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Wear and mechanical properties of Ekonol/G/MoS_2/PEEK composites

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High performance resin materials, such as poly(ether ether ketone) (PEEK) and its composites, are becoming more widely used as bearing, bushing and slider materials [1, 2]. Their mechanical properties and tribological behavior are, therefore, of interest and importance. Early research showed that the graphite can cooperate with MoS_2 in lowering the friction coefficient of composites [3]. Ekonol has a similar crystal structure to graphite (a layer structure), and also has a high glass transition temperature, melting point and compressive strength. The purpose of this work was to modify PEEK with Ekonol and the solid lubricant (graphite and MoS_2), and investigate the mechanical and tribological properties. It was believed that this work would be helpful for understanding the function of Ekonol as a main filler in PEEK and for providing guidance to the tribological application of PEEK.

The preparation of the PEEK composites was shown in Fig. 1, in which raw materials were PEEK, Ekonol, G, MoS_2, and other aids. In all the composites prepared, the total content of the graphite and MoS_2 was kept at 8 percent, and the ratio of the graphite to MoS_2 was 7 to 1. The contents of the major filler (Ekonol) was changed from 10 percent to 40 percent, at intervals of 5 percent. The composite modified only by the solid lubricant (graphite and MoS_2) will be referred to as GM. Fillers were treated with a coupling agent. The mixed powders was pre-pressed in the model, heated at a rate of 10 °C min^{-1} to the temperature of 380–390 °C and held for 90–100 min. Then it was cooled at a rate of 5 °C min^{-1} to room temperature.

The impact strength was measured on a tester of type XJJ-5, with no notch in the specimen. The bending strength and compressive strength were examined on an electron omnipotence tester of type RGT-5. The bend rate was 2 mm · min^{-1}, and the compression rate was 1 mm · min^{-1}. All the presented results are the average of five specimens.

The friction and wear tests were conducted on a ring-block tester of type MRH-5A. The experimental parameters were: rotation speed 200 r · min^{-1}, load 196 N and test time 2 h. All tests were carried out in dry friction state and at room temperature. The friction coefficient, μ, was calculated by the formula

$$\mu = \frac{9.45(B + R)}{10(A + C) - 2.5(B + R)}$$

where $A = 19.6$ N, $C = 7.8$ N, B is the weight of weights exerted by the pole of friction force, R is the scale reading of the free weights. The abrasion characteristics were assessed by the weight loss, W, which was calculated by the following relationship

$$W = W_1 - W_2$$

where W_1 and W_2 are respectively the weight of a sample before and after its test.

The morphologies of the worn surfaces were observed by a KYKY-2800 scanning electron microscope.

Fig. 2 shows the effect of the Ekonol content on the impact resistance of the Ekonol/G/MoS_2/PEEK composites. It can be seen that the impact resistance increased at first and then decreased with the increase of Ekonol content; it reached the maximum when the Ekonol content was about 10 percent. The relation between the compressive strength and the Ekonol content

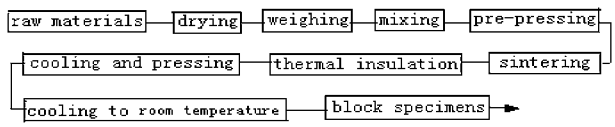

Figure 1 The preparation process of the PEEK composites.

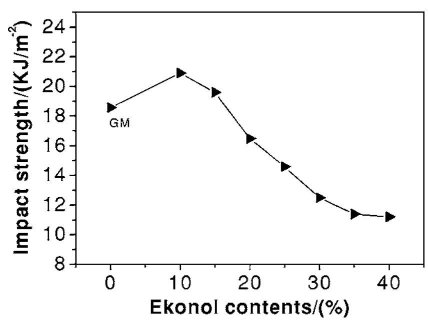

Figure 2 The relation between Ekonol contents and impact strengths.

