Wear Properties of Nanocrystalline Electrodeposits

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Recent advances in the understanding of the abrasive wear properties of nanostructured electrodeposits are reviewed. Taber wear data for several nanocrystalline metals, alloys and composites are presented and analyzed in terms of microstructural evolution of these materials in the as-plated and heat-treated state. It has been shown that increased hardness of the materials as a result of grain size reduction is a necessary but not sufficient condition to achieve high wear resistance. Other factors such as ductility and the ratio of surface hardness to elastic properties also play important roles. A comparison between wear data obtained on numerous nanocrystalline coatings for two different abrading wheels (CS-10 and CS-17) is also presented.

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Extended Abstract

The hardness of a material is one of the most important mechanical properties in wear and is often[1-3] employed as a simple criterion to predict the abrasive wear resistance of many conventional materials; higher hardness values giving higher abrasive wear resistance. One of the most widely used tests to assess the abrasive wear resistance of materials is the Taber wear test, which is often applied in the case of electrodeposited coatings. In this paper, we examine whether or not the simple relationship between hardness and abrasive wear resistance is also applicable for the case of nanocrystalline coatings which usually exhibit very high hardness values.

Fig. 1 shows the effect of grain size reduction on the hardness and Taber wear index (TWI, weight loss in mg per 1,000 cycles) of nanocrystalline Ni and Ni-P coatings. As the grain size was decreased from 90 ìm (polycrystalline Ni) to 5 nm (Ni-5.9 wt.% P), the structure changed from polycrystalline, to nanocrystalline and finally to amorphous. A transition from regular to inverse Hall-Petch relationship was observed, i.e. for grain sizes between 90 ìm and 9 nm, the hardness increased with decreasing grain size, while it decreased with decreasing grain size for coatings with grain sizes less than 9 nm.

Qualitatively, Fig. 1 also shows that the TWI of the as-plated pure Ni coatings is inversely proportional to the hardness, as previously reported for many engineering materials [e.g. 1-3]. However, for the Ni-P coatings, the relationship between hardness and TWI is more complex. In order to demonstrate more clearly that hardness is not necessarily a good indication of the wear behaviour of nanocrystalline materials, Figs. 2,3 and 4 show the Taber wear resistance (TWR, the number of cycles required for 1 mg wear) as a function of hardness for three groups of materials. First, Fig. 2, which is derived from Fig. 1, shows that the TWR for pure Ni coatings increases with hardness. However, upon alloying with P the TWR initially decreased even though the hardness continued to increase. Second, a more drastic effect can be observed after heat treating the Ni-P coatings (Fig. 3), where the two coatings with the highest hardness exhibited the lowest TWR. Third, Fig. 4 shows a comparison of TWR data for pure Ni (also taken from Fig. 1) and pure Co coatings. While grain size reduction in pure Ni coatings has a remarkable effect on TWR, such behaviour is not found for Co coatings.

The results presented in Figs. 1~4 show that parameters such as grain size or hardness cannot fully explain the abrasive wear behaviour of the nanocrystalline coatings investigated in this study. However after examining the surface morphologies of the worn surfaces after wear testing, it was found that the TWR of the coatings is closely related to their ductility, irrespective of grain size, chemical composition, crystallographic structure or heat treatment. Fig. 5 shows the relationship between the TWR and ductility (determined from SEM micrographs of worn surfaces) for all coatings investigated in this study. It can be seen that higher coating ductility results in lower TWR. Therefore, it can be concluded that, in addition to hardness, ductility is another important factor that controls the Taber wear resistance of nanocrystalline materials.

References

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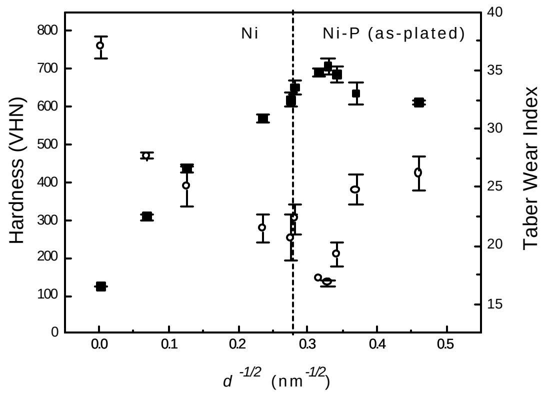

*Fig. 1 Vickers hardness and Taber wear index (**CS-17** wheel) as a function of the inverse root of grain size for Ni and Ni-P coatings (Hall-Petch type)*

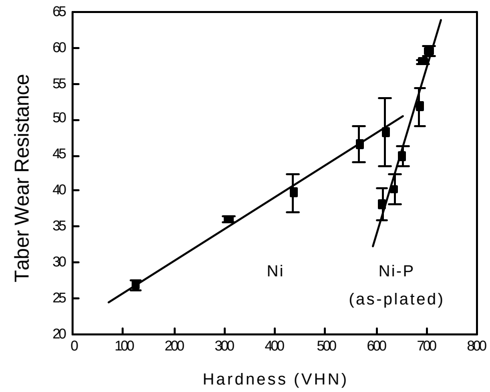

*Fig. 2 Taber wear resistance (**CS-17** wheel) as a function of hardness for Ni and Ni-P coatings (from [4])*

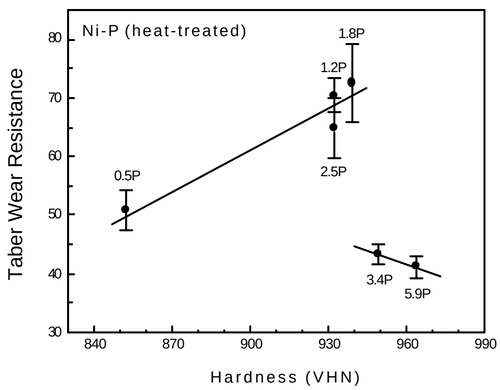

*Fig.3 Taber wear resistance (**CS-17** wheel) as a function of hardness for heat-treated Ni-P coatings (from [5])*

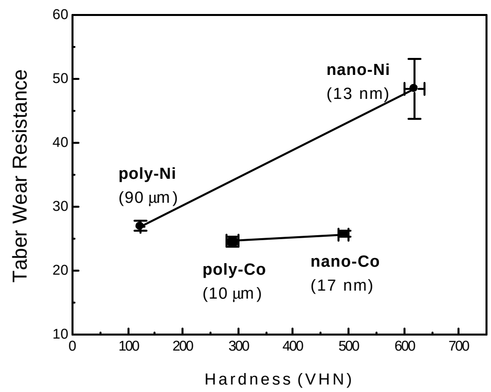

*Fig. 4 Taber wear resistance (**CS-17** wheel) as a function of hardness for Co coatings*

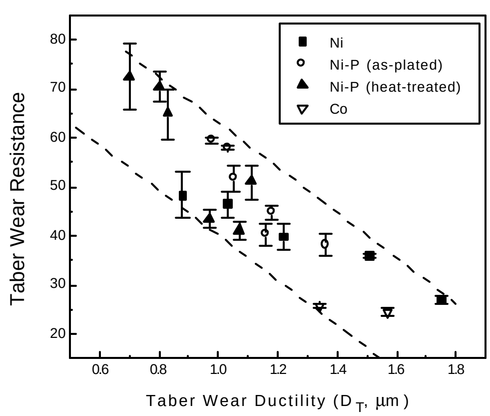

*Fig.5 Taber wear resistance (**CS-17** wheel) as a function of Taber wear ductility for all coatings*