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Joining of AA2014 and AA5059 dissimilar aluminium alloys by Friction Stir Welding

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ABSTRACT

Purpose: This work aims to investigate the microstructure and mechanical properties achieved by FSW of butt joints, namely of dissimilar sheets namely of 2014-T3 to 5059-H11 Al alloys by bonding the two materials perpendicular to their rolling directions.

Design/methodology/approach: AA 2014T3 and AA 5059H11 were two dissimilar aluminium alloys friction stir welded. The joint has been examined in terms of hardness, microstructure, and mechanical properties. The microstructure of the weld area was characterized by using optical microscopy. Seven diverse regions of the microstructure in the joint can be illustrious.

Findings: It has been noticed that a structure of fine grain is formed in the nugget region as a consequence of recrystallization. The thermos mechanically affected and heat affected zones of aluminium alloy 2014 are characterized by the lowest hardness values in spite of there are a general hardness decrease through the weld zone compared to both base metals. The ultimate tensile strength values of the dissimilar joint were found to be varying between 54% to 66% those of the base metal.

Research limitations/implications: The t joining in FSW takes place with the base materials remnant in the solid state, which gives a considerable possibility to produce joints between the alleged difficult-to-weld heat treatable aluminium alloys.

Originality/value: The outcomes display that friction stir welding can be effectively applied for the joining of dissimilar aluminium alloys.

Keywords: Dissimilar aluminium alloys, Friction stir welding, AA2014, AA5059

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PROPERTIES

1. Introduction

Friction stir welding (FSW) has illustrated very extraordinary suitability for the joining of aluminium alloys. It is a solid state joining process, invented by the welding Institute (UK) in 1991 [1]. FSW can prevent many problems, namely porosity, compaction cracks, and vacancies [2]. This process progresses in a solid state where temperature throughout welding is comparatively a smaller amount than the melting point of welded metal

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[3]. At this time, the FSW study has largely focused on joining Al alloy plate, which has the greatest demand in the aerospace, aircraft, electronic, missile, nuclear and commercial fields [1,4]. It has appeared in many applications, and has mainly aroused the interest of the automotive industries, aerospace aircraft, and owing to its ability of making sound joints in difficult to fusion weld aluminium alloys [5]. Friction between the welding tool and weld metal causes heat generation, that makes the surrounding material around the tool is soft and permits the tool to move along the joint line [6]. The truth that the joining in FSW takes place with the base materials remnant in the solid state, gives a considerable possibility to produce joints between the alleged difficult-to-weld heat treatable aluminium alloys [7]. Dissimilar joints of 2014-T3 to 5059 Al alloys are obligatory for some application to enhance chemical and mechanical properties. Though, there are few number of publications available in the literature about dissimilar joining , there is no information about the influence of welding conditions on the mechanical properties and micro-structure of stir welded joints. This work aims to investigate the microstructure and mechanical properties achieved by FSW of butt joints, namely of dissimilar sheets namely of 2014-T3 to 5059-H11 Al alloys by bonding the two materials perpendicular to their rolling directions.

2. Experimental procedure

Dissimilar sheets of aluminium alloys 2014 in condition T3 and 5059 in condition H11 have been welded by FSW. Table 1 demonstrates the chemical composition of both aluminium alloys.

Table 1.
Chemical composition of AA 5059 and AA 7075, wt. %

Materials	Zn	Mg	Cu	Fe	Cr	Mn	Ti	Others	Al
AA2014	0.25	0.5	4.4	0.7	0.1	0.8	0.15	0.81	Balance
AA5059	0.46	5.2	0.01	0.09	0.003	0.77	0.02	0.16	Balance

