



# Corrosion properties of carbon ions implanted chromium coating prepared on CSS-42L aerospace bearing steel

Fangfang Wang<sup>a,b</sup>, Lijing Zheng<sup>a,\*</sup>, Qiushi Li<sup>b</sup>, Fengxiang Zhang<sup>a</sup>, Xiaohui Chen<sup>a</sup>, Hu Zhang<sup>a,\*</sup>

<sup>a</sup> School of Materials Science and Engineering, Beihang University, Beijing 100191, China

<sup>b</sup> School of Energy and Power Engineering, Beihang University, Beijing 100191, China

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## ABSTRACT

In this work, carbon ions implanted chromium coating deposited on CSS-42L aerospace bearing steel by using the filtered cathodic vacuum arc deposition-metal evaporation vacuum arc duplex technique had been investigated. Film structure and properties after carbon implantation have been characterized by glancing incident XRD, AFM, SEM, TEM, AES, XPS and potentiodynamic polarization test. Carbon ions implanted chromium coating showed an increase in the pitting potential, promoting higher pitting corrosion resistance. The improvement was attributed to the reduction of surface roughness, the irradiated amorphous phase, the inert graphitic solid state carbon and the formation of nanocrystalline Cr<sub>2</sub>C and CrC.

## 1. Introduction

Bearings on engine shafts have to tolerate increased system temperature, speed, load capability and a corrosive environment [1]. The lubricant initially can protect bearing alloys from corrosion attack. However, when the oil is contaminated, bearing alloys will become susceptible, particularly in a marine environment. Under high stress-rolling contact fatigue conditions, corrosion of the engine bearings would result in premature bearing failure [2]. The requirement for future advanced aerospace engine bearings is becoming more and more rigorous [1, 3–5]. They need good corrosion resistance, maximum hardness to carry loads at higher temperatures, good fracture toughness in core for high DN situation (D-diameter of bearing bore in millimeters, N-shaft speed in revolution per minute) [6]. CSS-42L is a kind of highly alloyed carburizing steel and its chromium content is up to 13 wt %. It possesses a balance of high surface hardness and good core fracture toughness, coupled with a modest corrosion resistance. CSS-42L is one of the most promising candidate materials for future advanced aerospace engine bearings [7, 8]. Comparing with other common stainless bearing steels such as Cronidur 30 and AISI 440C, CSS-42L is more susceptible to corrosion problems [6, 9]. So, it is meaningful and needed to improve corrosion resistance of the CSS-42L steel for the present and future bearing applications.

Chromium coatings are commonly performed to increase the corrosion and wear resistance of steels and various alloys [10]. Electroplating process for the production of chromium coatings using Cr (VI) or Cr (III) electrolytes is harmful to environment [11, 12]. New

technologies and new coatings, which are environment friendly and provide better performance, are urgent needed. A filtered cathodic vacuum arc (FCVA) plasma deposition system, which is developed from metal vapor vacuum arc (MEVVA) ion implantation techniques, has been widely used for the preparation of coatings. According to the published data, films deposited by this technique have better compactness and higher corrosion resistance [13–16]. However, the micro-cracks or pin-holes are also observed and the electrochemical properties of pure chromium coating are compromised [17].

Physical or chemical post-coating treatments have been applied to enhance the corrosion and wear resistance of coatings [10, 17–19]. Ion implanted surface layer, in forms of either dense structure or new phases which may not exist in equilibrium phase diagrams, is proposed to modify the corrosion and wear resistance of substrate materials [20, 21]. The non-equilibrium ion implantation technique as a post-deposition surface treatment has been used to improve physical and chemical performances of thin films. As implanting carbon permits thicker modification layer, it is one of the most widely used implantation elements [22–27]. Rao et al. [27] investigated the effect of carbon ion implantation on the tribological response of electroplated chromium coating. Experimental results showed a reduction in the coefficient of friction and a remarkable improvement in the wear resistance for Cr coating implanted with carbon ions at a proper parameter. Although there are some works on the corrosion performance of carbon implanted steels [20, 28], little information has been revealed on the crystal structure and corrosion characteristics of carbon-implanted electroless chromium coating.

\* Corresponding authors.

E-mail addresses: [zhenglijing@buaa.edu.cn](mailto:zhenglijing@buaa.edu.cn) (L. Zheng), [zhanghu@buaa.edu.cn](mailto:zhanghu@buaa.edu.cn) (H. Zhang).

**Table 1**  
Composition of experimental CSS-42L steel.

Steel	Cr	Mo	Mn	Ni	V	Co	Si	C	B	Nb
CSS-42L	13.73	4.60	0.33	2.11	0.6	13	0.2	0.14	0.002	0.024

**Table 2**  
Processing history of CSS-42L steel used during the surface modification and corrosion assessment part of this study.

Steel	Austenitizing temperature (°C)	Number of deep cryogenically treat	Tempering temperature (°C)
CSS-42L	1095 (oil quenching)	2 (liquid nitrogen)	496

In this study, a thin chromium film was deposited on CSS-42L aerospace bearing steel by FCVA deposition system, and then a MEVVA ion source was set up for carbon ion implantation into the chromium coating. The aim of present work is to analyze the microstructure evolution and corrosion resistance for chromium film on CSS-42L aerospace bearing steel after ion implantation post-treatment.

## 2. Experimental methods

Composition for the CSS-42L steel used in this study is presented in Table 1. A detailed processing history for the CSS-42L steel is showed in Table 2. All samples of  $10 \times 10 \times 5 \text{ mm}^3$  were cut from the hardened CSS-42L bar. Specimens were mechanically polished with SiC emery paper up to #2000, and then polished with diamond paste to  $1.5 \mu\text{m}$  grit.

