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Effect of post-weld aging on the mechanical and microstructural properties of friction stir welded aluminum alloy 7075

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ABSTRACT

Purpose: of this paper is to investigate the effect of post-weld artificial aging on the friction stir welding of Aluminum Alloy 7075 (AA 7075) for a welding condition of 1600 rpm and 100 mm/min using right and left helical screwed pins for two different shoulder diameters.

Design/methodology/approach: The method followed is that first artificial aging has been carried out as 24 hours at 125°C. Afterwards, in order to study the effect of post-weld aging on tool geometry, microstructural examination, hardness measurements and room temperature tensile tests have been carried out.

Findings: The results show that left helical screw yields higher mechanical properties and hardness values compared to right helical screw when tested at the same shoulder diameter. It has been observed that post weld aging process compensates the hardness decrease observed in as-welded joints; no significant decrease in hardness is obtained throughout the weld region.

Research limitations/implications: For future work it can be suggested to vary the post weld aging condition, such as 12 hours at 125°C. Welding and rotation speeds are other parameters affecting the microstructural and mechanical properties; therefore the effect of varying these parameters should be considered.

Practical implications: This study has practical implications and direct applicability. It indicates that helix angle rather than shoulder diameter directly affects the quality of the joint. At certain post weld aging conditions, for obtaining a sound welded joint the right tool selection will be of critical importance.

Originality/value: The authors have examined the effect of post weld aging for different helix angles and shoulder diameters. It is believed that examination of the effect of the variation of these parameters on the joint quality provides originality to this study.

Keywords: Mechanical properties; Post weld aging; AA 7075; Microstructure; Friction stir welding

PROPERTIES

1. Introduction

Friction stir welding (FSW) is a solid – state joining process that takes place below the melting point of the materials to be joined. FSW offers ease of handling, precise external process control and high levels of repeatability, thus creating very homogeneous welds. No special preparation of the sample is required during the welding process.

FSW of aluminum alloys offers the advantages of low heat input, reduced distortion, therefore, low residual stresses and higher mechanical properties compared to conventional fusion welding methods. Owing to these advantages, FS welded aluminum alloys are widely used in commercial transportation systems and in aerospace industry, where reduced fuel consumption is of vital importance [1].

In this welding process, a rotating welding tool is driven into the material at the interface of, for example, two adjoining plates, and then translated along the interface. Friction heats the material which is then essentially extruded around the tool before being forged by the large down pressure [2]. The FSW tool is fixed to the rotating axis of a CNC machine in the clockwise direction in this study. The basic principle of the FSW process is illustrated in Fig. 1 [3].

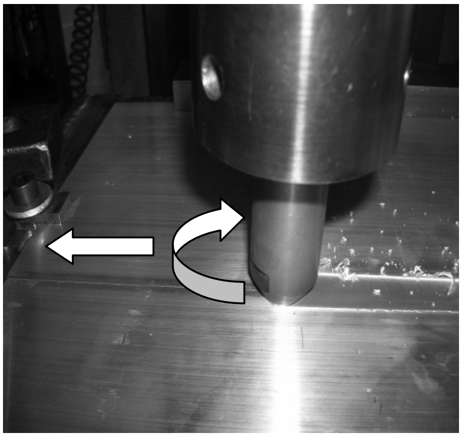

Fig. 1. FSW technology schematic view

The microstructure of the welded joint is formally divided into four zones: base material, heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ) and the nugget zone (NZ). The nugget zone is composed of fine-equiaxed grains which are formed under high temperature and large deformation in the weld center due to the stirring process[4]. The TMAZ is the region surrounding the nugget on either side where there is less heat deformation compared to the weld center [5]. The simultaneous rotational and translational motion of the welding tool during the welding process creates a characteristic asymmetry between the adjoining sides. The side where the tool rotation coincides with the direction of the translation of the welding tool is called the advancing side (AS), while the other side, where the two motions, rotation and translation counteract is called the retreating side (RS) [6, 7]. Fig. 2 shows the weld region macrostructure of an aluminum alloy joined by friction stir welding [3].

