Study on Tribological Properties of Frictional Material Based Aromatic Polyamide

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ABSTRACT: The effect of inorganic fillers on the friction and wear behavior of frictional material based poly(m-phenylene isophthalamide) (PMIA) is investigated. The polymer composites are prepared by compression molding. The friction and wear of PMIA composites are investigated on a block-on-ring machine by running the PMIA composite block against plain carbon steel. The morphologies of the worn surface of PMIA composite and the ring counterface are examined by using electron probe microanalysis. It is found that copper compounds including CuCl, $CuCl_2$, Cu_2O, and CuO filled PMIA exhibit considerably higher friction coefficient than unfilled PMIA, while the wear rate of those composites decrease. Especially, CuCl is the optimal filler in the copper compounds investigated above. The filled PMIA composite containing CuCl, graphite, and short carbon fiber shows the best properties for frictional material. The friction coefficient of CuCl–PMIA composite is higher than that of unfilled PMIA because of the abrasive action of CuCl particle. It is probably the smoother surface of counterpart ring and composite block that resulted in the lower wear rate and friction coefficient of PMIA composite. © 2001 John Wiley & Sons, Inc. J Appl Polym Sci 80: 2790–2794, 2001

Key words: PMIA composite; frictional material; tribological behavior; surface analysis

INTRODUCTION

A lot of researchers focused on frictional material based polymer because they are widely applied. Aromatic polyamide fiber was usually used as filler to produce the frictional material.[1–4] But there was no study on their application as polymer basis in fictional material. Earlier studies revealed that poly(m-phenylene isophthalamide) (PMIA) with good wear resistance and higher friction coefficient might be a good polymer basis for frictional material.[5,6]

In this work, fillers such as copper compounds, graphite, and short carbon fiber filled PMIA to manufacture the frictional material is studied. The effect of those fillers on the friction and wear behavior of the PMIA is investigated. The mechanism of the friction and wear behavior of filled PMIA is also discussed.

EXPERIMENTAL

PMIA powder was supplied by Oiles Corporation in Japan. The fillers including CuCl, $CuCl_2$, Cu_2O, and CuO were supplied by Jianan chemical factory in China. All the copper compounds were analytically pure powders. Graphite was supplied by Nanshu chemical factory in China. Short carbon fiber was supplied by Nanjing carbon fiber factory in China. The PMIA powder was fully mixed with the filler powder by high speed dis-

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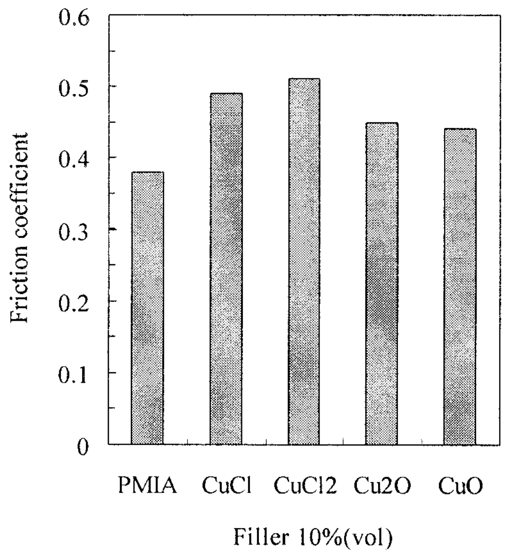


Figure 1 The effect of copper compounds filler including CuCl, $CuCl_2$, Cu_2O and CuO on the friction coefficient of PMIA. (Sliding was performed under ambient and conditions over a period of 120min at a sliding speed of 0.42m/s and a load of 196N at room temperature.

persing instrument. Then the mixture was dried at 100°C for 2 h to remove the moisture. The block specimens for friction and wear tests were prepared by compression molding during which the mixture was heated at a rate of 5°C min^{-1} to 330°C, held there for 15 min and then cooled to room temperature. In this experiment, friction and wear experiments were run in a tribometer with block-on-ring configuration. The block was made of composite specimens and the ring of plate carbon steel. Before each testing, the surface of the steel ring and PMIA composite block was polished with number 900 water-abrasive paper, cleaned with cotton dipped in acetone and dried in air. Sliding was performed under dry ambient conditions at a speed of 0.42 ms^{-1}, under a load of 196N and over a period of 120 min. The morphologies of the wear traces were observed using an EMP-810 model electron probe microanalysis.

