Electrochemical Preparation & Mechanical Properties Of Amorphous Nickel-SiC Composites

By D.H. Cheng, W.Y. Xu, L.Q. Hua, Z.Y. Zhang & X.J. Wan

In this study, an attempt was made to incorporate SiC particles into an amorphous nickel-phosphorus alloy matrix by electrodeposition. The bath composition and operating conditions of electrodeposited Ni-P-SiC composite coatings were studied and the structure and mechanical properties of the deposits were determined.

The technique for incorporating inert particles into conventional or electroless plating baths to obtain composite coatings of a metal matrix containing finely dispersed inert particles is well developed.[1] Sound, coherent electrodeposited composite coatings have been obtained from many electrolytes, including nickel, cobalt, copper and a variety of alloys. A large number of powders, such as metal oxides, carbides, borides, etc., have been incorporated into these matrices to improve wear resistance hardness and lubricity.

It is well known that amorphous alloys, compared with their crystalline counterparts, have better corrosion resistance and mechanical properties because of the absence of well-defined crystal grain boundaries.[2,3] In view of the excellent properties exhibited by amorphous alloys, increasing numbers of researchers want to incorporate various types of inert particles into the amorphous metal matrix.

Experimental Procedure

Mild steel and copper specimens (4 x 7 cm) having a thickness of 0.25 mm were used as substrates. The specimens were mechanically polished, cleaned in alkaline solution and chemically etched in dilute HCl. After each step, the specimens were carefully rinsed.

The baths were prepared from analytical reagents and distilled water. The electrodeposition was carried out galvanostatically. The anode was high-purity nickel sheet. During electrodeposition, the baths were continuously agitated by an ultrasonic generator (250 watts) to keep the SiC particles suspended in the bath. Deposit thicknesses were 15 to about 25 µm. The weight concentration of SiC particles incorporated into the Ni-P alloy matrix was determined by inductively coupled plasma (ICP) spectrometry. The effect of heat treatment on the structure and the mechanical properties, such as wear resistance (the surface was abraded with abrasive paper, using 100 g weight, with an abrasion rate of 25 cycles/min) and microhardness were investigated. Hardness was determined normal to the surface, using the Vickers method with 400 g weight. The bath compositions and operating conditions are listed in the table.

Bath Composition & Operating Conditions

	Ni-P Bath g/L	Ni-P-SiC Bath g/L
Nickel sulfate	140	140
Nickel chloride	45	45
Sodium hypophosphite	110	120
Phosphoric acid, mL/L	50	50
CiC particles, 5 µm diam.	—	100
pH	2	3
Temp °C	65	70
Current density, A/dm^2	15	15
Time, min	30	30

Results & Discussion

Effect of Bath Composition & Operating Conditions

As shown in Fig. 1, the content of phosphorus in electrodeposited Ni-P alloy coatings was found to be a function of current density. The phosphorus content in the deposit decreases with increase of current density.

Figure 2 shows the structure of Ni-P alloys containing various amounts of phosphorus. It can be seen that as the wt

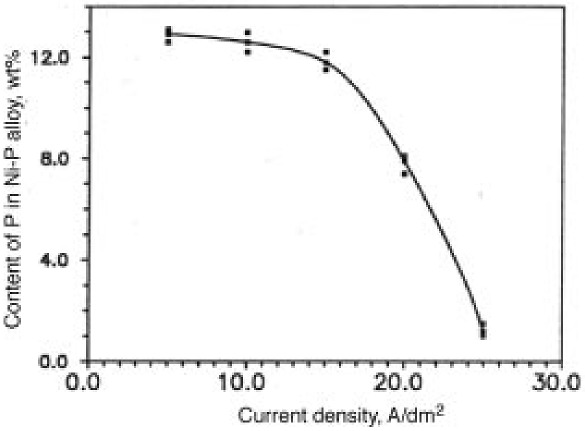

Fig. 1—Current density vs. conc. phosphorus.

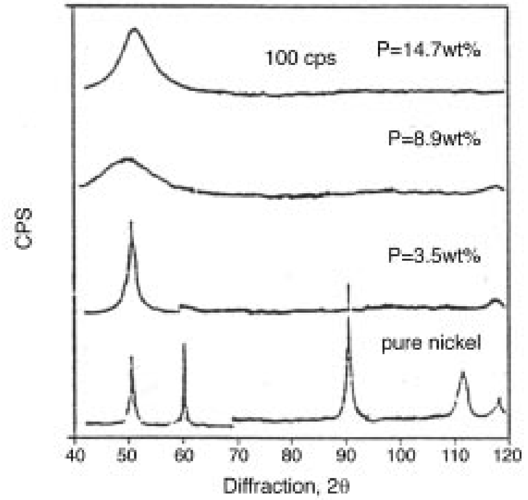

Fig. 2—X-ray diffraction patterns of Ni-P alloy coatings.

