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Microstructural Characterization and Mechanical Properties in Friction Stir Welding of Aa7075 Aluminium Alloy

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Abstract. The heat treatable aluminium alloy AA7075 is used extensively in the aircraft industry because of its high strength to weight ratio and good ductility. In this present study the effect of process parameters on the mechanical and micro-structural properties of AA 7075 joints produced by friction stir welding was analyzed. The two sheets, aligned with perpendicular rolling directions, have been welded successively. The welded sheets have been tested under tension at room temperature in order to analyze the mechanical response with respect to the parent materials. Effects of welding speed and fixed location of base metals on microstructures, hardness distributions, and tensile properties of the welded joints were investigated. Optical microscope and SEM analysis revealed that the stir zone contains a mixed structure and onion ring pattern with a periodic change of grain size as well as a heterogeneous distribution of alloying elements. The maximum tensile strength was achieved for the joint produced at rotation speed of 800rpm and a welding speed of 20 mm/s.

Introduction

The fusion welding of aluminum alloys leads to the melting and re-solidification of the fusion zone which results in the formation of brittle inter-dendrite structure and eutectic phases. The formation of brittle structure in the weld zone leads to a drastic decrease in the mechanical properties like low hardness, strength and ductility [1-3]

Friction stir welding (FSW) is a solid-state joining process invented at The Welding Institute (UK) in 1991. The joining process proceeds in a solid-state where temperature during welding is relatively less than the melting point of welded metal [4,5]. The heat generation caused by the friction between the welding tool and weld metal makes the surrounding material around the tool soft and allows the tool to move along the joint line. The Friction stir welding (FSW) technology is being widely considered by the modern aerospace and automotive industry for high-performance structural demanding applications [6]. Such joining process is demonstrated to avoid severe distortions and the generated residual stresses are proved particularly low, when compared to the traditional welding processes [7,8].

A schematic illustration of the friction welding tool is shown in Fig. 1. The process applied to join the two metal sheets by the FSW process is shown in Fig.2. A special tool is mounted on a rotating probe which travels down through the length of the base metal plates in face-to-face contact. The interference between the welding tool and the metal to be welded generates the plastically deformed zone through the associated stirring action. At the same time, the thermo-mechanical plasticized zone is produced by friction between the tool shoulder and the top plate surface and by contact of the neighbour material with the tool edges, inducing plastic deformation [9]. The probe is slightly shorter than the thickness of the work piece and its diameter is typically equal to the work piece thickness [10]. The present study aims to investigate the effects of welding speed and fixed location of material on microstructure, hardness distribution, and tensile properties of AA7075-T6 Aluminium alloy joints produced by FSW.

Experimental Work

The FSW machine used for welding of aluminum alloy plates is shown in Fig. 1. Rolled plate of 6 mm thick were cut into 50mm×200mm to make a welded part of 100 mm wide and 200 mm squared butt and the direction of welding was normal to the rolling direction of the base metal. The nominal chemical composition (wt.%) is given in table.1 The alloy was received in the T6 temper. The FSW tool was made of HSS in the quenched and tempered condition with a shoulder diameter of 18mm pin, 6mm pin diameter and length 5.7mm. The hardness value was 60 HRC. All the welds were produced with the following optimized welding parameters: axial load—7 KN, tool rotation—800 rpm, and welding speed—300 mm/min

Fig 1 Schematic diagram of friction stir welding tool

Fig 2 Schematic diagram of friction stir welding process

Table 1 Chemical composition (wt. %) of base metal

Element	M	Mn	Zn	Fe	Cu	Si	Cu	Al
Base metal	2	0.12	5.1	0.35	1.2	0.58	1.2	Bal

The welded joints were sliced in the transverse direction using power hacksaw and then machined to the required dimensions to prepare tensile specimens (ASTM-E8 M-04) [11]. Tensile test was carried out at 100 KN in a servo controlled Universal Testing Machine. The micro-structural analysis was carried out at the weld region of the joints using optical Microscope. The specimens were etched with Keller's solution to reveal the macrostructure of all zones in order to identify the presence of macro level defects.

Results and Discussion

Mechanical Properties and Hardness. Micro-hardness was measured at mid-thickness region across the weld and the values are shown in Fig.4. The weld region exhibits the 'W' shaped hardness distribution which is typical of many friction stir welds in precipitation hardening alloys. The base metal recorded a hardness value, which is lower than stir zone (SZ) but higher than TMAZ region. The hardness of the SZ is considerably higher than that of the base metal irrespective of the tool rotational speed used. There are two main reasons for the improved hardness of the SZ (i) The grain size of SZ is much finer than that of base metal (ii) the difference in hardness between the HAZ and SZ is attributed to the grain refinement in the SZ. Micrographic aspect of welds exhibits four distinct regions, as shown in Fig 4, namely (A) base metal, (B) heat-affected, (C) thermo mechanically affected and (D) stirred (nugget) zone [12].

