Friction and Wear Characteristics of Copper and Its Compound-Filled PTFE Composites Under Oil-Lubricated Conditions

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ABSTRACT: Four kinds of polytetrafluoroethylene (PTFE)-based composites, such as pure PTFE, PTFE + 30(v)%Cu, PTFE + 30(v)%Cu_2O, and PTFE + 30(v)%CuS composite, were prepared. Then the friction and wear properties of the PTFE composites filled with Cu, Cu_2O, or CuS sliding against GCr15-bearing steel under both dry and liquid paraffin-lubricated conditions were studied by using an MHK-500 ring-block wear tester. Finally, the worn surfaces and the transfer films of these PTFE composites formed on the surface of GCr15-bearing steel were investigated by using a scanning electron microscope (SEM) and an optical microscope, respectively. Experimental results show that the antiwear properties of these PTFE composites can be greatly improved by filling Cu, Cu_2O, or CuS to PTFE, and the wear of these PTFE composites can be decreased by two orders of magnitude compared to that of pure PTFE under dry friction conditions. Meanwhile, CuS increases the friction coefficient of the PTFE composite, but Cu and Cu_2O reduce the friction coefficients of the PTFE composites. However, the friction and wear properties of Cu, Cu_2O, or CuS-filled PTFE composites can be greatly improved by lubrication with liquid paraffin. The friction coefficients of these PTFE composites can be decreased by one order of magnitude compared to those under dry friction conditions, while the wear of these PTFE composites can be decreased by one to two orders of magnitude. The PTFE + 30(v)%Cu composite exhibits excellent friction and wear-reducing properties under higher loads in liquid paraffin-lubricated conditions, so the PTFE + 30(v)%Cu composite is much more suitable for application under oil-lubricated conditions in practice. Optical microscope investigation of transfer films shows that Cu, Cu_2O, and CuS enhance the adhesion of the transfer films to the surface of GCr15-bearing steel, so they greatly reduce the wear of the PTFE composites. However, the transfer of the PTFE composites onto the surface of GCr15-bearing steel can be greatly reduced by lubrication with liquid paraffin, but the transfer still takes place. SEM examination of worn surfaces shows that the interaction between liquid paraffin and the PTFE composites, especially the absorption of liquid paraffin into the surface layers of the PTFE composites, creates some cracks on the worn surfaces of Cu_2O or CuS-filled PTFE composites, the creation and development of the cracks reduces the load-carrying capacity of the PTFE composites; this leads to the deterioration of the friction and wear properties of the PTFE composites under higher loads in liquid paraffin lubrication. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci 70: 1455–1464, 1998

Key words: PTFE composites; copper and its compounds; oil lubrication; friction and wear; frictional surfaces

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Table I Chemical Composition of GCr15-Bearing Steel (wt %)

C	Mn	Si	Cr	P	S	Fe
0.950 ~ 1.050	0.200 ~ 0.400	0.150 ~ 0.350	1.300 ~ 1.650	<0.027	<0.020	Remainder

INTRODUCTION

It is known that copper (Cu) and its compounds CuO, Cu_2O, CuS, CuF_2, etc., are important inorganic fillers for polymers, their effects on the friction and wear behaviors of polymers, have been studied by some scholars. Bahadur et al.[1,2] studied the role of copper compounds as fillers in the transfer and wear of nylon (PA) and polyetheretherketone (PEEK). They found that copper compounds CuO, CuS, and CuF_2 enhanced the adhesion of the transfer films of PA or PEEK composites to the counterfaces; therefore, they greatly reduced the wear of the PA or PEEK composites. However, CuO, CuS, and CuF_2 increased the friction coefficients of the filled PA or PEEK composites. Bahadur and Tabor,[3] Tanaka et al.,[4] and Gong et al.[5,6] found that Cu, CuO, CuS, etc., were effective in reducing the wear of PTFE, but some of them increased the friction coefficient of PTFE. However, until now, almost all of these studies have been carried out under unlubricated (dry friction) conditions.

With the enlargement of application fields of the PTFE composites filled with copper and its compounds in practice, it is essential to study the friction and wear behaviors of copper and its compound-filled PTFE composites in fluid environments. It has been found that many polymers wear much more in water than in air, and the wear of the PTFE composites filled with only glass fibers is much greater than that of other PTFE composites in water.[7–9] However, until now, much less information has been available on the friction and wear behaviors of the PTFE composites filled with copper and its compounds under oil lubricated conditions.

The purpose of this work is to study the friction and wear behaviors of copper and its compound-filled PTFE composites under oil lubricated conditions, and give some insights into the friction and wear mechanisms of the PTFE composites in oil lubrication. It is expected that this study may be helpful to the application of copper and its compound-filled PTFE composites under oil-lubricated conditions in practice.