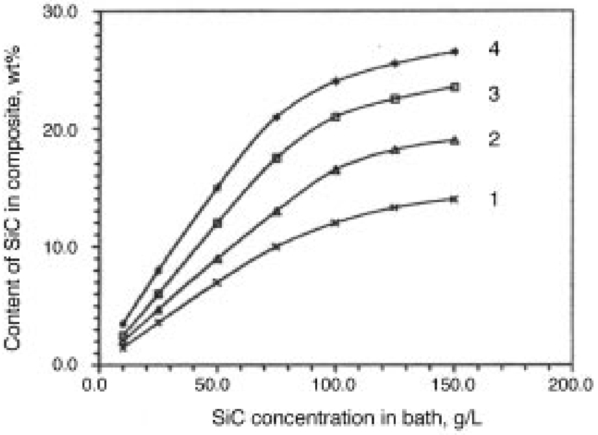

Fig. 3—Effect of SiC conc. on SiC content of deposit at various current densities (A/dm^2): (1) 10; (2) 15; (3) 20; (4) 25.

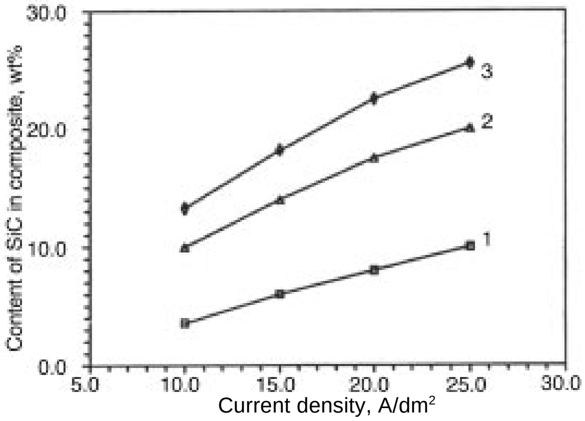

Fig. 4—Current density vs. SiC conc. in composite coatings at different bath loadings (g/L): (1) 25; (2) 75; (3) 125.

pct of phosphorus in the deposit increased beyond nine, the coating structure changed from crystalline to an amorphous pattern. This result is supported by the work of Cargill.[4]

The wt pct of SiC particles incorporated in the Ni-P-SiC composite coatings was a function of bath loading at various current densities. The results are shown in Fig. 3. It can be seen that the content of SiC in the deposit increases with increase of SiC in the bath, tending to a saturation value.

Figure 4 indicates the variation in SiC particles incorporated in the composite coatings with current density, at different bath loadings. The wt pct of SiC particles in the deposit increases with increase of current density. From Figs. 1 and 4, it is concluded that the use of lower current density can enhance the content of phosphorus in the deposit and produce amorphous Ni-P alloys; however, this also decreases the SiC concentration in the composite coatings. On the other hand, using higher current density will increase the SiC particles concentration in composite coatings, decrease the content of phosphorus in the deposit and produce a crystalline Ni-P alloy matrix. There exists, therefore, a current density suitable for obtaining a composite coating simultaneously with a high content of phosphorus and a high concentration of particles, This current density was found to be 15 A/dm^2.

The structure of Ni-P-SiC composite coating is shown in Fig. 5. It can be seen that both the amorphous nickel-phosphorus alloy matrix and the SiC particles maintained their original structures.

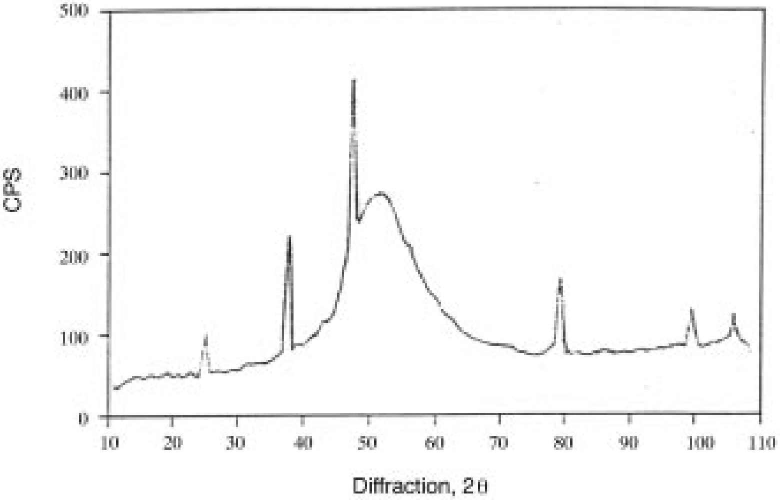

Fig. 5—X-ray diffraction patterns of Ni-P-SiC composite coating with 8.8 wt pct P and 18.9 wt pct SiC.

