The Tribological Behavior Of Electroless Ni-P-SiC (Nanometer particles) Composite Coatings

by X. Huang,* Y. Wu & L. Qian

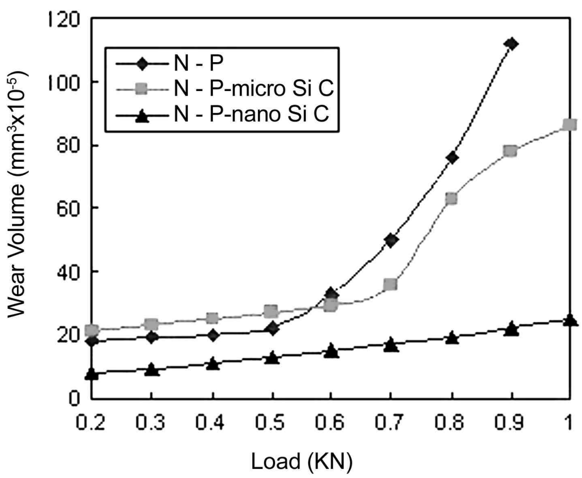

Fig. 1—Dependence of wear volume on load.

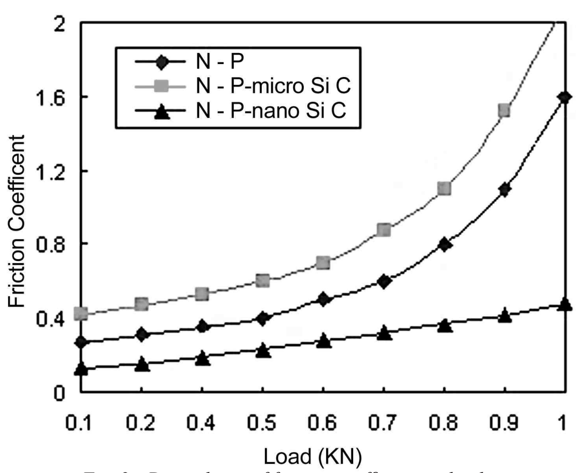

Fig. 2—Dependence of friction coefficient on load.

The tribological behavior of electroless nickel-phosphorus-silicon carbide (Ni-P-SiC) (nanoparticulate SiC) composite coating was studied and compared with Ni-P-SiC (microparticulate SiC) and electroless Ni-P composite coatings. The results showed that the Ni-P-SiC (nanoparticulate SiC) coating had the highest wear resistance and the lowest friction coefficient. Under high loads in particular, its wear resistance was far superior to the other two coatings.

In order to improve the wear-resistance of electroless Ni-P composite coatings, a new type of surface coating consisting of microparticles has been studied extensively.[1,2] The wear resistance and hardness of these microparticulate coatings are better than those of simple electroless Ni-P coatings,[3,4] although they have the same characteristic of hardness and wear resistance varying with heat treatment temperature. Optimum performance is reached at about 400°C (752°F). One disadvantage of incorporating microparticulates, is that, under practical wear conditions, the microparticles are easily separated from the surface and act as abrasives. The development of nanoparticulate materials however, brings composite deposits into a new paradigm.[5]

In this paper, the preparation and tribological behavior of composite coatings containing nanoparticles are presented. This work provides experiment data for further research and application of nanoparticulate composite deposition.

Experimental

Table 1 gives the solution composition and operating conditions of for the composite plating solutions under study. Deposits with high phosphorus content (~9 to 10%) were obtained. The size of the SiC nanoparticles was about 30 nm, as indicated by transmission electron microscopy. The SiC content in the coating was ~9% with particle sizes ranging from 30 to 80 nm.

Quenched and tempered medium steel bars (6×6×30 mm; 0.24×0.24×1.18 in.) were used as substrates. Samples for heat treatment were individually treated at 200, 300, 400, 500 and 600°C (392, 572, 752, 932 and 1112°F) under a protective atmosphere after plating. Wear-resistance was tested by an MM-200 wear tester under lubricated condi-

Nuts & Bolts: What This Paper Means to You

No plating process can work unless there is adequate cleaning and rinsing. At the same time, these operations generate wastewater, spent solutions and sludge, and as a result, use too much water, energy and chemicals ($$$). This paper covers a mathematical means of providing the most effective cleaning and rinsing with the least production of waste and consumption of resources. While the math may be daunting to some, there is likely an engineer in many organizations who could put this information to good use.

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tions. Friction rings, ϕ40×10 in size, were made of medium steel. The lubricating oil used was #20 machine oil.

The friction coefficient was automatically recorded during the wear testing. The wear capacity was equivalent to the volume of the grinding crack. The structure of the composite coating and the appearance of grinding crack were observed separately by TEM and SEM.

