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Corrosion behavior of spray formed 7055 aluminum alloy joint welded by underwater friction stir welding

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ABSTRACT

Friction stir welding with water cooling method had modified the microstructure of spray formed 7055 aluminum alloy but the corrosion behavior of alloy had been affected as well. Despite the tensile property having increased 15%, the corrosion behavior of underwater joint was more complex than base metal and traditional joint. Underwater joint characterized with an atypical pattern of intergranular corrosion (IGC) that its corrosion paths were not along the grain boundary though it still suffered a rank 4 IGC. At the same time, underwater joint was slightly sensitive to exfoliation corrosion (EXCO) and crossed 3-level-leap of corrosion rank within 24 h. Tafer curves illustrated more negative corrosion potential and lower corrosion current density for underwater joint than base metal and traditional joint. High potential phase $MgCu_2$ in traditional joint blocked corrosion process to some extend but non-uniform distribution of $MgCu_2$ led to weak zone for corrosion. In comparison with traditional joint, underwater joint avoided the formation of $MgCu_2$ and kept a large quantity of efficient strengthening particles ($MgZn_2$) in the matrix. Though $MgZn_2$ with more negative potential than that of $MgCu_2$ would lead to a higher sensitivity to corrosion, underwater joint still showed better corrosion resistance compared with base metal. In the process of underwater friction stir welding, $MgZn_2$ had been stirred into grains leaving grain boundary a high potential zone. Since corrosion paths were discontinuous and not along with the grain boundaries, corrosion process was blocked so it performed better resistance to corrosion and corrosion rate of underwater joint had decreased a lot compared with traditional joint and base metal.

1. Introduction

With the development of manufacture technology of light alloys, traditional Friction Stir Welding (FSW) faces new challenge as well. Spray formed 7055 aluminum is one of the new type alloy which increases the content of Zn considerably (reach up to 8%, even up to 14%) through spray forming technology and the mechanical properties of alloys improves a lot [1,2]. Such a high strength aluminum alloy with Zn hyper saturating in the matrix is very sensitive to welding heat input.

In order to reduce the heat generated during traditional FSW process, Submersion Friction Stir Weld (SFSW) emerges. Cooling media in SFSW can be different (i.e. liquid nitrogen [3,4]) and water is the most economical one. Sakurada et al. [5] were the first who used submersion in a rotary friction weld for 6061 aluminum alloys. The results showed that it was possible to generate enough friction heat for welding even though the samples were submerged in the water. Thomas adopted submerged FSW to improve the strength of the FSW joint of 6061 aluminum alloy [6]. Liu et al. [7,8] conducted a study of properties and microstructure of 2219-T6 joints welded by underwater friction stir welding (underwater FSW), and the results showed that with the help of water cooling method, the strength of joints were improved. However, present study of underwater FSW is just focus on the improvement of strength but few pays attention to the effect of water cooling method on corrosion resistance of joint.

The intergranular corrosion (IGC) and exfoliation corrosion which characterized by uncertainty and imperceptibility are common corrosion forms of aluminum alloy [9]. In most cases, the corrosion susceptibility is correlated with wide precipitate-free zones and coarse precipitates such as Mg[Zn2, AlCu] and MgAlCu as for aluminum alloy [10,11]. Also, corrosion resistance of the 7xxx alloys depends strongly on the size and distribution of particles forming intermetallic precipitation [12]. According to the study of Huang Lanping et al. [13], the corrosion resistance of 7055 aluminum alloy was related to the rich Cu phase and precipitation on the grain boundary. There have been a number of reports [14–16] highlighting the microstructural changes due to

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the plastic deformation and frictional heat associated with traditional FSW. Dissolution and coarsening of strengthening precipitates [17–19] as well as the formation of wide precipitate-free zones [20,21] have been found in the weld region and these problems will be more serious to spray formed alloys. Thermal cycle will be modified by water cooling method and then microstructure of weld will be different. Dissolution and coarsening of strengthening phase may be less serious due to lower heat input, but under such rapid cooling process owing to water cooling, the distribution and type of strengthening precipitations will change significantly. Corrosion behavior which is related to strengthening phase closely will be affected.

In the present work, Ultra-high strength spray formed 7055 aluminum alloy was welded by friction stir welding in air and underwater respectively. The intergranular corrosion (IGC) and exfoliation corrosion tests were conducted to figure out the change of corrosion resistance of joints. Electrochemical test was carried out to achieve Tafer curves of joints and base metal. The impact of water cooling method on strengthening phases was investigated and, furthermore, the relationship between water cooling method and corrosion resistance had been figured out.

2. Material and experimental procedures

Spray formed 7055 aluminum alloy (T6) was used as base metal consisting of 7.6–8.4% Zn, 1.8–2.3% Mg, 0.05% Mn, 0.04% Cr, 0.15% Fe, 0.1% Si, 0.06% Ti, 2.0–2.6% Cu in wt% and Al on balanced. $250 \times 100 \times 4$ mm sheets were welded through traditional and underwater FSW by FSW-3LM-002 machine. The friction stir tool was made of H13 steel consisting of a concave 10 mm diameter shoulder and a 4 mm diameter pin with the length of 3.75 mm. During FSW, a constant tile angle of 2.5° was maintained. Welding speed was 100 mm/min and rotation speed of tool was 1000 rpm. Water-immerging environment was provided by a self-made water tank. The metallographic specimens were observed under optical microscopy (OM) after being etched with Keller's reagent (2 ml HF + 3 ml HCl + 5 ml HNO_3 + 190 ml distilled water). The tensile tests were conducted by CMT5205 tensile testing machine under the guide of GB/T2652-2008 [22].

