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Investigations on Post-Weld Heat Treated Friction Stir Welds of High Strength Aluminum Alloy

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Abstract - High strength aluminum alloys such as 7075 are extensively used in variety of applications and they are considered unweldable using traditional fusion welding processes. Friction stir welding, being a solid state process, is considered to be a suitable technique to successfully weld these high strength alloys. However, as thickness of the plates to be welded increases, the welds exhibit degraded mechanical properties due to dissolution and over aging of strengthening precipitates. In this study, with an intention to improve mechanical properties, 16 mm thick AA7075-T651 aluminum alloy friction stir welds were subjected to a special heat treatment process. It includes a cyclic solution treatment, repeated heating between 400 and 480 ºC for 15 minutes and water quenching, followed by artificial aging at 130 ºC for 24 hours (CST+AA). The mechanical properties were evaluated using hardness, tensile and impact tests. The weld microstructures were also investigated by optical microscopy. The CST+AA treatment was found to significantly improve the hardness of the weld and homogenize the hardness profile across the joint. However, the tensile and impact tests were found to result in lower values than that of the welds without post-weld heat treatment. The post weld heat treatment also caused notable grain growth in the weld nugget which could be a reason for lower strength values.

Keywords: *Thick section aluminum alloy, Friction stir welding, Post weld heat treatment, Optical microscopy, Mechanical properties.*

1.INTRODUCTION

In the aerospace industry, heat-treatable aluminum alloys such as alloy 7075 are widely utilized. [1]. However, these alloys are considered almost unweldable using fusion welding processes. Friction stir welding (FSW), a solid-state joining process, can be used to produce sound welds, particularly in aluminum alloys [2,3]. Even though quite an amount of research has been published on joining AA7075 through friction stir welding [4-7], there remain numerous unanswered problems regarding the poor mechanical performance of the welded joints. [8,9].

Post-weld heat treatment (PWHT) is determined to be the best appropriate method for restoring degraded mechanical properties of the welds [10, 11] among the several techniques used to restore the mechanical properties of friction stir welded joints. However, only a small number of studies [12-14] have revealed positive benefits of PWHT on friction stir-welded AA7075. Recently, a new technique for heat treating high strength aluminum alloys based on cyclic solution treatment (CST) followed by artificial ageing has been developed [15], and Bayazid et al. [16] have studied the positive effects of CST and artificial ageing on the mechanical properties of friction stir welded joints.

The majority of these studies exhibited beneficial effects of PWHT on friction stir welding. AA7075, although they only investigated at welds between 3 and 10 mm thick. In fact, as the thickness of the plates to be welded increases, the drop in mechanical properties increases. For this reason, investigating the positive effects of PWHT on thick section friction stir welded joints is of paramount importance. The effects of PWHT on friction stir welds made from AA7075-T651 that are 16 mm thick have been considered in this work.

2. Experimental

On 16 mm thick plates of AA7075–T651 aluminum alloy, friction stir welding was performed. The chemical composition of the alloy is Al-6 Zn-2.5 Mg-1.4 Cu-0.2 Cr-0.08 Fe (in wt.%). The plates were cut and machined into coupons measuring 110 mm in width and 250 mm in length. The plates were butt-welded longitudinally with friction stir welding equipment. In one of the previous investigations conducted on friction stir welding of 10 and 16 mm thick AA7075 plates, 16 mm thick plates with the tool geometry shown in Table 1 were used to generate friction stir welded joints. In this study, the tool's rotating speed, welding speed, and tilt angle were 500 rpm, 25 mm/min, and 1.5, respectively. These welding parameters were found to yield defect free joints [7]. Thus, the same were used in this work to make the welds.

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Type of material	Profile of Pin	Pin major diameter (mm)	Pin minor diameter (mm)	Length of pin (mm)	Shoulder diameter (mm)	Pitch of threads (mm)
M2 tool steel	Left hand taper threaded	10	8	15.5	30	1.5

The post-weld heat treatments were performed using a solutionizing technique known as cyclic solution treatment (CST), which consisted of repeated heating between 400 and 480 ° C. for 1.5 hours (0.25 hours per cycle) and water quenching followed by artificial aging for 24 h at 130 ºC (Fig. 1a).

