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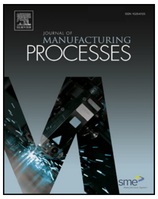

The influence of process parameters on mechanical properties and corrosion behavior of friction stir welded aluminum joints

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ABSTRACT

Aim of the present paper is to analyze if and how the process parameters (namely rotational speed S and feed rate f) affect both the mechanical properties and the corrosion behavior of friction stir welded (FSWed) butt joints made of AA7075 and AA2024 alloys and their combination. Tensile tests were performed orthogonally to the welding direction on specimens having the welding nugget placed in the middle of gage length. Rockwell tests were carried out on each specimen moving from the joint axis until the hardness of the base material was reached. A clear dependence of the Ultimate Tensile Strength (UTS) from the process parameters were observed when the joints are obtained using the same material while the effect is not so evident when two different materials are concerned. In almost all cases, the best conditions, in terms of mechanical resistance, were obtained for intermediate values of rotational speed and feed rate. Further tests were performed for evaluating the corrosion behavior and the stress corrosion cracking susceptibility of FSWed joints. In particular, local corrosion potential measurements were executed and longtime immersion tests were carried on four points bending specimens loaded up to 80% of the Yield Strength (TYS), in 35 g/L sodium chloride solution. The same tests were replicated on unloaded specimens. The potential trends are always well defined and much higher for the AA2024 alloy, since it is more noble than the AA7075 alloy. Mixed welding allows to identify the AA7075 alloy as an anode part, having a lower copper concentration and a high concentration of zinc. A correlation of some corrosion behaviors to the mechanical characteristics was evidenced, in particular for the AA2024 alloy.

1. Introduction

Friction Stir Welding (FSW) technology, patented by TWI in 1991 [1,2] has been successfully used to join different aluminum alloys (e.g. 2024-T3 [3], 6082 A A-T651 [4]) and other materials that are difficult to be welded, such as Ti-alloys [5] and Mg-alloys [6] but also advanced high-strength steels [7] and metal-matrix composites [8]. The technique is now widely used in naval [9], aerospace [10], automotive and railway applications [11]. The rotation of the tool and the movement along the joint axis cause an increase in temperature because of friction between tool and workpiece and within the stirred material [12]. In such conditions, the plasticization of the material occurs due to the combination of the mixing effect of the tool pin and the pressure applied by the tool shoulder, that cause the formation of a solid bonded region [13,14]. This technology permits the solid-state welding in several configurations and also the joining of dissimilar alloys [15]. The FSW technology has a large interest especially for high resistance aluminum alloys (e.g. 2000 and 7000 aluminum alloys series, because of their aeronautical use), which are difficult to be joined with traditional techniques because of the microstructure alteration during age hardening. The high plastic flow and the heat generated by FSW may result in remarkable local microstructural modifications and local changes of material characteristics [16].

When considering the behavior of Friction Stir Welded joints, it is normal practice to focus the attention on the mechanical characteristics of the welds through the execution of tensile tests and the analysis of the hardness distributions inside the joined materials. For these reasons, it is very important to understand the effects of process parameters and process setup on the weld quality. Several Authors studied these aspects with particular attention to the quality of FSW joints in terms of

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Table 1
Chemical composition (%w) and mechanical properties of the AA2024-T3 alloy.

Cu	Mg	Si	Fe	Mn	Zn	Ti	Yield Strength (MPa)	UTS base material (MPa)	Elongation %
4.4	1.6	0.08	0.10	0.48	0.1	0.04	345	459	17

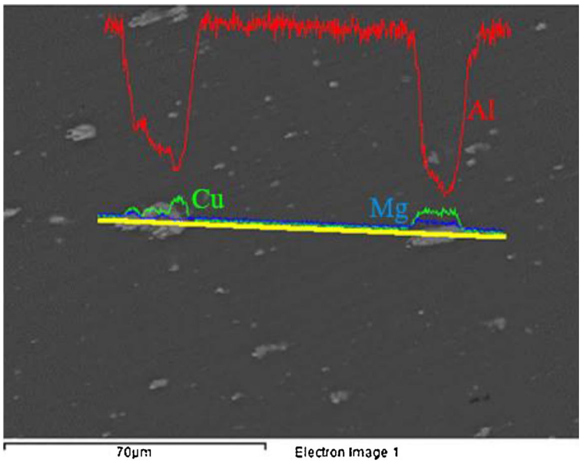

Fig. 1. EDS maps of the AA2024-T3 base alloy Al_2CuMg intermetallic precipitates.

