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Studies on POM/graphite/Ekonol composites

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Abstract. POM/graphite/Ekonol composites were prepared by the Torque Rheometer mixing and compression molding, and their hardness, compressive and impact strengths have been tested. The tribology behaviour was also investigated by the friction and wear experiment. The worn surface of the composite was studied by SEM technique, and on its basis, the wear mechanism was analysed. Results show that it was possible to prepare POM/graphite/Ekonol composites of high tribology performance and good mechanical properties by the Torque Rheometer mixing and compression molding. With the rise of Ekonol content, the wear mechanism was changed from adhesion plus plough to fatigue wear plus abrasive wear.

Keywords. Mechanical properties; tribology performance; wear mechanism; POM/graphite/Ekonol composite.

1. Introduction

Polyoxymethylene (POM) is an engineering plastic of high performance, which has been widely used for the parts of drive transmission and conductive usage in the fields of mechanical fabrication, various precision machines and hardwares. It was one of the plastics used for gears in the early years. However, the plain POM can only be used for the parts of low load and velocity. So much work has been done on improving the load-carrying ability and tribology performance by modification (Mens and de Gee 1991; Odi-Owei and Schipper 1991; Yuan *et al* 1993; Ha and Jiang 1998). Ekonol is a high crystalline polymer of great interest because of its engineering properties, such as high compressive strength and hardness, excellent thermal stability and conductivity, and good tribology behaviour. In particular, Ekonol has a similar crystal structure as that of graphite in a layer form and it was hoped that both Ekonol and graphite together improved the tribology behaviour of the composites.

In this paper, we aim at modifying POM by filling it with various contents of Ekonol and a constant content of graphite, preparing POM/graphite/Ekonol composites by compression molding, and studying their mechanical and tribological properties. It is believed that this work would be helpful in understanding the function of Ekonol as a filler in POM and in providing guidance to the tribological application of POM.

2. Experimental

2.1 *Materials*

The POM powders used, of a diameter smaller than 0·076 μm, were supplied by Shanghai Solvent Plant, China. The Ekonol powders as filler were produced by the Chenguang Institute of Chemical Ministry with a size smaller than 0·05 μm. The graphite powders were produced at the Colloid Chemical Plant, Shanghai. The other materials were bought in the market.

2.2 *Sample preparation*

The POM/graphite/Ekonol composites were prepared by the Torque Rheometer mixing and compression molding method. The contents of Ekonol as filler was changed from 10–35 wt.%, with an interval of 5 wt.%. The graphite was kept constant at 8 wt.%. The rest is POM and other materials. Fillers were dealt with the coupling agent in order to improve compatibility between the filler and the matrix. At first, all the powders were dried sufficiently. The powders were then proportionally weighed and mixed by the Torque Rheometer of type RM-200/300, at temperature of 190–195°C for 10 min. Then the mixture was heated at a rate of 10°C·min^{-1} to 260°C, held for 40–50 min, and pressed into a block by the compression mould under a pressure of 4–6 MPa. At last it was cooled at a rate of 5°C·min^{-1} to room temperature.

2.3 *Measurement*

The composite blocks were cut into specimens of a certain size to meet the experimental design. The microhardness was determined on a HVS-1000 digit-display hardness tester with a load of 200 g and a test duration of 15 s. The compressive strength was determined on an electron omnipotence tester of type RGT-5, with a compression rate of 1 mm·min^{-1}. The impact strength was measured on a tester of type XJJ-5, with no notch in the specimens. All the results were the average of five specimens.

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The friction and wear tests were conducted on a ring-block wear tester of type MRH-5A, as shown in figure 1. The size of the block was 19 × 12 × 12 mm, and the size of the ring was 40 × 8 mm (with a circular arc outer-surface and a conical inner-surface), the hardness and the surface roughness was HRC48–53 and 1·6–0·8 μm, respectively. The experimental parameters were 200 r·min^{-1} in rotate speed, 200 N in load, 1 h in test time. All the experiments were done in dry friction state and at room temperature. The friction coefficient, m, was calculated by the formula

$$m = \frac{9\cdot 45(B+R)}{10(A+C)-2\cdot 5(B+R)},$$

where A = 19·6 N, C = 7·8 N, B is the weight of weights exerted by the pole of friction force in the right, R the scale reading of the free weights. The abrasion characteristics was 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 the weight of a sample before and after its test, respectively. In order to eliminate the effects of de-molding agent on experimental results, the samples should be pre-abraded with metallographic papers from coarse to fine. At the end of each test, the ring and block should be cleaned with alcohol and dried in order that the weight loss can be precisely measured and the worn surface can be explicitly observed and analysed.

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

3. Results and discussion

As in all the POM/graphite/Ekonol composites, the content of graphite was kept constant at 8 wt.%, so the effect of graphite on the performance of composites has not been specially analysed here as it was discussed in another paper (Long 2003).

