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Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6

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ABSTRACT

A mechanical and metallurgical characterization of friction stir welded butt joints of aluminium alloy 6061-T6 with 6082-T6 was carried out. For comparison, similar material joints made from each one of the two alloys were used. The work included microstructure examination, microhardness, tensile and bending tests of all joints. An approximate finite element model of the joint, taking into account the spatial dependence of the tensile strength properties, was made, modelling a bending test of the weldments. This study shows that the friction stir welded dissimilar joint present intermediate mechanical properties when compared with each base material. In tensile tests the dissimilar joint displayed intermediate properties. For instance in the hardness profile the lowest values were obtained in the AA6082-T6 alloy plate side where rupture occurred, and in the nugget all type of joints present similar values.

1. Introduction

Friction stir welding (FSW) [1], a solid-state joining process developed and patented by the The Welding Institute (TWI), emerged as a welding technique to be used in high strength alloys that were difficult to join with conventional techniques. The process was developed initially for aluminium alloys, but since then FSW was found suitable for joining a large number of materials. Conventional fusion welding of aluminium alloys often produces a weld which suffers from defects, such as porosity developed as a consequence of entrapped gas not being able to escape from the weld pool during solidification. In contrast, with FSW the interaction of a non consumable tool rotating and traversing along the joint line creates a welded joint through visco-plastic deformation and consequent heat dissipation resulting in temperatures below the melting temperature of the materials being joined. Other interesting benefits of FSW compared to fusion processes are low distortion, excellent mechanical properties in the weld zone, execution without a shielding gas, and suitability to weld all aluminium alloys, [2].

Further to joints of similar alloys, FSW is being studied for welding dissimilar alloys which can be of particular interest in some industrial applications. Some works can be found in the literature, e.g. [3–7], but data is still scarce on the characterisation of this joint type. In this work the ability to join dissimilar alloys by FSW was studied using butt welded plates. The mechanical characterization of friction stir welds of aluminium alloy 6061-T6 with 6082-T6 was carried out. For comparison, similar joints made from each of the two alloys were also performed. The work included microstructure examination, microhardness, tensile and bending tests of all joint types. An approximate finite element model of the joint, taking into account the spatial dependence of the tensile strength properties, was made, modelling a bending test of a welded specimen.

2. Material and methods

The alloys AA6082-T6 and AA6061-T6 are high strength Al–Mg–Si alloys that contain manganese to increase ductility and toughness. The chemical composition was determined before welding by spectrometry using a SPECTROLAB M7, Table 1. For both aluminium alloys a good agreement was found between the present measurements and the supplier values. The T6 condition is obtained through artificial ageing at a temperature of approximately 180 °C [8]. The friction stir welds of 3 mm thick plates were performed along the rolling direction. The process parameters implemented in this study resulted from a development process based on visual analysis of top and bottom surfaces of the joint and preliminary bending tests with the root under tensile stresses enabling to minimize the level of root defect. The selected parameters were travel speed of 224 mm/min; tilt angle of 2.5°; rotating speed of 1120 rpm. In all trials, a modular tool was used with the following geometry: M5 threaded pin; shoulder was smooth and 7° concave with 17 mm diameter.

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Table 1
Chemical composition (%) of the AA6082-T6 and AA6061-T6

Element	AA6082-T6		AA6061-T6	
	SPECTROLAB M7	Supplier 6082-T6	SPECTROLAB M7	Supplier 6061-T6
Mg	0.69	0.6–1.2	0.84	0.9
Al	97.4	Remaining	97.7	Remaining
Si	0.91	0.7–1.3	0.54	0.59–0.62
Mn	0.56	0.4–1	0.01	0.01
Fe	0.23	0.5	0.40	0.5
Cu	0.062	0.1	0.24	0.24–0.26
Cr	0.035	0.25	0.18	0.18–0.19
Zn	0.098	0.2	0.006	0.01–0.02
Ti	0.019	0.1	0.031	0.02–0.03

Tensile tests of 3 mm thick specimens drawn transversal to weld line were performed according to ASTM E8-M [9] in order to determine the mechanical properties (yield stress σ_y, rupture stress σ_t and Young's modulus E) of the welded and base materials, using a 25 mm gage length and 1 mm/min cross-head speed. The reduced section length is 60 mm and its width is 12.5 mm; the overall specimen length is 200 mm and the width of the grip section is 20 mm. The specimen was obtained by CNC machining.

