A Study of Wear Resistance of a New Cr Replacement: An Electrodeposited Ni-Co-X Alloy

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Abstract

Friction and wear tests have been conducted to determine the wear characteristics of a new chromium replacement, an electrodeposited Ni-Co-X alloy, without lubrication at the contact surface. The results show that the wear resistance of this alloy layer was superior to that od an electrodeposited chromium layer under the same conditions. The microstructure and surface morphology of this allay before and after the wear process were analyzed by transmission electron microscopy and scanning electron microscopy. The mechanisms of its excellent wear resistance are discussed.

Keywords: Wear resistance, without lubrication, chromium replacement

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1. Introduction

Chromium plating coating has been widely used to increase the surface wear resistance of materials. In the chromium plated coating, atoms are bound closely together owing to the relatively small radii of chromium atoms and the strong interactions between 4d electrons and 3d electrons. These mechanisms create a relatively high level of hardness and wear resistance. However, as the temperature increases, thermal motion of atoms weakens the bounding strength, and thus the hardness and wear resistance of the plated coating decrease. In order to overcome this disadvantage, and more importantly, to avoid harm of electrodeposited chromium for human health and environment, we developed a new chromium replacement coating, - Ni-Co-*X* Alloy. This coating has a beautiful appearance and excellent corrosion resistance. In this paper, we conducted comparison experiments of wear under high speed and heavy load without lubricant. By microstructure analysis before and after wearing, the mechanism of excellent wear resistance of Ni-Co-X alloy coating will be discussed.

2. Experimental details

We carried out dry rolling-sliding wear tests on an Amster wear test machine. The counterpart materials were a 52100 bearing steel with a hardness of Hv750 and roughness Ru=0.17ìm. The test sample wheels were 50 mm in diameter and the counterpart 38.5 mm, with 10 mm wheel thickness, and its surface roughness is 0.16-0.18ìm. During wear testing, the test sample rotates at 200 rpm against the counterpart upper wheel at 180 rpm. This gave a sliding ratio of 30% at contact motion. The applied loads were 98, 157 and 392 N, respectively, corresponding to a maximum Hertzian stress of 157, 199 and 315 Mpa.

We weighed the samples after each period of testing using a balance accurate to 0.1 mg. The results given here are the average of three tests.

The torque induced by the frictional force was indicated by the swung angle of a pendulum and was recorded from a scale during testing. The coefficient of friction was calculated from the measured value of torque.

We analyzed the worn surface of the test samples and the counterpart steel wheel, transverse and longitudinal sections of the test samples, and the collected wear debris using scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDAX), and x-ray diffraction analysis (XRD) with copper K2 radiation. Transmission electron-microscopy (TEM) was employed to study the change in the microstructure alloy plated coating before and after wearing testing.

Micro-hardness indentations were made into the surface and cross-section. The measurement was performed with a 50g load for 15 seconds along the wear track and the hardness was calculated by averaging five measurements.

3. Results

Fig. 1 shows the wear rates of both the electrodeposited chromium coating and the electrodeposited Ni-Co-*X* alloy coating under different applied loads. It can be seen that the wear rate has been reduced for Ni-Co-*X* alloy in all the cases. The wear rate for electrodeposited chromium increased quite significantly with increasing applied load, while that of the Ni-Co-X alloy coating increased only slightly. It appears that at heavy load, the wear resistance of this alloy coating is much better than that of a chromium-plated coating.

