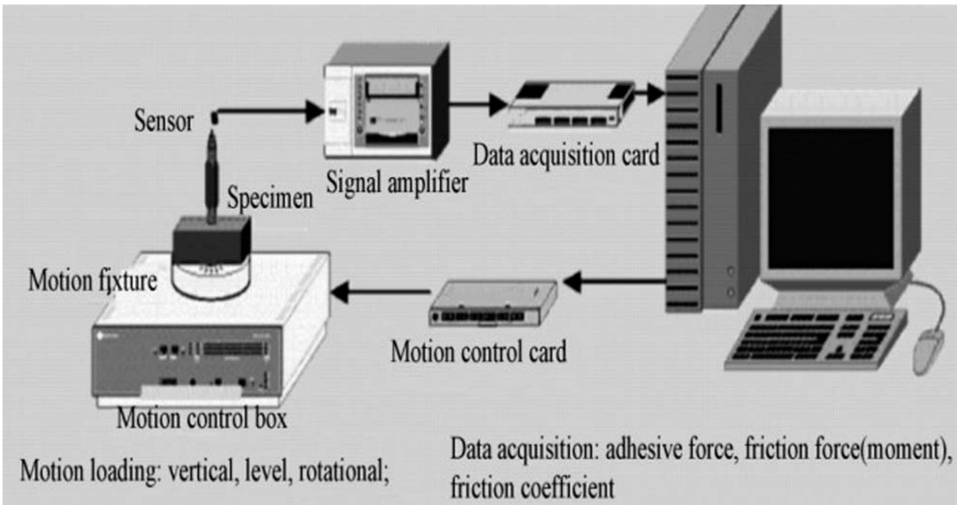

Figure 1 Schematic diagram of the quasi-static tribometer.

and tribological properties of PTFE-based friction materials. It is expected that this study may be helpful for researching the friction materials of USMs.

EXPERIMENTAL

Materials

PTFE powder with an average particle size of 5 μm was supplied by Zhining Plastic Filling Co., Ltd., Shanghai, China. PTW was purchased from Yixing Whisker Minerals Co., Ltd., Shanghai, China. The average diameter and length of the PTWs were 1 and 6 μm, respectively.

Specimen preparation

The fillers and PTFE powders were weighed in the proportions needed and blended mechanically. The mixtures were compressed into test samples at 25°C and 35 MPa for 15 min, sintered at 180°C for 1 h in a stove, and then maintained for 3 h at 380°C. Then, the frictional materials were stuck on the rotor after being cut into 0.2-mm slices.

Performance testing

The hardness tests of the friction materials were performed by a Shore hardness tester (TH-210) produced by Beijing Time Ricon Technology Co., Ltd., Shanghai, China. The elastic modulus tests were carried out on a computer-controlled universal testing machine (WDW-5000N, Beijing, China) at room temperature.

The wear and friction of the samples were measured by a quasi-static tribometer[4] designed by our laboratory, as shown in Figure 1. Although open to the air, the entire apparatus was located inside a clean room with conditioned laboratory air of relative humidity between 40 and 50% and a temperature of 20°C. The rotors revolved at speed of 12

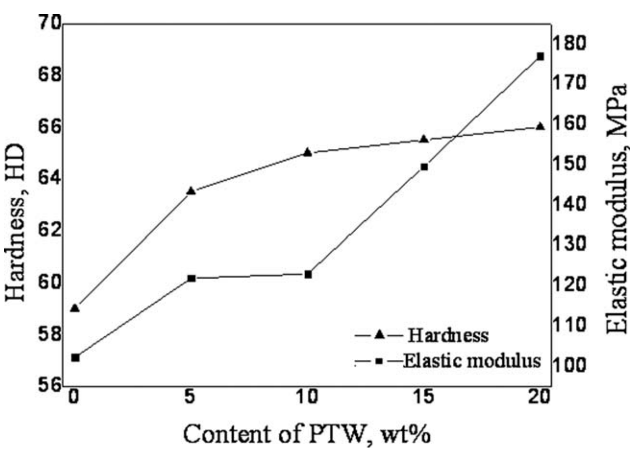

Figure 2 Mechanical properties of the PTFE composites with various contents of PTW.