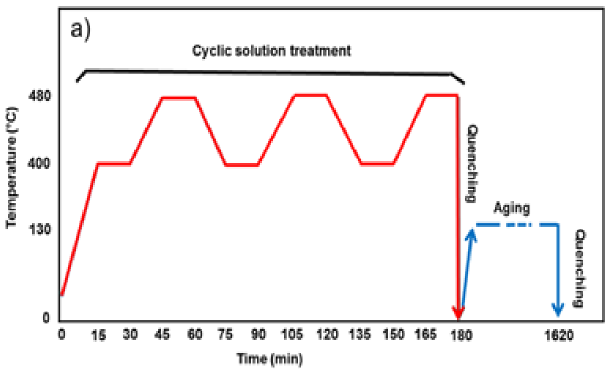

Fig -1: a) schematic illustration of CST+AA.

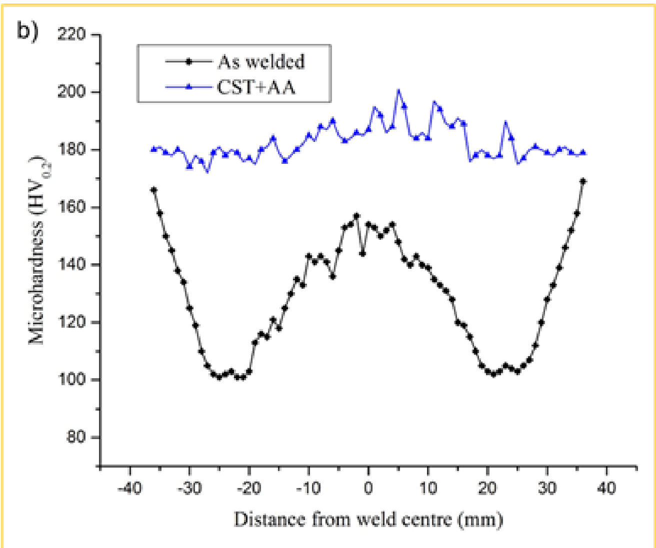

Fig -1: b) profiles of the welds' microhardness under as-welded and CST+AA conditions.

With a force of 200 g applied for 15 seconds, the micro Vickers hardness was measured at the middle thickness of the weld cross-section across the weld joint. The hardness readings were taken with a 1 mm distance between adjacent indentations. In accordance with the ASTM B557 standard, perpendicular to the direction of the weld, tensile test specimens were created. Using a universal tensile testing machine, tensile tests were conducted at room temperature. With a loading rate of 5 mm/min, the experiments were undertaken. Using stereo and optical microscopy, weld microstructures were analyzed. The weld was also examined for micro structural analysis with metallographic samples. To visualize the macro and micro-structures of the weld, the samples were etched for 60 seconds with standard Keller's reagent (5 ml HNO3, 2 ml HF, 3 ml HCL, and 190 ml of distilled water).

3 RESULTS AND DISCUSSION

3.1 Hardness curves

The as-welded and CST+AA hardness distributions of the welded joints are displayed in Fig. 1b. As can be seen, the hardness of the combined weld region was significantly lower than that of the base material. In addition, a substantial amount of heterogeneity was seen in the hardness measurements across the weld, with lower hardness values in the heat-affected zone (HAZ) and greater hardness values in the weld nugget. This is a frequent issue in thick section friction stir welded high strength aluminum alloys, as similar findings have been reported in prior research [7]. It was discovered that the CST+AA treatment applied on friction stir welds greatly increased the hardness across the weld. Fascinatingly, it was also discovered that this treatment improved the homogeneity of hardness values across the various zones of friction stir welded joints.

3.2 Tensile behavior

The tensile properties of the welds in both as-welded and CST+AA conditions are presented in Table 3.

Table 3. Tensile properties influence the tensile strength of friction stir welds prior to and following post-weld heat treatment.

Material	Yield Strength (0.2% proof) (MPa)	Tensile Strength	Material	Yield Strength (0.2% proof) (MPa)	Tensile Strength	Material
Base material	563	610	10	---	---	6.67
As-Welded	192	330	8	35	HAZ	5.5
CST+AA treated	143	350	2	25	WN	6

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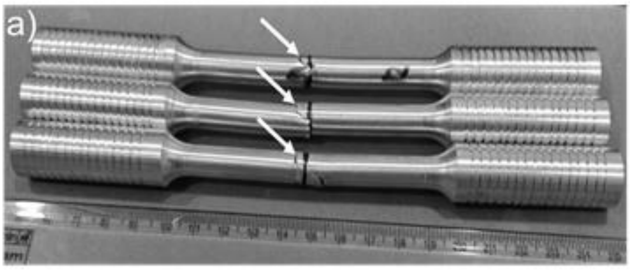

Fig -2: Photographs of a) tensile tested samples showing fractures in WN (arrows show fracture location).