EXPERIMENTAL

The friction and wear tests were carried out on an MHK-500 ring-block wear tester (Timken wear tester) with a steel ring, which is 49.2 mm in diameter and 13.0 mm in length, rotating on a PTFE composite block, which is 12.3 × 12.3 × 18.9 mm in size. The surfaces of the PTFE composite blocks were polished with number 800 grade SiC abrasive paper to a surface roughness of $R_a = 0.2–0.4\ \mu m$. The steel ring, made of GCr15-bearing steel (SAE52100 steel, its chemical composition is listed in Table I), was polished with number 900 grade SiC abrasive paper to a surface roughness of $R_a = 0.15\ \mu m$.

The materials used for preparing the PTFE composites include PTFE powder with a grit size of about 30 μm, Cu, Cu_2O, and CuS powders about 76 μm. The proportion of fillers in the polymer (PTFE) in each case was 30% by volume. First, Cu, Cu_2O, and CuS powders were mixed completely with the PTFE powder, respectively, then the mixtures were molded and sintered into the PTFE composite blocks. Four kinds of PTFE-based composites, such as pure PTFE, PTFE + 30(v)%Cu, PTFE + 30(v)%Cu_2O, and PTFE

Table II Typical Characteristics of Liquid Paraffin

Viscosity ($\times 10^{-6}$ m^2 s^{-1})					
40°C	100°C	Viscosity Index	Flash Point (°C)	Boiling Point (°C)	Main Composition
21.49	4.42	117	226	>300	Paraffin

Table III Friction and Wear Results of Copper and Its Compound-Filled PTFE Composites Under Dry Friction Condition

Material	Friction Coefficient	Wear (mg)
PTFE	0.257	385.4
PTFE + 30(v)%Cu	0.242	1.4
PTFE + 30(v)%Cu_2O	0.245	5.9
PTFE + 30(v)%CuS	0.454	4.4

Sliding speed: 1.5 m/s; load: 100 N; time: 30 min.

+ 30(v)%CuS composite, were prepared. The lubricating oil used in the experiments was liquid paraffin (its typical characteristics are listed in Table II), which was added to the frictional surfaces at a rate of 30 drops per minute during the tests.

The friction and wear tests were performed at room temperature, with a sliding speed from 1.0 to 2.5 m/s and loads from 100 to 400 N for the dry friction conditions or 100 to 1200 N for the oil-lubricated conditions. Each friction and wear test was performed for 30 min. Before each test started, the surfaces of the PTFE composite block and the GCr15-bearing steel ring were cleaned by rubbing with a soft cloth dipped in acetone and then dried in air. The wear was detected by the weight loss of the PTFE composite blocks after each test by an analytical scale (precision, 0.1 mg). The friction coefficient was determined by measuring the friction torque, while the friction torque was detected by a torque measuring system. The friction coefficient was the average value of those in the last 10 min. Finally, the worn

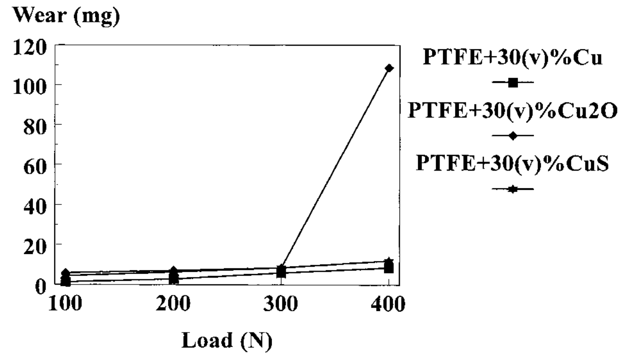

Figure 2 Variation of wear with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under dry friction conditions (sliding speed: 1.5 m/s).

surfaces of copper and its compound-filled PTFE composites were examined by using a JEM-1200EX/S scanning electron microscope (SEM), while the transfer films of the PTFE composites formed on the surface of GCr15-bearing steel ring were investigated by using an optical microscope.

RESULTS AND DISCUSSION

Friction and Wear Properties Under Dry Friction Conditions

The friction and wear results of copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under dry friction condition are shown in Table III. It can be seen from Table III that CuS increases the friction coefficient of the PTFE composite, but Cu and Cu_2O reduce the friction coefficients of the PTFE composites.

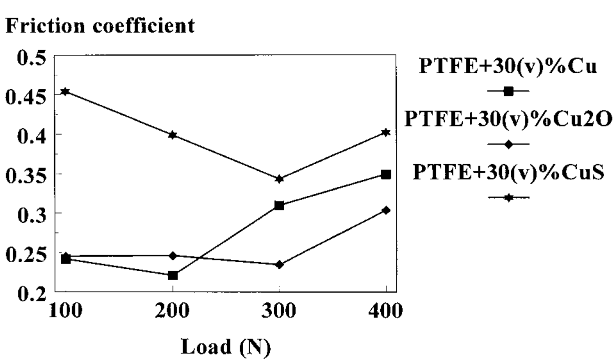

Figure 1 Variations of friction coefficients with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under dry friction conditions (sliding speed: 1.5 m/s).