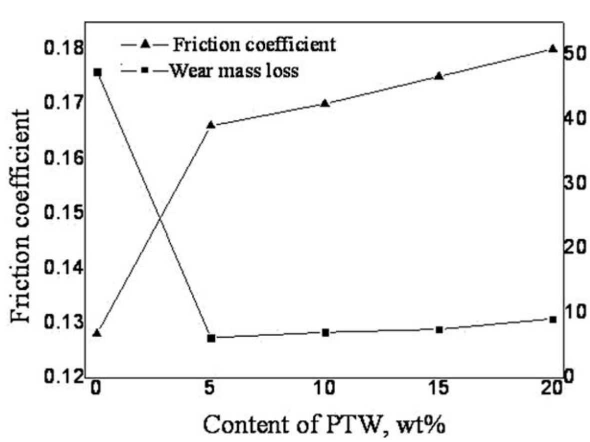

Figure 3 Tribological properties of the PTFE composites with various contents of PTW.

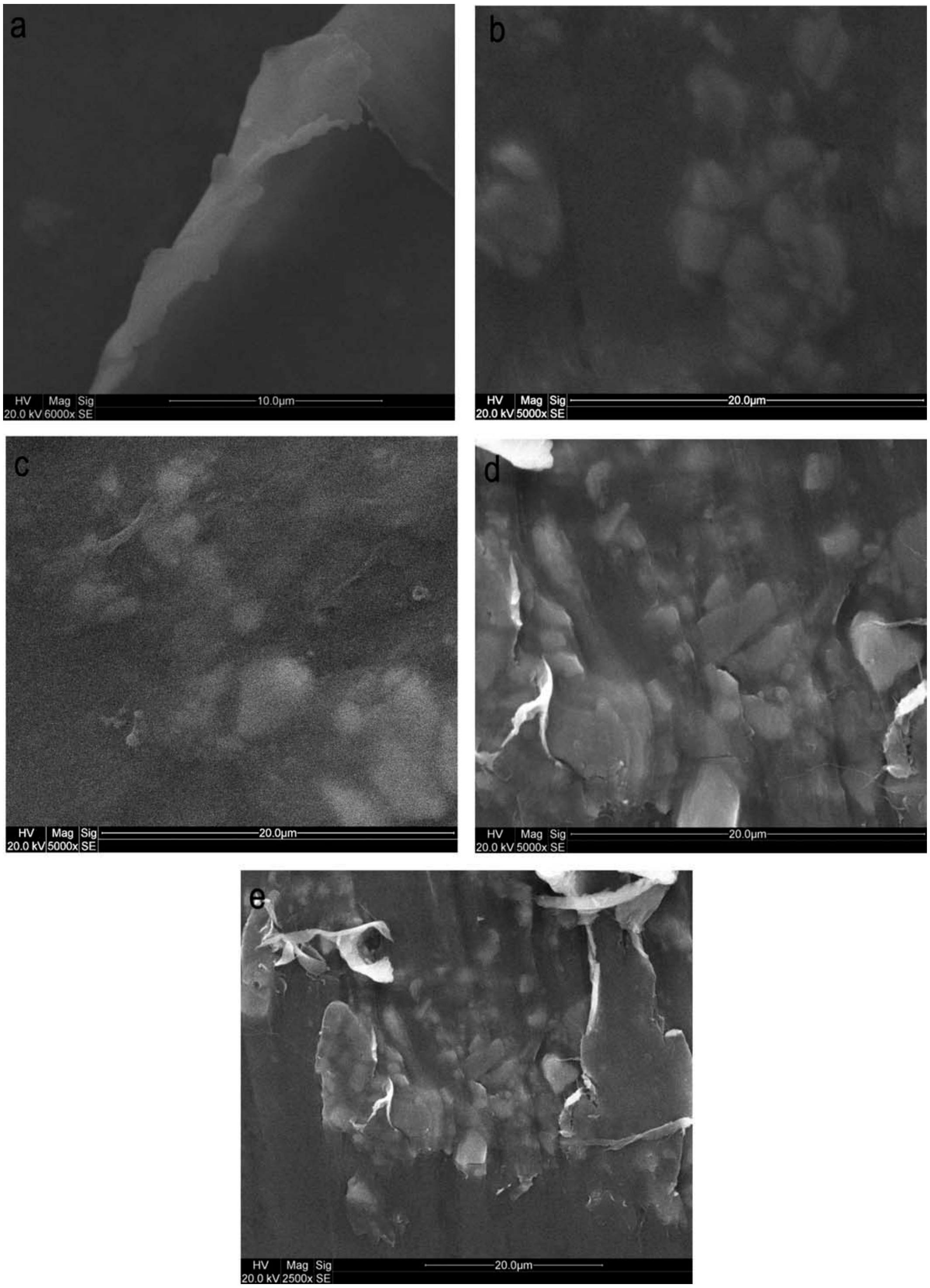

Figure 4 (a) SEM morphologies of the worn surfaces of the (a) neat PTFE, (b) 5 wt % PTW/PTFE composites, (c) 10 wt % PTW/PTFE composites, (d) 15 wt % PTW/PTFE composites, and (e) 20 wt % PTW/PTFE composites.

rpm, and the stator was mounted to the tribometer. Before testing, the counterfaces were cleaned with methanol and dried. A normal force of 200 N was applied, and the load was continuously monitored and computer-controlled with an electropneumatic valve. Instantaneous data were collected for normal load and friction force. After 100 h, the mass loss was measured by an electronic balance, and the morphology of the worn surfaces of the friction materials was observed by scanning electron microscopy (SEM, Made by Japanese electronics corporation (JEOL) in Japan and purchased from Beijing in china). The specimens were coated with gold before observation.

A USM-60 motor mechanical properties testing system (Shanghai Institute for New Technologies, Shanghai, China) was used to test the mechanical properties of the USMs with different rotors at a voltage of 15 V, a frequency of 38 kHz, and a preload of 200 N.

RESULTS AND DISCUSSION

Mechanical properties of the friction materials

Figure 2 shows the mechanical properties of the PTFE-based friction materials blended with different contents of PTWs. It was obvious that the hardness and elastic modulus properties of the PTFE composites were greatly improved when the content of PTWs was increased. As a hard phase in the soft polymer matrix, the PTWs increased the hardness and elastic modulus of the PTFE composites.

