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High-temperature Friction and Wear Resistance of Ni-Co-SiC Composite Coatings

Fang Guo, Wan-chang Sun*, Zong-wei Jia, Xiao-jia Liu, Ya-ru Dong

College of Materials Science and Engineering, Xi'an University of Science and Technology, Xi'an, Shaanxi 710054, P.R.China
*Corresponding author. Prof.; sunwanchang@tsinghua.org.cn (Wan-chang Sun); Tel: +86-29-85587373
Abstract: Ni-Co alloy and SiC micro-particles were co-deposited on 45 steel by electrodeposition for high temperature performance. The high temperature tribological characteristics were studied by use of a ball-on-disk method. The micrographs and phase structure of the Ni-Co-SiC composite coatings after high-temperature friction were observed by using a field emission scanning electron microscope(FESEM). The results reveal that the Ni-Co-SiC composite coating presents better wear resistance and lower friction coefficient at high temperature in comparison with that of Ni-Co coating and 45 steel substrate. The embedded SiC particles could strengthen the alloy coating by dispersion strengthening effect and changing the friction mechanism from adhesive wear to abrasive wear.

1. Introduction
In various engineering applications, the long term performance under high-temperature, high-pressure and high-speed conditions in aggressive solution or atmosphere are crucial to mechanical products and parts, made of carbon steels. For example, major failure for hot forging process is originated from high temperature wear, and proportion of which can reach 70-80% [1,2]. Moreover, the majority of engines and cutting tools are also damaged due to the reason mentioned above. In order to improve the wear resistance, corrosion resistance and high temperature oxidation resistance of carbon steels, surface strengthening techniques are needed, of which preparing high-temperature coating is a good choice. Fine particles reinforced metal matrix composite coatings, possessing favorable comprehensive performance, are made up of matrix metal and dispersed ceramic particles such as ZrO_2 [3], B_4C [4] ,Si_3N_4 [5], WC [6] ,Al_2O_3 [3,5,7] ,CeO_2 [8],and SiC particles [5,9] ,among which SiC particles is commonly used as the second ceramic phase owing to its high hardness, low thermal conductivity, relatively high thermal expansion coefficient and high temperature oxidation resistance. On the other hand, Ni-Co alloys present excellent thermal, physical and mechanical properties than pure Ni [10,11]. Therefore, the incorporation of different particles within Ni-Co matrix, achieved by electrodeposition,

could lead to a new type of composite coatings that present particular chemical and physical properties [7-9]. Currently, most research works focus on improving the micro-indentation hardness, corrosion resistance, wear resistance, and electro catalytic activity of Ni-Co composite coatings [7-9, 12]. However, there is little report about their high-temperature tribological behavior.

In this work, SiC micro-particles reinforced Ni-Co matrix composite coating which can overcome lots of restrictions under harsh work conditions was prepared by electrodeposition. The high temperature tribological properties of Ni-Co-SiC composite coatings were investigated. For comparison, the high temperature tribological properties of Ni-Co alloy coatings on 45 steel substrates were also investigated.

2. Experimental procedures

The chemical composition and operating condition of electrodeposition of Ni-Co-SiC coatings were collected in Table 1 [13]. The wear resistance of the composite coatings was tested under dry sliding conditions in air at room temperature by the ball-on-disk method, using a high-temperature friction and wear testing machine (HT-1000, Lanzhou Zhongkai LTD., China). The test was carried out with a track radius of 5 mm at 0.3 m/s, using a bearing Si_3N_4 ball (6mm in diameter, ≥HV1300 in micro-indentation hardness) under a load of 5 N for 10 min. The friction coefficient and sliding time were recorded automatically during the test. Each friction pair was cleaned by ultrasonic in acetone before and after each test. The weight loss of the coatings was measured by weighing the samples before and after each wear test. The test conditions were selected based on lots of experiments, according to relevant literature [14-15] . At least five samples of each set of materials were tested for each data, so as to avoid the fluctuations in the data.

The micrographs and phase structure of the Ni-Co-SiC composite coatings after high-temperature friction were observed by using a field emission scanning electron microscope (FESEM, JSM-6390A, Japan).

3. Results and discussion

Fig.1shows the weight loss of 45 steel, Ni-Co coating and Ni-Co-SiC composite coating after 15 min friction. It can be seen that the wear rate decreases from 25.1×10^{-3} mg/m for uncoated substrate to 22.3×10^{-3} mg/m for Ni-Co coating and to 12.6×10^{-3} mg/m for Ni-Co-SiC composite coating. It was clearly demonstrated that Ni-Co-SiC composite coating has the best wear resistance in Fig.1. Furthermore, SiC particles could strengthen the Ni-Co alloy via dispersion strengthening effect [7]. In the meantime, Ni-Co alloy and SiC present different coefficient of thermal expansion, thus the stress between Ni-Co and SiC phases is large enough to form microcracks at high temperature and high pressure. Consequently, lots of tiny particles are easily dug out during the test, whereas, the friction mechanism was changed from adhesive wear to abrasive wear for the existence of many free particles [9, 12]. The weight loss of Ni-Co-SiC composite coating is small, thus exhibiting better high-temperature wear resistance than that of Ni-Co alloy coating, because abrasive wear will not lead to large block debris as adhesive wear.