RESULTS AND DISCUSSION

Friction and Wear of Copper Compound Filled PMIA Composites

The reason of copper compounds were chosen was because Bahadur and co-workers found that copper compound fillers such as CuO and CuS could increase the friction coefficient while reducing the wear rate of fatty polyamide and other polymers.[7–9] The effect of copper compounds filler including CuCl, $CuCl_2$, Cu_2O, and CuO on the friction coefficient of PMIA is shown in Figure 1. Here the proportion of fillers in the polymer in each case was 10% by volume. It may be seen that all four fillers above increase the friction coefficient of PMIA. The highest friction coefficient is attained to 0.51 as the composite containing $CuCl_2$.

The effect of these fillers on the wear volume of PMIA is shown in Figure 2. It is seen that with the addition of copper compounds the wear rate of PMIA decrease. The wear rate of the composite containing CuCl is lowest.

In the combination of the friction coefficient and wear rate of composites, we recommend that the optimal filler in the composite for frictional material should be CuCl.

Bending Strength of CuCl-PMIA Composites

Figure 3 shows that the bending strength of the composite as a function of CuCl contents in PMIA. Note that the bending strength of composites is almost linearly decreased with increasing CuCl content. The lowest bending strength is got in this experiment when the CuCl content reached 15 vol %.

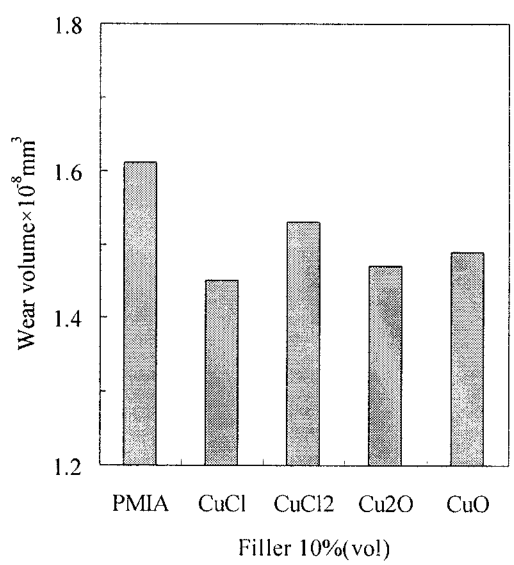


Figure 2 The effect of copper compounds filler including CuCl, $CuCl_2$, Cu_2O and CuO on the wear volume of PMIA. (Sliding was performed under ambient and conditions over a period of 120min at a sliding speed of 0.42m/s and a load of 196N at room temperature).

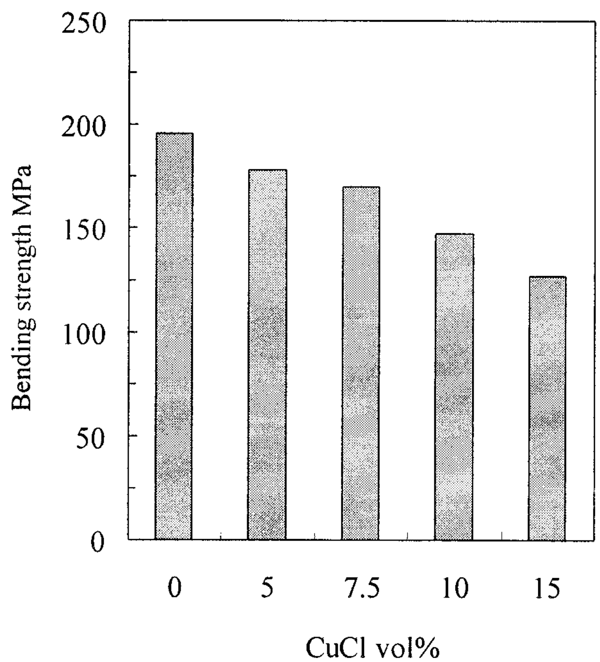


Figure 3 Effect of the content of CuCl on the bending strength of the filled PMIA.

