Friction and Wear Characteristics Of Electrodeposited Copper Composites

By V. Bhalla, C. Ramasamy, N. Singh and M. Pushpavanam

Composite coatings, with their synergistic behavior, are more readily adapted to adjust to changing industrial environments. One such coating that has received attention recently is the copper composite, containing selflubricating particles, utilized in areas where exceptionally low friction and good release are required. This paper concerns the friction and wear properties of copper composites containing graphite, molybdenum disulfide, and PTFE particles as the dispersoids.

Use of solid lubricants is an effective alternative to boundary condition lubrication.^{1,2} A solid lubricant can generally be defined as a material that provides lubrication to two relatively moving surfaces, in contact, under dry conditions, to reduce friction and wear.

Solid lubricants are generally considered for use where grease and oil lubricants cannot be used. Such conditions include high temperatures, excessively low temperatures, or high vacuum. Although solid lubricants are, by necessity, used in such extreme conditions, they can also be used advantageously in moderate conditions and in situations where ordinary lubricants, such as oil and grease are adequate.² Several kinds of solid lubricants, such as polytetrafluoroethylene (PTFE), graphite, talc, mica, flowers of sulfur and white lead are used as solid lubricants.

Electrodeposition of composite coatings consisting of second-phase particulate material dispersed in a metal matrix is gaining importance for potential engineering applications.³ By codepositing self-lubricants in a metal matrix the need for periodic lubrication of the component is eliminated and the range of temperature, loads, and speeds at which the material can be used increase considerably.⁴⁻⁶ Other special advantages are the virtual absence of waste, or spent lubricant, and greater chemical stability. Where access after assembly is difficult or impossible, a solid lubricant is clearly advantageous.^{7,8} This paper presents the friction and wear properties of copper composites containing graphite, molybdenum disulfide and PTFE.

Experimental Procedure

A conventional acid copper bath containing 200 g/L copper sulfate and 80 g/L sulfuric acid, with suitable pretreatments, was used as the electrolyte.⁹ Graphite powder (1-3 μ m) was treated with trichloroethylene to remove greasy matter, then dried. It was then treated with 10-percent v/v nitric acid to remove metallic impurities, washed free of acid, rinsed and dried. Analytical grade molybdenum disulfide (1-3 μ m), was used as such without pretreatment. A PTFE suspension containing 40 percent PTFE was treated with warm alkali, washed free of alkali and preserved as a suspension in water. This treatment is essential because the particles settle easily on the substrate only with this treatment.

The particles were blended with a little of the plating electrolyte along with 0.2 mL/L of a non-ionic wetting agent, then introduced into 800 mL of the bulk electrolyte. The PTFE suspension with a known mass of PTFE was directly added to the plating electrolyte containing the wetting agent and stirred well to provide a uniform suspension. The electrolyte was placed in a cylindrical glass cell 15 cm in diam. and 7.5 cm in height and positioned on a magnetic stirrer/heater.

Cathodes, made of cold-rolled steel, were positioned in the horizontal plane with the anodes kept above them, maintaining an interelectrode distance of 5 cm. Special jigging arrangements were used for each type of specimen. Steel specimens $2.5 \times 7.5 \times 0.1$ cm, $10 \times 10 \times 0.1$ cm and discs of 3 cm diam. x 0.5 cm thick were used for cathode efficiency determination, wear testing and friction measurement respectively. Polished steel substrates were electrocleaned cathodically, then anodically, dipped in 5-percent hydrochlo-



Fig. 1—Effect of concentration of particles in suspension on the wear index. Scale I at 30 °C. Scale II at 50 °C.



Fig. 2—Effect of cathode current density on the wear index.



Fig. 3—Effect of cycle increase on the wear index.

ric acid, washed, rinsed and given a copper strike $5 \,\mu m$ thick from a rochelle copper bath. The deposits were dried and unneeded portions were masked suitably prior to composite plating.

The exposed portions of the specimens were cathodically cleaned to remove the tarnish film prior to composite plating. Deposition was conducted for one hr at 2.0 A/dm² at 30 ± 2 °C unless otherwise stated. The electrolyte was stirred for one min after every five min to bring the particles into suspension, followed by sedimentation. Fresh electrolytes were used after each set of experiments.