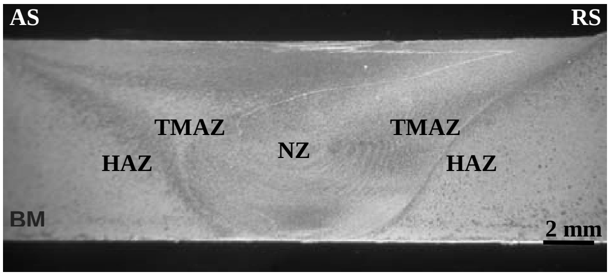

Fig. 2. Cross section of FSW joint; (BM) Base Material, (HAZ) Heat Affected Zone, (TMAZ) Thermo Mechanically Affected Zone, Nugget Zone (NZ), Advancing Side (AS), Retreating Side (RS)

Tool geometry, which consists of a threaded pin and a shoulder, is one of the most influential aspects of the friction stir process (FSP) development. The tool geometry plays a critical role in material flow and in turn, governs the traverse rate at which FSW can be conducted [3]. In this study, right and left helical pin screwed welds have been utilized in order to study the effect of pin structure on the mechanical and microstructural properties of the post-weld aged welded joints. For the right helical screwed pin, two different shoulder diameters have been employed to observe the effect of temperature input into the workpiece. Optimum rotation and welding speeds have been determined as 1600 rpm and 100 mm/min as the result of studies investigating the effect welding parameters on the FSW of AA7075 [8].

While there has been several studies focused on the variation of rotation and welding speeds to optimize the welding parameters and study their microstructures for aluminum alloys, limited research has been carried out on the effects of tool structure. Moreover, further research needs to be carried out on the effect of post-weld aging on the tool structure. Therefore, in this study, AA 7075-T651 plates have been post-weld aged after being joined by FSW. The effect of post weld aging on tool geometry, namely the helix angle and shoulder diameter, has been investigated in terms of microstructure, hardness variation and tensile properties.

2. Materials and experimental procedure

The material used in this study is Aluminum Alloy 7075 (AA 7075) in T651 condition produced as extruded flat plate, with dimensions of 275 x 150 mm^2 (length x width). The chemical composition of aluminum alloy 7075 is given in Table 1.

FSW was carried out on 6 mm thick AA 7075 plates. Before FSW, the abutting faces of the plates were finely milled in order to avoid surface scaling intruded with the tool. The longitudinal direction of the FSW line was parallel to the rolling direction of the AA 7075. The FSW tool had a conical pin diameter of 6 mm, a pin length of 5.6 mm. Tool rotation and welding speeds were taken as 1600 rpm 100 mm/min, respectively. Welding was carried out using two different helical angles of the threaded pin, namely right and left helicals and for right helical pin, two different shoulder diameters has been utilized as 15 mm and 20 mm (Fig. 3). Joints are named from A to C representing these three different conditions, Table 2.

Table 1.
Chemical composition of AA 7075 (wt%)

Zn	Mg	Cu	Fe	Cr	other	Al
5.7	2.4	1.8	0.15	0.04	0.55	Balance

Table 2.
Variation of weld parameters

Joint	Helix angle	Shoulder diameter, D (mm)
A	Right (R)	20
B	Left (L)	20
C	Right (R)	15

For all conditions: welding speed 100 mm/min, rotation speed 1600 rpm

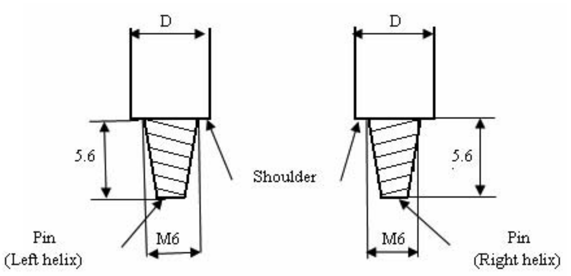

Fig. 3. Tool configuration

The post-weld aged samples were characterized for their microstructural aspects using optical microscopy. Fracture surfaces have been prepared by standard metallographic techniques and etched with Keller's reagent (150 mL H_20, 3 mL HNO_3, 6 mL HF). The etching solution was cooled to 0°C and specimens were etched for about 20 s in order to study the grain structure of the weld zones and to allow for optical microscopy characterization [9]. The Vickers hardness profiles of the joints have been obtained using a Vickers indenter with 85 gf load to reveal the hardness variations across the weld regions. Room temperature tensile properties of the weld joints are determined by the use of flat transverse tensile specimens according to ASTM E 8-95a standard code. Results are compared with the base metal values.