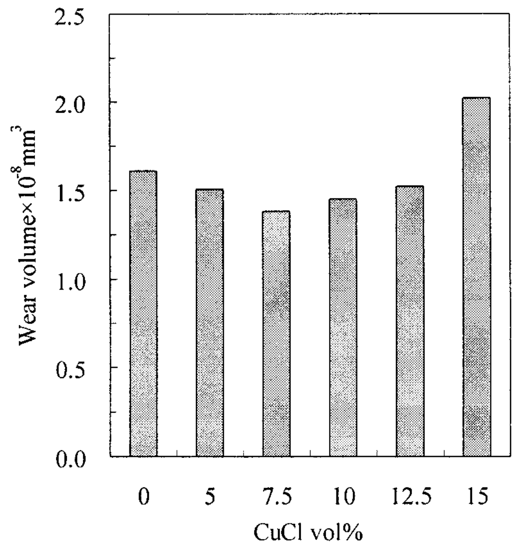


Figure 5 Effect of the content of CuCl on the wear volume of the filled PMIA. (Sliding was performed under ambient and conditions over a period of 120min at a sliding speed of 0.42m/s and a load of 196N at room temperature.)

Friction and Wear Properties of CuCl–PMIA Composites

Figures 4 and 5 show the friction coefficient and wear rate of CuCl filled PMIA as a function of CuCl content. It is seen that the friction coefficient and wear rate of CuCl filled PMIA show different change with different CuCl content. The friction coefficient raises sharply from 0.38 to 0.48 when CuCl content is below 5 vol %. But the friction coefficient then approaches a constant about 0.48–0.50 when the CuCl content between 5–15 vol %.

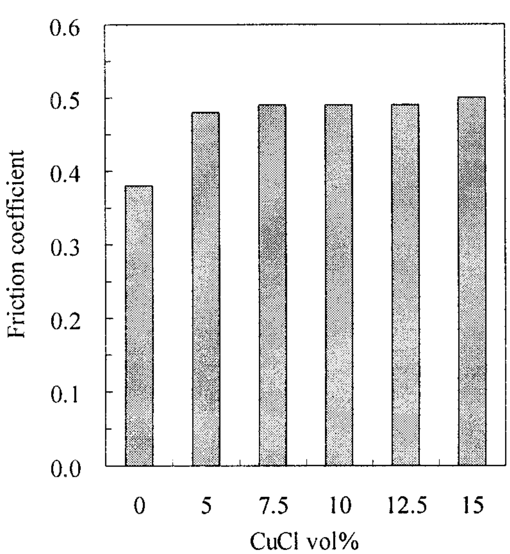


Figure 4 Effect of the content of CuCl on the friction coefficient of the filled PMIA. (Sliding was performed under ambient and conditions over a period of 120min at a sliding speed of 0.42m/s and a load of 196N at room temperature.)

Furthermore, the wear rate of the composite decreased with the increase in CuCl content to 7.5 vol %. Then the wear rate of the composite increases with the CuCl content to 15 vol %. Note that the wear rate of the composite is higher than the unfilled PMIA material when the content of CuCl is 15 vol %. The reason of the wear rate of the composite with CuCl above 7.5 vol % increases should be that the mechanical strength of CuCl filled PMIA composite becomes lower. It indicates that mechanical strength is the factor determining the tribological behavior of materials.[6,10] In the combination of tribological properties and mechanical strength, we recommend that the optimal content of CuCl in the composite should be 7.5 vol %.