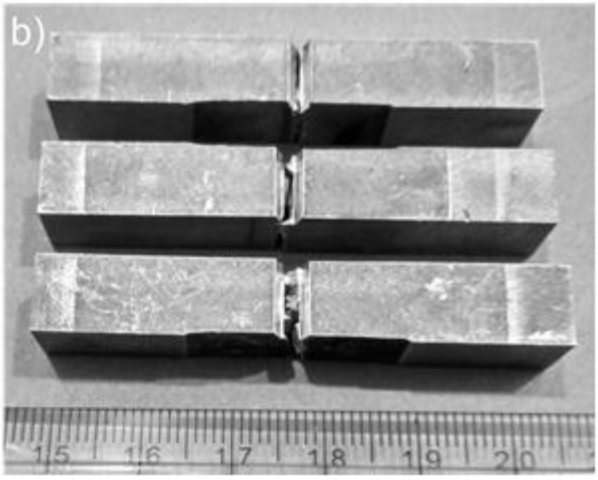

Fig -2: b) typical impact tested samples

As a result of friction stir welding, the strength and elongation values were significantly lowered. Tensile failures were seen in the HAZ, which may have been caused by low grain development and the creation of precipitated free zones in the HAZ during friction stir welding, as previously reported [7]. It was determined that the CST+AA treatment did not improve the tensile characteristics of the joint. Specifically, the percentage of elongation was negatively impacted. This can be due to the increase in hardness in the weld zone. The same was also found for 7075 Al alloy plates with a small segment and T6 condition [13]. The CST+AA-treated welds in WN failed (Fig. 2a).

3.3 Impact toughness

The impact test results are summarised in Table 3. The impact resistance of the welds was lower than that of the underlying material. The CST+AA treatment additionally decreased the welds' tensile strength. Exemplary specimens for impact testing are shown in Fig. 2b.

3.4 Microstructure

The outcomes of optical microscopy are shown in Figures 3 and 4. The foundation material showed the characteristic pancake-shaped, elongated grains of hot-rolled material (Fig. 3a).

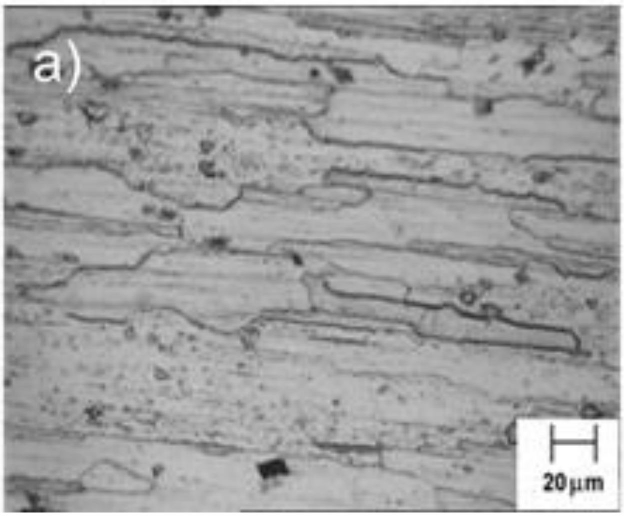

Fig -3: a) base material

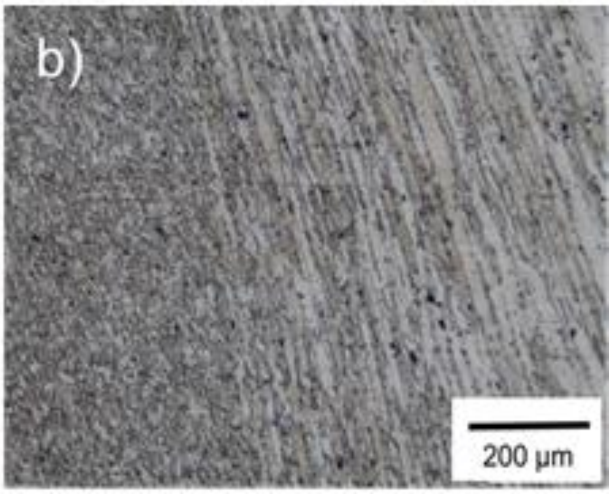

Fig -3: b) typical thermo-mechanically-affected zone (TMAZ)

