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An investigation on the mechanical properties of the hard chromium layer deposited by brush plating process on AISI H13 steel

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ABSTRACT

Purpose: This study aims to investigate the potentiality of brush chromium plating process to replace conventional hard chromium plating.

Design/methodology/approach: In this study brush chromium plating was applied over a H13 quality tool steel. Electron microscopy examinations and X-ray diffraction analysis were conducted in order to reveal the structural features of the coatings. Mechanical properties of the coatings were determined by hardness measurements and wear tests. Wear tests were conducted at room temperature and 500°C.

Findings: Brush chromium plating, which is an environmental friendly alternative for conventional chromium plating, has potentiality to enhance wear resistance of steels.

Research limitations/implications: Brush chromium plating process has good potential to replace hexavalent chromium. Further studies should focus on effect of electro-chemical parameters on structural properties of trivalent based hard chromium deposit by brush plating process.

Originality/value: There have been significant researches on replacement of hexavalent based hard chromium plating in literature. Replacement by brush plating process with trivalent chromium containing electrolyte has been scarcely investigated especially for utilization in wear related applications at elevated temperatures.

Keywords: Thin & thick coatings; Brush plating; Hard chromium; Wear resistance

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Chromium plating is one of the most common surface coating treatments that is preferred in the engineering fields such as aerospace, automotive, petro-chemistry to enhance the material properties [1]. The most important properties of chromium coating are its innate protective and decorative characteristics. For decorative purposes, chromium is deposited on smooth surfaces (usually over nickel layer). The thickness of hard chromium goes up to 100 µm [2]. Hard chromium coating provides high hardness, excellent wear and corrosion resistance along with a low coefficient of friction. Due to these properties of chromium coating, high reflectivity of the deposit is maintained in service [1]. Most commonly hard chromium plating is applied in an hexavalent chromium (Cr^{+6}) ion containing electrolyte as the conventional chromium plating process. Conventional chromium plating has been applied for about 130 years. In recent years, a need to find environmental friendly technologies as an alternative for hexavalent chromium became an attractive issue. Since hexavalent chromium has intense toxicity and carcinogenicity, U.S. Environmental Protection Agency (EPA) categorizes the hexavalent chromium to one of seventeen kinds of carcinogen and toxic substances [3]. For this reason, a lot of researchers around the world have fulfilled many experiments in order to replace this highly hazardous electro-deposition technology. Alloy electro-deposition, trivalent chromium (Cr^{+3}) electro-deposition and composite electro-deposition are major technologies applied. Among these technologies, trivalent chromium electro-deposition has been the most favorable and potential process and has been implemented for several decades [4].

Brush plating (Fig. 1), which is also known as selective plating or contact plating, is one of the electrodeposition methods [5,6] and has appeared as an attractive alternative for conventional process owing to the nontoxic effect of Cr^{+3} solutions and possibility to apply on-site chromium plating to large parts. Brush plating process is portable and suitable for maintenance of plated deposits onto localized surfaces [7,8]. In this process the work piece is not immersed in the electrolyte. Instead of this, the plating solution come into contact with the part and applied by a hand-held anode or stylus for applying the solution in the work piece (cathode). The basic principal of brush plating process is based on the movement of the abrasive brush on the material surface when plating, stripping, activating and so on [9]. In this process the sections that not desired to be plated is first masked and then a series of base material preparatory steps are applied to get an adherent deposit. Many studies have been applied to study the preparation and properties of brush plated deposits. To our knowledge, this is the first paper on investigating the high temperature tribological behavior of hard chromium coating prepared by brush plating technique. Therefore the aim of this study is to enhance the mechanical properties of AISI H13 hot work tool steel by depositing hard chromium by brush plating process which is trivalent chromium electrolyte is used instead of hexavalent chromium electrolyte that has carcinogen effect.

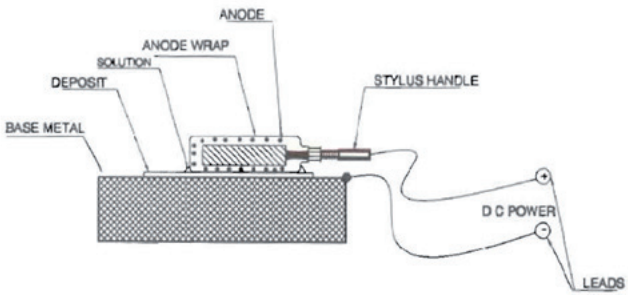


Fig. 1. Schematic of brush plating process [9]