From the above, note that the optimal content of CuCl could increase the friction coefficient and decrease the wear rate of PMIA, while the result shows that the wear rate of composite was higher when the composite was applied in the ultrosonic wave motors using a frictional material. We selected the graphite and short carbon fiber as the filler basis of our work to decrease the wear rate of composite; the proportion of the graphite and carbon fiber in the polymer in this case is 2% by

Table I Friction Coefficient and Wear Volume of PMIA Composites

Composite	Friction Coefficient	Wear Volume $\times 10^{-8} mm^3$
CuCl-PMIA	0.49	1.38
CuCl-G-PMIA	0.43	0.90

volume.[6] This composite (defined as CuCl–G-PMIA in this work) showed the best properties when it was applied in the ultrosonic wave motors for frictional material.

Table I gives that the friction coefficient and wear volume of PMIA composite. It can be seen that the graphite and short carbon fiber contribute to a reduction in the wear rate of PMIA, but the friction coefficient of composite is decreased too.

SEM Analyses

Figures 6a and 6b show the scanning electron micrographs of the working surface of the counterpart ring worn by CuCl–PMIA and CuCl–G–PMIA respectively. Figures 6c, 6d, 6e, and 6f give the related Cu and N element distribution on the worn surface of the ring. It may be seen that in all cases of the filled PMIA composite in this work, the transfer film including Cu and N element

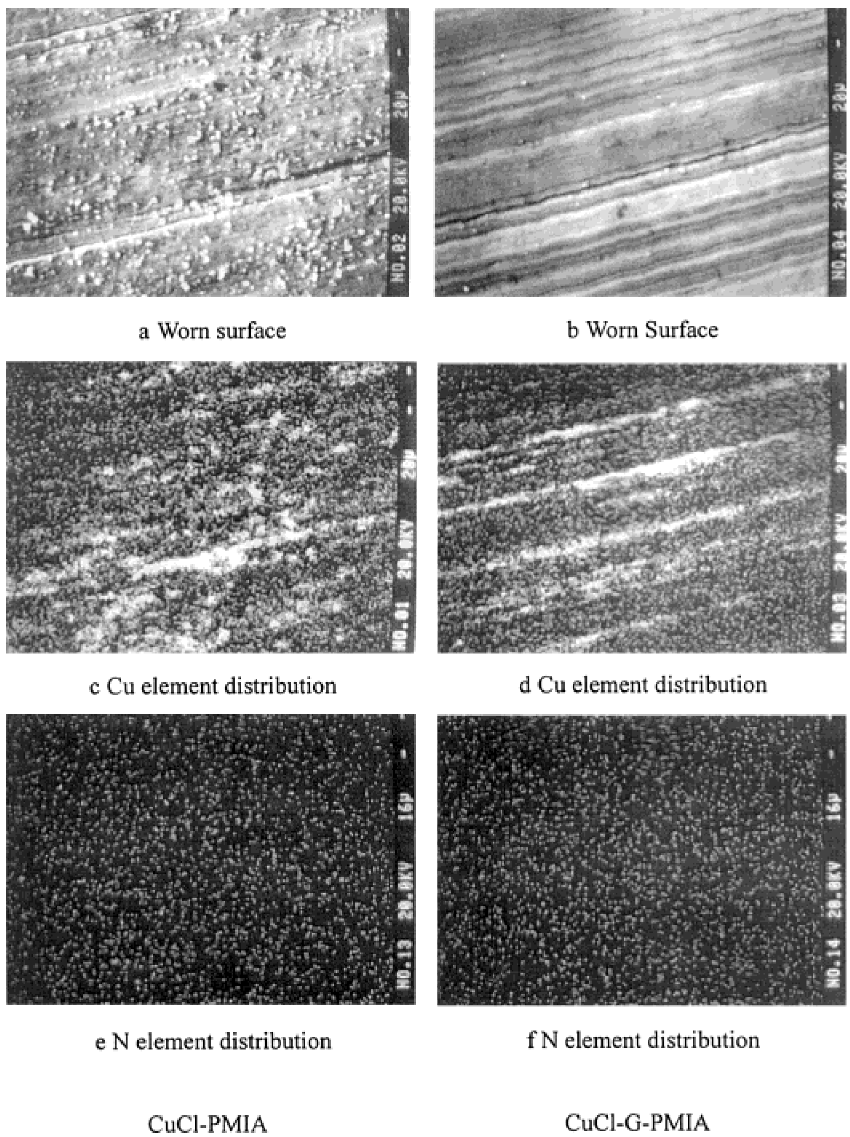
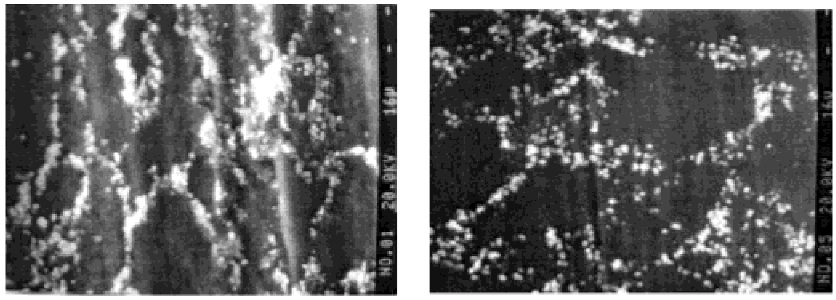