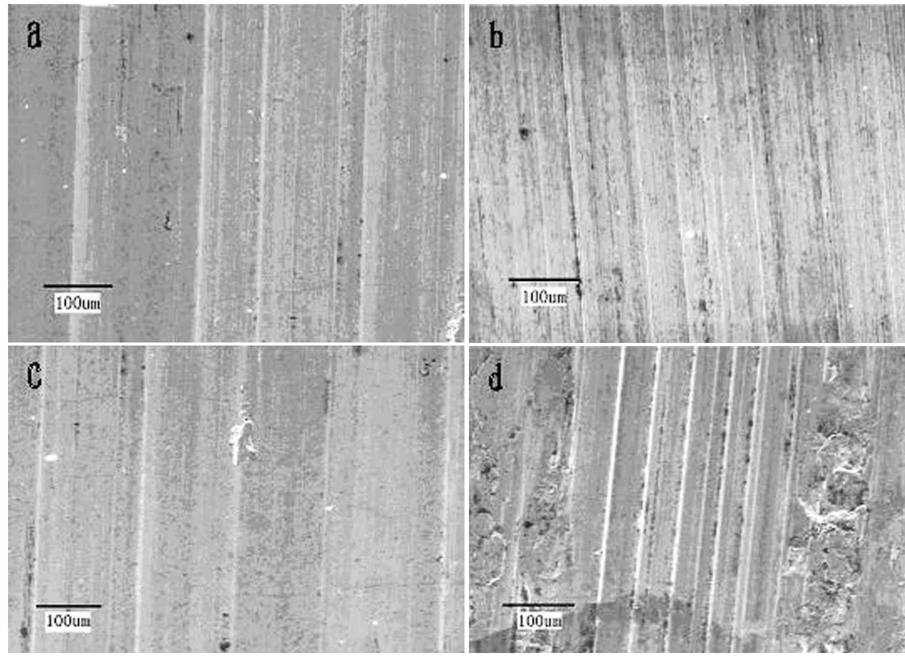

Fig. 3—The wear scar of (a) Ni-P/nano-SiC coating under 0.5 kN load; (b) Ni-P/micro-SiC coating under 0.5 kN load; (c) Ni-P/nano-SiC coating under 0.8 kN load; (d) Ni-P/micro-SiC coating under 0.8 kN load.

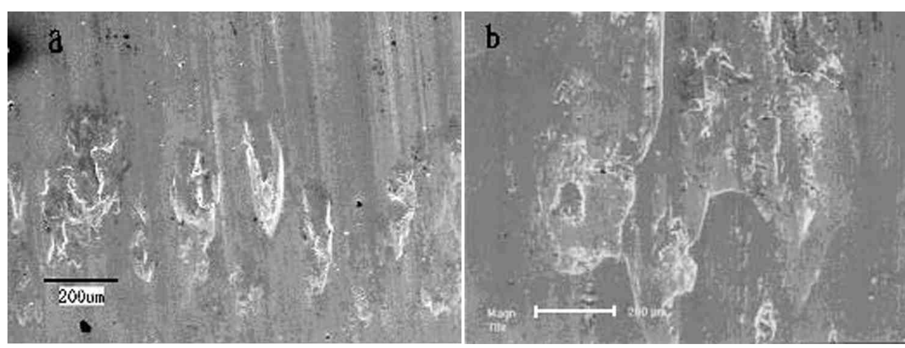

Fig. 4—The sticking friction mark of (a) Ni-P/nano-SiC coating and (b) Ni-P/micro-SiC coating.

Results & Discussion

Figures 1 and 2 show the wear test results. The coatings were all treated at 400°C (752°F) for 1 hr before the wear test. The lubricating conditions were held constant. From Fig. 1, we found that the effect of varying the test load yielded different results for the three different coatings. The wear volume of the nanoparticulate composite increased linearly with increasing load, albeit a small increase. Under low loads, the linear behavior was also observed with electroless Ni-P and the microparticulate composite. At higher loads however, for those two coatings, the linear relationship no longer obtained and the wear volume increased sharply.

Figure 2 shows that the coefficient of friction of the nanoparticulate composite increased slightly with load, even under high loads. On the other hand, the friction coefficients of the electroless Ni-P and the microparticulate composite coatings increased sharply. This indicates that friction and wear are interrelated. When the load was increased, the wear volume increased rapidly. The resulting damage to the surface would then lead to a rapid increase in friction. Further, the friction produced an increase in temperature, which further exacerbated the wear. With this interrelationship between friction and wear, the wear volume of many coating materials increases exponentially.

Figure 3 contains photographs of the wear surfaces of the two SiC composite materials under two loads, 0.5 and 0.8 kN. The wear surface of the nanoparticulate composite coating was the smoothest (Figs. 3a & c). By contrast, obvious scuffing and furrow lines can be seen on the surfaces of the microparticulate composite coating. We can conclude that the wear-resistance of the nanoparticulate Ni-P-SiC coating was superior to that of the other two coatings.

When the load was further increased to 1.6 kN, lubricant wear turned into dry friction. Severe sticking friction occurred on the surface of the microparticulate composite coating, but only slight friction appeared on the surface of the nanoparticulate material. These results can be seen in Fig. 4.