2. Material and method

Hard chromium coating was brush plated on AISI H13 hot work tool steel substrate by using LDC brand trivalent chromium solution that contains chrome alum and formic acid. Before chromium plating, nickel plating was made by brush plating process to get better interface compatibility between the coating and the substrate. The nickel solution was also LDC brand consisted of nickel sulphate and formic acid. Table 1 presents the plating parameters of chromium and nickel. Surface preparation of the substrate (with the diameter of 2.5 cm and the thickness of 0.55 cm) consisted of grinding by SiC papers from the number of 180 to 2500, rinsing with technical quality ethanol and rinsing with distilled water, respectively. The surface of the nickel coating, which was plated before hard chromium, was polished by 3 µm sized diamond. In the plating process, graphite was used as the anode and the anode was covered by abrasive red sponge (3MTM 07447). The plating process was carried out by a brush plating system which the components of the process were synchronized. The electrical contact of the substrate was supplied by fixing the screw by stud welding onto the substrate surface that was isolated from the solution. The solution was supplied to the anode-cathode interface by the peristaltic pumps. The current needed for the brush plating process was supplied by DC power supply which had input capacitance of 220 V AC/50 Hz and output capacitance of 300 V DC. The beaker, which contained the trivalent chromium solution, was placed into the case type resistance to heat the solution.

Table 1.
Plating conditions

Coating	Plating Voltage	Plating Time	Plating Temperature
Hard Chromium	6 V	10 min.	73°C
Nickel	18-14 V	3 min.	Room temperature

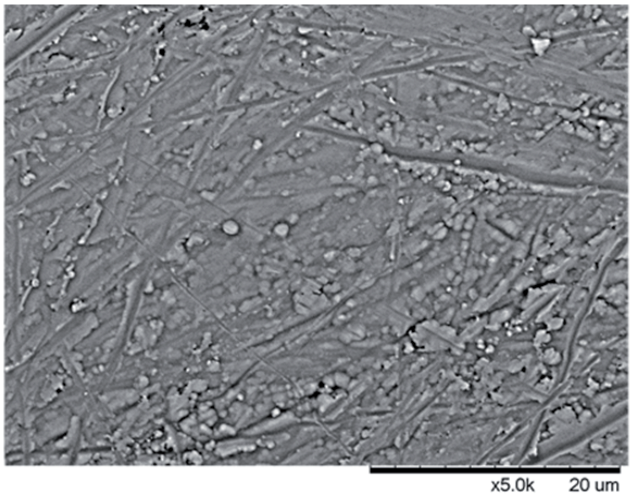
Microscopic surface morphology of the deposits were examined by Hitachi TM-1000 scanning electron microscope (SEM). Cross-section examinations and measurements of deposit thickness were applied by Leica optical microscope. XRD analysis of the deposits was applied by using the CuKα tube and scanning the deposit surface between 10°-90° with the raise of 2°/min. Hardness of the deposits were measured on the cross-sections by utilizing depth sensing hardness tester (CSM) under indentation load of 25 mN. Hardness measurements were conducted on 5 different locations of coatings. Wear tests were carried out under dry sliding conditions at room temperature and at 500°C on CSM ball-on-disc type tribometer. The counterface was alumina ball with diameter of 6 mm. Wear testes were carried out under load of 2 N, for the sliding distance of 250 m. After the wear testes, the surfaces of the alumina balls were investigated by optical microscope. The wear tracks developed on surfaces of the samples were analyzed by a profilometer (Veeco Dectac 6000M) and optical and scanning electron microscopes.

3. Results and discussion

3.1. Microstructural examinations

Surface and cross-section appearances of the brush plated samples are presented in Fig. 2. On the surface micro cracking, that is the biggest problem of trivalent chromium, was identified in limited amount: The coating was dense and bright without porosity. In a previous work, Saravanan and Mohan had detected many micro-cracks on surface of the brush plated chromium (15 μm thickness) after 20 minutes of deposition at current density of 24 A dm^{-2} [10]. Cross-section examinations revealed good interface binding between nickel and hard chromium layers whose thicknesses were measured about 13 μm and 10 μm, respectively. However, tensile type cracks were detected in chromium layer. Since chromium plating generates heavy residual stresses [11], it is suggested that these cracks were formed during cutting of the samples for metallographic examinations.

a)



b)

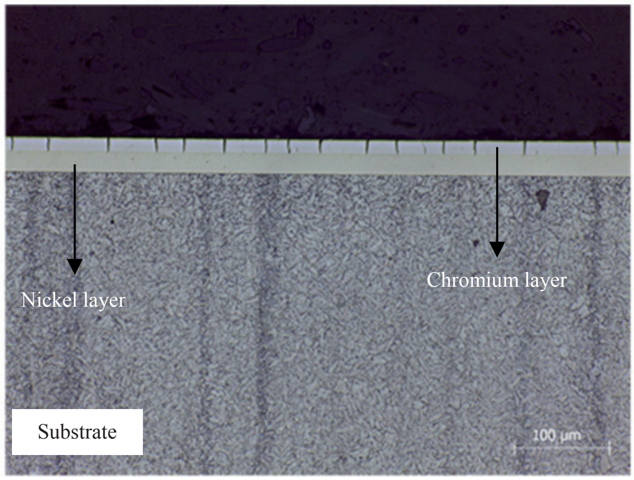


Fig. 2. a) Surface SEM and b) cross-section optical microscope images of the brush plated sample