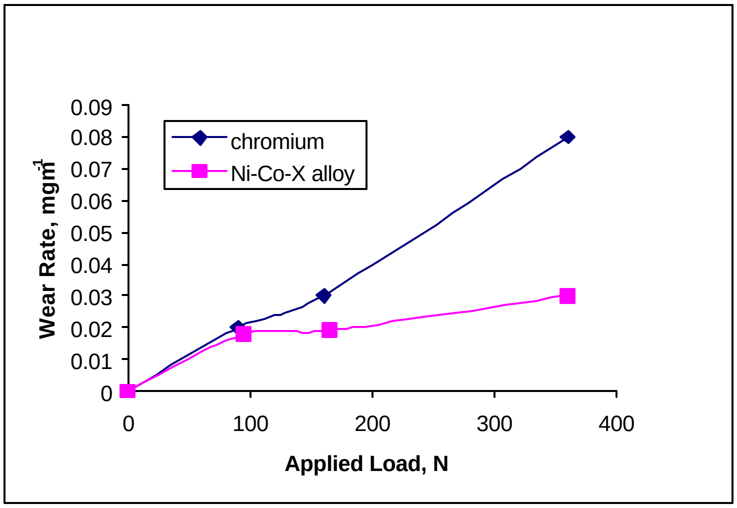


Fig.1- Wear Rate of Chromium and Alloy Coating Samples under Different Loads

Fig. 2 shows that the friction coefficients of the electrodeposited chromium and electro-deposited Ni-Co-*X* alloy against the wear distance under the loads of 98 and 392 N. Generally, the friction coefficient of the alloy was close to constant throughout the wear testing, only the chromium coating's gets a little higher when heavy loads are applied. Clearly, the coefficient of friction for Ni-Co-*X* alloy is lower than that of chromium coating. The values for chromium coating and the alloy coating were about 0.18 and 0.12 respectively.

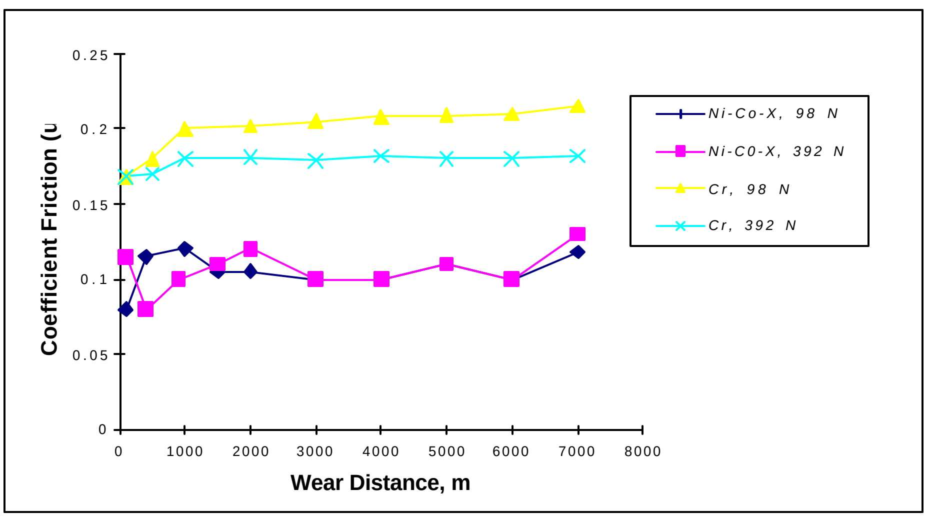
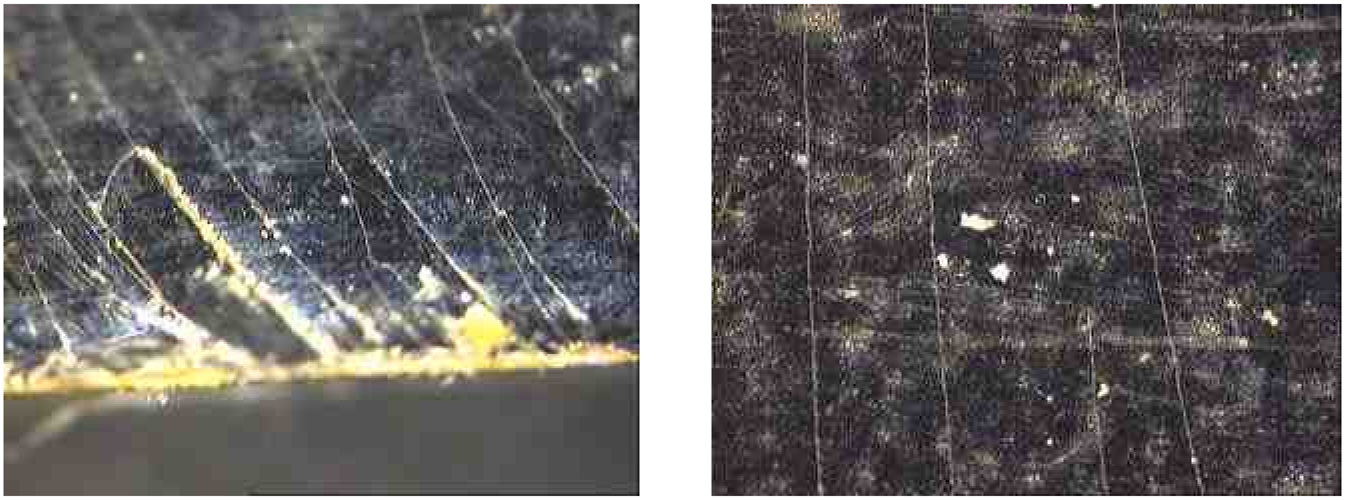


