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COMPARISON OF WEAR BEHAVIOURS OF ELECTROLYTIC HARD CHROMIUM COATED AND NITRIDED AISI 4140 STEELS

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Abstract

There are various techniques for improving wear and corrosion resistance of steels by hardening the surface. Two of them are known as electroplating and nitriding. Electroplating is an electrochemical process by which metal is deposited on a substrate by passing a current through the bath, and nitriding involves a case hardening process that depends on the absorption of nitrogen into the steel. In this study, the wear behaviours of electrolytic hard chromium coated and nitrided AISI 4140 steel samples were investigated in pin-on-ring system. Wear experiments were performed in dry sliding and room temperature conditions, and sliding speed and normal load were used as variable parameters. The wear track width on the samples and the average coefficients of friction in steady-state sliding regime were determined. After the tests, the surface topography of the samples were observed by SEM. According to the test results it was found that hard chromium coated samples showed better wear resistance than nitrided samples.

Keywords: *wear, electrolytic hard chromium coating, nitriding*

1. Introduction

Since the 1920's, electrolytic hard chromium (EHC) coatings have been widely used for improving wear and corrosion resistance of engineering tools and components in the aerospace, automotive and petrochemical fields [1-6]. Chromium is considered as a strategic metal because of its use in metal alloys, especially steels and other alloys and wear performance of hard chromium coating is better than most metallic coating. Hard chromium electrodeposition processes use wet chemical baths containing the hexavalent chromium ion, Cr^{6+}, some of which is emitted into the environment as effluent or sludge [1,7]. There are limitations in the applications of electroplated chromium coatings. The microcracks generated during electroplating reduce the wear as well as the corrosion resistance [1,5,6]. On the other hand, in some studies, the beneficial effect of the cracks is observed and explained by the extension of the fraction of area covered by liquid lubricant [1]. It is also known that the hardness of electroplated chromium decreases significantly with increasing temperature, thereby reducing the wear resistance of electroplated chromium, especially at temperatures above 350 °C [5]. Also hexavalent chromium is classified as a carcinogen compound, which causes health risks if used in production, and environmental problems due to the toxic character of the wastes [1]. Because of these limitations there are suitable alternatives proposed for hard chromium. Previous studies showed that PVD-CrN coatings can be an alternative for hard chromium [1,7]. Nevertheless, today, although challenged by new technologies, hard chromium continues to be the most effective and economical material to protect and repair parts subjected to extreme forces.

Nitriding is known to enhance surface hardness, fatigue strength, tribological properties, and, to some extent, corrosion resistance [8,9]. Salt bath nitriding (SBN) process provides an alternative to surface treatments such as gas nitriding, induction hardening, and hard chromium and electroless nickel plating. Processing ferrous parts in a molten salt bath improves metal hardness, fatigue strength, wear properties, and corrosion resistance. The SBN treatment produces two distinct microstructural zones-on the surface a shallow, hard, ductile case of epsilon iron nitride is formed; beneath it lies a much deeper nitrogen diffusion zone. Low operating temperatures and controlled cooling during SBN processing produces distortion-free results, allowing machining to be performed prior to SBN processing [10]. Nowadays, salt bath nitriding is often used as a substitute for traditional coatings, such as chromium, nickel and zinc.

Dry sliding wear behaviours of AISI 4140 steel subjected to different surface treatments have been previously studied [11-20]. In this study, the wear behaviours of electrolytic hard chromium coated and nitrided AISI 4140 steel samples were investigated in pin-on-ring system and the results were compared.

2. Experimental details

2.1. Sample preparation

AISI 4140 steel was used as substrate. This material was chosen because it can be nitrided to a high surface hardness without losing its toughness, which makes it suitable for highly loaded machine parts. Chemical composition of the substrate is indicated in Table 1. The cylindrical samples with dimensions of 20 mm diameter and 9 mm height were used for wear tests. The samples were quenched from 850 °C in oil and tempered at 630 °C for 1 h. The hardness value of the samples after the heat treatment were 310 Hv (10 g). The samples were polished and cleaned before electrolytic hard chromium coating and nitriding. EHC coating parameters are listed in Table 2. Salt bath nitriding was carried out in a molten salt bath during 135 min at the temperature of 560 °C.