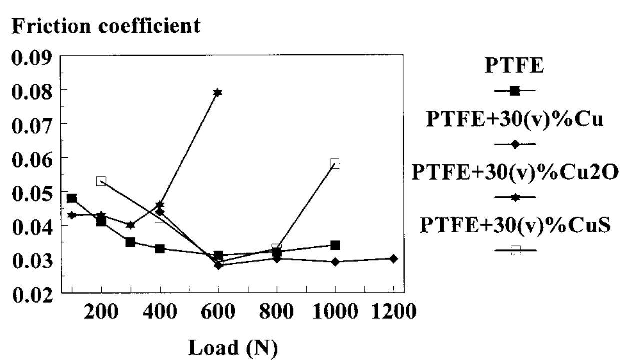

Figure 3 Variations of friction coefficients with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under lubrication of liquid paraffin (sliding speed: 2.5 m/s).

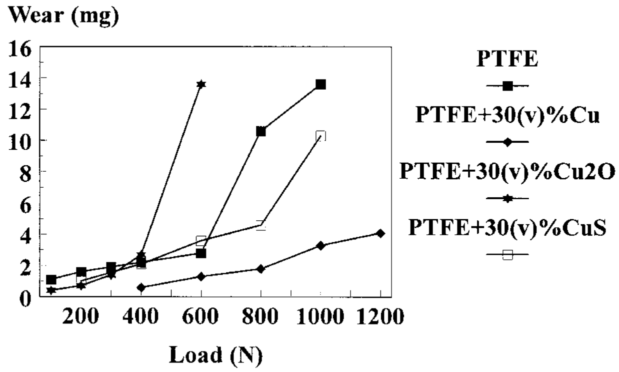

Figure 4 Variation of wear with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under lubrication of liquid paraffin (sliding speed: 2.5 m/s).

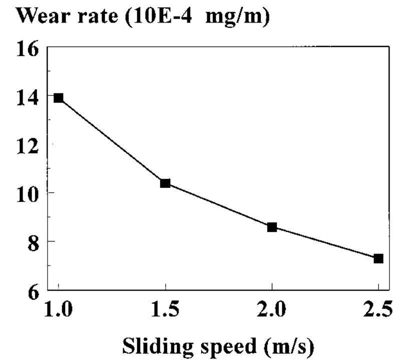

Figure 6 Variation of wear rate with sliding speed for PTFE + 30(v)%Cu composite sliding against GCr15-bearing steel under lubrication of liquid paraffin (load: 1000 N).

Therefore, the friction properties of the PTFE + 30(v)%Cu and PTFE + 30(v)%Cu_2O composites are better than that of the PTFE + 30(v)%CuS composite under dry friction conditions. Meanwhile, the results in Table III show that the antiwear properties of the PTFE composites can be greatly improved by filling Cu, Cu_2O, or CuS to PTFE, and the wear of the PTFE composites can be decreased by two orders of magnitude compared to that of pure PTFE. However, the wear-reducing action of Cu is the most effective, that of CuS is the second, and that of Cu_2O is the worst. Therefore, the friction and wear-reducing properties of the PTFE + 30(v)%Cu composite are the best of all under the dry friction condition.

The variations of friction coefficients and wear with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under dry friction conditions are shown in Figures 1 and 2, respectively. It can be seen from Figure 1 that the friction coefficients of the PTFE + 30(v)%Cu_2O and PTFE + 30(v)%CuS composites decrease with the increase of load from 100 to 300 N, and then increase as the load increases. But the friction coefficient of the PTFE + 30(v)%Cu composite decreases with the increase of load from 100 to 200 N, and then increases with the increase of load. When the load is higher than 200 N, the friction property of the PTFE + 30(v)%Cu_2O composite is the best, that of the PTFE + 30(v)%Cu composite is the second, and that of the PTFE + 30(v)%CuS composite is the worst. The results in Figure 2 show that the wear of Cu, Cu_2O, or CuS-filled PTFE composites increases with the increase of load under dry friction conditions. When the load is higher than 300 N, the wear of the PTFE + 30(v)%Cu_2O composite increases sharply, but the wear of the PTFE + 30(v)%Cu and PTFE + 30(v)%CuS composites is still very low. Therefore, the antiwear properties of the PTFE + 30(v)%Cu and PTFE + 30(v)%CuS composites are better than that of the PTFE + 30(v)%Cu_2O composite under dry friction conditions.

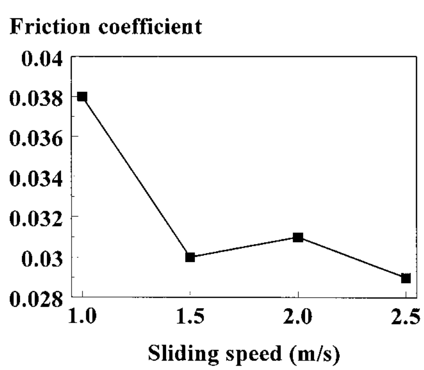

Figure 5 Variation of friction coefficient with sliding speed for PTFE + 30(v)%Cu composite sliding against GCr15-bearing steel under lubrication of liquid paraffin (load: 1000 N).