3.1 *Mechanical properties of POM/graphite/Ekonol composites*

The effect of Ekonol as a filler on the hardness of composites is shown in figure 2. It shows that the hardness at first sharply increased and then decreased gradually with increasing Ekonol content. The highest hardness value was about 45% higher than that of pure POM, of which the Ekonol content was 15 wt.%. Figure 3 shows the relations between compressive strengths and Ekonol contents. It can be seen that the addition of Ekonol could beneficially improve the compressive strength. The maximum strength was obtained as the Ekonol content reached 20 wt.%, which is 22% higher than that of POM. It began to decrease when the Ekonol content was above 25 wt.%. Figures 2 and 3 imply that Ekonol was effective for increasing the load-carrying capacity of Ekonol filled-POM. Figure 4 shows the impact strength effect of the composite as a function of different Ekonol contents in graphite/POM. It can be seen that the impact strength at first increased with an increase in Ekonol content, the highest value was obtained when the Ekonol content reached 15 wt.%, then the impact strength began to decrease almost

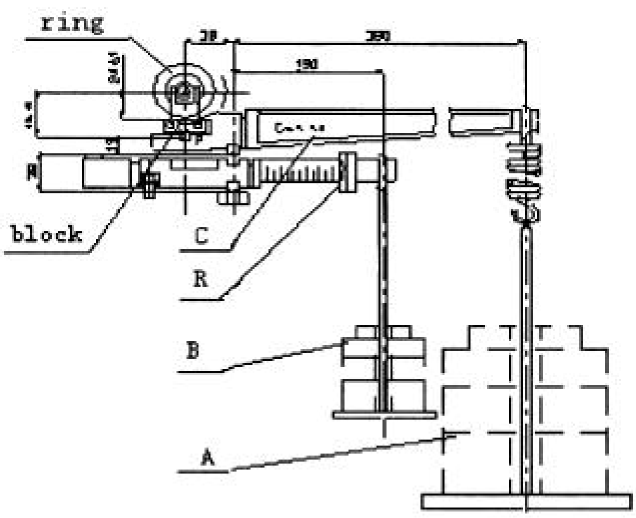

Figure 1. The principle chart of the ring-block wear tester.

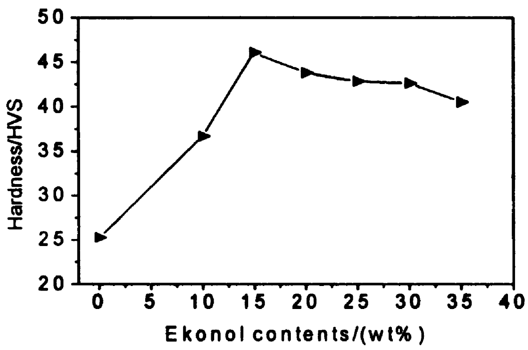

Figure 2. Effect of Ekonol content on hardness.

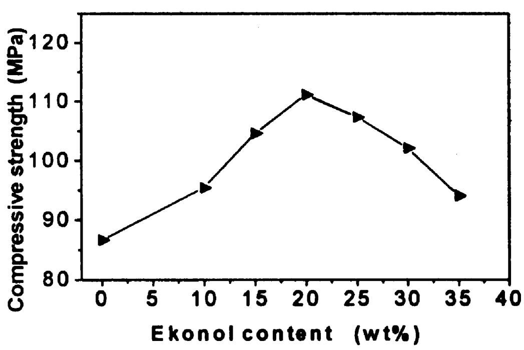

Figure 3. Effect of Ekonol content on compressive strength.

sharply. Thus it can be concluded from the above that only a suitable Ekonol content (of 15–20 wt.%) is beneficial for improving the mechanical properties of POM.

3.2 *Friction and wear properties of POM/graphite/Ekonol composites*

The relationship between the Ekonol content and wear loss of different POM composites are shown in figure 5. It can be seen that the wear loss of the composite at first decreased sharply when the Ekonol content reached 20 wt.%, it reached the minimum which was 74% lower than that of pure POM. It was accompanied by a continuously slight increase as the Ekonol content was between 20 and 25 wt.%. When the Ekonol content was above 25 wt.%, the wear loss began to increase sharply with an increase of the filler content. The above indicates that a suitable Ekonol content (< 25 wt.%) can effectively improve the wear resistance of POM. This is because, on the one hand, of the heterogeneous nucleation effect of Ekonol in the process of crystallization, which resulted in ultra-fine grains and improved the strength of materials, especially the hardness, and on the other hand, of the transfer film formed on the surface of the counterpart ring during the friction process. In the meantime, the friction coefficient can also be apparently decreased by an appropriate content (< 20 wt.%) of Ekonol filling in POM, as shown in figure 6, which shows a similar trend as in figure 5. This might be attributed to the fact that Ekonol has a similar crystal structure with graphite in a layer form, so it would function as a lubricant in the friction course, and along with graphite it decreased the friction coefficient of the composites. As to why wear loss and friction coefficient increased when the Ekonol content was above a certain value, it may be due to the compatibility between the filler and the matrix. As the POM/graphite/Ekonol composite was a partially compatible system as reported elsewhere, the excessive Ekonol content may result in the cracking-off of the Ekonol particles from the matrix and it would speed up the abrasion of the composite as a function of grinding medium (see figure 10). At the same time, it may also break the continuity of the transfer film and weaken its lubricating and protection abilities.