2.2. Surface characteristics

The cross-section of the EHC coated and nitrided samples were observed by scanning electron microscopy (SEM) (Fig. 1 and Fig. 2). The thickness, surface roughness R_a and microhardness values of the EHC, SBN and the substrate are listed in Table 3. For SBN, 1 and 2 indicate white layer and nitrogen diffusion zone, respectively.

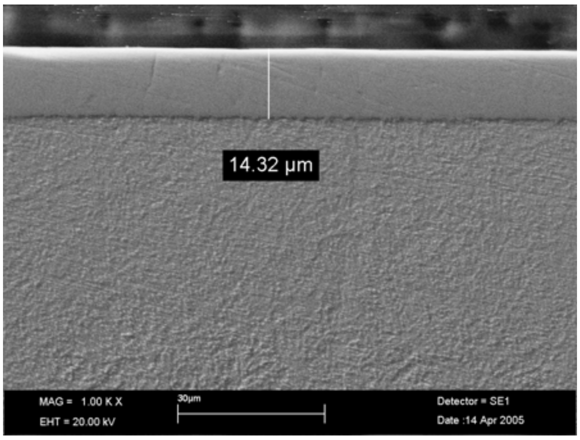

Fig. 1. SEM cross-sectional micrograph of EHC coated sample.

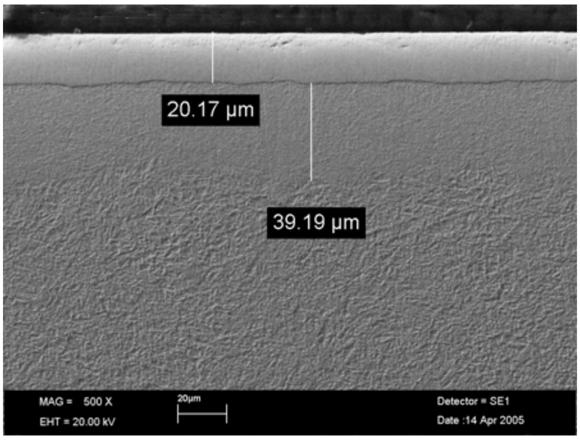

Fig. 2. SEM cross-sectional micrograph of nitrided sample.

2.3. Wear testing

The wear behaviours of electrolytic hard chromium coated and nitrided AISI 4140 steel samples were investigated in a wear tester adapted to pin-on-ring system (ASTM G-77) (Fig. 3 and Fig. 4). DIN 100Cr6 rings (surface roughness R_a 0.12 µm, 61 HRC) with 26 mm diameter and 5 mm height were used as counter material. Counter material composition is as

Table 1
Chemical composition of AISI 4140 steel substrate

AISI 4140	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
Wt.%	0.4400	0.3280	0.8245	0.0082	0.0162	0.8137	0.1512	0.0886	Bal.

Table 2
EHC coating parameters

CrO_3 (g/l)	252.17
H_2SO_4 (g/l)	4.68
Temperature (°C)	53
Current density (A/dm^2)	25
Voltage (V)	4
Bath volume (l)	1500
Time (min)	130

Table 3
Characterisation of the EHC, SBN and the substrate

	Thickness (μm)	R_a (μm)	Microhardness (Hv, 10 g)
Substrate	-	0.05	310
EHC	14	0.09	929
SBN	20[1]/39[2]	0.16	714[1]/457[2]

follows: C 0.99%, Mn 0.38%, Cr 1.42%, Mo 0.02% and Fe balance. Wear experiments were performed in dry sliding and room temperature conditions, and sliding speed (0.3, 0.5, 0.7, 0.9 and 1.1 m/s) and normal load (50, 75, 100 and 125 N) were used as variable parameters. The test time was stable at 25 min. The wear track width on the samples and the average coefficients of friction in steady-state sliding regime were determined. After the tests, the surface topography of the samples were observed by SEM.

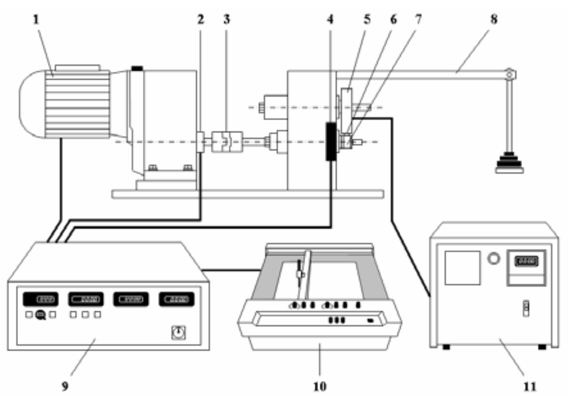

Fig. 3. Schematic of pin-on-ring system 1.motor, 2.tachometer, 3.coupling, 4.load measurement unit, 5.specimen holder, 6.specimen, 7.counter ring, 8.weight loading arm, 9.control unit, 10.x-y recorder, 11.high temperature unit.