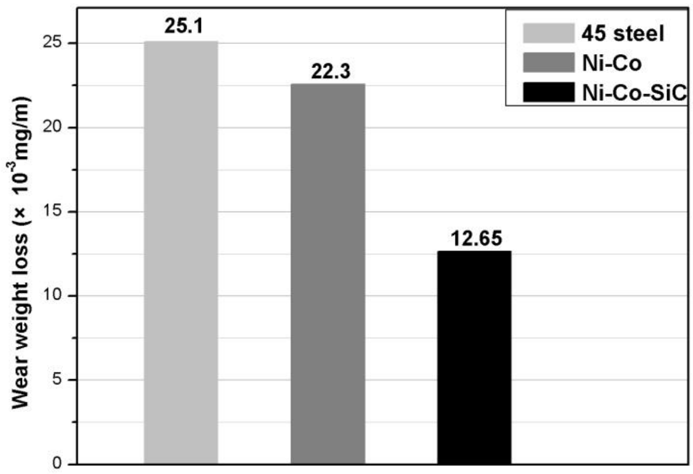

Fig.1. Wear weight loss of 45 steel, Ni-Co alloy coating and Ni-Co-SiC composite coating at 873 K for 15 min.

Fig.2 illustrates the correlation between friction coefficient and sliding time for 45 steel substrate, Ni-Co alloy coating and Ni-Co-SiC composite coating at 873 K. It reveals that the friction coefficient of Ni-Co-SiC composite coating is lower than that of Ni-Co coating, and much lower than that of 45 steel substrate, and which is attributed to different friction mechanisms. For Ni-Co coating, sliding friction is the main form of friction, while the friction mechanism of Ni-Co-SiC composite coating consists of adhesive friction and abrasive attrition. Under high temperature and pressure, the friction mechanism changed and the frictional force reduced greatly when a large number of SiC particles and oxidation scraps were dug out from the coating surface, showing a lower friction coefficient for Ni-Co-SiC composite coating.

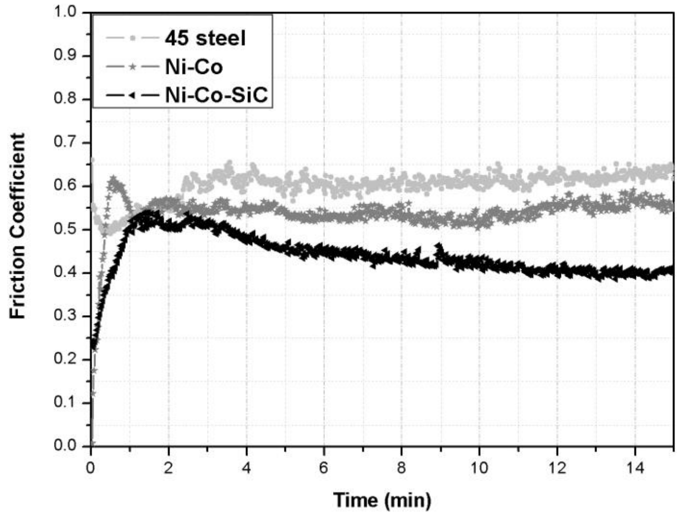

Fig.2. Friction coefficient of 45 steel, Ni-Co alloy coating and Ni-Co-SiC composite coating at 873 K.

Fig.3 shows SEM morphologies of the worn traces on the surface of 45 steel substrate, Ni-Co and Ni-Co-SiC coatings. Fig.3(a-b) present the morphologies of a typical worn surface of 45 steel substrate at 873 K. Fig.3(a) shows that it has a wide and dark furrow in the sliding direction, which may be formed by plowing and adhesive effect when the sample surface contacts with Si_3N_4 ball. The furrow indicates a higher wear loss. Arrows in Fig.3 (b) show the oxides formed under high temperature. The brittle oxide layer cannot effectively prevent the sliding cut from the contact surface of counter-part. Fig.3(c-d) present the wear traces of Ni-Co coating. Arrows in Fig.3 (d) demonstrate that there are many cracks along the sliding tracks of 45 degree, and thus the integrity of Ni-Co coating is poor. The darker areas which are directed by the arrows are high temperature oxides. The grooves formed on the surface along the sliding direction are most likely as the result of the fragments produced by friction which will cause welding phenomenon and increase the friction force and friction coefficient due to