Friction and Wear Properties Under Oil-Lubricated Conditions

The variations of friction coefficients and wear with load for copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under lubrication of liquid paraffin are shown in Figures 3 and 4, respectively. Comparison the friction results in Figure 3 to those under dry friction conditions shows that the friction properties of copper and its compound-filled

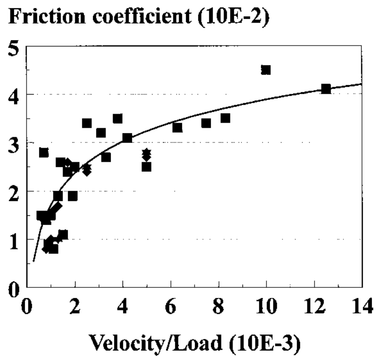

Figure 7 Variation of friction coefficient as a function of velocity/load for pure PTFE sliding against GCr15-bearing steel under the lubrication of liquid paraffin.

PTFE composites can be greatly improved by lubrication with liquid paraffin, and the friction coefficients of the PTFE composites can be decreased by one order of magnitude. Meanwhile, the results in Figure 3 show that, under lubrication of liquid paraffin, the friction coefficients of these PTFE composites first decrease with the increase of load, and then increase with the increase of load. Under higher loads in liquid paraffin lubrication, the friction property of the PTFE + 30(v)%Cu composite is better than those of the other PTFE composites. Comparison of the wear results in Figure 4 to those under dry friction conditions shows that the antiwear properties of copper and its compound-filled PTFE composites can be greatly improved by lubrication with liquid paraffin, and the wear of these PTFE composites can be decreased by one to two orders of magnitude. Meanwhile, the results in Figure 4 show that, under lubrication of liquid paraffin, the wear of copper and its compound-filled PTFE composites increases with the increase of load, and the antiwear property of the PTFE + 30(v)%Cu composite is better than those of the other PTFE composites. When the load increases to the load limits of the PTFE composites, the wear of these PTFE composites increases sharply.

The variations of friction coefficient and wear rate with sliding speed for the PTFE + 30(v)%Cu composite sliding against GCr15-bearing steel under lubrication of liquid paraffin are shown in Figures 5 and 6, respectively. The results in Figures 5 and 6 show that the friction coefficient and the wear rate of the PTFE + 30(v)%Cu composite decrease with the increase of sliding speed under lubrication of liquid paraffin. It is believed that, with the increase of sliding speed, a layer of lubricating oil film can be more easily formed on the rubbing surfaces, then the lubrication condition at the rubbing surfaces can be greatly improved; this would lead to the decrease of the friction and wear of the PTFE composite. Therefore, it can be deduced from the results in Figures 3 to 6 that the PTFE + 30(v)%Cu composite can be used in practice as a kind of PTFE composite that has excellent friction and wear properties under oil-lubricated conditions.

When the sliding speed is a constant, the variations of friction coefficients with load for copper and its compound-filled PTFE composites under lower loads in liquid paraffin lubrication can be described by the Stribeck's curves of friction coefficients against the Sommerfeld variable η**N/P,** where η is the viscosity of liquid paraffin, **N** is the rotation speed of GCr15-bearing steel ring and, **P** is the load applied.[10,11] At a constant sliding speed, the temperature at frictional surfaces increases with the increase of load, while the viscosity of liquid paraffin decreases with the increase of temperature but increases with the increase of load. The variations of viscosity with temperature and load result that the effect of viscosity on the Sommerfeld variable η**N/P** is so small compared to the effect of load on it that η**N/P** can be approximated to **N/P.** Figure 7 gives the variation of friction coefficient as a function of Velocity/Load (**N/P**) for pure PTFE sliding against GCr15-bearing steel under lubrication of liquid paraffin. The results in Figure 7 show that, at a constant sliding speed under lubrication of liquid paraffin, the friction coefficient of the PTFE decreases with the increase of load. Therefore, the variations of friction coefficients with load for copper and its compound-filled PTFE composites under lower loads in liquid paraffin lubrication can be explained properly by the Stribeck's curve as given in Figure 7. However, under higher loads in liquid paraffin lubrication, the temperature in-

Table IV Load Limits of Copper and Its Compound-Filled PTFE Composites Under Lubrication of Liquid Paraffin

Material	Load Limit (N)
PTFE	1000
PTFE + 30(v)%Cu	>1200
PTFE + 30(v)%Cu_2O	600
PTFE + 30(v)%CuS	1000

Sliding speed: 2.5 m/s.