The hardness of the deposits was determined by the Vickers indentation method at a load of 20 g. The specimens were mechanically polished and degreased before the measurement to get a clear indentation.

The wear resistance of the composites was determined using a Taber abraser at a load of 1 kg and CS10 calibrase wheel. The wear loss and wear index were calculated in the usual manner. The effect of changing the load and the cycles were also estimated.

The coefficient of friction was determined using a special device as described earlier.¹⁰ It was measured by abrading the specimens under a constant load of 2.25 kg at a speed of 1200 rpm. The coefficient was calculated using the formula







Fig. 4—Effect of concentration of particles in the suspension on the coefficient of friction. Scale I at 30 °C. Scale II at 50 °C.

where u = Coefficient of frictionT = Frictional torque in N-m F = Applied load in N D = Diam. of test specimen in m

The effects of the applied load and speed on the coefficient were also estimated. The structure of the composites was examined with a metallurgical microscope.

Results and Discussion

In sedimentary codeposition, the settling rate of the particles plays a major role because they block the sites available for metal deposition. In the case of graphite and molybdenum disulfide, the particles were conductive and did not totally inhibit metal deposition. Being inert, the particles completely blocked nucleation sites for deposition and with increasing particle density and, at higher current densities, caused a wavy, non-uniform appearance.

The hardness of the electrocomposites showed a slight decrease with increasing particle content, possibly attributable to the sliding and soft nature of the lubricating particles (Table 1).

Figures 1 and 2 illustrate the wear behavior of the three composites with increasing particulate concentration, current density and operating temperature. Cu-PTFE composite showed the lowest wear index, with Cu-graphite the highest. The high wear rate of the latter may be a result of the rough nature of the composite. As observed earlier, increased bath temperature resulted in more copper deposition, decreasing



Fig. 5—Effect of cathode current efficiency on the coefficient of friction. | Fig. 6—Effect of increasing load on the coefficient of friction.



Fig. 7—Photomicrographs of deposits: (a) pure copper; (b)-(g) Cu-graphite and Cu-MoS₂ at 2, 15, and 10 g/L, respectively, at 4 A/dm²; (h)-(j) Cu-PTFE with 10, 40 and 40 g/L, respectively, at 4 A/dm².

the particle-to-metal ratio. Moreover, at high operating temperatures, the deposit obtained was quite rough, resulting in higher wear index (Table 2).

As wear occurs, the top layer of the composite, which always has relatively great roughness, wears easily, showing a high wear index. As wear proceeds, however, a glaze develops on the surface¹¹ and the wear index drops considerably. Accordingly, the true picture of wear resistance is brought out only with extended cycles of testing. As indicated in Fig. 3, after 2000 cycles, all three composites had an almost similar wear index. Consequently, it could be understood that the high wear index observed in the case of coppergraphite is caused by the roughness of the initial surface, a common phenomenon prevalent while codepositing conducting particles.¹²

When the load applied for testing wear is increased, the wheel comes into intimate contact with the deposit, resulting in more abrasion. This is clearly seen in Fig. 3 and Table 3.

The results of the determination of the coefficient of friction are shown in Figs. 4-6 and in Tables 4 and 5. The coefficient increased with increase in particle percentage in the deposit. Contrary to the wear testing results, Cu-PTFE showed a higher value than the other two. This behavior is almost similar to the wear results obtained after 2000 cycles. Minimum friction was experienced when deposition was conducted at 2.0 A/dm² and 30 °C.

With increasing load, the friction should decrease, because load is inversely proportional to u. A similar trend is observed in Fig. 6, where the Cu-graphite system showed the least coefficient of friction compared to the other two systems. It was also observed that the speed of rotation caused negligible change in the coefficient of friction.

Table 1Hardness (VHN) of Copper Composites

Amount of Solid Lubricant (g/L)	Cu Graphite	Cu MoS ₂	Cu PTFE
0	72	72	72
2	65	68	60*
5	60	62	_
* with 10 g/L PTFE.			