The two plates have been manufactured with the same dimensions of 275 x 150 x 6 mm (length, width, thickness) by rolling. The direction of the friction stir welding line was longitudinal and parallel to the rolling direction of the 2014 and 5059 alloys. The tool used in this study composed of 12 mm a shoulder diameter and a pin with a diameter of 4 mm and a length of 5.7 mm. The fixed FSW tool was 3° tilted from the normal direction of the plate and rotated clockwise. The translational motion and simultaneous rotational of the welding tool thru the welding process generates a characteristic irregularity between the adjoining sides. Advancing side (AS) of the tool is the side where the tool rotation synchronize with the direction of the translation of the welding tool, whereas another side, where the two motions, rotation and translation counteract is so-called the retreating side (RS) [8]. Throughout FSW, the 2014 aluminium alloy plate was fixed so as to be in the advancing side (AS) and 5059 to be in the retreating side (RS). Welding was achieved in three steps, the first two are alike as 2014 to 2014 and 5059 to 5059 and the third step is unlike welding as 2014 to 5059. Afterward welding, the joins were cross-sectioned vertical to the welding direction for metallographic analysis. The metallographic specimens were cut and polished with alumina suspension; two diverse etching solutions were utilized in order to obviously establish the grain structure differences in dissimilar joints. In the foremost stage, the polished sample has been etched by 3 ml nitric acid and 1 ml hydrofluoric acid solution, for 20 s at 0 °C in 150 ml water, and the 5059 aluminium alloy side has been examined for microstructural variations. Then, the re-polished sample is being etched by 9 g 40% phosphoric acid (H_3PO_4) solution, for 4 min. at 50°C in 100 ml water, to detect the microstructural variations at the 2014 aluminium alloy side. An optical microscope was used to investigate the microstructural features of the welds. Furthermore, EDS analyses have been achieved for revealing the concentricity of alloying elements inside the weld region. Vickers indenter with 0.85 N loads for 10 s was used to obtain the Vickers hardness profiles at the weld cross section of the welded zones. Hardness mensurations have been achieved along the middle section and transverse to the welding direction of the joints. Tensile tests have been done at a crosshead speed of 1 mm/min using a computer-controlled testing machine at room temperature, to estimate the mechanical properties of the welded joints. Tensile tests were carried out at room temperature. The tensile samples were cut out vertical to the weld axis. Tensile tests are achieved according to ASTM E8-95a standard code.

3. Results and discussion

3.1. Microstructure

In the current study, dissimilar aluminium alloys 2014 and 5059 have been effectively joined using the friction stir welding process and no noticeable macroscopic defects or porosity have been observed on the weld cross-section. The FSW process used on dissimilar 2014 and 5059 aluminium alloys exposed the first-rate formation of the onion ring "elliptical" structure to some extent in the thermo-mechanical affected zone (TMAZ) and entirely in the nugget zone (NZ); this is assured by the concentricity of diverse alloying elements on the rings of the onion shaped structure, as will be illuminated later. Figure 1 shows the microstructure of the weld cross-section etched by two different etching solutions. Contrary to friction stir welding of similar alloys show four distinct regions, namely heat affected zone (HAZ), nugget zone (NZ), thermo-mechanically affected zone (TMAZ), and parent material (also called base material/BM), dissimilar welds show seven distinct regions as shown in Figure 1. The nugget region is the zone that undergoes the highest strain and experiences recrystallization. The mechanical action of the tool probe is responsible for the formation of such microstructure that generates a continuous dynamic recrystallization process. In the weld nuggets of all joints, grains have been refined as a result of continuous dynamic recrystallization [9]. The strain hardened base material was likely completely recrystallized in TMAZ close to the nugget, and the fraction of recrystallized material decreased to zero as the distance from weld nugget increased. Also with low speed FSW, increasing heat treating effect provided microstructurally and mechanically better joints while maintaining weld zones from any imperfection.