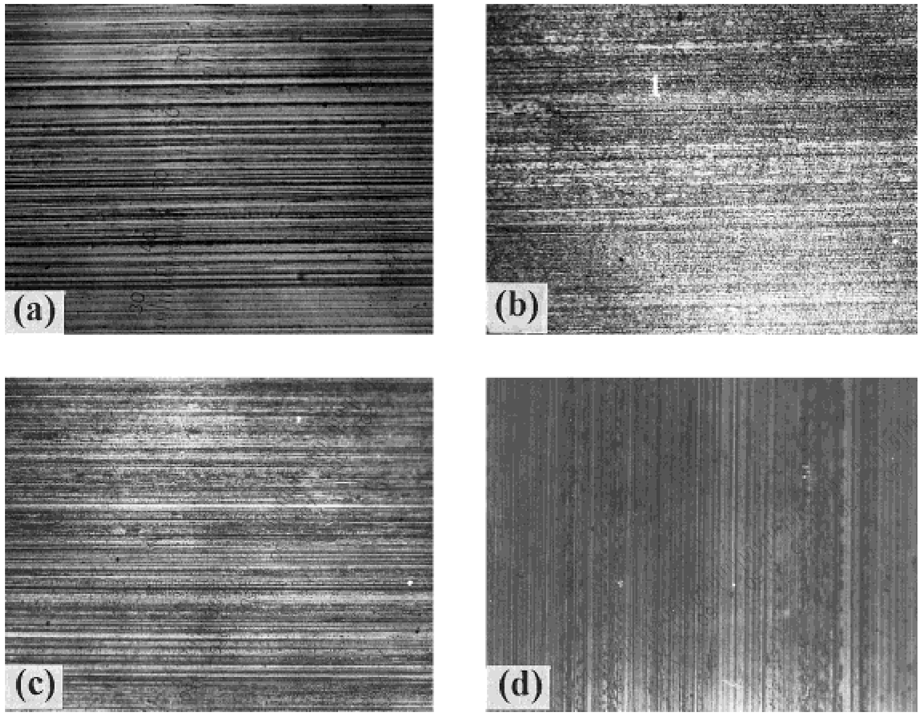

Figure 8 Optical micrographs of transfer films formed on the surface of GCr15-bearing steel for copper and its compound-filled PTFE composites under dry friction condition (128×; sliding speed: 1.5 m/s; load: 100 N): (a) PTFE; (b) PTFE + 30(v)%Cu; (c) PTFE + 30(v)%Cu_2O; (d) PTFE + 30(v)%CuS.

crease at rubbing surfaces results in the reduction of mechanical strength and load-carrying capacity of the PTFE composites; this would further lead to the increase of the friction and wear of the PTFE composites.

It was found in the experiments that there were some serious deformation or obvious cracks on the worn surfaces of pure PTFE and copper compound-filled PTFE composites under certain loads in liquid paraffin lubrication, but no serious deformation or obvious cracks occurred on the worn surface of the PTFE + 30(v)%Cu composite, even under the load of 1200 N. The loads under which serious deformation or obvious cracks occurred on the worn surfaces of the PTFE composites are the load limits of the PTFE composites in liquid paraffin lubrication.

Table IV gives the load limits of copper and its compound-filled PTFE composites sliding against GCr15-bearing steel at the sliding speed of 2.5 m/s in liquid paraffin lubrication. It can be seen from Table IV that the load limits of pure PTFE and the PTFE + 30(v)%CuS composite are 1000 N, while that of the PTFE + 30(v)%Cu_2O composite is 600 N, but the load limit of the PTFE + 30(v)%Cu composite is higher than 1200 N. This indicates that Cu increases the load-carrying capacity of the PTFE composite, but copper compounds Cu_2O and CuS reduce the load-carrying capacity of the PTFE composites. It is believed that the interaction between liquid paraffin and the PTFE composites, especially the absorption of liquid paraffin into the surface layers of the PTFE composites, reduces the mechanical strength and load-carrying capacity of the PTFE composites[12,13]; this would lead to the deterioration of the friction and wear properties of copper and its compound-filled PTFE composites under higher loads in liquid paraffin lubrication. Therefore, the friction and wear of the PTFE composites increase rapidly with the increase of load under higher loads in liquid paraffin lubrication. When the load increases to the load limits of the PTFE composites, the friction and wear of the PTFE composites increase sharply.

