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Technical Paper

Effect of precipitation hardening heat treatment on mechanical and microstructure features of dissimilar friction stir welded AA2024-T6 and AA6061-T6 alloys

Hossein Karami Pabandi [a], Hamid Reza Jashnani [b], Moslem Paidar [c,*]

[a] Department of Materials Science and Engineering, Sharif University of Technology, Tehran, Iran
[b] Department of Mechanical Engineering, Amirkabir University of Technology, Tehran, Iran
[c] Department of Materials Engineering, South Tehran Branch, Islamic Azad University, P.O.B. 11365-11155, Tehran, Iran

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ABSTRACT

The friction stir welding of AA2024-T6 to AA6061-T6 plates with a 4 mm thickness has been studied at constant traverse and rotational speeds of 1000 rpm and 100 mm/min, respectively. The position of alloys and the effects of precipitation hardening heat treatment in retreating and advancing side in the friction stir welding were analyzed. The tool with taper threaded pin was used for welding. Macro and microstructural analysis were investigated by using Optical and Field Emission-Scanning Electron Microscopes (FE-SEM) to check out the welded joints. Micro-hardness and Tensile tests were also done to study mechanical attributes of the joints. Microstructural analysis revealed some grain coarsening in the weld zones and base metals after heat treatment. The results also showed that mixing between the two alloys and their tensile strength improved when AA6061 alloy was placed on the advancing part. Furthermore, the ultimate tensile strength of the heat treated welds was higher than non-heat treated welds which can be attributed to increasing of strength and hardness of weld zones, especially HAZ. Besides, the fracture area of the welded joints shifted from the HAZ of AA6061 to the SZ which confirms significant role of precipitation hardening heat treatment on the mechanical effects of the welded joints. In the SEM images of the fracture surface, precipitated Mg_2Si particles in HAZ were observed.

1. Introduction

The usage of lightweight metals such as Aluminium, Magnesium and Titanium in the aerospace and automotive industries decline structural weight and its fuel consumption [1]. For this reason, the welding and then joining of these alloys, that is, special aluminium alloys, are important. On the other hand, dissimilar welding is an effective and interesting idea in the industry. The purpose of dissimilar welding, combining various properties of metals and raise the productivity of the structure. Including the dissimilar welding can note the welding of different aluminium alloys to each [2].

In 1991, friction stir welding (FSW) was reinforced by The Welding Institute (TWI) for welding of Al alloys to get over difficulties related to fusion welding such as solidification cracking, eutectic melting, porosity etc. [3]. FSW joint is recognized to typically have four zones like intensively deformed zone called stir zone (SZ), thermomechanical affected zone (TMAZ), heat affected zone (HAZ), and base metal (BM) [4]. The HAZ in FSW joint practiced a thermal cycle, however, did not receive any plastic deformation. In the precipitated hardening aluminium alloys including 2xxx and 6xxx, the HAZ held the same grain form like the base metal, however the thermal revelation over 250 °C derived from notable coarsening of the growth and precipitates of the precipitate free region [5]. The HAZ displays the lowest strength and hardness and the fracture takes place usually in the HAZ. Post weld heat treatment (PWHT) i.e. precipitation hardening heat treatment, is a possibility to recuperate the loss of power in the HAZ caused by over ageing because of the weld thermal cycle [6]. Precipitation hardening heat treatment includes increasing the temperature of the alloy into the single phase zone in order to all of the precipitates dissolve. To make an alloy system that is able to be precipitation-strengthened, there is required to be a terminal solid solution with a declining solid solubility when the temperature dwindles. This condition is normally convened by most aluminium equilibrium systems of heat treatable types, like the Al-Cu and Al-Si alloys etc. [7].

* Corresponding author.
E-mail address: m.paidar@srbiau.ac.ir (M. Paidar).

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Table 1
Chemical formation of alloys.

Alloys	Elements						
	Al	Mg	Si	Fe	Cu	Cr	Mn
AA2024	Base	1.20	0.50	0.50	3.80	0.10	0.30
AA6061	Base	0.90	0.60	0.40	0.19	0.19	0.06

Table 2
Mechanical characteristics of alloys.

Alloys	Ultimate Tensile Strength (MPa)	Yield stress (MPa)	Elongation (%)	Hardness (Hv)
AA2024	492	362	5	137
AA6061	310	276	12	107

Priya et al. [6] tried the PWHT of friction stir welded AA6061-T6 and AA 2219-T6 aluminium alloy. Their outcomes show that the ultimate and hardness tensile strength increase after PWHT due to the presence of precipitated fine particles. Also, abnormal grain growth (AGG) after PWHT perceived in the microstructure of weld regions. In the other report, investigation of the different ageing ways following solution heat treatment on friction stir welded AA2024-T6 alloy was investigated by Aydin et al. [8]. It was stated that effect of artificially ageing in 190 °C for 10 h on mechanical properties of the weld was more rather than natural ageing after 8 months. Zhili et al. [9] have presented that PWHT subsequent FSW of AA2024 produced an increase in elongation of resultant welds without reducing their strength.