From these results, we can see that, under low load, there was little difference in wear-resistance among the three coatings. Under high load however, there was a marked distinction. The high wear-resistance of the nanoparticulate coating derives from its structure and mechanical properties. The curves in Fig. 5 show the response to heat treatment temperature among the three coatings. Once again, the behavior of the nanoparticulate coating differed from the other two coatings. For the electroless and microparticulate coatings, the maximum hardness was obtained at 400°C (752°F), while the nanoparticulate coating reached its peak hardness at 500°C (932°F). At 600°C (1112°F) the hardness of the electroless and microparticulate coatings fell to 800 VHN, but that for the nanoparticulate remained above 1000 VHN.

The matrices of these coatings are all Ni-P alloys with high phosphorous content. The structure of this type of alloy gradu-

Table
Composition & Plating Conditions of the Composite Plating Solutions

	Bath 1 (Ni-P)	Bath 2 (Ni-P/micro-SiC)	Bath 3 (Ni-P/nano-SiC)
$NiSO_4•6H_2O$ (g/L)	18	18	18
$NaH_2PO_2•H_2O$ (g/L)	24	24	24
Boric Acid (g/L)	12	12	12
$CH_3COONa•3H_2O$ (g/L)	9	9	9
Pb^{+2} (mg/L)	4	4	4
Particle SiC (g/L)		8 (<3µm)	8 (30-50nm)
Dispersion Mode	Air agitation	Air agitation	Ultrasonic

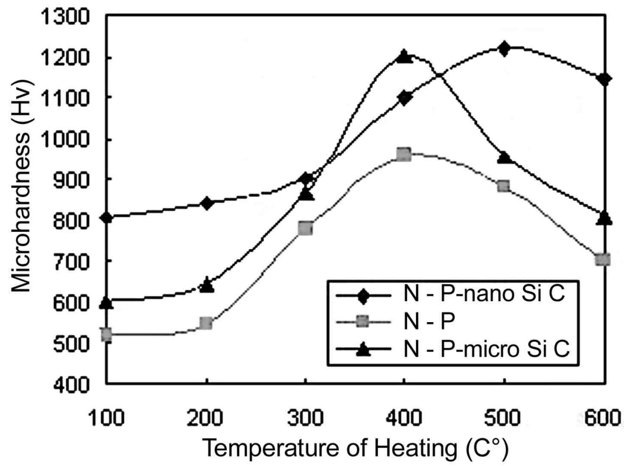

Fig. 5—Hardness vs. heating temperature.

ally transforms from the amorphous state to a crystalline nickel-based solid solution plus a Ni_3P compound during heat treatment. Although nano- and microparticles are stable in these coatings, their effect on the structural transformation of the Ni-P alloy is distinct. The microparticles have little effect because of their larger size (Fig. 6). That is why the hardness relationship is similar to that of the electroless Ni-P coating. The nanoparticles are as small as the nickel-based solid solution regions in the early stages of structural transformation, so they can significantly impede the separation and growth of the nickel-based solid solution and Ni_3P. Thus the nanoparticulate coating can retain high hardness at higher temperature.

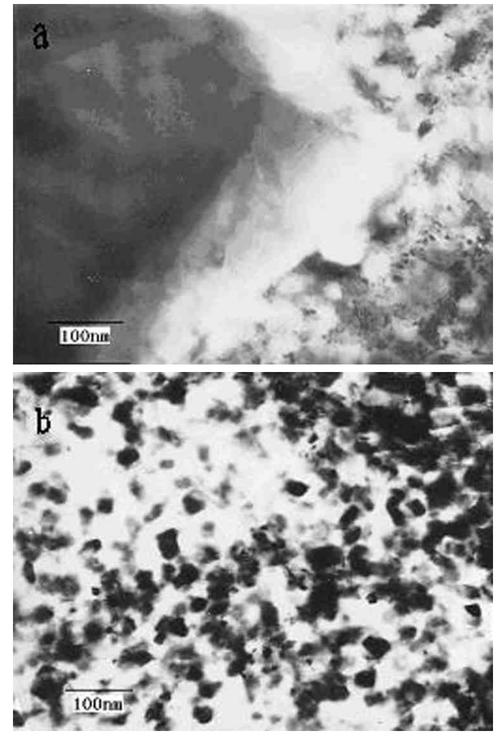

Fig. 6—The structure of (a) Ni-P/micro-SiC coating and (b) Ni-P/nano-SiC coating.

Surface appearance is another factor influencing wear-resistance. The microparticles render a rougher surface. Some of the larger micro-sized particles can act as an abrasive. The finer nanoparticles, on the other hand, won't even alter the epitaxial growth of the coating. As a result, the friction coefficient of the nanoparticulate coating is not only small, but also stable. A stable friction coefficient causes the wear temperature to increase only slightly. Further, the structure of the nanoparticulate coating remains stable at high temperature.

Conclusion

A Ni-P composite coating containing SiC nanoparticles has a lower coefficient of friction and better wear resistance than a coating consisting of one containing microparticles or a conventional electroless Ni-P coating, particularly under high load. Its tribological behavior is superior.

Acknowledgement

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