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Characterization and properties of plasma electrolytic oxidation coating on low carbon steel fabricated from aluminate electrolyte

Wenbin Yang [a, b], Qingbiao Li [a, b], Weimin Liu [a], Jun Liang [a, *], Zhenjun Peng [a], Baixing Liu [a]

[a] State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[b] University of Chinese Academy of Sciences, Beijing 100039, China

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A B S T R A C T

Plasma electrolytic oxidation (PEO) coating was prepared from aluminate electrolyte on low carbon steel. The structure, composition, microhardness, anti-wear and anti-corrosion properties of the PEO coating were explored. The results show that the PEO coating possesses a uniform and dense structure and is mainly composed of α-Al_2O_3 as well as some γ-Al_2O_3 and Fe_3O_4. The PEO coating exhibits lower friction coefficient and wear rate than that of uncoated low carbon steel under dry sliding condition. The corrosion potential of coated sample shifts toward positive direction by 380 mV and the corrosion current density decreases by 2 orders of magnitude. Therefore, the PEO coating prepared from aluminate electrolyte can offer a good protection to low carbon steel from wear and corrosion.

1. Introduction

Carbon steel is the most widely used metal material across all industries due to its excellent features: high strength, good machining ability and low cost [1]. While, carbon steel is not a perfect material due to their weaknesses of inferior wear and corrosion resistance, limiting its application under the conditions where materials are required to possess superior tribological and anti-corrosion properties. Fabricating protective coatings on carbon steel is a very effective way to enhance wear or corrosion resistance of substrates. Hitherto, surface treatment techniques, such as PVD [2], CVD [3], magnetron sputtering [4] and so on, have been widely used to prepare coatings to offer a protection to substrate. Plasma electrolytic oxidation (PEO) is a relatively new surface modification technique to in-situ form a ceramic coating on substrate from water-based electrolyte. The PEO process is simple in equipment and friendly to the environment. The PEO technique is developed from traditional anodic oxidation but uses much higher working voltage and current density than the traditional anodic oxidation. Sparks occurring randomly on the anode due to the voltage above the dielectric breakdown voltage of barrier layer is the key characteristic for the PEO process. Localized high temperatures and pressures produce along with the sparks. Under the high temperature and pressure condition, elements from substrate and electrolyte participate in the complex physicochemical reactions and turn into ceramic coating on the anode surface. The ceramic coatings show a three-layered structure (a porous outer layer, a dense inner layer and a thin barrier layer) [5] and are characterized by good adhesion, high hardness and superior wear and corrosion resistance [6]. Generally, the performances of PEO coatings are mainly related to the microstructures and compositions which can be optimized by adjusting electrical parameters (voltage [7], current density [8], etc.) and electrolytic compositions [9,10] conveniently.

Up to now, PEO technique has been widely used to grow ceramic coatings on valve metal (Al, Mg, Ti and their alloys) [11–16] from different electrolytes [17–20] to improve their wear resistance, corrosion resistance, antibacterial property or biocompatibility [21–24]. To date, ceramic coatings have been successfully prepared by PEO technique on carbon steel from silicate electrolyte and aluminate electrolyte [25–30]. The PEO coating presents a two-layered structure (the inner dense layer and the outer porous layer) and possesses microcracks and micropores, similar to the PEO coating prepared on the valve metals. The PEO coatings prepared from aluminate electrolyte and silicate electrolyte offered a protection to carbon steel substrate from wear or corrosion to some extent. In addition, composite coatings have been prepared on carbon steel in combination with PEO coating (as the sublayer). It

* Corresponding author. Tel.: +86 931 4968381; fax: +86 931 8277088.
E-mail address: jliang@licp.cas.cn (J. Liang).

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was found that the corrosion protection of the top layers (nano-composite superhydrophobic coating or organic coating) has been significantly improved [31,32].

Reportedly, the PEO coating was prepared on low carbon steel from electrolyte with 10 g/L $NaAlO_2$. Micropores with open mouth can be observed on the coating surface. The open micropores are detrimental to the anticorrosion performance, confirmed by the low corrosion resistance shown in the Bode plot [30]. In this paper, the PEO coating was prepared from the electrolyte with 20 g/L $NaAlO_2$. The morphology and performances were investigated and it was found that the micropores on this PEO coating surface were sealed by molten materials, resulting in much higher corrosion resistance than that reported. Meanwhile, the PEO coating possesses good tribological property. Therefore, it can offer a much better protection to low carbon steel substrate from wear and corrosion.