Tribological properties of the friction materials

The variations of the friction coefficient and wear mass loss of PTFE composites are shown in Figure 3. It was obvious that the friction coefficient of the PTFE composites increased as the content of PTWs was increased. Moreover, the wear mass loss of the PTFE composites decreased first and then increased as the content of PTWs was increased. As a hard phase in the soft polymer matrix, PTWs not only strengthened the combination of the interface between the reinforcements and the PTFE matrix but also increased the sliding resistance caused by the mechanical chimerism of the asperities. When the surface with hard microasperities was pressed to the soft surface, the friction force was formed because of the ploughing resistance.[2] Therefore, it exhibited an important influence on reducing the adhesion between the relative sliding parts. What is more, the addition of PTWs improved the friction coefficient and wear resistance of the PTFE composites, and the 5 wt % PTW-reinforced PTFE composite exhibited the highest wear resistance. The unfilled PTFE composites showed, in general, the highest mass wear of all of the specimens tested under the same sliding conditions. Additionally, the high percentage of fillers in the composites degraded the wear resistance of the PTW/PTFE. The fillers themselves caused stress concentrations in the matrix and reduced the binding force between the PTWs and PTFE gradually, so the PTWs could be brushed off easily. Finally, the whiskers and their scraps in the interface actually enhanced the grain abrasion, which increased the friction coefficient and the wear mass loss.