The XRD pattern of the brush plated hard chromium is presented in Fig. 3. On XRD pattern a strong Cr (110) peak and low Cr (221) peak have been attained. This pattern is in accordance with the analysis by Saravanan et al. Strong (110) pattern is due to small grain size [10]. The nucleation and growth interface by hydrogen affects the surface energy and growth mechanism, and then enables the formation of smaller grain size [10]. The hardness of the chromium layer was measured as 1017±28 HV.

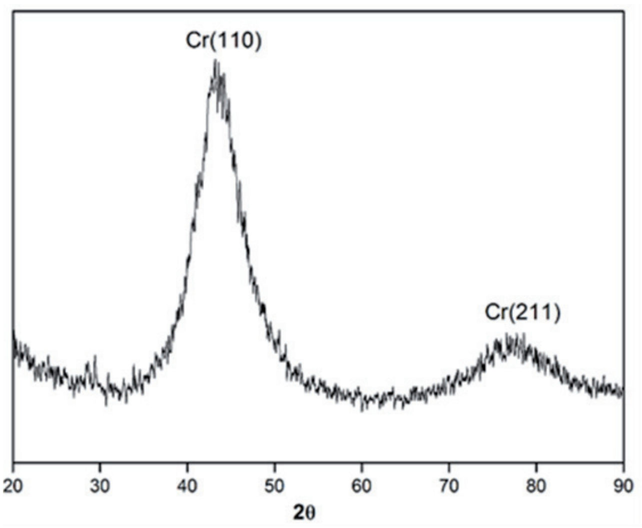


Fig. 3. XRD pattern of the brush plated hard chromium

3.2. Wear tests

Results of the wear tests are quantified in Table 2 in terms of the average size of the wear tracks (depth and width) and wear loss calculated by multiplying the wear track area with the circumference of the sliding path. As a general trend, samples exhibited lower wear loss at 500°C as compared to room temperature. Reduction of wear loss was accompanied by a decrease in friction coefficient as can be seen in Fig. 4. When contact surface appearance of the samples and alumina ball are of concern (Fig. 5) room temperature wear mechanism was identified as adhesive wear. Worn surfaces of the samples tested at 500°C were covered with oxide layers. It is therefore concluded that generation of thick oxide layer at the sample /alumina ball interface prevented direct contact of the alumina ball with the samples so that no material transfer to the contact surface of the alumina ball had taken place (Fig. 5). In this respect dominant wear mechanisms were identified as oxidative wear at 500°C.

It is apparent from Table 2 and Fig.4 that chromium coating provided better wear resistance and friction coefficient than substrate both at room temperature and 500°C. This observation can be correlated with the high hardness of the chromium layer.