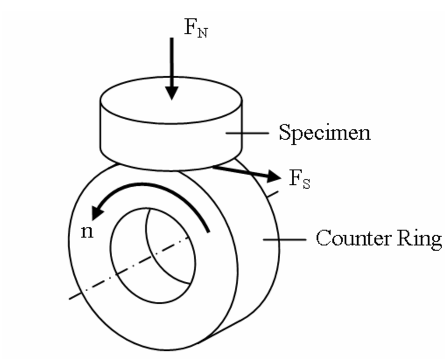

Fig. 4. Contact geometry and forces for pin-on-ring system.

3. Results

The wear track width and coefficient of friction as a function of normal load at 0.7 m/s sliding speed, and as a function of slidind speed at 50 N normal load were presented in Fig. 5 and Fig. 6, respectively.

It was found from the load-wear track width graph of EHC coated and nitrided samples at constant sliding speed of 0.7 m/s that the wear track width increased with load. At the same load and speed value, wear track width of nitrided samples was larger than that of EHC coated samples. This indicates that EHC coated samples have a higher wear resistance. It was found that at constant sliding speed coefficient of friction of EHC coated samples was somewhat higher than that of nitrided samples, and it was observed a decrease in coefficient of friction with increased load.

It was found from the sliding speed-wear track width graph of EHC coated samples at constant load of 50 N that the wear track width increased with sliding speed. In case of nitrided samples it was observed a decrease and later an increase in wear track widths. Relatively higher wear track widths of nitrided samples at low sliding speeds (0.3 and 0.5 m/s) may be due to high coefficient of friction values. When the sliding speeds are taken into consideration, 0.7 m/s is the optimum sliding speed value for nitriding samples. For EHC coated samples the optimum sliding speed is 0.3 m/s. It was found that at constant load coefficient of friction of EHC coated samples was somewhat higher than that of nitrided samples, and it was observed a decrease in coefficient of friction with increased sliding speed. It is suggested that the frictional heat produced at high sliding speeds and high loads is able to cause surface oxidation and results in a decrease in the coefficient of friction.

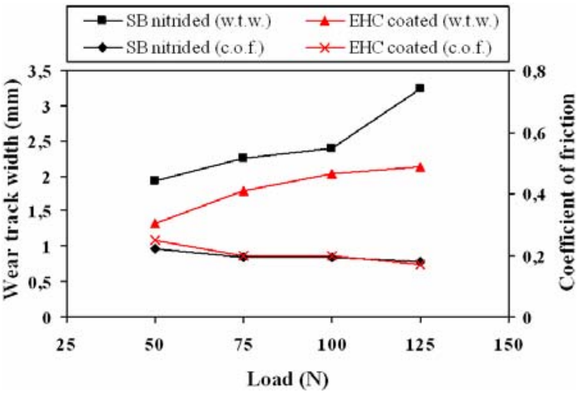

Fig. 5. Wear track width and coefficient of friction as a function of normal load at 0.7 m/s sliding speed.

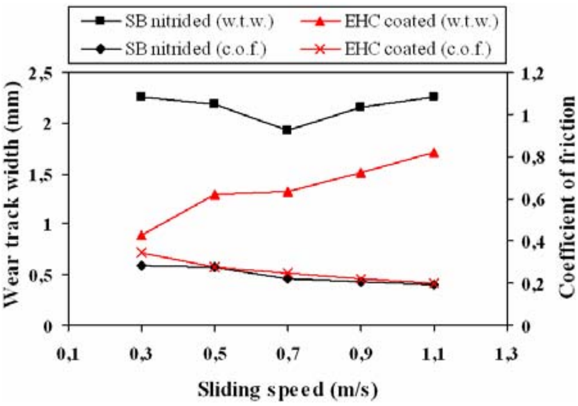

Fig. 6. Wear track width and coefficient of friction as a function of slidind speed at 50 N normal load.