Table 2
Effect of Solution Temperature on the Wear Index

Composite	30 °C	50 °C
Cu-Graphite	210	274
Cu-MoS ₂	151	180
Cu-PTFE	148	160

Table 3Effect of Applied Load on the Wear Index

Composite	0.5 kg	1.0 kg
Cu-Graphite	143	210
Cu-MoS ₂	103	151
Cu-PTFE	130	148

Table 4
Effect of Temperature on the Coefficient of Friction

Composite	30 °C	50 °C
Cu-Graphite	0.41	0.56
Cu-MoS ₂	0.45	0.48
Cu-PTFE	0.50	0.52

Table 5
Effect of Rotational Speed on the Coefficient of Friction

Composite	1200 rpm	1300 rpm
Cu-Graphite	0.41	0.44
Cu-MoS ₂	0.45	0.46
Cu-PTFE	0.50	0.50

The difference in the wear and friction results should be attributed mainly to the roughness of the top layer. The friction measurement involves intimate metal-to-metal contact at high loads and high rpm, the abrading surface being a high-strength tool steel. Consequently, the top layer is removed rapidly, whereas relatively long duration is needed in wear testing.

Surface topography of the composites is shown in Fig. 7. In Figs. 7b and 7c, the graphite powder is uniformly distributed at 2 g/L concentration, but strongly agglomerated in Fig. 7c. The deposit obtained at 4 A/dm² shows nodular growth (Fig. 7d). A similar trend is observed with Cu-MoS₂ composites, as in Figs. 7e-g. In the case of Cu-PTFE composite (Figs. 7h-j), the particle size of PTFE is much smaller than the other two. Even with 10 g/L concentration in the bath, almost complete coverage is observed in the deposit. With 40 g/L concentration, severe agglomeration could be observed, and

at 4 A/dm^2 , copper deposition has occurred with assorted outgrowth, which should account for the wavy nature of the deposit.

Conclusions

Based on friction measurements, copper-graphite composite appeared to be the best self-lubricating coating. Wear testing should be carried out for extended cycles in order to realize the self-lubricating nature.

Editor's note: Manuscript received, February 1995; revision received, May, 1995.

References

- 1. L.C. Lipp, Lubrication Eng., 32, 11, 574 (1976).
- 2. M.P.Petersen, ibid., **31**, 7, 357 (1975).
- 3. J.R. Roos, J.P. Celis, J. Fransaer and C. Buelens, J. *Metals*, **42**, 60 (1990).
- 4. M. Ghouse and E.G. Ramachandran, *Metal Fin.*, **76**(6), 85 (1981).
- 5. M. Ghouse, M. Viswanathan and E.G.Ramachandran, *Metal Fin.*, **78**(11), 55 (1980).
- 6. M. Ghouse, M. Viswanathan and E.G.Ramachandran, *Metal Fin.*, **78**(3), 31 (1981).
- 7. Products Fin., 56(7), 50 (1992).
- 8. H. Matsuda, Y. Kiyono, M. Nishira and O. Takano, *Trans. Inst. Met. Fin.*, **72**(5), 55 (1994).
- 9. F.A. Lowenheim, Ed., *Modern Electroplating*, John Wiley & Sons, New York, NY, 1974.

- 10. E.C. Kedward, Plat. and Surf. Fin., 56, 38 (Aug. 1978).
- 11. R. Bazzard and P.J. Boden, Trans. Inst. Met. Fin., 50, 207 (1972).
- 12. M. Pushpavanam, N. Arivalagan, N. Srinivasan, P. Santhakumar and S. Suresh, submitted to *Plat. and Surf. Fin.*

About the Authors

Vineet Bhalla holds a BS in mechanical engineering from Annamalai University, Annamalai Nagar 608 002, Tamil Nadu, India.

C.T. Ramasamy is pursuing an M. Tech. at the Indian Institute of Technology, Bombay. He holds a BS in mechanical engineering from Annamalai University.

Navneet Singh holds a BS in mechanical engineering from Annamalai University and is currently employed in Madras, Tamil Nadu.



Dr. Malathy Pushpavanam is a researcher at the Central Electrochemical Research Institute (CECRI), Karaikudi 623 006, India. She is a graduate of Madras University, has published more than 40 papers and holds 12 patents in metal finishing.