3.3 *SEM observation of the morphologies of the worn surface*

Figure 7 shows SEM morphology of the worn surface of POM. It can be seen that the wide and deep ploughs were

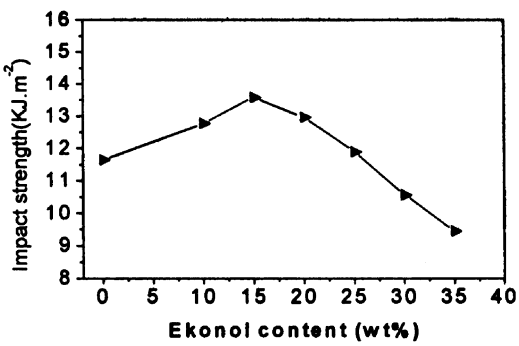

Figure 4. Effect of Ekonol content on impact strength.

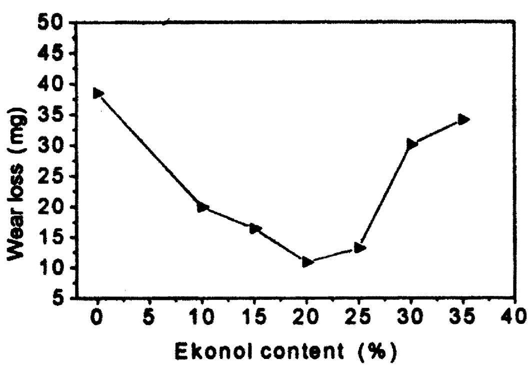

Figure 5. Effect of Ekonol content on wear resistance.

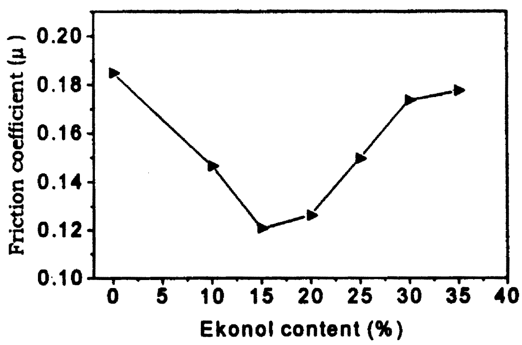

Figure 6. Effect of Ekonol content on friction coefficient.

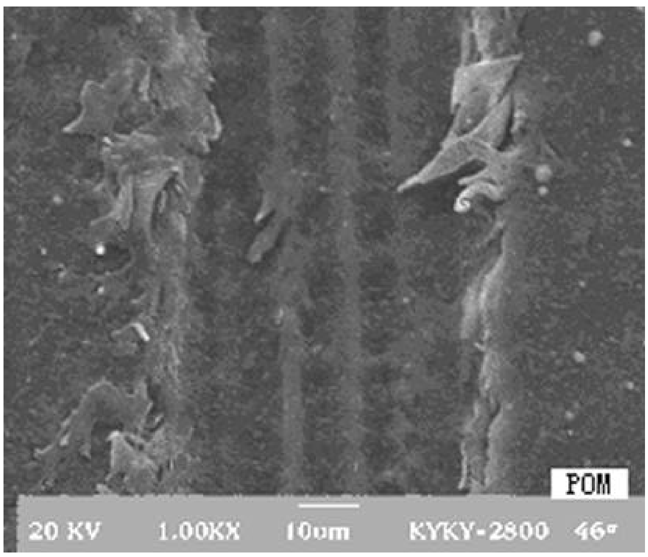

Figure 7. SEM morphology of the worn surface of POM.

