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Characterization of micro-arc oxidation coatings on aluminum drillpipes at different current density

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ABSTRACT

Micro-arc oxidation coatings were fabricated on 7E04 aluminum drillpipes materials in Na_2SiO_3-NaOH electrolyte system containing 3.0 g/L SiC particles at different current density (1, 5, 10, 15 and 20 A/dm^2). The oxidation voltage, coating thickness, surface morphologies, surface micro-hardness, phase composition and potentiodynamic polarization curves of the MAO coatings were investigated. The results showed that the oxidation voltage increased and the coatings thickened with the increment of current density. The coating surface morphologies got coarser gradually which led to the reduction of the surface micro-hardness. The phase composition of the coatings consisted of SiO_2 because of the oxidation of SiC particles and the corrosion resistance of the coatings increased slightly.

1. Introduction

Aluminum alloy is considered to be an attractive candidate material to replace the steel as the drillpipes in petroleum industry. Compared with steel drillpipes (SDPs), the specific gravity of aluminum is approximately 1/3 that of steel which is beneficial for operating and transporting. In addition, the aluminum drillpipes (ADPs) possess quite better yield strength, higher resistance to temperature, lower torque and drag, stronger fatigue resistance and lower cost, etc. relative to SDPs [1]. So far, the ADPs have been extensively used in developed countries such as Russia [2] and America [3]. However the further application of ADPs is restricted by their poor properties, for instance, the relatively low hardness, poor wear resistance and corrosion resistance. These defects of the ADPs are prone to cause the serious surface wear and corrosion damages [4] under the erosion corrosion of the drill fluids. As a consequence, it is imperative to find out an operable method to improve their surface wear and corrosion resistance.

The utilization of surface treatment technologies on aluminum alloy is thought to be a practical method to strengthen its surface performance. Among the wide variety of surface treatments, micro-arc oxidation (MAO) is an emerging ecofriendly coating technique which is capable of forming ceramic coatings on Al, Mg, Ti and their alloys by one step [5–7]. MAO process is carried out at the voltages higher than the breakdown voltage of the oxygen gas layer enshrouding the anode and characterized by some luminous electric arcs on the anode surface [8]. The ceramic coatings produced by MAO treatment have high micro-hardness, good adhesion to the alloy matrix and exhibit excellent wear resistance and corrosion resistance [9]. Meanwhile the operation of MAO is relatively convenient without any environmental pollution. However, the influence factors of MAO process such as the electrolyte composition [10,11], electrochemical parameters [12] and the type of power supply [13] have a significant effect on the comprehensive properties of the ultimate MAO coatings. It has been proved that the addition of SiC particles in electrolyte could provide good wear resistance for aluminum alloys [14,15] compared with the MAO coatings without the addition of SiC. Hence, MAO treatment doping SiC particles in electrolyte is a feasible method to improve the surface performance of ADPs materials. Therefore, there is a need to understand the effect of the current density on the MAO coatings in the electrolyte containing SiC particles. In that, current density is a crucial factor for MAO coatings performance. Consequently, we have focused our attention to investigate the influence of the variation of the current density on the properties of the MAO coatings on ADPs materials with the addition of SiC particles in

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electrolyte.

7E04 aluminum alloy is a new type material which is developed by China prepared for drill pipe [16]. In this investigation, MAO coatings were fabricated on 7E04 aluminum drillpipes materials at 1, 5, 10, 15 and 20 A/dm^2 separately with 3 g/L SiC particles in Na_2SiO_3-NaOH electrolyte system. The main objective of this investigation was to study the effect of different current density on the oxidation voltage, surface morphologies, main element distribution, coating thickness, surface micro-hardness, phase composition and corrosion resistance of the MAO coatings.

2. Material and methods

Rectangular samples (5 mm × 5 mm × 7 mm) of 7E04 aluminum drillpipes materials (with chemical composition by wt%: Zn 5.0–6.5%, Mg 1.8–2.8%, Cu 1.4–2.0%, Cr 0.1–0.25%, Mn 0.2–0.6%, Fe 0.05–0.25%, Si = 0.1%, Ni = 0.1%, Ti = 0.05% and Al balance) were used as the substrate in the experiments. The base electrolyte consisted of Na_2SiO_3 15 g/L, NaOH 1 g/L, $C_3H_8O_3$ 2 mL/L, SiC 3 g/L. The SiC particles with the size around 50 μm were stirred continuously during the treatment in order to keep uniform dispersal in the electrolyte. The MAO process was carried out by a pulsed electrical power which provided positive pulse voltage. The MAO coatings were obtained under peak anodic current density of 1, 5, 10, 15 and 20 A/dm^2 respectively for 30 min, with fixed frequency of 100 Hz and duty cycle of 45%. The electrolyte temperature was kept below 30 °C by a heat exchange system during the MAO process. After MAO treatment, samples were rinsed with hot water at 90 °C for 20 min and dried in warm air.