Before Cr film deposition, all samples were ultrasonically degreased in acetone. The Cr film was deposited in a FCVA-MEVVA duplex machine. The deposition process was preceded by applying a pulse arc current of 100 A and a dc pulsed negative bias of  $-80 \text{ V}$  with a duty cycle of 90% in a  $180^\circ$ -bend magnetic FCVA system. In order to increase the adhesion between Cr coating and substrates, all samples were sputter-etched with Cr ions prior to each experiment in the vacuum chamber, and then continuously pre-implanted with Cr ions to get a Cr transition layer before deposition. The implantation process was conducted at acceleration energy of 8 keV with ion fluxes of  $1 \times 10^{17}$  ions/ $\text{cm}^2$ . The thickness of deposited film was about  $1 \mu\text{m}$ . Then chromium coatings were implanted with carbon ions by using MEVVA source implanter. The carbon ions implantation process was carried out at energy of 30 keV with ion fluxes of  $3 \times 10^{17}$  ions/ $\text{cm}^2$ . The CSS-42L was abbreviated to C, the chromium film coated CSS-42L with and without carbon implantation were abbreviated to C-Cr-C and C-Cr, respectively.

The cross-section microstructure of the film was observed by scanning electronic microscopy (SEM, JEOL, JSM6010) and its composition

was detected by EDS. Atomic force microscopy (AFM) was applied to measure the surface topography and the arithmetic means of roughness Ra was calculated using the NanoScope Analysis software. The crystallographic phases were determined by X-ray diffraction (XRD, 40 kV, 100 mA) Cu K $\alpha$  and the glancing incident angle X-ray diffraction (GIXRD, 40 kV, 100 mA) at  $0.5^\circ$  was used to detect phase changes in carbon implanted Cr film. Elemental depth profiles and the chemical bonding states of implanted carbon were obtained from Auger electron spectroscopy (AES, PHI-700) and X-ray photoelectron spectroscopy (XPS, PHI Quantera SXM), respectively. The transmission electron microscopy (JEOL TEM 2100, 200 kV) was also used to observe the microstructure of both carbon ion implanted and un-implanted Cr films.

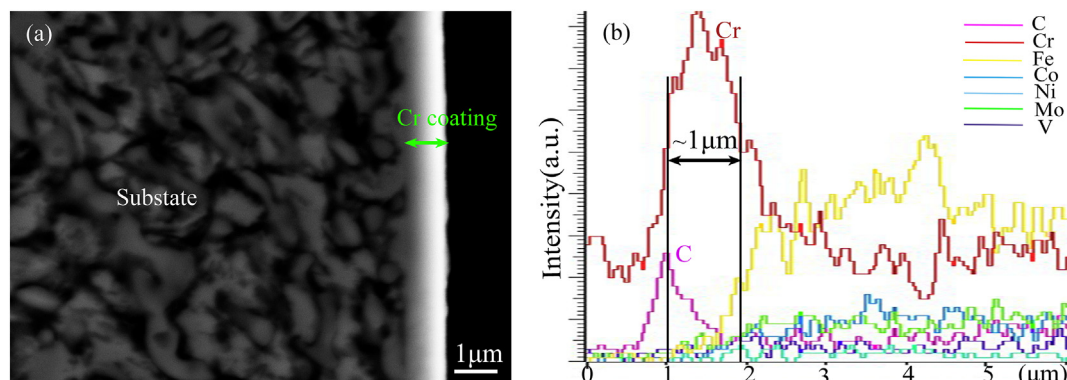
The corrosion behavior of both implanted and un-implanted coatings were determined by polarization studies in 3.5 wt% NaCl solution. Potentiodynamic polarization scans were carried out using a CS300 electrochemical work station. The NaCl solution was maintained at  $30^\circ\text{C}$  open to air and the potentiodynamic curves were initiated once the open circuit potential (OCP) was stabilized. A conventional three-electrode cell setup consisting of the working electrode, a saturated calomel electrode (SCE) as the reference electrode, and a platinum sheet counter electrode was used. The scanning rate was  $0.5 \text{ mV/s}$ . The surface chemistry of both implanted and unimplanted coatings after electrochemical tests was determined by X-ray photo electron spectroscopy (XPS). The corrosion morphology was examined by SEM and the composition of corrosion products was analyzed by SEM/EDS.

## 3. Results and discussion

### 3.1. Characterization of the chromium coating with carbon implantation

Fig. 1 presents the cross-sectional microstructure and the linear distribution of the compositional elements in the carbon implanted chromium coating obtained by SEM-EDS. A compact surface layer with a layer thickness about  $1 \mu\text{m}$  is formed.

The depth profiles acquired by AES technique from carbon ions implanted chromium coating are showed in Fig. 2. After carbon ion implantation, the carbon concentration is obviously increased in the outside surface of chromium coating. The thickness of carbon implanted layer is approximate  $156 \text{ nm}$  which accumulated through the sputtering rate ( $17 \text{ nm/min}$ ). The carbon atomic fraction at the surface is very high (around 90 at.%) and decreases until an almost constant concentration range between 52 at.% and 45 at.% (sputtering time: 1.4 min–4 min). Then the carbon concentration decreased until over the implantation depth (sputtering time: 4 min–9.2 min). There is no drastic change in composition between the carbonaceous layer and the chromium coating, indicating a gradual interface. Former researches revealed that the chemical state of the implanted carbon was related to the carbonaceous concentration [15, 24–27]. The carbon atoms trend to form chromium carbides until a net carbon fraction over 20 at.% is



**Fig. 1.** Cross-sectional micrographs (a) and linear distribution of the compositional elements (b) of the carbon implanted chromium coating, using SEM-EDS.

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