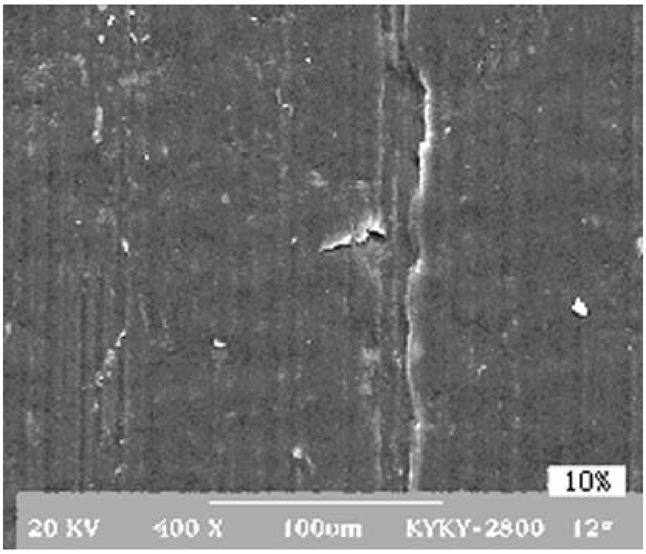

Figure 8. SEM morphology of the worn surface of 10 wt.% Ekonol composite.

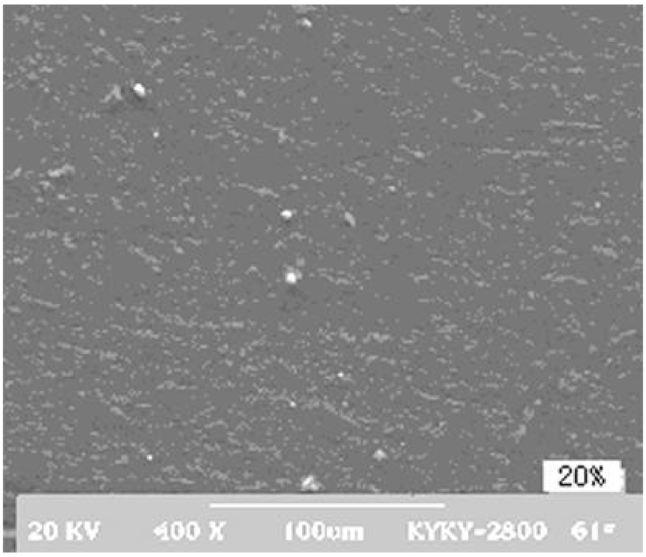

Figure 9. SEM morphology of the worn surface of 20 wt.% Ekonol composite.

parallelly arranged along the friction direction on the wear scar of the pure POM block. Splitting can also be seen. Obviously, the wear mechanism of POM was adhesion plus plough (Xue and Wang 1997). SEM morphology of the worn surface of POM composites whose Ekonol content was 10 wt.%, 20 wt.% and 35 wt.%, respectively are shown in figures 8–10. In figure 8, the ploughs became narrow and shallow, and the splitting became weak as compared with figure 7. In particular, for 20 wt.% Ekonol

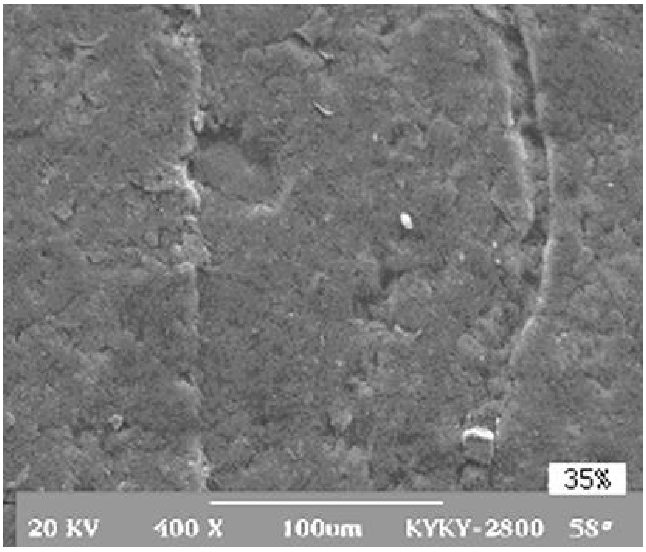

Figure 10. SEM morphology of the worn surface of 35 wt.% Ekonol composite.

composite, the worn surface was smooth and no ploughed marks could be observed. But in figure 10, the wear of the surface became severe again, quite a few pits of fatigue flaking and a bending groove with a inlay particle could be seen. This indicates that the wear mechanism of 35 wt.% Ekonol composite was fatigue wear plus abrasive wear. In the meantime, it can be inferred from the above that the morphologies of the worn surface were relevant to the wear loss of the composites.

4. Conclusions

(I) It is possible to prepare POM/graphite/Ekonol composites by the Torque Rheometer mixing and compression molding method.
(II) The composite filled with an appropriate Ekonol content (15–20 wt.%) has relatively ideal mechanical properties and tribology performance.
(III) With addition of more Ekonol to POM, the wear mechanism of the composites was changed from adhesion plus plough to fatigue wear plus abrasive wear.

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