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Improving Corrosion Resistance of Friction Stir Welding Joint of 7075 Aluminum Alloy by Micro-arc Oxidation

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An attempt has been made to improve the corrosion resistance of friction stir welded joints of 7075 aluminum alloys by micro-arc oxidation (MAO), and the effects of Na_2SiO_3 concentration in electrolyte on the corrosion resistance of the coatings were discussed. Morphology and phase constituents of the MAO coatings produced in electrolyte with different Na_2SiO_3 concentrations were analyzed by scanning electron microscopy, confocal laser scanning microscopy and X-ray diffraction. Electrochemical tests were conducted to evaluate the corrosion resistance of the coatings. The results show that the corrosion resistance of the coated joints is much better than that without the ceramic coating, and the ceramic coating produced in the electrolyte with Na_2SiO_3 concentration 20 g/L showed better corrosion resistance than the others.

KEY WORDS: Aluminum alloy; Micro-arc oxidation; Friction stir welding joint; Corrosion resistance

1. Introduction

Aluminum alloy 7075 (Al−Zn−Mg−Cu) is attractive for a number of structural applications owing to its high strength to weight ratio and natural aging characteristics[1,2]. The choice of welding methods for its further applications are important. Friction stir welding (FSW) is a new and potential weld method in industry, and it strongly reduces distortion and residual stresses compared to fusion welding techniques[3,4]. However, the major problem for the 7075 aluminum alloy in FSW is the weld joints exhibiting corrosion susceptibility[5]. Having recognized this as one of the major concerns in FSW of high-strength 7075 aluminum alloys, a few attempts have recently been made to overcome the problem using post-weld heat treatments, laser surface treatments and other approaches[6−10]. Nonetheless, the durability of the corrosion protection by these methods might be short-term.

Micro-arc oxidation (MAO) is a novel technique that can be used to form a thick ceramic coating on aluminum substrate by plasma discharge in aqueous solution on aluminum surface at high voltage[11−13]. Furthermore, the coating has been proved as an effective method to improve the corrosion resistance of aluminum FSW joints[14]. It is known from our previous study[15] that, electrolyte composition is one of the most important parameters affecting microstructure and properties of the coating in the process of MAO. In the electrolyte, SO_4^{2-}, Cl^-, SiO_3^{2-} and CO_3^{2-} show different impedance values, while SiO_3^{2-} shows that the highest impedance value of the film is 36,005 Ω. It is believed that the formation of a compact coating with high impedance value on the sample surface is primary; hence, Na_2SiO_3 is chosen as the main contents of the electrolyte in the present study[16]. The final objective in this study is to present routes for the optimization of MAO electrolyte concentration, and thus the effect of Na_2SiO_3 concentration in electrolyte on the corrosion resistance of Al_2O_3 coatings formed on friction stir welding joint was analyzed.

2. Experimental Procedure

The morphology of the welds is shown in Fig. 1. It is seen that the welding nuclear zone and heat affected zone with fine microstructure were obviously formed on it. Samples cut from 7075 aluminum alloy FSW welds with dimensions of 40 mm × 60 mm × 7 mm were used as substrates for micro-arc oxidation. MAO units used in this work mainly consist of a power source with approximate 1000 V and an electrolyte consisting of Na_2SiO_3 10 g/L, 15 g/L, 20 g/L and NaOH 5 g/L, current density was kept at less than 5 A/dm^2. During the coating process, the temperature of the electrolyte was maintained at approximately 30 °C controlled by a heat exchanger. All the samples were oxidized for approximately 40 min.

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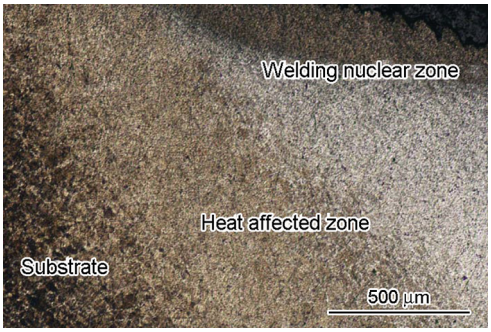

Fig. 1 Morphology of the FSW weld for aluminum alloy.

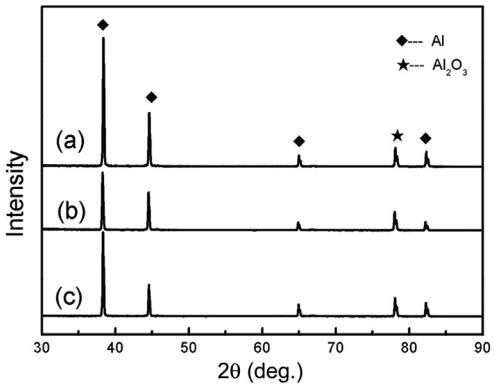

Fig. 3 XRD results of the coatings formed in electrolyte with different Na_2SiO_3 concentrations: (a) 10 g/L; (b) 15 g/L; (c) 20 g/L.