Surface and cross morphologies of the five coatings were examined by Scanning Electron Microscopy (SEM, ZEISS EVO MA15) equipped with an Energy Dispersive Spectrometer (EDS, OXFORD 20). Phase composition of MAO coatings was analyzed by X-ray Diffraction (XRD, DX-2700B). Diffraction data were acquired over scattering angle 2θ from 10° to 80°, scanning speed was 0.1° s^{-1}. The surface charge of SiC particles was investigated by ZETA Potential Meter (Zetaprobe). The coating thickness and surface micro-hardness were tested by Digital Thickness Gauges (TT230) and Digital micro-hardness tester (HXD-2000TM/LCD) at 2 N for 10 s severally. In addition, the potentiodynamic polarization curves were performed in 3.5 wt% NaCl solution at room temperature by the Electrochemical Workstation (IM6) and fitted by software CorrView.

3. Results and discussion

3.1. Oxidation voltage versus time curves during MAO process

Fig. 1 shows the variation of oxidation voltage with the time at different current density (1, 5, 10, 15 and 20 A/dm^2). Generally, the oxidation voltage increased with the increment of the current density. All the curves increased linearly at the initial anodic oxidation stage which is the necessary condition for dielectric breakdown and electric arc discharge and consistent with the general formation mechanism of the MAO coatings [17]. The growth rate of oxidation voltage grew up firstly and then fell down. The gradually ascending current density induced the rise of oxidation voltage at different current density due to the growing electric energy. In addition, the surface charge of SiC particles in the electrolyte was negative at 226.9 mV. As we explained in our previous work [18] about the added particles, the surface negative charged particles easily move towards the surface of anode specimen with the effects of the electric field and mechanical stirring. Then the SiC adsorbed on the coating surface and enhanced the electrical resistance of the barrier layers, giving rise to the further improvement of the oxidation voltage according to Ohm law. The coating thickness is 2.66, 4.19, 8.99, 11.74 and 14.81 μm respectively (in Fig. 2) in accordance with the trend of the oxidation voltage varying with current density. It revealed that the improvement of current density is beneficial for the formation of MAO coatings.

3.2. The surface and cross morphologies of coatings

The coating surface at 1 A/dm^2 was smooth with few visible discharge channels in Fig. 3(a) since the intensities of discharge sparks and the dielectric breakdown were very weak at a relatively low current density. From Fig. 3(b)-(e), the number of the discharge channels increased obviously and even some small micro-pores appeared on the sintering discs. The diameter of the discharge channels on the coating surface enlarged gradually (approximately from 10 μm to 30–40 μm). As the discussion of the oxidation voltage above, the higher current density provided the higher

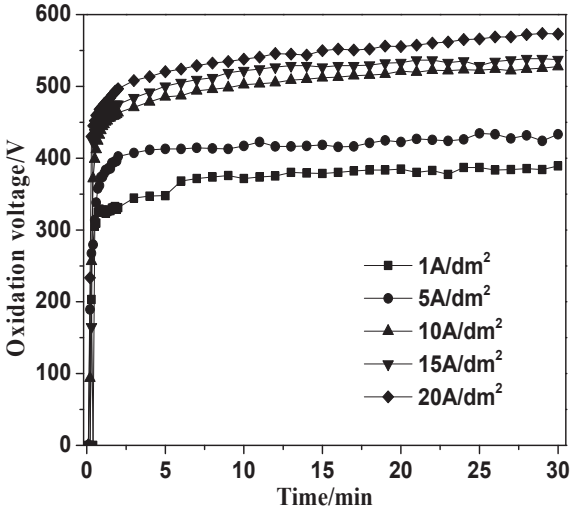

Fig. 1. Oxidation voltage-time curves during MAO under different current density.

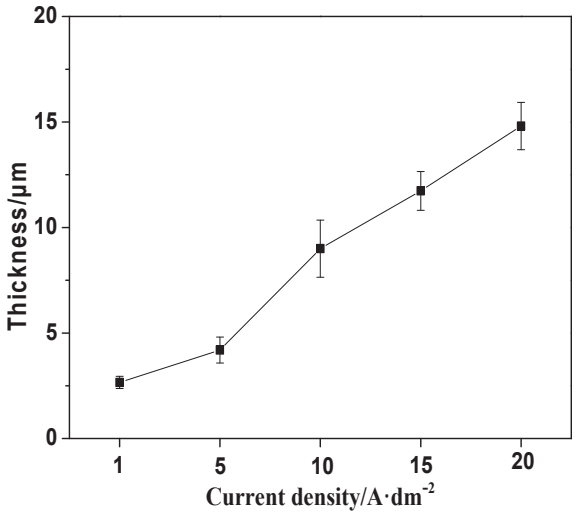

Fig. 2. The thickness of the MAO coatings at different current density.