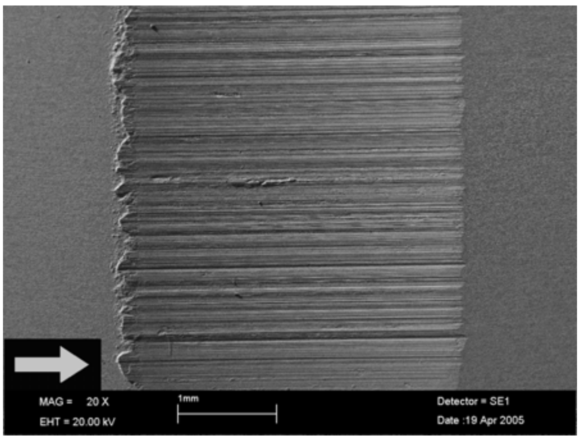

Fig. 7. SEM micrograph of wear track on nitrided sample. The arrow indicates sliding direction (V=0.7 m/s, F=125 N, t=25 min).

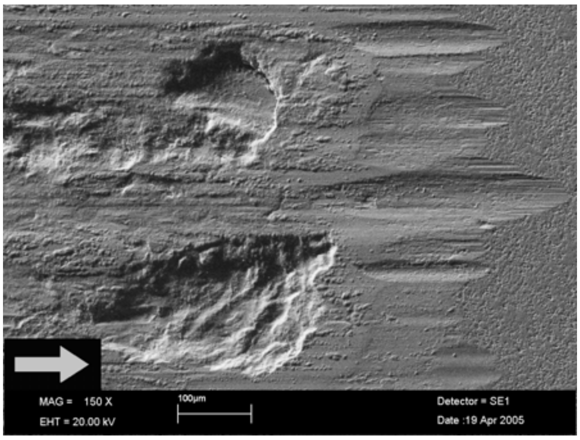

Fig. 8. SEM micrograph of right side of wear track on nitrided sample. The arrow indicates sliding direction (V=0.7 m/s, F=50 N, t=25 min).

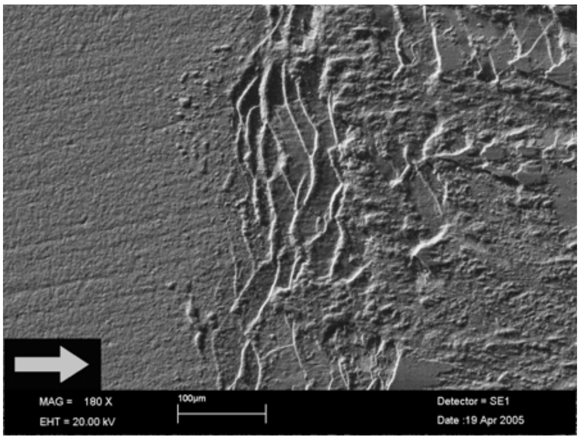

Fig. 9. SEM micrograph of left side of wear track on EHC coated sample. The arrow indicates sliding direction (V=0.3 m/s, F=50 N, t=25 min).

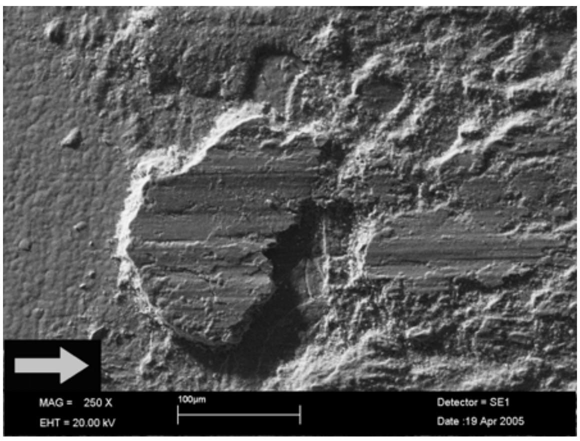

Fig. 10. SEM micrograph of left side of wear track on EHC coated sample. The arrow indicates sliding direction (V=0.9 m/s, F=50 N, t=25 min).