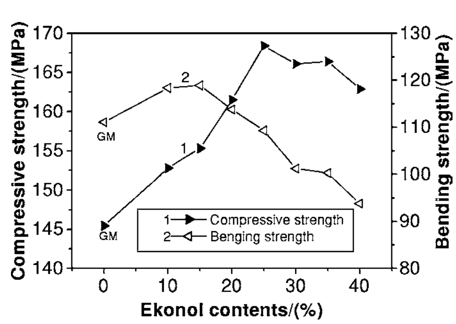

Figure 3 The relation between compressive strengths, bending strengths and Ekonol.

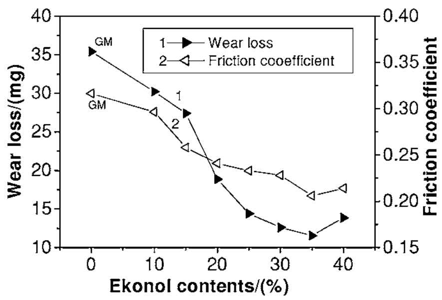

Figure 4 Effect of Ekonol contents on the friction coefficient and wear loss of different PEEK composites.

is shown in Fig. 3 line 1. The addition of Ekonol beneficially improved the compressive strength of the composites. It reached a maximum (168.4 MPa) when the composite contained 25 percent of Ekonol, the strength of the composite was 21 percent higher than that of PEEK (139.1 MPa) and 16 percent higher than that of the GM (145.5 MPa). Although the compressive strength begins to decrease after an Ekonol content of 25 percent, it is still much higher than that of the matrix PEEK. Line 2 in Fig. 3 shows the effect of the Ekonol content on the bending strengths of the composites. The strength curves are somewhat analogous with that for the impact resistance with just the Ekonol content of the maxima differing for the bending strength.

The relationships between the wear loss and the Ekonol content of the PEEK composite are shown in Fig. 4 line 1. It can be seen the wear loss of the GM (35.4 mg) is lower by 24 percent than that of PEEK (46.3 mg). This shows the cooperative effect of the graphite and MoS_2 in the wear-reduction. The wear loss decreases with the increase of the Ekonol content. It is lower by 75 percent than that of PEEK when the Ekonol content is 35 percent. This is, on the one hand, attributed to the heterogeneous nucleation of Ekonol in the process of cooling and crystallization, which refines the grains and improves the strength of materials. On the other hand, it is also due to the fact that the graphite and MoS_2 can transfer to the counterface and form transfer films which function as a self-lubricant and protect the composite from wear. The relationships between the friction coefficient and Ekonol content are shown in Fig. 4 line 2, the trend is almost the same as that of the wear loss to the Ekonol content. It indicates that the Ekonol can cooperate with the graphite and MoS_2 in decreasing the friction coefficient of the composites. This is because the Ekonol has a similar layer crystal structure to that of graphite. So the Ekonol/G/MoS_2/PEEK composite is a better self-lubricated composite than the GM and Matrix PEEK.

Fig. 5a shows the SEM morphology of the worn surface of PEEK. Severe skin wear can be found in a large area besides the wide and deep ploughs parallel arranged. Obviously, the wear mechanism of PEEK is micro-cutting plus skin wear. This is consistant with the results of Stuart and Briscoe [4]. Fig. 5b–d are the SEM morphology of the worn surface of different