The aim of this study was to test the impacts of precipitation hardening heat treatment and fixed location of alloys on the features of dissimilar FSW of AA2024-T6 and AA6061-T6 aluminium alloys. The tensile tests, microhardness and also microstructural results were discussed in detail.

2. Materials and experimental procedures

The base materials utilized in the present examination were AA6061-T6 and AA2024-T6 aluminium alloy plates (solution heat fixed then unnaturally aged) with 4 mm thickness. The mechanical properties and chemical compositions of the obtained materials can be observed in Tables 1 and 2, respectively. The whole of the samples utilized in this work was cut before welding into dimensions 50 mm in width (rolling direction), 100 mm in length, and longitudinally friction stir butt welded. The tool with taper threaded pin was used for welding. The height of pin was 3.5 mm. The traverse and rotational speeds of the tool, 100 mm/min and 1000 rpm were considered, respectively, according to previous authors' research [10–12]. As Fig. 1 indicates, the welding tool was formed of H13 tool steel and contained a shoulder with a diameter of 20 mm. The tool axis was designated by 3° according to the vertical axis. The respective positions of both alloys were differed to investigate its effect on the materials flow. After welding, the samples were sliced into two parts as shown in Fig. 2. One part is utilized for the analysis of the as-welded situation and the other part for the precipitation hardening heat treatment studies. The precipitation hardening heat treatment contained solution treatment at 520 °C for one hour went along with ageing in the air at 165 °C for 18 h to study the key role of heat treatment on FSW.

Before and after precipitation hardening heat treatment, the welded samples were cross-sectioned vertical to the welding direction for microstructural and macrostructural characterization and also Vickers microhardness measurements. The cross-sections of welded joints were then carved with Keller's reagent for the development of mixing between as-received materials. Subsequent to metallographic polishing, the specimens were electro-carved with Barker's reagent by 5 ml HBF_4 in 200 ml water in 20 V for 90 s. The metallographic analyses were accomplished by Stereo and Optical Microscopy for microstructure and macrostructure studies, respectively. The fracture surface examined by Field Emission-Scanning Electron Microscope (FE-SEM) at 15 kV. The title of specimens utilized in this work is shown in Table 3. The transverse tensile specimens are prepared with reference to ASTM E8/E8M–09 standard and in Fig. 3 their dimensions and geometry are indicated. The room temperature tensile test was accomplished by utilizing

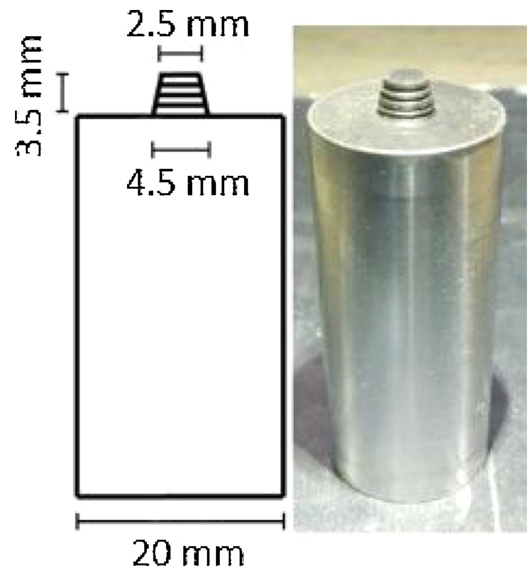

Fig. 1. A view of the welding tool and its dimensions.

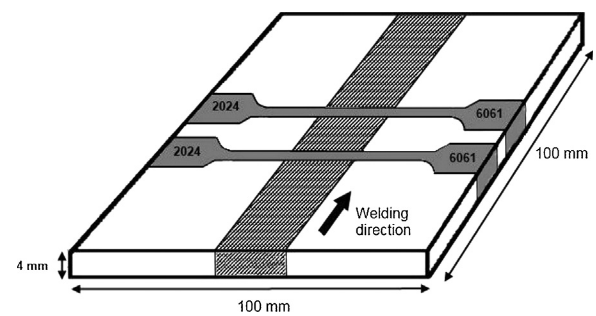

Fig. 2. Dimensions of butt FSW configurations.

Table 3
Samples names.

Samples names	Advancing Side	Retreating Side	Precipitation hardening heat treatment
6A-2R	AA6061	AA2024	×
6A-2R-H	AA6061	AA2024	√
2A-6R	AA2024	AA6061	×
2A-6R-H	AA2024	AA6061	√

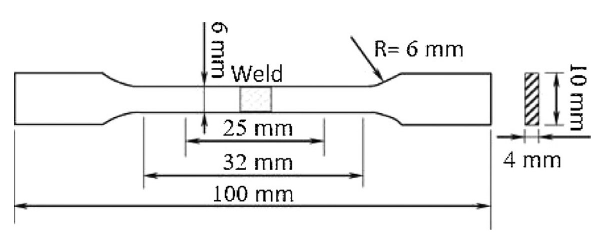

Fig. 3. Tensile test specimen and its dimensions.