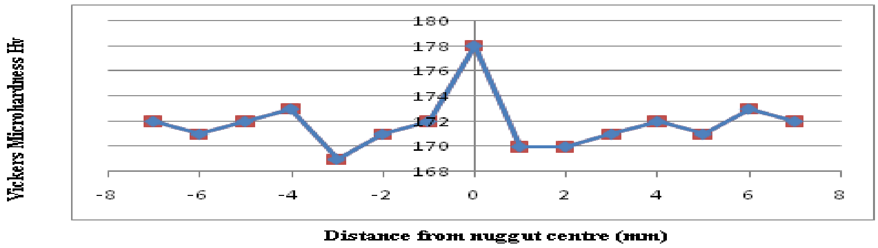


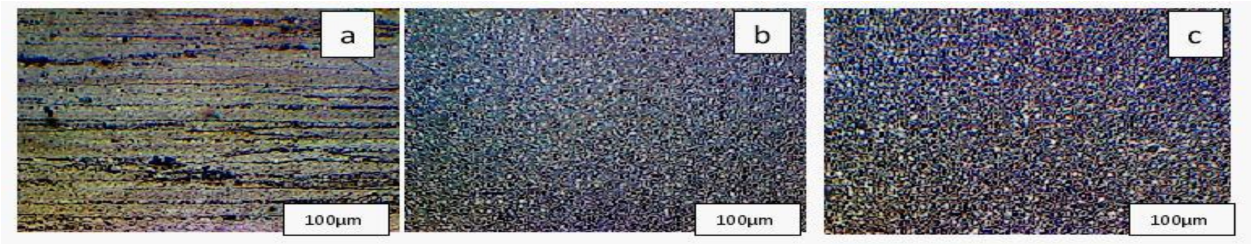
Fig 4 Micro hardness of AA 7075-T6 aluminum alloy.

Transverse tensile strength properties of FSW joints were tested at each condition. The joint efficiency is defined as the ratio of the tensile strength of the welded joint to that of the base metal. The fracture locations were at or near the interface between the weld nugget and the TMAZ on the retreating side. The interface between the weld nugget and TMAZ corresponds to a low hardness area because the original structure in this region is over aged. Therefore, this area of the weld will be relatively ineffective in inhibiting dislocation motion and the strain localization in the softened area of the weld. This results in a reduction of overall elongation in transverse tension. The joint fabricated by applying tool rotational speed of 800 rpm and welding speed of 20 mm/min. The weld efficiency has been observed 67%.

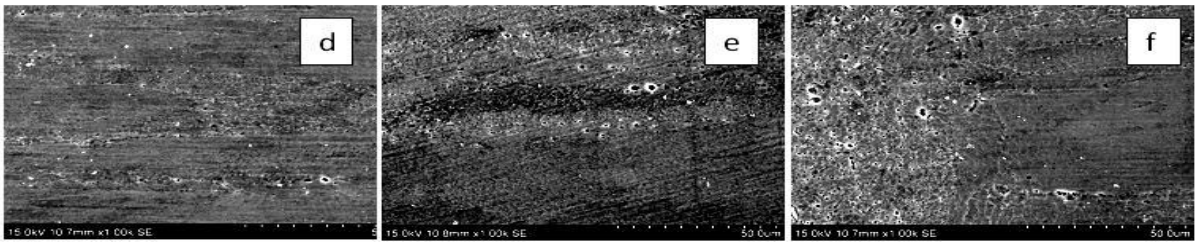
Weld Microstructure. The specimens for metallographic examination were sectioned to the required sizes from the joint comprising FSW zone, TMAZ, HAZ and base metal regions. Further it has polished using different grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) in the disc polishing machine. The polished samples were etched using 10% NaOH to show the general flow structure of the alloy. A standard Keller's reagent made of 5ml HNO_3 (95% concentration), 2 ml HF, 3ml HCL, 190ml H_2O was used to reveal the microstructure of the welded joints. Macro and micro-structural analysis have been carried out using a light optical microscope incorporated with an image analyzing software and Scanning Electron Microscope (SEM).

The optical micrographs of the base metal AA7075-T6 as shown in Fig-5 (a & d) consists of insoluble (Fe, Mn) Al_6 formed along the direction of rolling. Elongated grains of aluminum were seen. Some fine precipitates of Mg_2Si are also noted. Nugget zone of the joints are shown in Fig. 5(b & c). From the micrographs, it is understood that there is an appreciable variation in the average grain size because coarse grains of base metal are changed into fine grains in the nugget region. This may be due to the higher temperature and extensive plastic deformation. The microstructure analysis on FSW of AA

7075-T6 were also analyzed in previous works [13, 14]. The presence of very fine grains in the nugget region provides better tensile properties (385MPa) from the observation of optimum joint (tool rotational speed 800 rpm, welding speed 20 mm/min). The detailed SEM micrographs of the TMAZ region in both the advancing and retreating side is shown in Fig 5(e & f). From the SEM micrograph it is noted that there is an appreciable difference in grain size in the nugget region and TMAZ. The grain size of TMAZ is coarser than the nugget region, due to the mechanical action from the welding tool. The HAZ is unaffected by the mechanical effects from the welding tool. The grain structure in that region resembles the parent material grain structure due to no mechanical action from the welding tool.



(a) Parent metal AA7075alloy (b) Nugget region at 800 rpm (c) Nugget region at 1000
rpm



(d) Parent metal AA7075alloy (e) Nugget region at 800 rpm (f) Nugget region at 1000 rpm
Fig 5 (a-f) Microstructure of the friction stir welded AA7075 aluminum alloy

Conclusions

In this paper, the mechanical properties of FSW joints of AA7075 aluminum alloy were tested and analyzed. From this investigation, the following important conclusions have been derived.

- ❖ The weld joints have been fabricated using the FSW process with optimum parameters of tool rotational speed 800 rpm and welding speed of 20 mm/min
- ❖ The maximum tensile strength tested on the weld joint is observed as 385MPa. The weld joint efficiency is also observed as 67%.
- ❖ The hardness profile indicates a decrease in the weld hardness and this has been attributed to the dissolution of precipitates into solution. The transition region indicates a reduction in hardness.
- ❖ Higher tensile strength of the weld joint has been achieved. This is obtained because of presence of the defect free fine grains of weld nugget and uniformly distributed finer Mg_2Si particles in the weld nugget.

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