Effect of Heat Treatment on Structure

X-ray diffraction patterns of heat-treated Ni-P alloy at various temperatures are shown in Fig. 6. The structure of the Ni-P alloy is transformed from amorphous to the crystalline grain of Ni$_3$P. Figure 7 indicates that as temperature increases, the structure of the Ni-P alloy matrix in the Ni-P-SiC composite coating is changed from amorphous to crystalline, similar to the pattern in Fig. 6.

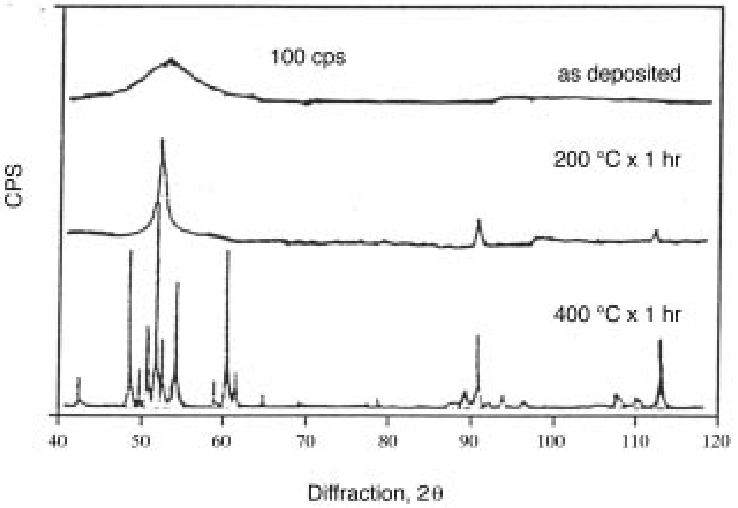

Fig. 6—X-ray diffraction patterns of heat-treated Ni-P alloy at various temperatures.

Effect of Heat Treatment on Hardness

Figure 8 shows the variation in hardness as a function of the wt pct of SiC particles in the deposit and the heat treatment temperatures. At the same temperature, the hardness is increased with increase of SiC content in the composite coatings. It is also found that there exists a maximum hardness near 400 °C. The improvement in hardness of the composite is related to the hardness effect caused by SiC particle dispersion in the composite coatings.

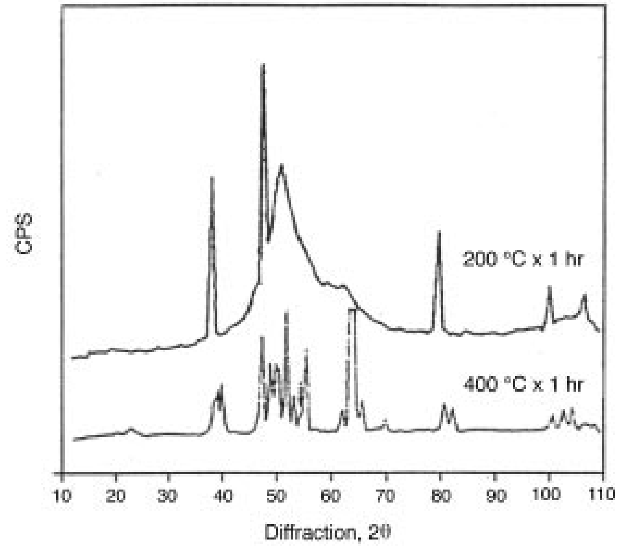

Fig. 7—X-ray diffraction patterns of heat-treated Ni-P-SiC composite at various temperatures.