Fig. 2 – Friction coefficient of chromium coating and Ni-Co-X alloy against wear distance under the loads of 98 and 392N

After wear testing, examination of sectional samples showed that a deformed layer was present at the worn surface area for all samples. But the deformed areas in the alloy coating samples were smaller than in the chromium coating samples *Fig. 3(a, b).*

Surface and sub-surface cracks were observed in the transverse and the longitudinal sections of the specimens. Cracks could be found both in the deformed and the highly deformed areas, and along the boundaries among them. *Fig. 4* shows the sub-surface cracks in the chromium coating and alloy coating samples after wear testing under 392 N. Sub-surface cracks in the worn chromium coating are easily found. Under the applied

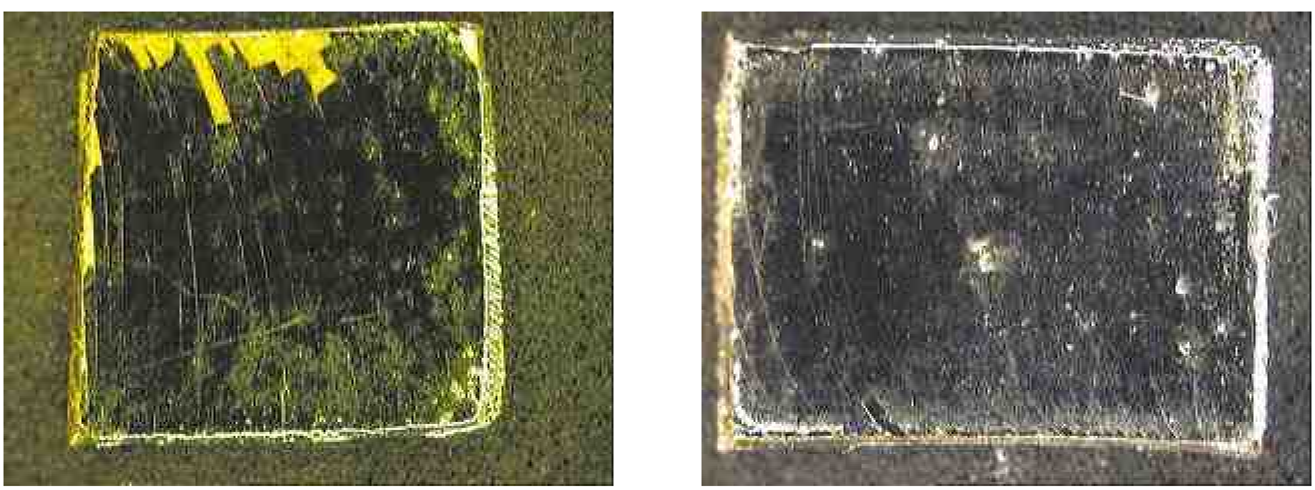


(a) (b)

Fig. 3 – Sections of the chromium (a) and Ni-Co-X alloy (b) after wear testing on the 392 N, showing the deformed areas

load of 392 N, sub-surface cracks were found up to around 40 ìm deep from the surface in the chromium. But subsurface cracks in the alloy coating samples were shallower and cracks as deep as the one shown in *Fig.* **4(b)** (about 10 ìm in depth) were rare.

In *Fig. 4(a)*, it shows that cracks are at a similar depth level and are capable of joining among one another.



(a) (b)

Fig. 4 – Sections of the chromium (a) and the Ni-Co-X alloy (b) after wear testing under 392 N, showing sub-surface cracks.

We discovered the surface of the counterpart steel wheels with a layer of the testing material shortly after starting the wear test. This means that materials have been transferred from the testing specimen to the counterpart wheel. This was confirmed by the weight grain of the steel wheels and by EDAX analysis of their surface. After wear test, all the counterpart steel wheels showed a positive weight gain of a few milligrams, as shown in *Fig. 5*. From this Figure, we conclude that, for the same applied load, a larger amount of the chromium coating than the alloy coating was transferred. We also noticed that the amount of materials transferred to the steel wheels increased with the applied load.