SEM studies of the worn surfaces

SEM micrographs of the worn surface of the PTFE composites are shown in Figure 4. In the case of unfilled PTFE [Fig. 4(a)], the peeling of PTFE was observed. The matrix material exhibited very poor wear resistance in the wear tests as it was removed, and so, the wear mass loss was high. In the PTW/PTFE composites, large sections of removal, as observed in the unfilled PTFE, were not observed with increasing PTW content, as shown in Figure 4(b,c). The worn surface of the 5 wt % PTW/PTFE sample was relatively smooth [Fig. 4(b)]. The PTWs effectively supported the load from the counterface and reduced the true contact area with the counterbody under certain loads. As a result, they exhibited an important influence on reducing the adhesion between the relative sliding parts. The composite exhibited a higher friction coefficient and wear resistance compared with the pure PTFE when it was filled with lower contents of PTWs.

However, large sections of removal were observed when the content of PTWs was increased further, as shown in Figure 4(d,e). The high percentage of PTWs degraded the wear resistance of the composites when the high content was greater than 5 wt %. This was because the high content of fillers led to stress concentrations in the matrix and gradually reduced the binding force between the PTWs and PTFE, and the PTWs could be brushed off easily. Therefore, whiskers and their scraps could be found, as demonstrated in Figure 4(d,e). The free whiskers and their scraps in the interface actually enhanced the grain abrasion, which increased the friction coefficient and the wear mass loss.

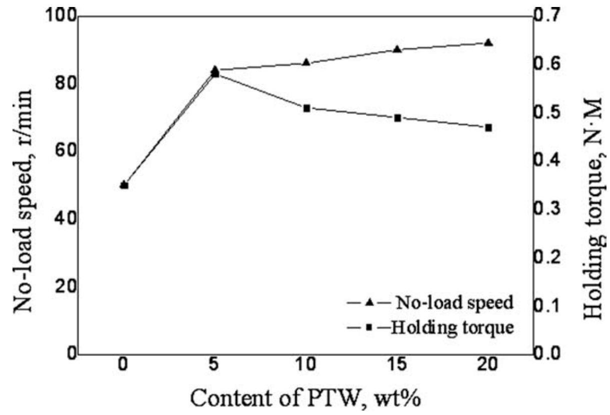

Figure 5 Mechanical properties of USMs with various contents of PTW.

Mechanical properties of the USMs

The mechanical properties of the USMs varied with the contents of PTW, as shown in Figure 5. It can be seen from Figure 5 that the no-load speed of the USMs increased as the content of PTWs was increased. Moreover, the holding torque of the USMs increased first and then decreased as the content of PTWs was increased. The ideal friction material of the USMs possessed a larger holding torque with a higher no-load speed. When the content of PTWs was 5 wt %, both the no-load speed and the holding torque of the USMs were higher, and the comprehensive performances of the USMs were best with low noise. Therefore, the PTFE composite with a content of PTWs of 5 wt % was the best friction material for the USMs in this study.

CONCLUSIONS

The mechanical and tribological properties of PTFE composites reinforced with various amounts of PTWs were studied. The mechanical properties of the corresponding USMs were also investigated. The following conclusions were made on the basis of this study:

1. The hardness and elastic modulus of the PTFE composite obviously increased with PTW filler.
2. The friction coefficient and wear resistance of the PTFE composites increased as the content of PTWs increased. Moreover, when the content of PTWs was 5 wt %, both the no-load speed and holding torque of the USMs were higher, and the comprehensive performances of the USMs were the best with low noise. Therefore, the PTFE-based friction material filled with 5 wt % PTWs was the preferable friction material of the USMs in this study.

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