3. Results and discussion

3.1. Microstructure

Irrespective of the tool design, the material that flows around the tool undergoes extreme levels of plastic deformation, which leads to a recrystallized, fine equiaxed grain structure on the order of 4-6 μm diameter formed under high temperature and plastic deformation in the weld region due to the stirring process.

In the base metal, equiaxed grains are oriented along the rolling direction, as shown in Fig. 4. In the transition region between the weld zone and the base metal (BM), the grain dimension increases compared to the nugget zone and the grain orientation possesses a less equiaxed character. The region adjacent to the nugget zone, i.e., TMAZ is characterized by a highly deformed structure, Fig. 4. The base metal elongated grains were deformed in an upward flowing pattern around the nugget zone. Although the TMAZ underwent plastic deformation, complete recrsytallization did not occur in this zone due to insufficient deformation strain [10-12]. In the HAZ, which starts at a distance of around 6-10 mm away from the weld center, a large amount of resident parent material grains start to appear, Fig. 4.

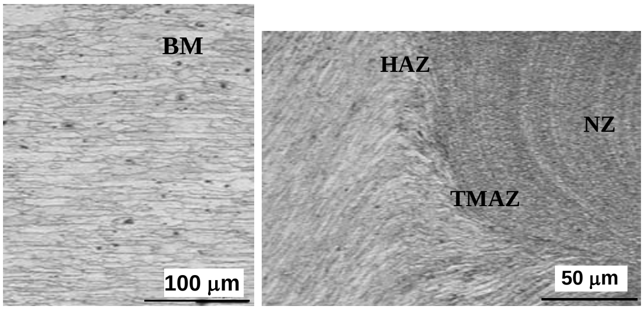

Fig. 4. Four different zones associated with FSW: equiaxed grains oriented along the rolling direction in the BM, deformed grains in TMAZ and fine recrystallized grains in the NZ and comparably larger grain sizes than the nugget zone in the HAZ

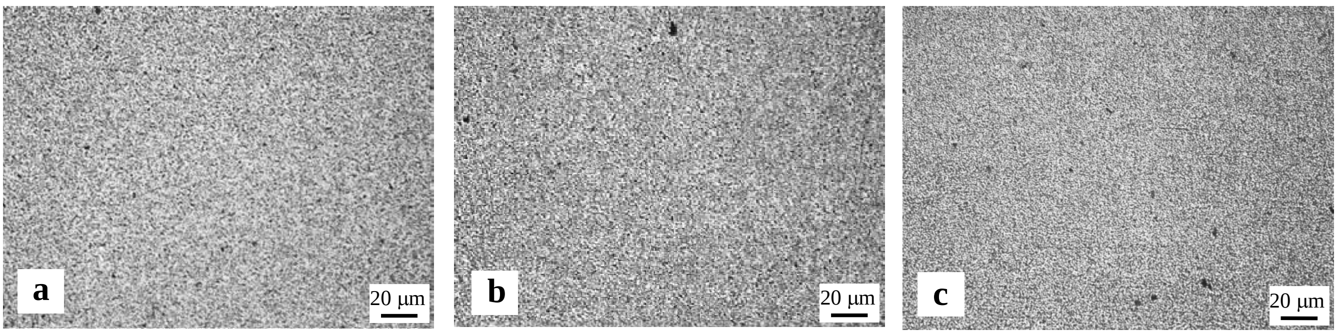

Fig. 5. Nugget zone microstructures of post weld aged (a) right helical screw with shoulder diameter of 15 mm, (b) right helical screw with shoulder diameter of 20 mm and (c) left helical screw with shoulder diameter of 20 mm

In Fig. 5, the nugget zone microstructures of the three conditions after post weld aging process are given. It can be seen that all three conditions possess less equiaxed grains compared to the base metal. Left helical screw, Fig. 5c, has comparably smaller average grain sizes compared to right helical screw, Figs. 5a and b. As can be seen from the Figures, there is no porosity formation in the nugget zone.