Optical Microscope Investigation of Transfer Films

The optical micrographs of the transfer films formed on the surface of GCr15-bearing steel for

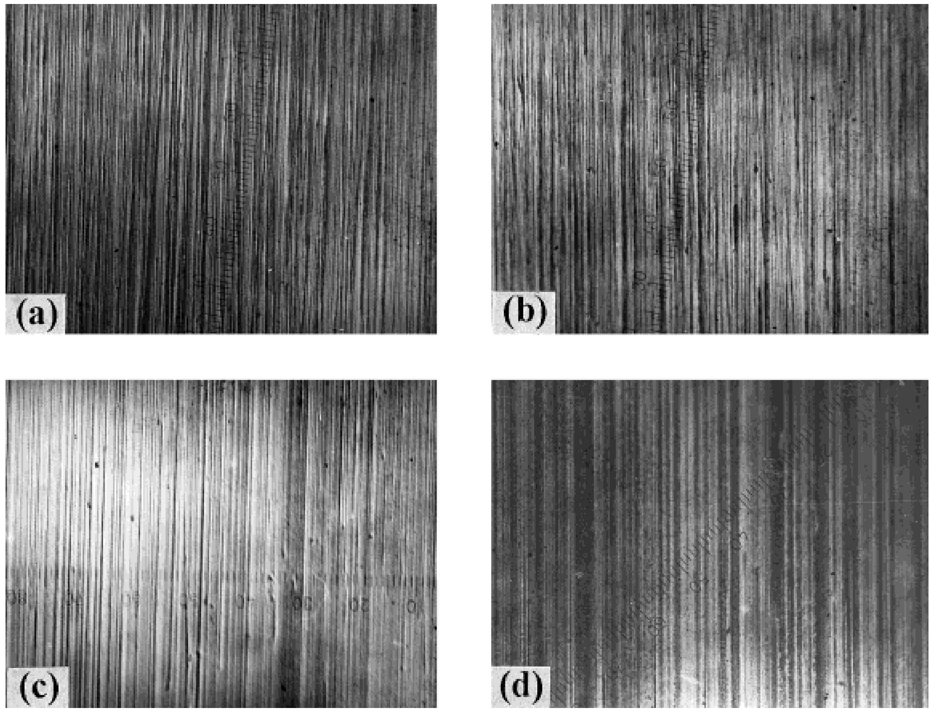

Figure 9 Optical micrographs of transfer films formed on the surface of GCr15-bearing steel for copper and its compound-filled PTFE composites under lubrication of liquid paraffin (128×; sliding speed: 2.5 m/s): (a) PTFE, 1000 N; (b) PTFE + 30(v)%Cu, 1000 N; (c) PTFE + 30(v)%Cu_2O, 300 N; (d) PTFE + 30(v)%CuS, 1000 N.

copper and its compound-filled PTFE composites under both dry and liquid paraffin lubricated conditions are shown in Figures 8 and 9, respectively. It can be seen from Figure 8 that there are some obvious transfer films formed on the surface of GCr15-bearing steel for Cu, Cu_2O, or CuS-filled PTFE composites under dry friction conditions, but no obvious transfer films formed on the surface of GCr15-bearing steel for pure PTFE. Correlating the above investigations with the results of friction and wear tests in dry friction conditions, it is believed that Cu, Cu_2O, and CuS enhance the adhesion of the transfer films to the surface of GCr15-bearing steel, and thus promote the transfer of the PTFE composites onto the surface of GCr15-bearing steel, so they greatly reduce the wear of the PTFE composites.[3,14] Meanwhile, the results in Figure 8 show that the transfer films formed on the surface of GCr15-bearing steel for Cu or Cu_2O-filled PTFE composites are much thicker than that of CuS-filled PTFE composite. This indicates that the PTFE composites filled with Cu or Cu_2O can easily form transfer films on the surface of GCr15-bearing steel; then the friction between the PTFE composites and GCr15-bearing steel can be transformed to the friction between the PTFE composites and its transfer films formed on the surface of GCr15-bearing steel. Therefore, the friction properties of Cu or Cu_2O-filled PTFE composites are better than that of CuS-filled PTFE composite under dry friction conditions.

Comparison the results in Figure 9 to those in Figure 8 shows that the transfer of Cu, Cu_2O, or CuS-filled PTFE composites onto the surface of GCr15-bearing steel can be greatly reduced by lubrication with liquid paraffin, but the transfer still takes place.[15,16] It is believed that, under lubrication of liquid paraffin, the formation of lubricating oil films on the rubbing surfaces changes the contact form of the friction pair, and greatly improves the lubrication condition of the frictional surfaces, so the friction and wear as well as the transfer of the PTFE composites can be greatly reduced. The above investigation analysis results are consistent with the results of the friction and wear tests.

SEM Examination of Worn Surfaces

It was found in the experiments that the width of the wear scar on the worn surface of pure PTFE