The worn surface of the alloy coating and chromium coating are not smooth. The average roughness (Ra) under the applied load of 98, 157 and 392 N are respectively 0.15, 0.17 and 0.19ìm for the alloy coating and 0.20, 0.25 and 0.55 ìm for chromium coating. The interesting phenomenon is that the surface roughness is reduced after wear under the lower applied load (98 N). Same results have happened in industry testing.

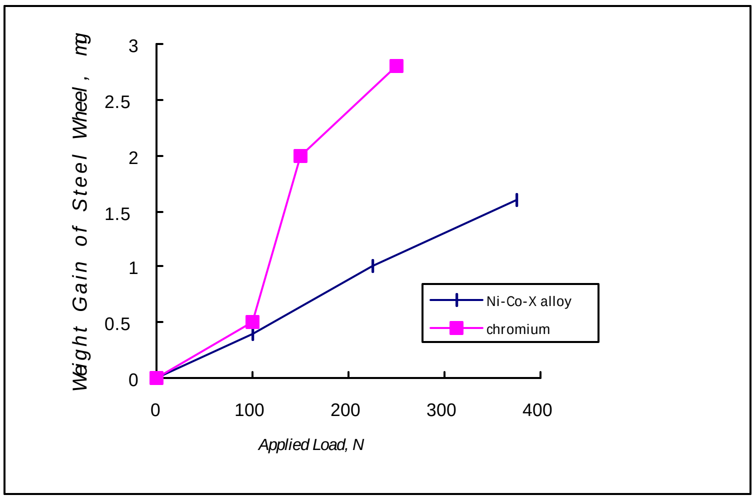


Fig. 5 – Weight gain of counterpart steel wheel after wear test against chromium coating and Ni-Co-X alloy under different loads

4. Discussion

The above results showed that the mechanisms involved in the dry rolling-sliding wear of chromium and alloy coating against steel include both adhesive and delamination wear. Wear debris forms in two ways: Direct formation from the test specimen by delamination wear through the formation extension and linking up of sub-surface cracks and indirect formation. The latter involves the transfer of the material from the test sample to the counterpart wheel by adhesion. Transferred material work-hardens and detaches from the counterpart wheel.

When v = 31m/min(200rpm, Ö50mm), L = 392N, flash temperature $T_f = 1400 - 1500$ °C. At this time, the material becomes softer and its strength become lower, the coefficient of friction and wear rate increases. *Table 1* shows the variation of hardness of both the alloy coating and chromium coating at different temperatures, after 200°C the alloy coating is obviously better than the chromium coating, and at 600°C, the alloy coating can still maintain a considerably satisfactory hardness, while the chromium coating decreased drastically.

Table I

Temp. / Coating	Room Temp.	100°C	200°C	300°C	400°C	500°C	600°C
Chromium	950	920	900	770	600	420	350
Ni-Co-*X*	910	910	1120	900	780	710	630

Archad believed that for pure metal adhesive wear rate ω had the following relationship with hardness:

$$\boldsymbol{w} = \frac{kw}{3H} \tag{1}$$

where ω is adhesive wear rate; k is coefficient of wear, w is loads and H is hardness of material.

This is, with the increase of loads, the friction heat increases, and the material becomes softer, resulting in the decrease of hardness and increase of adhesive wear rate. This is why the adhesive wear rate of alloy coating is much better than that of chromium coating samples.

In delamination wear, the effect of friction coefficient on crack nucleation and crack propagation has been discussed in Ref.(4.5). Their work has shown that the depth of void nucleation increases with both normal load and friction coefficient and that the characteristic crack propagation depth and propagation rate also increase with increasing coefficient of friction. Therefore, higher friction coefficient will lead to higher wear loss of the chromium coating.

5. Conclusion

From the above results and discussions, we conclude that this Ni-Co-*X* alloy coating has the following characteristic on the dry rolling-sliding wear behavior against bearing steel (52100) in comparison with chromium coating.

a. Ni-Co-X alloy coating has very good resistance to delamination wear. It has low friction coefficient and excellent microstructure are why it is.
b. Under non-lubrication wear, friction heat softens chromium coating. The reason that chromium's wear rate are greater than that of the alloy coating is that chromium coating adhesive wear have seriously taken place.

Fig. 6 – Transmission electron micrograph of the Ni-Co-X alloy as plated.

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