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The Effects of process parameters on mechanical properties and corrosion behavior in friction stir welding of aluminum alloys

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Abstract

The present study was carried out to evaluate how the process parameters affect the mechanical properties and the corrosion behavior of joints obtained by friction stir welding (FSW). The experimental study was performed by means of a CNC machine tool for the friction stir welding of two aluminum alloys, namely AA7075 and AA2024, taking also into account the combination between the two materials. The joints were executed varying the process parameters, namely rotational speed and feed rate. Tensile tests and hardness tests were carried out to evaluate the mechanical properties of the joints. The corrosion behavior of welded specimens was analyzed by means of local free corrosion potential measurements to determine anodic and cathodic areas of welds. The results evidenced that the low hardness areas have the free corrosion potential more anodic than the nearest zones. The differences of potential between the different areas of the welding have the consequence of galvanic corrosion of the less noble area. The location and the extension of the anodic areas depend both on the alloy and on the welding parameters. The preferentially corrosion of these areas were confirmed by means of long time immersion tests. The attacks morphology depends on the alloy: in AA2024 a severe crevice and pitting attack takes place, whereas the AA7075 shows exfoliation corrosion along the rolling bands. Coupling the two different alloys, a severe galvanic attack takes place on the AA7075, in the correspondence of the lower hardness areas. The decreasing of hardness and the different electrochemical behavior in the correspondence of the welding were due to the microstructural alteration of the alloys during the FSW. The correlation between process parameters and joints properties allowed to identify the most suitable welding conditions.

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Keywords: FSW, Aluminum alloys; Process parameters, Corrosion behavior.

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1. Introduction

When joining difficult to be welded materials (such as Al, Ti and Mg alloys but also Advanced High-Strength Steel [1]), it is possible to refer to Friction Stir Welding (FSW) technology (patented by TWI in 1991 [2, 3]). FSW has recently received large attention from automotive and transportation [4], aeronautical [5], in-white and other industrial sectors. Using this technology, it is also possible to join dissimilar materials [6-8] in several configurations.

The FSW process gives rise to large plastic flow and heat generation that determine remarkable microstructural modifications, resulting in local changes of material mechanical characteristics. In particular, moving from the periphery of the joined parts (base material - BM, without metallurgical modifications) towards the pin axis, a heat affected zone (HAZ) is initially found; in this zone the material undergoes to temperature increase that modifies microstructure and mechanical properties. Moving towards the pin axis, the thermo-mechanically affected zone (TMAZ), where the material is heavily plastically deformed by the tool stirring action, can be observed. Finally, in the nugget, located in the middle of the joint, there is a recrystallized area where fine grains of uniform size replace the original grains [9,10]. For this reason, it is very important to understand the effects of process parameters and process setup on the weld quality and strength in terms of material microstructure and material mechanical properties.

The FSW process is gaining importance especially for high resistance aluminum alloys (for example AA2024 and AA7075 are of great interest because of their aeronautical use), which are difficult to be joined with traditional techniques which alter the microstructure obtained during age hardening. Several Authors studied these aspects with particular attention to the quality of FSW joints in terms of mechanical properties (UTS, fatigue resistance etc.) [11-12]. In addition, particular attention has to be paid due to the well-known susceptibility of the alloy to stress corrosion cracking [13]. Despite the enhanced properties, the added elements introduce higher degree of heterogeneity especially evident in high strength Al alloys due to the presence of secondary phases or termed constituent particles [14]. Corrosion behavior can be mainly affected by the presence – size and distribution – of such phases, modifying the anodic and cathodic behavior of the zones of joining. [15,16]. Several works describing corrosion morphologies that can occur also concomitantly in form of localized corrosion, e.g., galvanic corrosion, pitting, dealloying or intergranular attack [17-19] were found, but very few data regarding the combination of different alloys and the systematic correlation between mechanical properties and corrosion behavior can be noticed. Under such considerations, the corrosion behavior can be significantly influenced by welding parameters and a strict correlation between them and alloy macro and microstructure has to be further investigated [20].

2. Experimental set up

2.1. FSW set up

The experimental analysis was performed by means of a CNC machine tool. Butt joints were obtained on sheets having a thickness equal to 4 mm. Two different aluminum alloys, namely AA2024-T3 and 7075-T6 were used for this purpose and the joints were executed with three different combination of materials: AA2024 – AA2024, AA7075 – AA7075, AA7075 – AA2024. Table 1 shows the mechanical properties of the materials. Sheets of 200 x 80 mm were welded by using tools with smooth plane shoulder (16 mm diameter) and pin having a frustum of cone shape (pin maximum and minimum diameters equal to 6 and 4 mm, pin height equal to 3.8 mm). The welding operations were carried out by varying tool rotational speed (S=1000, 1500, 2000 rpm) and feed rate (F=10, 35, 60 mm/min). Three welding repetitions were carried out for each combination of parameters.

2.2. Mechanical characterization of the joints

A universal testing machine Galdabini with a load cell of 50 kN was used to evaluate the mechanical properties of the FSW joints as a function of the different process parameters. Tensile tests were performed orthogonally to the welding direction according to UNI EN 10002-1:2004 on specimens with 160 x 20 mm, having the welding nugget placed in the middle of gage length. Tests were carried out under speed control (7.6 mm/min) on 3 specimens for