Microstructural observation was carried out by scanning electron microscopy (SEM, JSM-5600, Japan). The phase composition of the coatings was identified by X-ray diffraction (XRD, Model D/Max 2500PC Rigaku, Japan) operated with Cu $K\alpha$. The X-ray generator settings were 50 kV and 50 mA, and the scans were acquired from 30° to 90° (in 2θ). The 3D microstructure and the coatings thickness were observed by confocal laser scanning microscopy (CLSM, Olympus OLS3000, Japan).

The corrosion behaviors of the coatings prepared at different electrolyte concentration were evaluated by electrochemical impedance spectroscopy (EIS) and potentio-dynamic polarization test through an AUTO-PGSTAT 302 electrochemical analyzer in 3.5% NaCl solution at room temperature. The electrochemical measurement was conducted using a conventional three electrodes system with a saturated calomel electrode (SCE) as the reference, a Pt foil as the counter electrode, and the samples with the area of 1 cm^2 as the working electrode. For EIS study, AC impedance measurements were performed with the amplitude of 10 mV about the open-circuit potential versus frequency from 10 mHz to 1 MHz. The polarization scan rate was controlled at 0.2 mV/s. The electrochemical parameters of corrosion potential, corrosion current density and polarization resistance were analyzed.

3. Results and Discussion

Fig. 2 shows the top morphologies of the coatings formed in the electrolyte with different Na_2SiO_3 concentrations. All the coatings were compact, the crack-like structure and the small pores were observed. MAO coatings are known to exhibit some degree of porosity and micro-cracks, especially towards the top surface[15]. In the present study, some small residual pores can also be seen on the surface of the coatings. These pores are formed by the molten oxide and gas bubbles thrown out of micro-arc discharge channels. Besides, the microcracks generated from the thermal stress in fast solidification of melts also existed near the pores. As increasing the Na_2SiO_3 concentration from 10 g/L to 20 g/L, the coatings become denser, and the plasma discharging in aqueous solution on the surface of aluminum substrate at high voltage seems to be intensive. On the other side, the diameter of the pores apparently decreased with increasing Na_2SiO_3 concentration in electrolyte. The changes of the microstructure can be explained by the electrical conductivity of the electrolytes. The electrical conductivity of the electrolytes increases with increasing the Na_2SiO_3 concentration. The higher Na_2SiO_3 concentration corresponds to a higher current and thus a more intensive micro-arc discharge will occur on the surface. However, the obtained microstructure was quite different from that in our previous study[15]. This is attributed to that the samples in the present study experienced the FSW process making the original microstructure of as-received aluminum alloy changed. Fig. 3 displays the phase compositions of the alumina coatings on FSW joints in electrolyte with different Na_2SiO_3 concentrations. It can be found that all the coatings are mainly composed of Al_2O_3. There is no obvious difference from the XRD results.

Fig. 4 illustrates the two-dimension and three-dimension images of the coatings formed on 7075 aluminum alloy welds in the bath with different Na_2SiO_3 concentrations for 40 min. The micrographs clearly indicate that the pores presenting as dark circular spots distributed all over the surface of the ceramic coatings. It is also apparent that the number of pores increases, while the diameter of the pores obviously decreases with increasing the Na_2SiO_3 concentration in electrolyte, just as shown in the insets of Fig. 4. The results for coating thickness

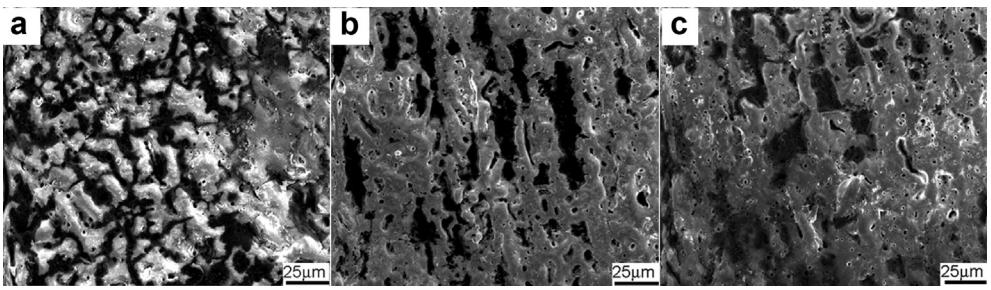

Fig. 2 Surface morphologies of the MAO coatings formed on the welds in electrolyte with different Na_2SiO_3 concentrations: (a) 10 g/L; (b) 15 g/L; (c) 20 g/L.