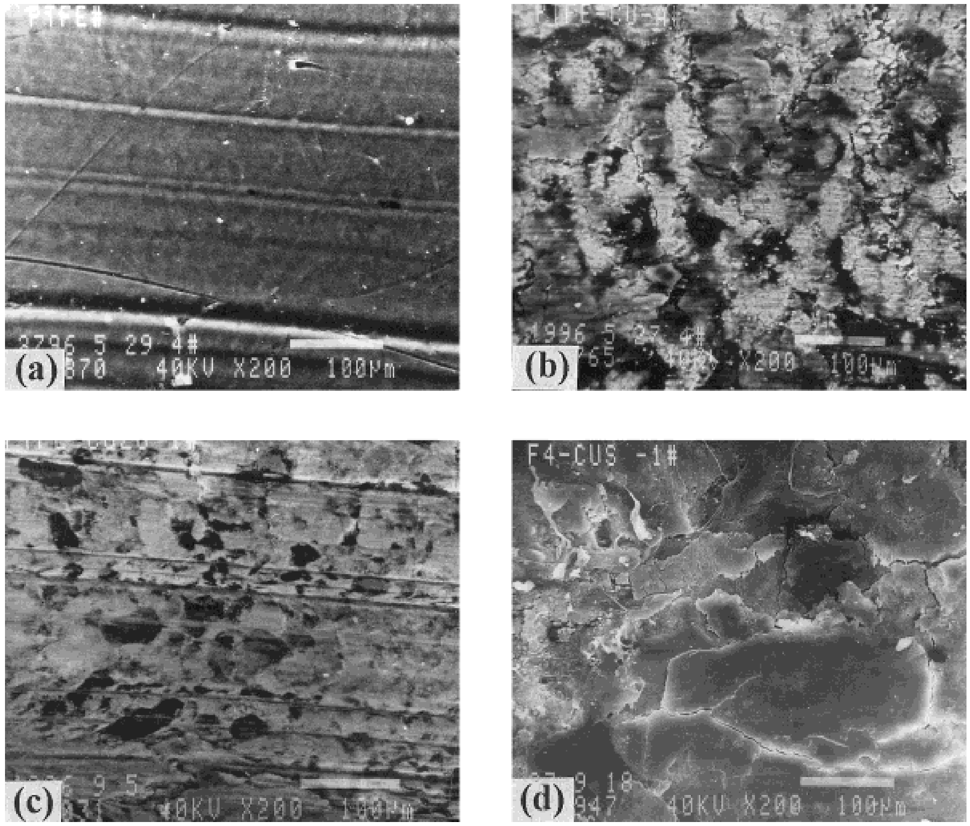

Figure 10 Electron micrographs of the worn surfaces of copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under dry friction conditions (sliding speed: 1.5 m/s; load: 100 N): (a) PTFE; (b) PTFE + 30(v)%Cu; (c) PTFE + 30(v)%Cu_2O; (d) PTFE + 30(v)%CuS.

was about 12 mm in the dry friction condition, but the width and the depth of the wear scars on the worn surfaces of Cu, Cu_2O, or CuS-filled PTFE composites were much smaller than those of pure PTFE. Figure 10 gives the electron micrographs of the worn surfaces of Cu, Cu_2O, or CuS-filled PTFE composites sliding against GCr15-bearing steel under dry friction conditions. It can be seen from Figure 10 that there are still some smaller wear scars in the large wear scar of pure PTFE, but the wear scars on the worn surfaces of Cu, Cu_2O, or CuS-filled PTFE composite are smaller than those of pure PTFE, and the wear scars on the worn surface of Cu-filled PTFE composite are the smallest of all. Therefore, it can be deduced that filling Cu, Cu_2O, or CuS to PTFE can greatly reduce the wear of PTFE, but the wear-reducing action of Cu is more effective than those of Cu_2O and CuS.

The electron micrographs of the worn surfaces of the PTFE composites filled with copper and its compounds sliding against GCr15-bearing steel under lubrication of liquid paraffin are shown in Figure 11. It can be seen from Figure 11 that there are still some obvious wear scars on the worn surface of pure PTFE under lubrication of liquid paraffin, but no obvious wear scars on the worn surfaces of Cu, Cu_2O, or CuS-filled PTFE composites. However, there are some obvious cracks on the worn surfaces of Cu_2O or CuS-filled PTFE composites, but no cracks on the worn surface of the Cu-filled PTFE composite. It is believed that the interaction between liquid paraffin and the PTFE composites, especially the absorption of liquid paraffin into the surface layers of the PTFE composites, creates some cracks on the worn surfaces of Cu_2O or CuS-filled PTFE composites, the creation and development of these cracks reduces the load-carrying capacity of the PTFE composites, and so, in turn, leads to the deterioration of the friction and wear properties of the PTFE composites under higher loads in liquid paraffin lubrication. These investigation