SEM micrographs of wear tracks are given in Fig. 7-Fig. 12. The wear tracks were homogeneous (Fig. 7). It was observed that both

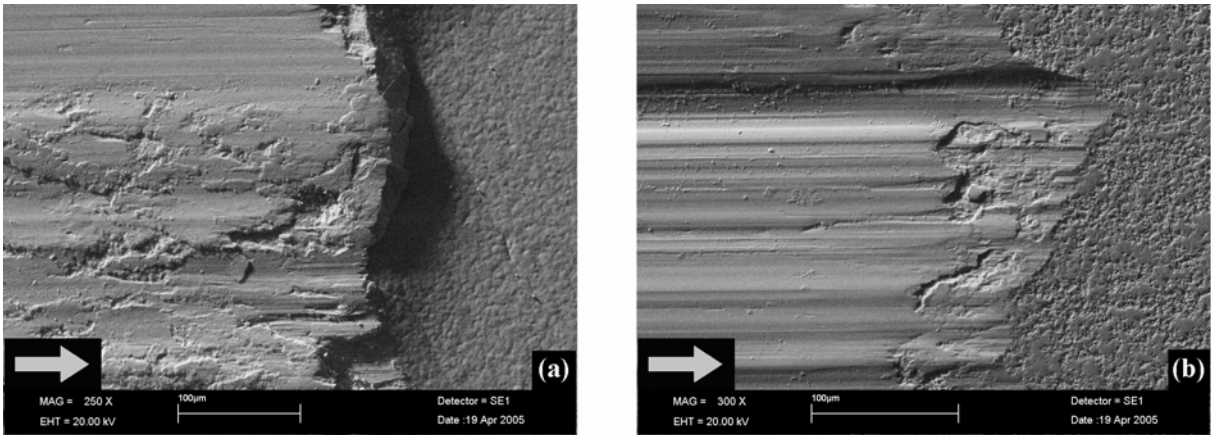

Fig. 11. SEM micrographs of right side of wear tracks on (a) EHC coated and (b) nitrided sample. The arrows indicate sliding direction (V=0.7 m/s, F=125 N, t=25 min).

EHC coated and nitrided samples showed similar wear behaviour. The main wear mechanisms observed were abrasive wear, adhesive wear and delamination. It was observed abrasive wear tracks, holes and also mass transfer parts as revealed in Fig. 8-Fig. 12.

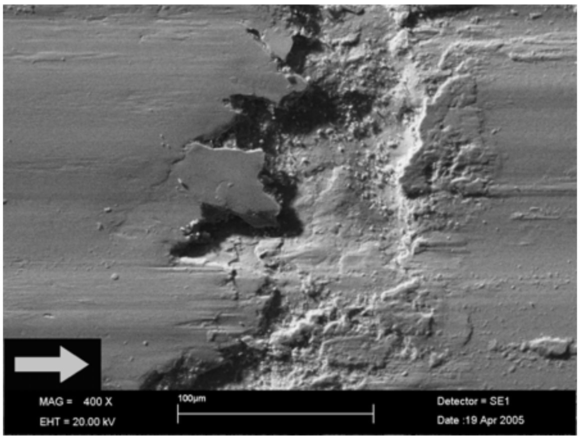

Fig. 12. SEM micrograph of inside of wear track on nitrided sample. The arrow indicates sliding direction (V=1.1 m/s, F=50 N, t=25 min).

4. Conclusions

Wear behaviours of electrolytic hard chromium coated and nitrided AISI 4140 steel samples were investigated in pin-on-ring system. The results obtained can be summarized as follows:

1. For both EHC coated and nitrided samples the wear track widths increased with load at constant sliding speed of 0.7 m/s. At the same load and speed value, wear track width of nitrided samples was larger than that of EHC coated samples. This indicates that EHC coated samples have a higher wear resistance.
2. For EHC coated samples the wear track widths increased with sliding speed at constant load of 50 N. In case of nitrided samples it was observed a decrease and later an increase in wear track widths. Relatively higher wear track widths of nitrided samples at low sliding speeds (0.3 and 0.5 m/s) may be due to high coefficient of friction values. When the sliding speeds are taken into consideration, 0.7 m/s is the optimum sliding speed value for nitriding samples. For EHC coated samples the optimum sliding speed is 0.3 m/s.
3. It was found that for almost all experiments coefficient of friction of EHC coated samples was somewhat higher than that of nitrided samples, and it was observed a decrease in coefficient of friction with increased load and also with increased sliding speed. It is suggested that the frictional heat produced at high sliding speeds and high loads is able to cause surface oxidation and results in a decrease in the coefficient of friction.
4. Consequently, it can be say that EHC coating offers better wear resistance for AISI 4140 steel than salt bath nitriding under the conditions used in this study.

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