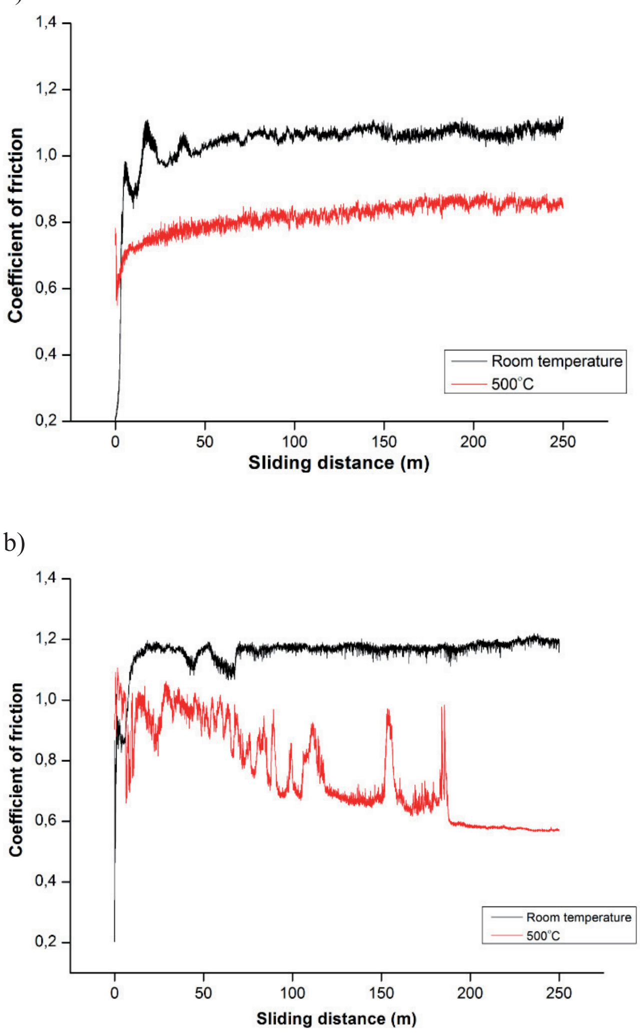


Fig. 4. Friction curves of (a) AISI H13, (b) brush plated hard chromium during wear tests at room temperature and in 500°C

Table 2.
Mean width of wear track, mean depth of wear track, and volume losses of brush plated hard chromium and the substrate at room temperature and in 500°C

Sample	Test temperature	Depth of wear track, µm	Width of wear track, µm	Wear loss, x 10^{-3} mm^3
Substrate	Room temperature	12.93 (±4.85)	555.5(±115.35)	208.07
	500°C	5.12 (±0.61)	400 (±30.32)	55.35
Chromium Coating	Room temperature	6.51 (±0.39)	375.5 (±45.06)	66.34
	500°C	3 (±0.73)	361.25 (±36.32)	29.41

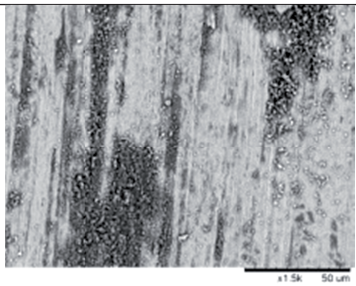
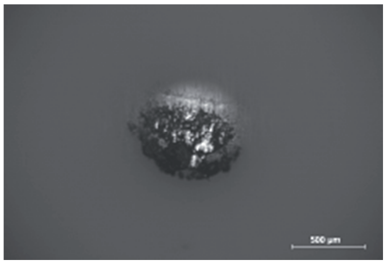
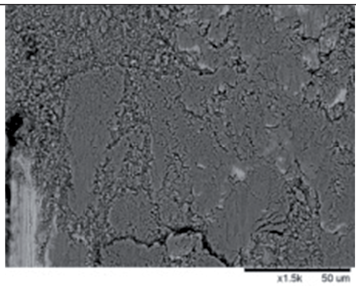
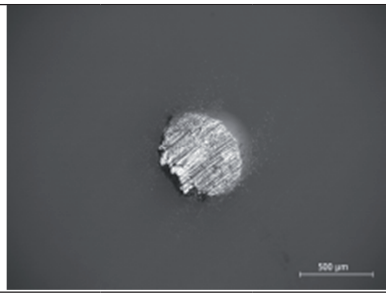
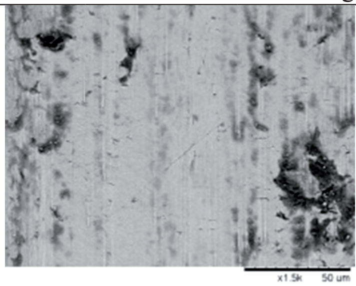
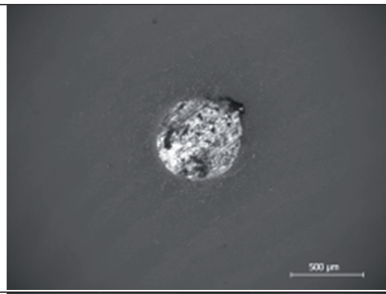
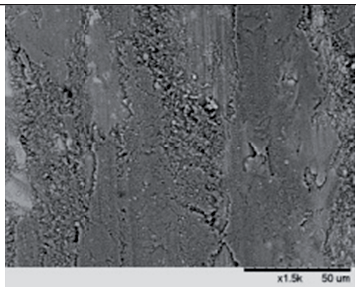
Test temperature	Wear track (SEM)	Ball (Optical microscope)
AISI H13 Steel		
Room temperature		
500°C		
Chromium Coating		
Room temperature		
500°C		

Fig. 5. Contact surface appearance of the wear track and the alumina ball after wear tests at room temperature and in 500°C

4. Conclusions

It is concluded that, brush chromium plating, which is an environmental friendly alternative option for conventional chromium plating, has potentiality to be applied over steels with the aim to enhance their wear resistance. Hard chromium coating deposited over AISI H13 tool steel by brush plating process successfully resisted mechanical degradation at room temperature and 500°C, without detaching from the substrate.

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Additional information

This paper will be presented at 15th International Materials Symposium (IMSP'2014) in Denizli Turkey.

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