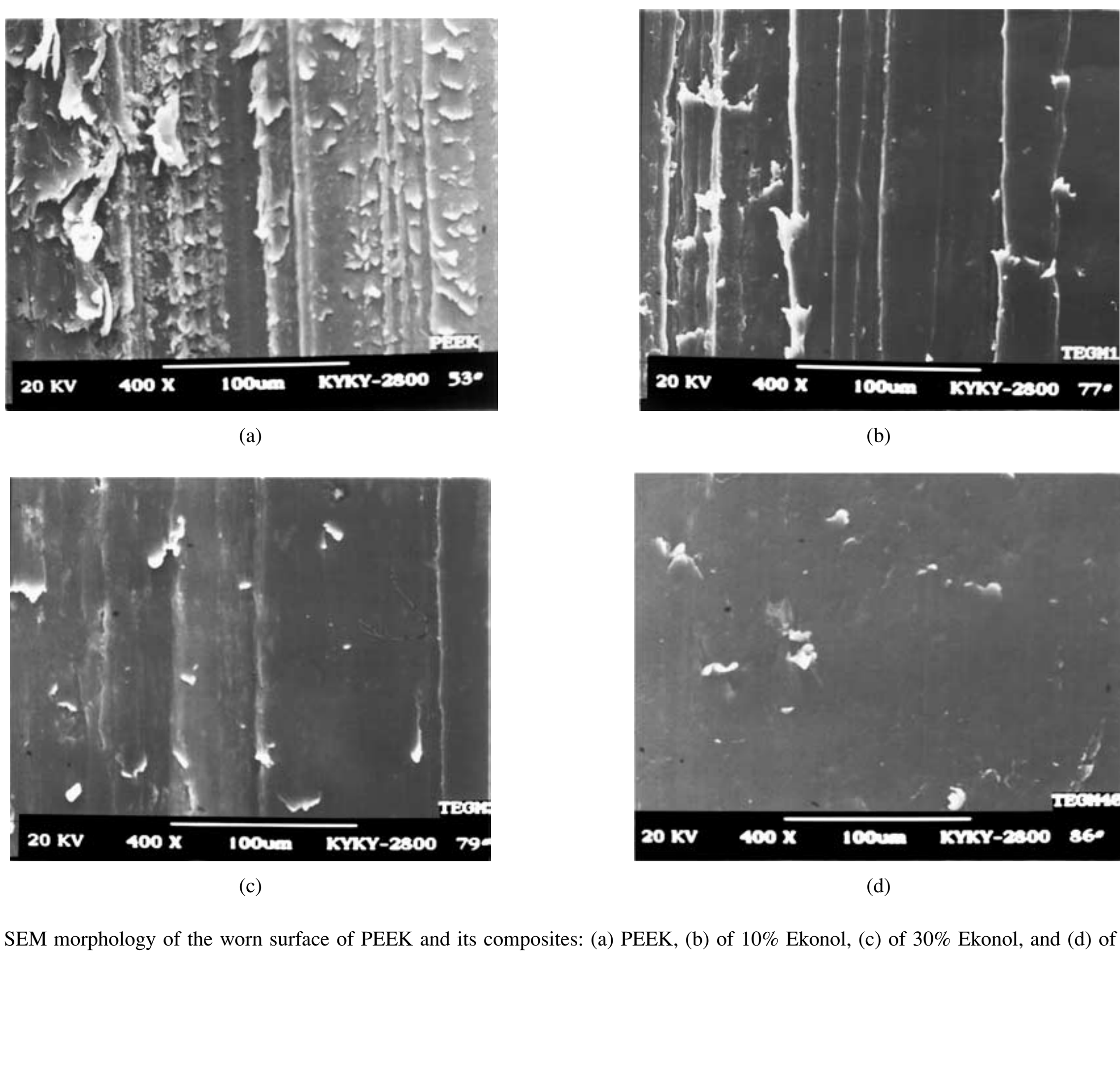

Figure 5 SEM morphology of the worn surface of PEEK and its composites: (a) PEEK, (b) of 10% Ekonol, (c) of 30% Ekonol, and (d) of 40% Ekonol.

PEEK composites whose Ekonol content is 10 percent, 30 percent and 40 percent, respectively. It can be seen that the ploughs are fewer in number and shallower the more Ekonol added to PEEK. Indeed ploughs almost cannot be found in Fig. 5d. Furthermore skin wear is becoming less apparent with increasing Ekonol contents. But for the higher Ekonol content PEEK composite, the wear mechanism is skin wear (see in Fig. 5d). So a conclusion can be drawn from the above that the wear mechanism of the composite is changed from the microcutting plus skin wear to skin wear with the increase of the Ekonol content. And the wear and friction performance of PEEK has been greatly improved with the addition of the Ekonol, graphite, and MoS_2.

Acknowledgment

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