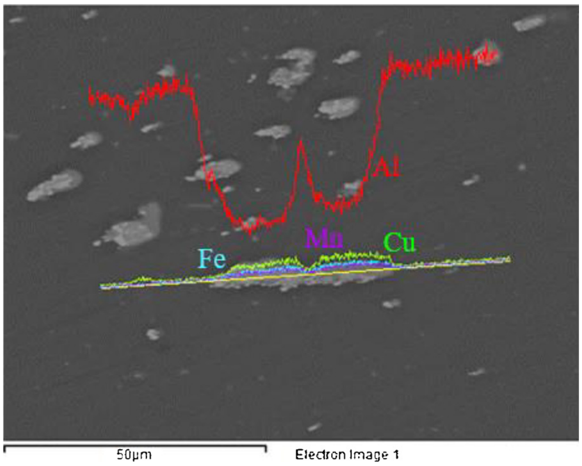

Fig. 2. EDS maps of the AA2024-T3 base alloy Al-Cu-Fe-Mn intermetallic precipitates.

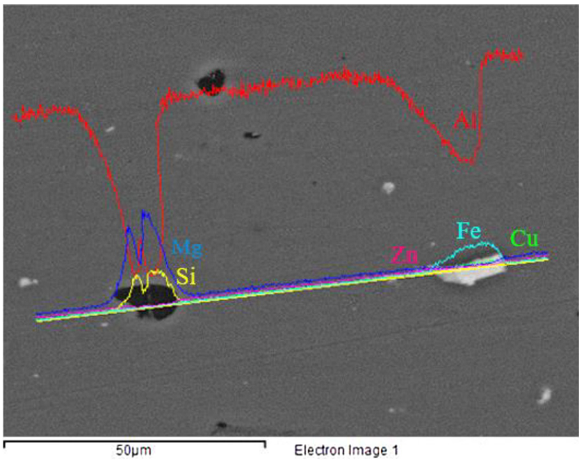

Fig. 3. EDS maps of the AA7075-T6 base alloy intermetallic precipitates.

Fig. 4. Weld sample (S = 1500 rpm f = 10 mm/min).

mechanical properties (UTS, fatigue resistance etc.) [17–19]. For example, in [20] the Authors evidenced how some very important issues related to the mechanical properties of aluminum friction stir welded joints are process parameters such as feed rate, rotational speed, tool geometry and pin axis inclination. Tool rotational speed was considered as one of the most important process variable: high rotational speeds may raise the strain rate, so affecting the re-crystallization process. Moreover, some authors showed how high welding speeds are related to low heat inputs, which gives rise to faster cooling rates of the joint. This can reduce the extent of metallurgical transformations taking place during welding (such as solubilization, re-precipitation and coarsening of precipitates) and hence the local strength of individual regions across the weld zone. Based on these considerations, the ratio between the tool feed rate and the rotating speed can be considered as a relevant parameter in determining the mechanical strength of the joints [21]. In [22] empirical relationships were developed to predict the tensile strengths of friction stir welded AA1100, AA2219-T87, AA2024-T3, AA6061-T6, AA7039-T4 and AA7075-T6 aluminum alloy joints. Other authors found that there is an optimal tool rotational speed range and that too low or too high speeds correspond to a low quality of the joints [23], demonstrating that these parameters can be optimized for obtaining sound parts.

On the other hand, these local microstructural modifications and local changes of material characteristics may affect the corrosion behavior [24]. Several literature works pointed out the corrosion behavior of FSW joints [25–29], but the effects on stress corrosion cracking are not yet completely understood. In addition, particular attention has to be paid to the well-known susceptibility of the copper-aluminum and zinc-aluminum alloys to stress corrosion cracking. Despite the enhanced properties, the added elements introduce higher degree of heterogeneity due to the presence of secondary phases or termed constituent particles [30]. 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 [27,31,32]. Several works describing corrosion morphologies that can occur also concomitantly in form of localized corrosion, e.g., galvanic corrosion, pitting, dealloying or intergranular attack [28] 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 [25].

Aim of this study is to analyze how the process parameters affect

Table 2
Chemical composition (%w) and mechanical properties of the AA7075-T6 alloy.

Zn	Mg	Cu	Fe	Mn	Si	Cr	Ti	Yield StrengthYS (MPa)	UTS base material (MPa)	Elongation %
5.9	2.7	1.5	0.12	0.02	0.06	0.19	0.05	511	578	11