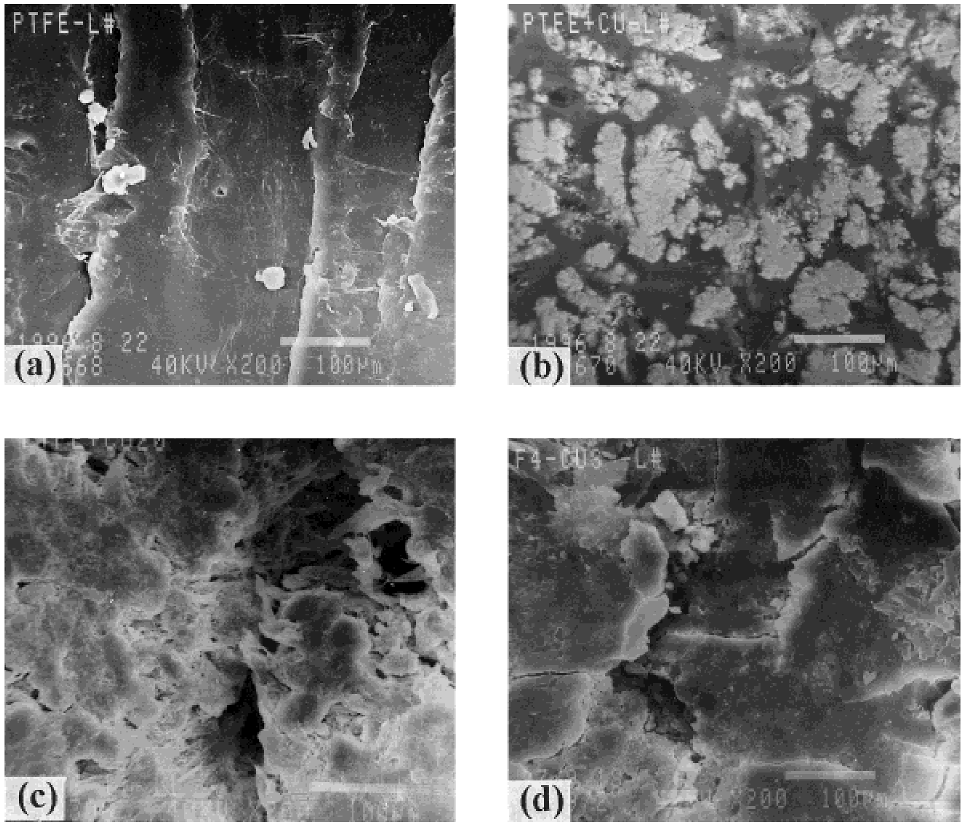

Figure 11 The electron micrographs of the worn surfaces of copper and its compound-filled PTFE composites sliding against GCr15-bearing steel under lubrication of liquid paraffin (sliding speed: 2.5 m/s): (a) PTFE, 1000 N; (b) PTFE + 30(v)%Cu, 1000 N; (c) PTFE + 30(v)%Cu_2O, 600 N; (d) PTFE + 30(v)%CuS, 1000 N.

and analysis results are consistent with the results of friction and wear tests.

CONCLUSIONS

1. The antiwear properties of the PTFE composites can be greatly improved by filling Cu, Cu_2O, or CuS to PTFE, and the wear of the filled PTFE composites can be decreased by two orders of magnitude compared to that of pure PTFE under friction conditions. However, the wear reducing action of Cu is the most effective, that of CuS is the second, and that of Cu_2O is the worst.
2. Filling Cu or Cu_2O to PTFE reduces the friction coefficients of the PTFE composites, but filling CuS to PTFE increases the friction coefficient of the PTFE composite. Therefore, the friction properties of Cu or Cu_2O-filled PTFE composites are better than that of CuS-filled PTFE composite under dry friction conditions.
3. The friction and wear properties of Cu, Cu_2O, or CuS-filled PTFE composites can be greatly improved by lubrication with liquid paraffin. The friction coefficients of these PTFE composites can be decreased by one order of magnitude compared to those under dry friction conditions, while the wear of these PTFE composites can be decreased by one to two orders of magnitude.
4. Under lubrication of liquid paraffin, the wear of Cu, Cu_2O, or CuS-filled PTFE composites increases with the increase of load, but the friction coefficients of these PTFE composites first decrease with the increase of load, and then increase as the load increases. Meanwhile, the friction coefficient and the wear rate of the PTFE + 30(v)%Cu composite decrease with the increase of

sliding speed under lubrication of liquid paraffin.

5. The friction and wear properties of the PTFE + 30(v)%Cu composite are better than those of the other PTFE composites under higher loads in liquid paraffin lubrication. Therefore, the PTFE + 30(v)%Cu composite is much more suitable for application under oil-lubricated conditions in practice.
6. Cu, Cu_2O, and CuS enhance the adhesion of the transfer films to the surface of GCr15-bearing steel, and thus promote the transfer of the PTFE composites onto the surface of GCr15-bearing steel, so they greatly reduce the wear of the PTFE composites. However, the transfer of Cu, Cu_2O, or CuS-filled PTFE composites onto the surface of GCr15-bearing steel can be greatly reduced by lubrication with liquid paraffin, but the transfer still takes place.
7. The interaction between liquid paraffin and the PTFE composites, especially the absorption of liquid paraffin into the surface layers of the PTFE composites, creates some cracks on the worn surfaces of Cu_2O or CuS-filled PTFE composites. The creation and development of these cracks reduces the load-carrying capacity of the PTFE composites. This leads to the deterioration of the friction and wear properties of the PTFE composites under higher loads in liquid paraffin lubrication. When the load increases to the load limits of the PTFE composites, the friction and wear of the PTFE composites increase sharply.

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