The hardness profiles can assist the interpretation of the weld microstructures and mechanical properties. Microhardness tests were performed in order to characterize the hardness profile in the vicinity of the weld affected area. The microhardness tests were performed on a cross section perpendicular to the weld line, at mid thickness across the weld zone and into the parent material, using a 100 gf load.

For the analysis of microstructural changes due to the FSW process, the joints were cross-sectioned perpendicularly to the welding direction and etched with HF reagent [10]. Microstructures were acquired in different zones: transition between welded and base material, welded material and base material.

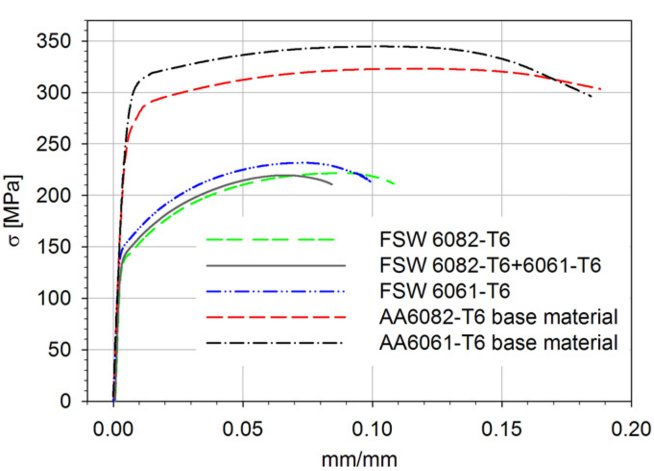

Fig. 1. Tensile tests for welded material specimens.

3. Results and discussion

3.1. Tensile tests

The stress/strain records of welded and base material specimens are presented in Fig. 1, whereas Table 2 presents the tensile properties for friction stir welded specimens and base material ob-

Table 3
Standard deviations for the tensile test results

Standard deviation (MPa)	σ_y	σ_r	E	$\sum$
FSW 6082-T6	1.8	0.8	5.6	0.2
FSW 6082-T6 + 6061-T6	0.9	1.4	5.5	0.1
FSW 6061-T6	0.3	1.2	1.0	0.1
Base 6061-T6	5.0	4.2	4.8	0.5
Base 6082-T6	0.3	0.4	3.2	1.3

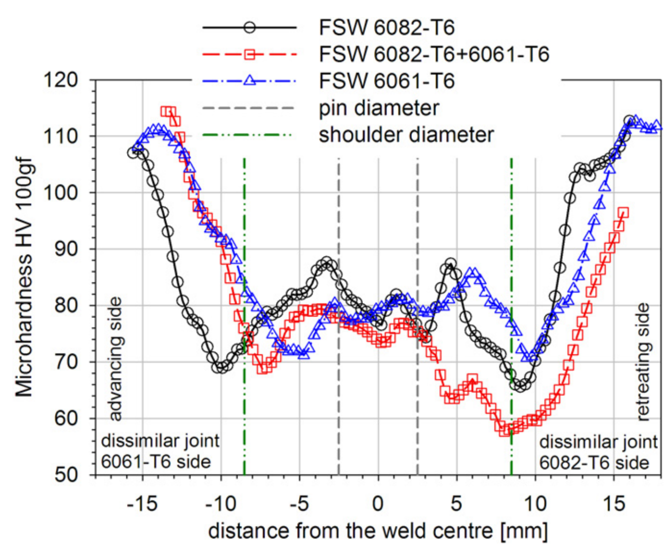

Fig. 2. Microhardness profile of the FS welded specimens. (Data on a cross section perpendicular to the weld line, at mid thickness).

Table 2
Material properties for FS welded specimens, data acquired in tensile tests

FSW	σ_y (MPa)	σ_t (MPa)	Elongation (%)	Joint efficiency (%)
Base 6082-T6	276.2	322.9	17.5	–
Base 6061-T6	306.3	342.0	17.1	–
FSW 6082-T6	134.3	221.3	6.5	68.5
FSW 6082-T6 + 6061-T6	140.5	218.6	5.5	67.7 (6082-T6) 63.9 (6061-T6)
FSW 6061-T6	148.3	231.6	5.9	64.2