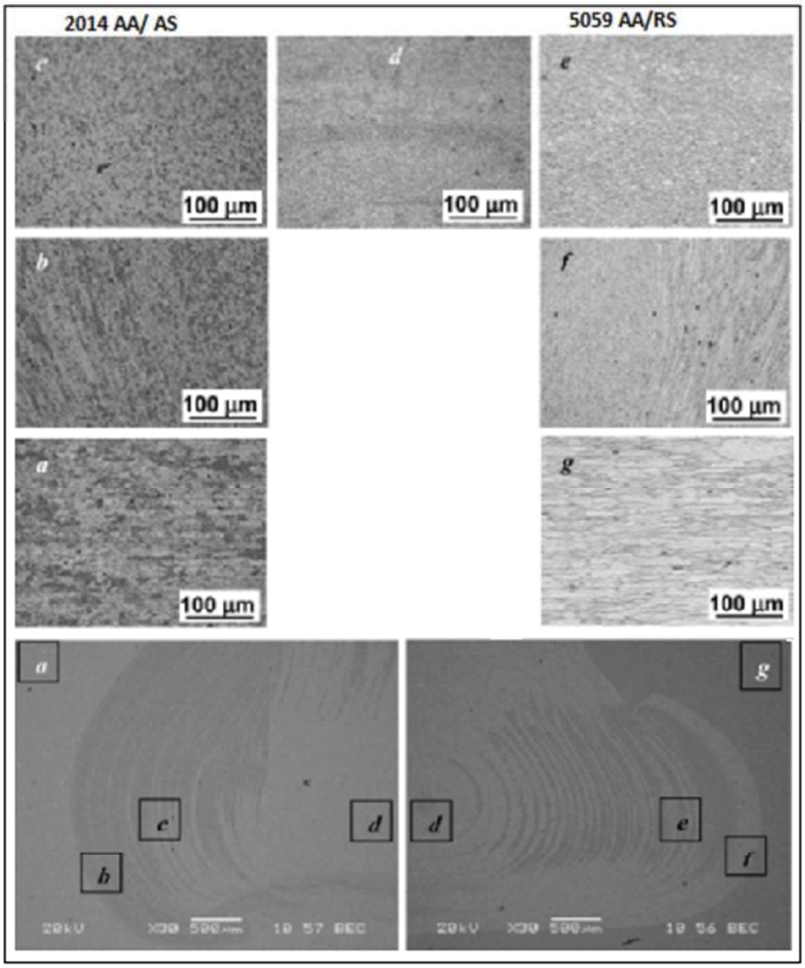

Fig. 1. a)-g). Weld region microstructure: a) BM AA 2014; b) HAZ AA 2014/AS; c) TMAZ AA 2014

The severe plastic deformation and the higher temperature during the welding in the NZ consequence in a renewed fine grain structure [10]. Figure 1d displays the nugget region for welded 2014 and 5059 aluminium alloy. By moving in the direction of the base metals, neighbouring to the nugget region, there lays the TMAZ (Fig. 1c for AA 2014 and Fig. 1e for AA 5059) where no recrystallization was noticed The zone neighbouring to the TMAZ is the HAZ (Fig. 1b for AA 2014 and 1f for AA5059), where the grain size is alike to the BM. Together the HAZ and the TMAZ experienced a uttermost temperature which results in hardness decrease. Neighbouring to the HAZ lies the BM (Fig. 1a for AA 2014 and Fig. 1g for AA 5059). From the different etching response of each material AA 2014 looks in darker colour than AA 5059.

The EDS examination conducted thru the weld zone of AA 2014 and AA 5059, Figure 2, has exposed that in both alloys, the rings forming the onion shaped structure are rich in Mg in light coloured ones, while the darker ones are rich in Cu. Table 2 provides the percentages of Mg and Cu in the nugget zones of AA5059 and AA 2014. It has been noticed that the quantity of Mg has increased in the NZ of AA 2014 after welding. This can be well thought-out as an indication of a good friction stir welding procedure.

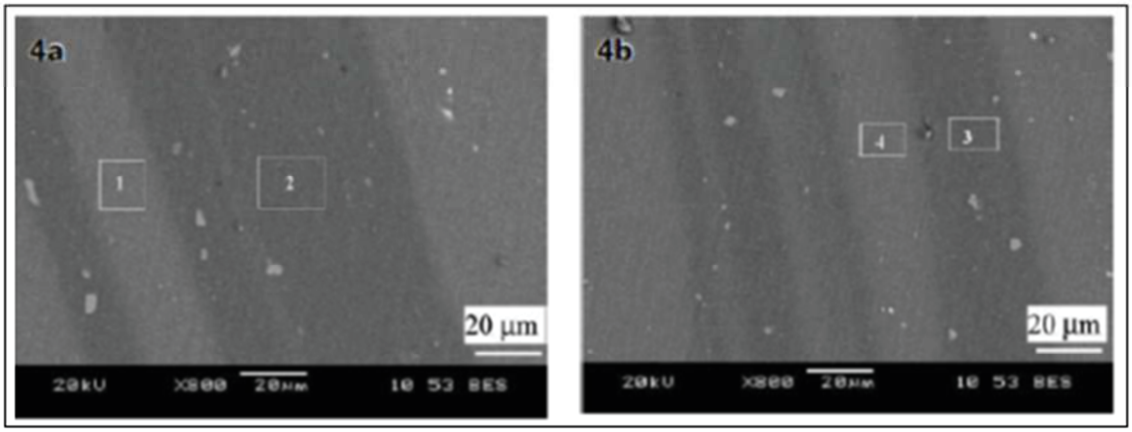

Fig. 2. a) and b). EDS examination results in the NZ close to the BM of: a) AA 5059; b) AA 2014

Table 2.
EDS analyses results of the weld region microstructure

Materials	Light coloured area		Dark coloured area	
	% Mg	%Cu	% Mg	%Cu
AA5059	5	2	0.9	4.6
	zone 1 in Fig. 2a		zone 2 in Fig. 2a	
AA2014	4.8	2.2	1.2	4.5
	zone 4 in Fig. 2b		zone 3 in Fig. 2b	

3.2. Hardness

Microhardness distribution over the weld cross section, of welded dissimilar aluminium alloys 2014 and AA 5059, shown in Figure 3.