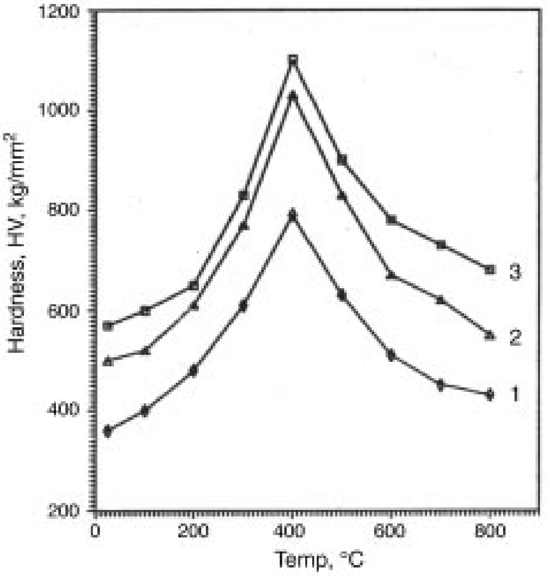

Fig. 8—Microhardness vs. SiC conc. with different heat treatment temp: (1) Ni-13.5 wt % P; (2) Ni-11.4 wt % P- 7.8 wt % SiC; (3) Ni-8.8 wt % p-18.9 wt % SiC.

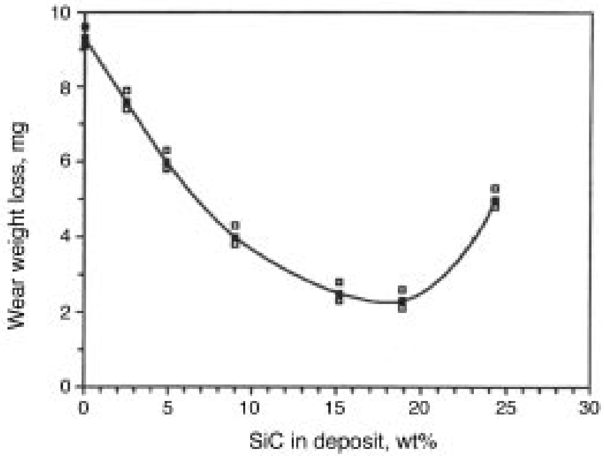

Fig. 9—Wear weight loss vs. composite SiC content.

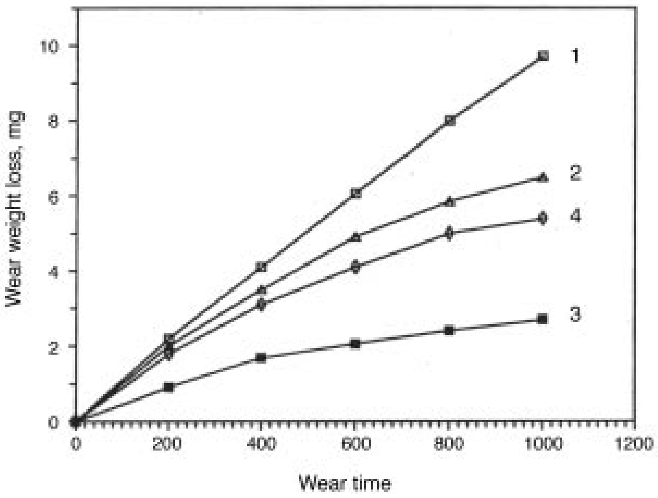

Fig. 10—Wear weight loss vs. wear times at various heat treatment temperatures: (1) as deposited; (2) 200 °C x 1 hr; (3) 400 °C x 1 hr; (4) 600 °C x 1 hr;(Ni-8.8 wt % P-18.9 wt % SiC).

Effect of SiC Concentration on Wear Resistance

A plot of wear resistance as a function of various concentrations of SiC particles in an Ni-P alloy matrix is shown in Fig. 9. With 600 wear cycles and 100-g load, weight loss decreases with increase of the content of SiC in the composite coatings, but increases again after attaining a minimum value with 20 wt pct SiC in the coatings. This may be caused by an excessive quantity of SiC particles heaped in the surface, forming a soft constituent.

Effect of Heat Treatment on Wear Resistance

Figure 10 shows lost weight as a function of wear time and heat treatment temperature. It was found that weight loss increases with increasing wear times, and that heat treatment can change the wear resistance of the same coating. For the same wear times, after treatment at 400 °C, the coating has minimum wear weight loss. This result reflects the maximum hardness, as shown in Fig. 8.

Conclusions

Amorphous nickel-phosphorus alloys were electrodeposited and SiC particles were successfully incorporated in the alloy matrix. The content of SiC in the composite coating increased with increase in bath loading and at higher current density. Heat treatment can change the coating's structure, hardness and wear resistance. After heat treatment, the structure of the amorphous Ni-P alloy matrix was changed from amorphous to crystalline. The coatings attain maximum hardness and wear resistance after heat treatment at 400 °C. The hardness and wear resistance were a function of the content of SiC particles, which were well-dispersed in the composite coatings.

Editor's note: *Manuscript received, August 1996; revision received, July 1997.*

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