Figure 6 SEM of worn surface of counterpart ring and related Cu and N element distribution map.



a CuCl-PMIA b CuCl-G-PMIA

Figure 7 Scanning electron micrographs of the worn surface of the PMIA composites.

covering the surface was formed. It indicated that all of the PMIA and CuCl transfer to the counterpart ring during sliding.

Note that a kind of transfer film that formed on the counterpart ring by CuCl–PMIA block (Fig. 6a) is rough. In our early work,[6] we found that unfilled PMIA formed a smooth film on the steel counterface under the same conditions. It indicated that the higher friction coefficient of CuCl–PMIA composite than that of unfilled PMIA is because of the abrasive action of CuCl particle. The reason of lower wear of CuCl–PMIA might be the elemental copper generated by tribochemical reactions during sliding provided strong adhesion between the transfer film and the steel ring.[7–9]

While the worn surface of counterpart ring by CuCl–G–PMIA composite block is smooth. It is probably the smooth surface in the case of CuCl–G–PMIA that resulted in its lower wear rate and friction coefficient than that of CuCl–PMIA. While the friction coefficient of CuCl–G–PMIA is higher than that of unfilled PMIA may be the same abrasion action of CuCl particle.

Scanning electron micrographes of the worn surface of the CuCl-PMIA composites (Fig. 7a) and Cucl–G–PMIA composite (Fig. 7b) are given in Figure 7. It is seen that obvious scuffing is observed on the CuCl–PMIA block surface. While the scuffing on the CuCl–G–PMIA block surface is considerably abated. It may be the other reason of the lower friction coefficient and lower wear rate of CuCl–G–PMIA than that of CuCl–PMIA.

CONCLUSIONS

From the above, the following conclusion could be drawn:

It is found that copper compounds including CuCl, $CuCl_2$, Cu_2O, and CuO filled PMIA exhibit considerably higher friction coefficient than unfilled PMIA, while the wear rate of those composite decreased. Especially, CuCl is the optimal filler in the copper compounds investigated above. The filled PMIA composite containing CuCl, graphite, and short carbon fiber shows the best properties for frictional material. The friction coefficient of CuCl–PMIA composite is higher than that of unfilled PMIA because of the abrasive action of CuCl particle. It is probably the smooth surface of counterpart ring and composite block in the case of CuCl–G–PMIA that resulted in its lower wear rate and friction coefficient than that of CuCl–PMIA.

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