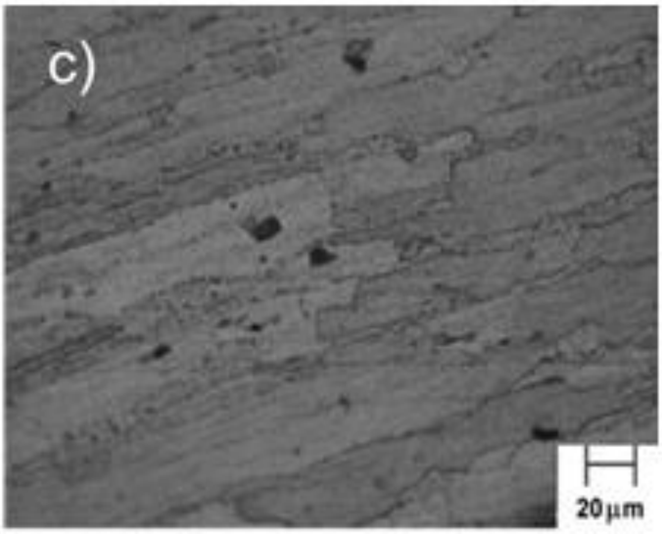

Fig -3: c) HAZ

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The TMAZ exhibited a plastically deformed structure (Fig. 3b), whereas the HAZ kept the same grain structure as the base material, with the exception of marginal grain development.

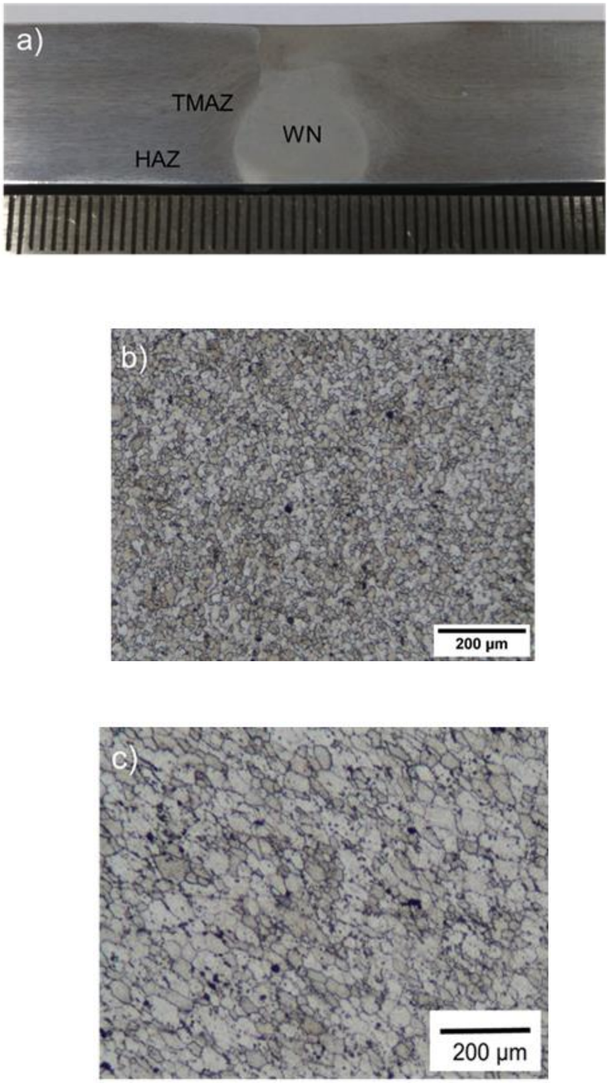

Fig -4: Microstructure analysis of friction stir weld

Figure 4a depicts the typical cross-sectional look of the weld. The microstructure of the weld nugget revealed very thin equiaxed grains (Fig. 4b) as a result of dynamic recrystallization occurring during friction stir welding. The CST+AA combination resulted in visible grain expansion in the nugget zone (Fig. 4c), also known as aberrant grain growth (AGG). This is expected to occur with the standard solution treatment, and other researchers have reported the same [17].

4. CONCLUSIONS

1. On 16 mm thick AA7075-T651 plates, friction stir welds are possible. Unfortunately, the increased heat inputs required to produce sound welds have a detrimental effect on the mechanical qualities of the joints.
2. The post-weld cyclic solution treatment followed by artificial ageing recovers the weld's hardness to a significant degree. In addition, the heterogeneity of hardness levels throughout the various zones of the combined weld region reduces.
3. The selected post-weld heat treatment does not show favorable effects on strength and impact toughness of the welds.

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