BM hardness values of AA 2014 and AA5059 are about 128 HV and 158 HV, respectively. In general, the hardness reduces, within the weld region composed of TMAZ and HAZ, due to softens of the material by the welding process which coarsening by thermomechanical conditions, while recrystallization owing to great plastic deformation causes hardness increase in the NZ. On the other hand, the variation of hardness values, for dissimilar FSW in the nugget zone, can be attributed to the variation of the concentration of alloying elements in this zone as in agreement with Chen and Kovacevic [11]. In the nugget region, area equal in width to pin diameter, both hardness decrease (on AA 5059 side) and increase (on AA 2014 side) have been noticed in this study. Recrystallization of a very fine grain structure effects hardness recovery in the nugget for AA 2014; this is in agreement with the classical behaviour of aluminium alloys welded by FSW [11].

Nonetheless on AA 5059 side in the nugget zone, as close to the AA 2014 side, there is decrease in hardness, while going in the direction of the TMAZ side the hardness increases. The lowest hardness values are measured at the TMAZ and HAZ on AS side (AA 2014 side), about 87 HV.

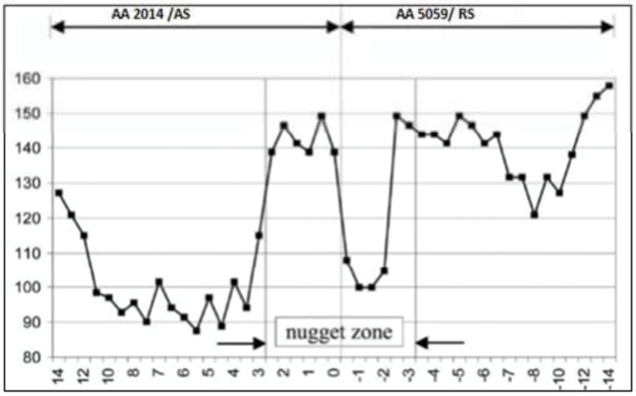

Fig. 3. Hardness deviation lengthways the weld cross-section

3.3. Tensile properties

Three tests were conducted to obtain the average values as the minimum tensile property. Tensile properties of BM and similar/dissimilar FSW are presented in Table 3. The fracture takes place at HAZ or the TMAZ for All the similar welded specimens. While, welded specimens have fractured for Dissimilar similarly at the HAZ or the TMAZ on the AS side (AA 2014 side). The cause for this could be attributed to the extreme decrease in hardness at these zones as revealed in Figure 3. The ultimate tensile strength efficiency for joint of similar welding of AA 2014 and AA 5059 were 60% and 62% respectively. While, for dissimilar welding, the joint efficiency for AA 2014 has increased to 66%, while for AA 5059 it has decreased to 54% compared to their base metal values. Although the dissimilar joint revealed lower tensile properties related to both base metal values, the outcomes can be considered fairly satisfactory taking into account the drastic conditions to which the materials undertake thru the friction stir process, in agreement with Cavaliere et al. [12].

Table 3.
Tensile strength of the BM and dissimilar /similar welded AA 2014- AA5059 joints

Materials	Yield strength, MPa	Ultimate Tensile Strength, MPa	Total elongation, %	Joint efficiency
BM AA2014	260	388	11.7	-
BM AA5059	381	471	13.9	-
FSW AA2014	190	239	3.4	60
FSW AA5059	262	300	0.8	62
FSW AA5059-AA2014	236	263	2.0	54-66

4. Conclusions

AA 2014 and AA 5059 were two dissimilar aluminium alloys friction stir welded by using a rotation speed of 1600 rpm and a welding speed of 100 mm/min. The following can be concluded from this study:

1) Friction stir welding was applied successfully to dissimilar AA2014 and AA5059 with no visible macro-scopic defects or porosity across the weld cross-section.
2) Seven different microstructural zones have been recognized for the dissimilar joint. EDS examination expose that after welding the Mg content of AA 2014 has increased from the base metal value of 0.5 % to 4.8 % in the weld region. This can be considered as an evidence of a good friction stir welding procedure.
3) The variation in the concentration of alloying elements and the recrystallization of a very fine grain structure may be the main reasons for the variation of hardness values within the nugget zone.
4) The lower tensile properties results obtained compared to both base metal values can be considered quite satisfactory by taking the drastic conditions to which the materials undertake thru the friction stir process into account.

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