3.2. Microhardness

Microhardness measurements (HV) have been conducted for all joints, in order to determine the hardness properties across the weld region. The middle section (3 mm from the top surface) has been chosen for the hardness measurements. Hardness distribution for the three types of joints is given in Fig. 6. As seen from the Figure, the hardness gradient is the same for both advancing and retreating sides. The hardness distribution reveals that helix angle is more dominant on the hardness compared to shoulder diameter. The average hardness value across the weld region is about 70 HV for the right helical screw joint for 15 and 20 mm shoulder diameters, while for the left helical screw it is around 75 HV. Also, for as welded FSW joints, some decrease in hardness is observed at the HAZ in literature [8], post weld aging seems to compensate this decrease; as the figure depicts there is no significant decrease in hardness throughout the weld region.

3.3. Tensile properties

The room temperature tensile properties of the post-weld aged FS welded joints obtained from flat transverse tensile tests are given in Table 3. The given results are the average of minimum three tests. The transverse flat welded specimens all have failed at the transition region between the nugget zone and the HAZ. As seen in Table 3, the mechanical properties of joint C is, which has a shoulder diameter of 15 mm, are higher compared to Joints A and B, with 20 mm shoulder diameters. For the same shoulder diameter, the joint welded by using left helical screw yielded higher mechanical properties. The reason for this could be Joint B possesses smaller average grain diameter in the nugget zone compared to Joint A, and also it has relatively higher hardness values throughout the weld region.

Table 3.
Mechanical properties of the post-weld aged FS welded joints and BM

Joint	Yield strength $R_{p0.2}$ (MPa)	Ultimate tensile strength R_m (MPa)	Total elongation (%)	Joint efficiency in terms of R_m (%)	Mismatch ratio, M $\left(M=\frac{R_{p0.2WM}}{R_{p0.2BM}}\right)$
A	143	206	0.41	43	0.36
B	183	258	0.87	54	0.47
C	223	300	0.79	63	0.57
BM	390	480	13.8	-	-

Mismatch ratio is defined as the ratio of the weld metal yield strength to that of the base metal. It provides a means of comparing the relative strength of the joints. From Table 3, it is seen that compared to the BM yield strength values post weld aged joints possess 36%-57% mismatch ratios.

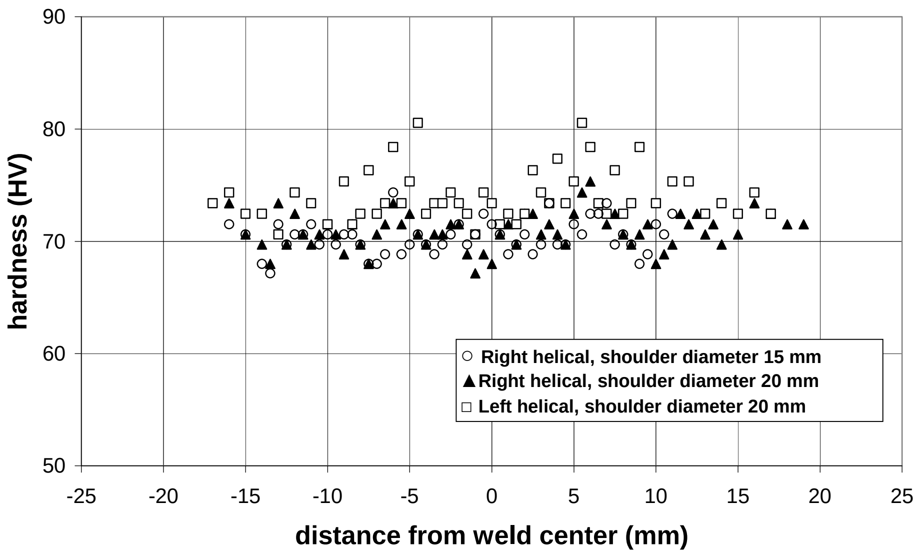

Fig. 6. Hardness distribution along the weld region

4. Conclusions

1. Welding was carried out using two different helical angles of the threaded pin, namely right and left helicals and for right helical pin, two different shoulder diameters has been utilized.
2. FSW was applied successfully to AA 7075 with no porosity observed in the nugget zone.
3. The nugget zone exhibited a recrystallized fine grain structure with grain sizes increasing moving from the weld region to the base metal.
4. Post weld aging process compensates the hardness decrease observed in as-welded joints; no significant decrease in hardness is obtained throughout the weld region.
5. It has been seen that left helical screw yields higher mechanical properties when tested at the same shoulder diameter.

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