A Study on Friction and Wear Characteristics of NANON-9, A Chrome-Alternative Electrodeposited Nanocrystalline Coating Plated on High-Strength Steel

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Wear resistance and hydrogen embrittlement are issues of great concern for steel plating operations. Steels that are susceptible to hydrogen embrittlement should be heat-treated to remove hydrogen. The temperature is of the order of 205°C (400°F) and exact temperature may be alloy dependent. Why not use this temperature to make the coating harder and more wear resistant? In this paper, friction, wear and hydrogen embrittlement tests were conducted before and after heat-treatment, and were compared to chromium coatings. The microstructures of NANON-9 coating before and after heat-treatment were analyzed by SEM, TEM and X-ray. The mechanism of the excellent wear resistance of this nano-structured materials is described.

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1. Introduction

Various techniques have been used to deposit coatings for tribological applications. Electrodeposited chromium has been popular for many years due to its high hardness, low coefficient of friction, good wear resistance and good corrosion resistance. However, chromium bath based on the metal's hexavalent form have serious technical, health and environmental disadvantages. The current problems associated with the use of electrodeposited chromium have stimulated an extensive search for alternative coating processes and materials.

A nanocrystalline Ni-Co alloy coating (Co^{+2} 0-30g/L) –NANON 9 has been developed which can be deposited by electroplating. It has been show to have low internal stress (80kgf/cm2) can be build up to 15 mils, and have good wear resistance (average Taber Wear Index is 8.6). Hence to be a possible replacement for hard chromium in some applications.

High Stressed, High- strength steel are susceptible to hydrogen embrittlement during normal plating operations. The pretreatment of steel prior to plalating, however, may require exposing the steel to acids, alkalis. During those operations, excessive the amounts of hydrogen may evolve which may damage steels. Susceptible to hydrogen embrittlement. Steel that are susceptible to hydrogen embrittlement should be heat treated to remove hydrogen. The time required may vary from 8 to 24 hours depending on the type of steel and the amount of hydrogen to be removed. The temperature is of the order of 400^{o}F (205^{o}C) and the exact temperature may be alloy dependent.

Why not use this temperature to make the coating harder and more wear resistant? We designed heat treatment temperature of Ni-Co alloy coating, which was conducted to achieve maximum wear resistance by precipitation of intermetallic compounds from as plated state.

In this paper Taber wear testing before and after heat treatment were conducted and its microstructure has been investigated.

2. Experiment

4130 steel panel with a size of 4 x 4 in^2 were used as substrates for electrodeposition of nanocrystalline NANON-9 with thickness 3 mils.

Heat treatment of NANON-9 coating used 375 ^{o}F (24 hours) and 392 ^{o}F (24 hours).

The microstructures of NANON-9 coating were characterized by transmission electron microscopy (TEM), scanning electron microscopy (SEM) and X-ray diffraction (XRD).

Energy dispersive X-ray spectroscopy was employed to determine the chemical composition of the coatings.

Hardness was measured using a HMV-2000 Vickers microhardness tester with a load 100 g applied for 15 s.

The abrasive wear resistance was assessed using a Taber wear tester equipped with a "CS-17 "wheel.

Consisting of hard Al_2O_3 particles embedded in a rubber matrix (ASTM D 4060-95).

3. Results and Discussion

Table 1 shows a strong linear relationship between hardness and Taber Wear Index (TWI). The TWI is inversely proportional to the hardness for the as-plated nonocrystalline coatings.

Table 1. Hardness and TWI of some nanocrystalline coatings and Chromium coating as-plated

	Ni	**Ni-P**	**NANON 9**	**Chromium**
Ave. Grain size d (nm)	12	9.2	4.0	0.5um
Hardness (Hv_{100})	600-640	660-680	820-900	900-1100
TWI	20-24	16-18	10-11	2.0-8.0
Reference	[1]	[1]		[2,3,4]

Fig. 1 shows the X-ray diffraction pattern of Ni-Co alloy coating as-plated. It can be seen that its structure is composed of nickel-based solid solution containing cobalt, and intermetallic compound Ni_2Co and Ni_3Co.
The peak profiles of Ni2Co and Ni3Co are broad, and that of the solid solution is diffuse, resulting from the scattering reflection of the nanocrystals.

Fig. 2 shows the TEM morphology of Ni-Co alloy coating. It can be seen that there are many finely dispersed precipitates, about 10 nm in size, present in matrix. So NANON 9 high hardness as-plated can be considered due to the solid solution hardening and intermetallic compounds precipitation hardening.

"Note: Figures not provided for inclusion on this CD."

Fig.1 X-ray diffraction pattern of NANON 9 coating as-plated

Fig. 2 TEM morphology of NANON 9 coating as-plated (a) and after heat treatment (b)

Table 2 still shows linear relationship between hardness and Taber wear Index (TWI). But it is just corresponding to the state of more precipitates produced coherent with the matrix as show in the TEM morphology of Fig. 2 (b). The hardness of NANON 9 coating can be further increased by heat treating mainly caused by precipitation hardening at this moment.

Table 2 Hardness and TWI of some nanocrystalline coatings and Chromium coating after heat treatment

	Ni (554°F)	Ni-P (554°F)	NANON 9 (375°F)	Chromium (375°F)
Ave. grain size d(nm)	20-24	12-15 (20-30)	6.0-8.0 (15-20)	0.5um
Hardness (Hv_{100})	500-550	900-950	1000-1150	900-1100
TWI	30-40	14-15	8.0-9.0	4.0-8.0
Reference	[1]	[1]		[2,3,4]

Taber abrasive wear consists of three distinct and consecutive processes: (I) indentation of the surface by the hard Al_2O_3 abrasive particles, (II) surface deformation by cutting or ploughing and (III) removal of worn material from the surface. Since the hardness of a material is a measure of its resistance to localized plastic deformation by surface indentation. The first two processes are strongly dependent upon both yield strength and fracture toughness of a material [1].

Grain size refinement in pure electrodeposited Ni has been shown to result in considerable increases in yield strength [1]. In particular, for grain size less than 30 nm [4]. This is mainly the result of reduced dislocation activity at such small grain size.

Consequently, increased hardness directly provides the nanocrystalline coatings with higher resistance both to the indentation of the surface by hard Al_2O_3 particles and to the surface deformation by cutting or ploughing during the abrasive wear resistance in Taber testing.

Is the higher of the hardness, the lower TWI is? The answer is NO. When NANON 9 hardness increased to about Hv 1200, the TWI increased more than 12. This is because when the hardness increased, the fracture toughness of the material decreased fast. Further studies of the relationships between fracture toughness and Taber Wear Index (TWI) will be seeing other paper.

4. Conclusion

(1) The hardness of NANON 9 is Hv 820-900 as-plated, and Hv 1000-1150 after 375°F heart treatment;
(2) Around temperature 375 °F is removed hydrogen from plated steels, it is not necessarily using another heat treatment to made coatings harder;
(3) Its Taber Wear Index (RWI) is about 8.0 and can be built up to 15 mils;
(4) NANON 9 can be replacement hard chrome in some applications.

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