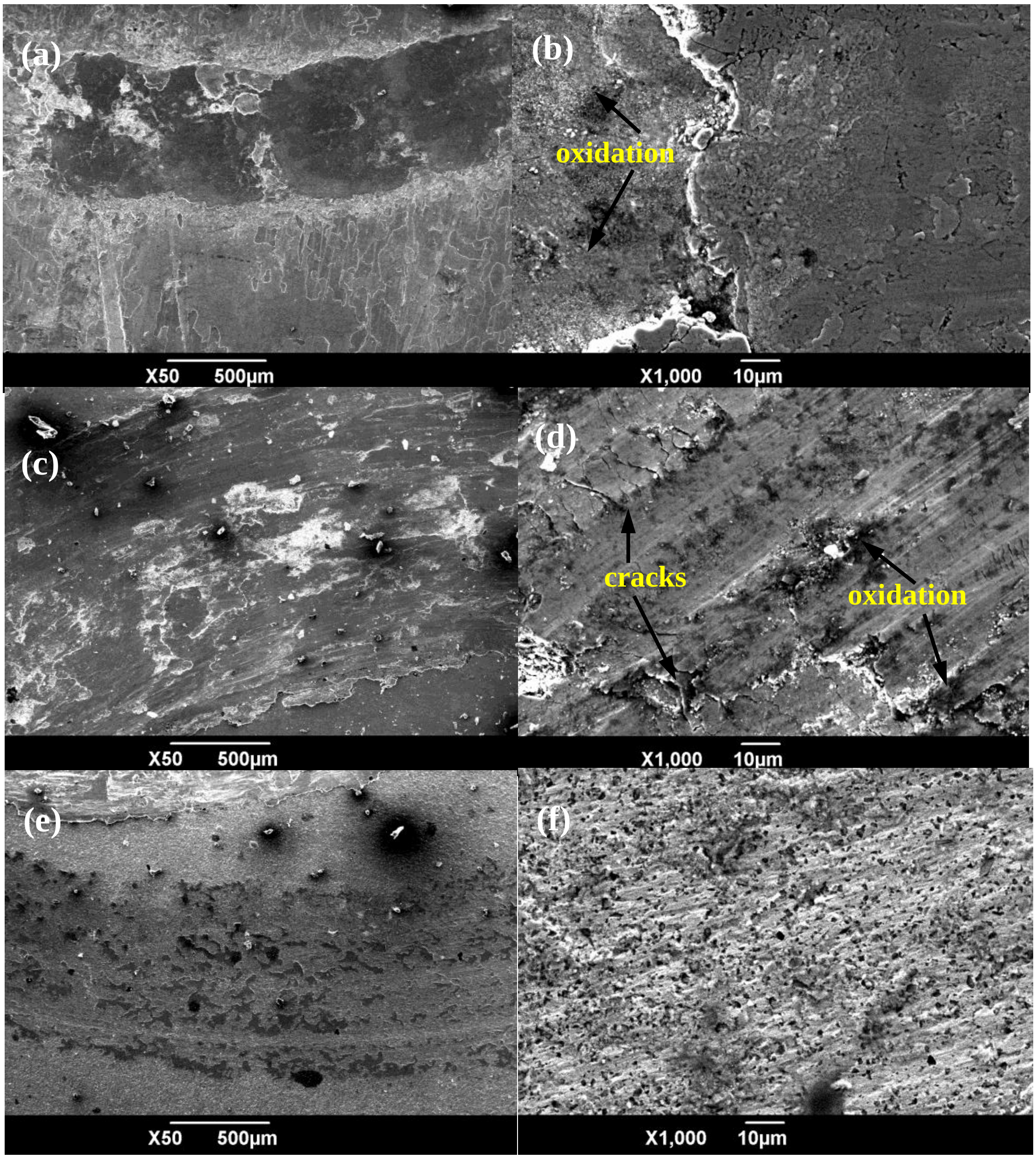

Fig.3. Worn surface morphologies of (a-b) substrate, (c-d) Ni-Co coating and (e-f) Ni-Co-SiC composite coating at 873 K

the presence of the fragments between specimen surface and the pin. Fig.3(e-f) present the worn morphologies of Ni-Co-SiC composite coating, showing that the surface of the composite coating is smooth and continuous, which can be attributed to the effect of embedded SiC particles. The embedded SiC particles carry the load and prevent the matrix alloy from friction by dispersive strengthening effects. And during the wear test, when a large number of ultra-fine SiC particles were dug out by the counter body from the surface of the coating, the friction mechanism was transformed from pure sliding to partly rolling as discussed above, which would reduce the friction force. The friction coefficient of Ni-Co-SiC composite coating is lower than that of Ni-Co coating, confirmed by Fig.2. Because Ni-Co-SiC composite coating possesses the best oxidation resistance, the surface of the composite coating is only slightly oxidized compared with Ni-Co coating and 45 steel, thus reducing the damage of Ni-Co-SiC composite coating, and showing an excellent wear resistance.

4. Conclusions

Ni-Co-SiC composite coatings were prepared by direct current electrodeposition. The embedded SiC particles could strengthen the alloy coating by dispersion strengthening effect, changing the friction mechanism from adhesive wear to abrasive wear. Lower wear loss rate and friction coefficient are presented in Ni-Co-SiC composite coating in comparison with that of Ni-Co coating and 45 steel substrate, indicating excellent wear resistance under high temperature.

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