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Microstructure and mechanical properties of ceramic coatings formed on 6063 aluminium alloy by micro-arc oxidation

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Abstract: The microstructure and mechanical properties of ceramic coatings formed on 6063 aluminium alloy obtained in silicate-, borate- and aluminate-based electrolyte without and with nanoadditive Al_2O_3 and TiO_2 by micro-arc oxidation (MAO) were studied by scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), microhardness and friction−abrasion tests, respectively. SEM results show that coatings with nanoadditive have less porosities than those without nanoadditive. XRD results reveal that nanoadditive-containing coatings contain more oxides compared with nanoadditive-free coatings in all cases, which are consistent with the EDS analysis. Mechanical properties tests show that nanoadditive Al_2O_3-containing coatings have higher microhardness values compared with the other coatings obtained in silicate-, borate- and aluminate-based electrolyte. On the other hand, nanoadditive has a positive effect on improving the wearing-resistance of MAO coatings in all cases. Furthermore, the borate-MAO coatings present an inferior anti-wearing property compared with the silicate- and aluminate-MAO coatings for both the nanoadditive-free and nanoadditive-containing coatings.
Key words: 6063 aluminium alloy; micro-arc oxidation; microstructure; mechanical properties; nanoadditive

1 Introduction

Aluminium alloys are widely used in aerospace and automotive industry because of their excellent properties such as high strength, low density, non-magnetic properties and good formability [1,2]. However, the poor surface hardness and wear resistance limited their application in many ways [3]. Various applications had been attempted to overcome its weakness, one of the effective ways to improve their mechanical properties is the surface modification by protecting coatings, which prevent the direct contact from our environment [4−6]. Among them, micro-arc oxidation (MAO) has been widely studied in recent years as an emerging environmentally friendly technology for preparing ceramic coatings on valve metals (such as Al, Mg and Ti) to restrict the directly contact with our environment [7−9].

The MAO process was extremely complicated and involved many influencing factors [10], which consisted of electrical breakdown voltage, electrolyte composition, the nature of the material itself, effects of additive incorporation and some processing parameters, like current density [11−14]. In our previous work, the 6063 aluminium alloy MAO coatings were obtained in nanoadditive-free and nanoadditive-containing electrolytes [15] and the influence of concentrations of nanoadditive TiO_2-containing electrolyte on MAO coatings was studied [16], but the influence among different main-electrolytes without or with different nanoadditive on aluminium alloys was not studied.

In the present study, the ceramic coatings were prepared on 6063 aluminium alloy by MAO technique with silicate-, borate- and aluminate-based electrolyte without or with nanoadditive Al_2O_3 and TiO_2, respectively. The aim of the study was to systematically investigate the microstructure, hardness and friction−abrasion properties of coatings and compare the difference among them.

2 Experimental

The substrate material in the present study was 6063

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aluminium alloy (0.45%−0.90% Mg, 0.35% Fe, 0.2%−0.6% Si, 0.10% Cu, 0.10% Mn, 0.10% Cr, 0.10% Zn, 0.10% Ti and balance Al, mass fraction) for MAO experiment. The commercial samples of 6063 aluminium alloy (30 mm × 25 mm × 3 mm) were ground by alumina waterproof abrasive paper up to 1800 grit and ultrasonically cleaned in pure ethanol for degreasing, and then cleaned by distilled water and dried in air. The MAO treatment was carried out using a pulsed AC power source in alkaline silicate-, borate-, aluminate-based electrolyte, respectively. Three types of electrolytes were composed of 10 g/L sodium silicate (Na_2SiO_3), 10 g/L sodium borate ($Na_2B_4O_7$), 10 g/L sodium aluminate ($NaAlO_2$) and 3 g/L KOH in distilled water, respectively. The nanoadditives were 3.2 g/L titania (TiO_2) and 3.2 g/L alumina (Al_2O_3) for each main-electrolyte, respectively. All the nanoadditives were with a size of about 10 nm and dispersed in solution evenly. Coatings were obtained at a current density of 15 A/dm^2 for 60 min in all electrolytes. The treatment temperature was always kept at (28±2) °C by a recyclable water cooling system. All the specimens were rinsed thoroughly with distilled water and dried in air immediately after the treatment.