The dimension of corrosion specimens was $10 \times 10 \times 4$ mm with an exposed working area of 1 cm^2 and other sides were sealed by gelatin. IGC test was carried out under the guide of GB7998-2005 [23]. IGC corrosive solution consists of 0.97 mol NaCl + 0.3 mol H_2O_2 + 1 L distilled water. After dipping for 6 h at 35 °C, samples were cleaned by 30% HNO_3. Corrosion depths were measured from cross-section of corrosion samples and ranked corrosion levels. The exfoliation corrosion test was conducted according to GB/T 22639-2008 [24]. The EXCO solution which was used in the exfoliation corrosion test employed 15 vol.% dilution of a solution of 4.0 mol NaCl, 0.5 mol KNO_3 and 0.14 mol HNO_3. The samples' surfaces were observed at 24 h and 48 h for ranking corrosion levels. Appearance of corrosion samples were observed by optical microscopy OM with super depth of field. Electrochemical corrosion test was conducted in electrochemical work station with EG&G PARV M283 potentiostat and &1025 lock-in amplifier. SCE (saturated calomel electrode) worked as reference electrode and platinum was auxiliary electrode. The all the electrodes were dipped in EXCO solution for 30 min when the circuit was connected.

The element contents of samples were detected by JSM-6460 scanning electron microscope (SEM) with Energy Dispersive Spectrometer (EDS). The evolution of strengthening precipitates was studied by D/max 2550VL/PC X-ray diffraction (XRD) with copper target employing the following conditions: 40 kV voltage and 200 mA current.

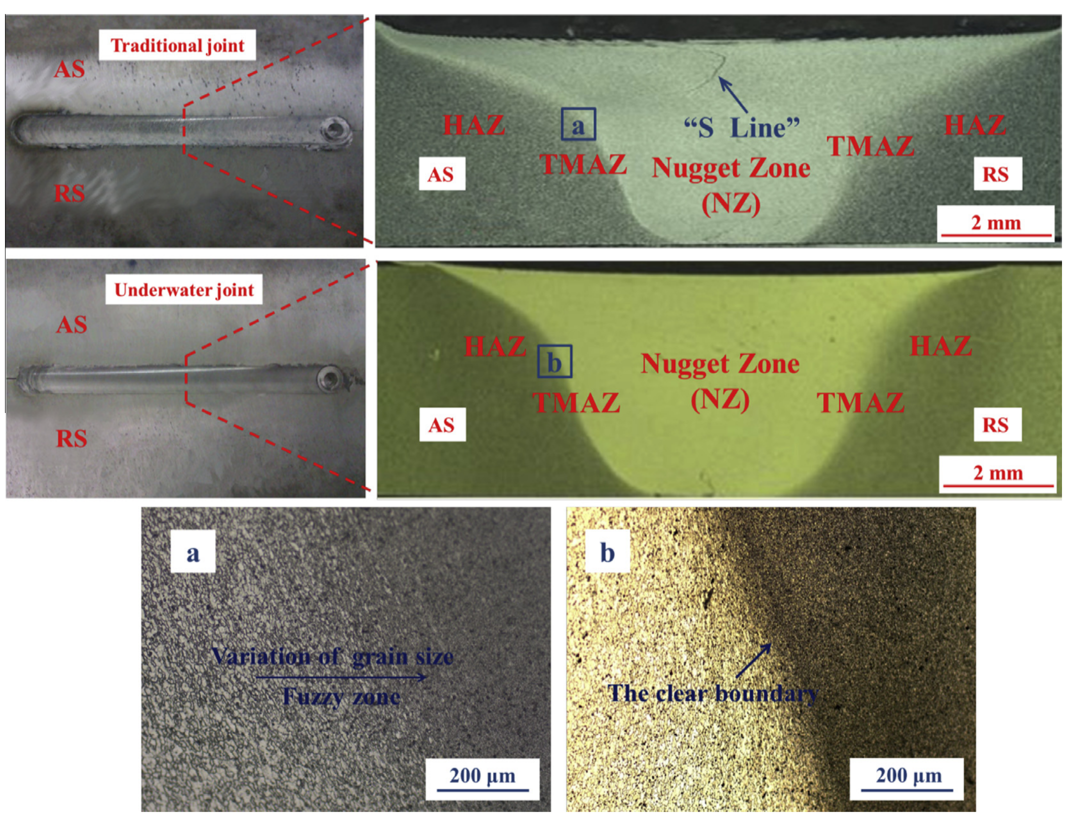

Fig. 1. Appearance and microstructure of joints welded by traditional and underwater FSW (RS and AS are short for retreating side and advancing side of the joint).