2. Experimental

2.1. Preparation of PEO coatings from aluminate electrolyte

Rectangular plates of low carbon steel with dimensions of 25 mm × 20 mm × 8 mm were used as the substrate for PEO treatment. The nominal compositions of the substrate are 0.14–0.22 C%, 0.30–0.65 Mn%, ≤0.30 Si%, ≤0.045 P%, ≤0.05 S% and Fe balance. The water cooling system made of stainless steel spiral pipe was used as the cathode material. The low carbon steel plates served as the anode. Prior to PEO treatment, the plates were polished by abrasive paper (#600, #1500 and #2000, sequentially) with water lubrication. Subsequently, the polished plates were decontaminated and degreased by acetone in ultrasonic environment, and then washed by distilled water and dried by warm air.

In the PEO process, the solution with 20 g/L $NaAlO_2$ and 1.2 g/L NaH_2PO_4 was chosen as the electrolyte. A 200 kW pulsed bipolar

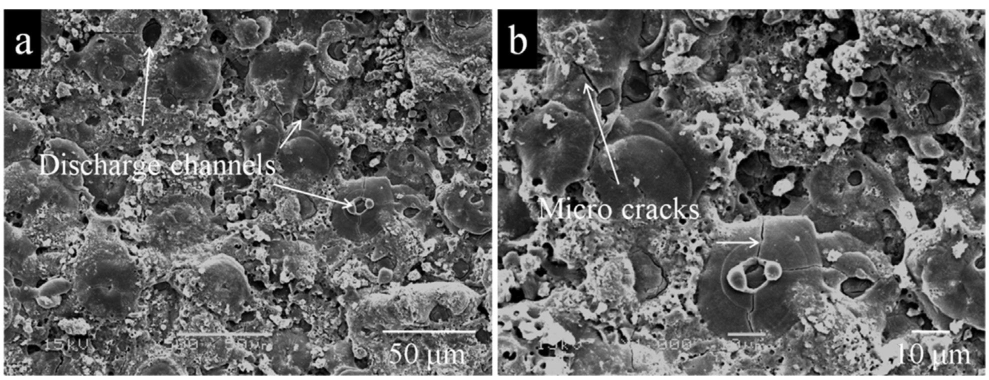

Fig. 1. The SEM surface morphologies of PEO coating prepared from aluminate electrolyte.

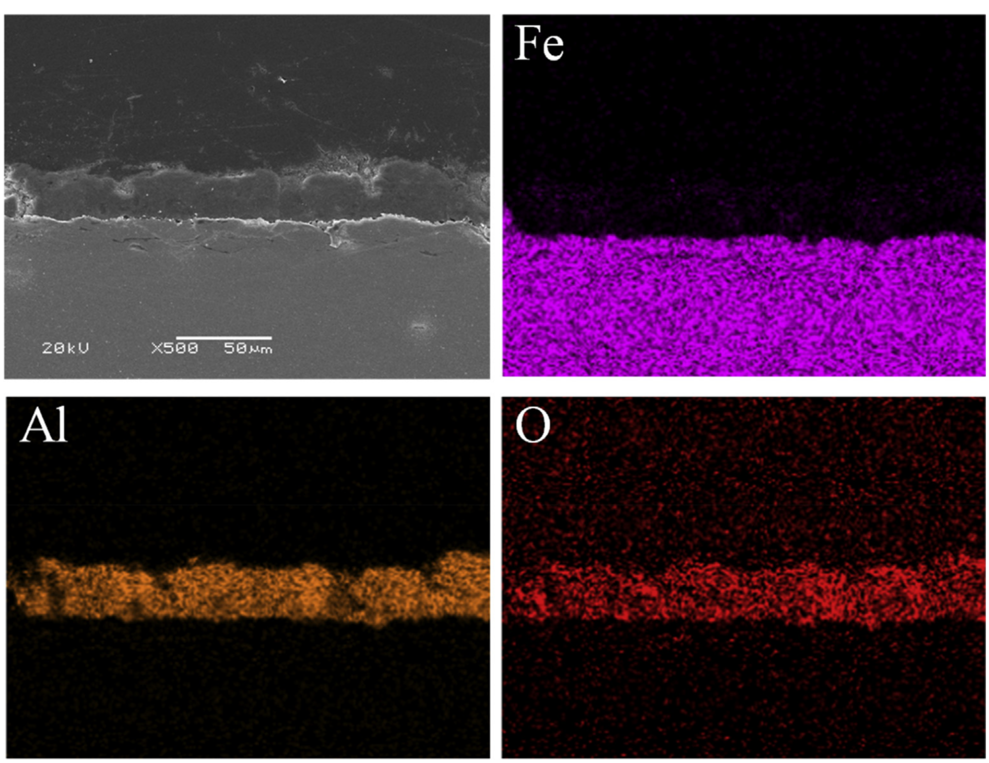

Fig. 2. The SEM cross-sectional morphologies of PEO coating prepared from aluminate electrolyte.