The surface morphologies of coatings were observed by scanning electron microscopy (SEM, Hitachi S−4700) with amplifying magnitude. The semi-quantitative chemical compositions of all coatings were analyzed by energy-dispersive X-ray spectroscopy (EDS) incorporated into scanning electron microscopy after Au deposition by sputtering. The scanning method was flat scanning with a duplication of three times for the reliability. The phase compositions of the MAO coatings were analyzed by X-ray diffraction (XRD, Thermo ARL X' TRA) using Cu K_α radiation at 2θ values between 25° and 75° with a step length of 0.02° at a scanning rate of 1 (°)/min. The hardness values of the coatings were evaluated by using an HMV−IT Vickers microhardness tester under a load of 200 g. The tribological properties of the coatings were performed on a WTM−2E ball-on-disk tribometer with a rotational speed of 336 r/min. The coating served as the disc, and the counterpart was Si_3N_4 ceramic ball (4 mm in diameter, HV 1550 in hardness). The abrasion loss was measured after 1 h friction measurement with an electronic direct reading balance (LJBROR L−200, readability 0.01 mg).

3 Results and discussion

Based on the main-electrolyte, the coatings prepared in silicate-, aluminate- and borate-based MAO coating are addressed as Si-, Al- and B-MAO coatings in the later discussion.

3.1 SEM observation and EDS analysis

Figure 1 demonstrates the evolution of surface

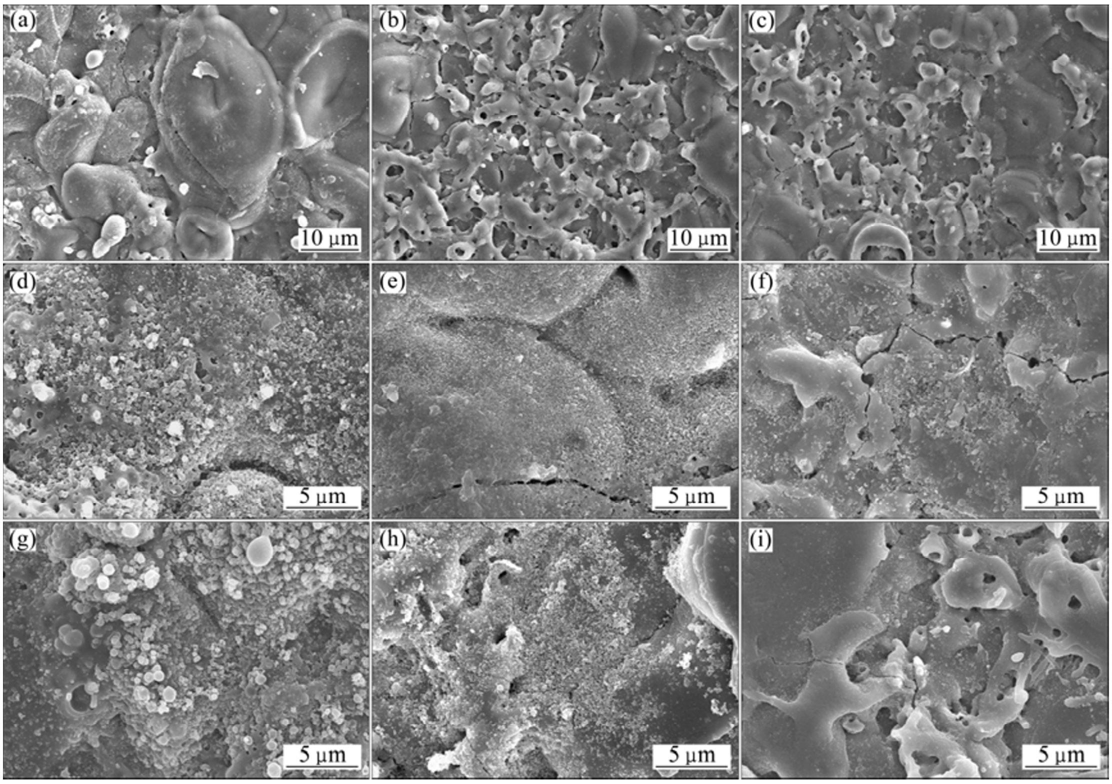

Fig. 1 Morphologies of MAO coatings without nanoadditive (a−c), with nanoadditive TiO_2 (d−f), with nanoadditive Al_2O_3 (g−i) prepared in silicate- (a, d, g), borate- (b, e, h) and aluminate-based (c, f, i) alkaline electrolytes