Microstructure evolution of Friction Stir Welded Dissimilar Aerospace Aluminium Alloys

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Abstract. Aluminium alloys exhibiting properties such as high strength to weight ratio, high corrosion resistance etc. has made them a choice for many industrial applications. Therefore, joining of aluminium alloys is of utmost importance, especially for the aerospace industry. Friction stir welding (FSW), a clean novel solid-state joining process, is being used to effectively join dissimilar materials for making different parts of space shuttles, aircrafts etc. 2.5 mm thick dissimilar aluminium alloys, AA2219-O and AA7475-T761, were joined using FSW. Evolution of microstructure for the traverse cross section of welded joint was studied. As a result, significant refinement of grains was observed in stir zone along with dissolution and coagulation of strengthening precipitates due to high rise in temperature and severe plastic deformation. Partial recrystallization was observed in TMAZ along with coarsening of grains and strengthening precipitates. In HAZ, coarser grains and strengthening precipitates was observed with no extent of plastic deformation.

1. Introduction

The use of aluminium alloys has increased significantly in modern industries [1]. Various desirable properties such as high corrosion resistance, high strength to weight ratio, good machinability etc. made the aluminium alloys a choice for various industrial sectors such as aerospace, automobile, railways, marine etc. [2]. Therefore, an effective joining process is required to join these materials. However, joining of aluminum alloys using conventional fusion welding methods is difficult due to the formations of various defects which degrades the joint strength.

W. M. Thomas invented and patented Friction stir welding (FSW) in The Welding Institute (TWI), UK. [3]. As a clean solid state joining process, FSW emerged as a remarkable technique to join high strength aluminium alloys effectively which are difficult to be welded by fusion welding processes [4]. FSW join materials at a temperature below their melting point to avoid defects which arise during fusion welding processes. In FSW, a non-consumable rotating tool is allowed to move along the joint line which results in the formation of weld. Figure 1 shows the schematic diagram of FSW [5]. FSW possess various advantages over conventional welding processes such as higher joint strength, low distortion, no evolution of toxic gases etc.

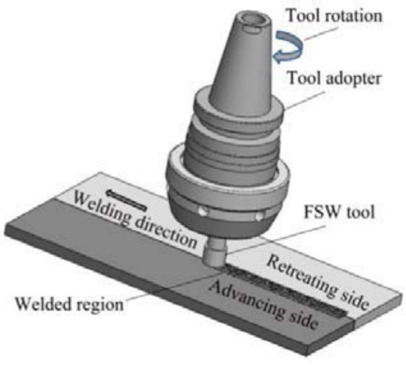

Figure 1. Schematic Diagram of Friction Stir Welding [5]

Joining dissimilar materials allows to produce components having properties of both the materials. Many researchers studied the joining of dissimilar aluminum alloys by conventional welding processes as well as FSW. Conventional welding techniques accompanies various defects such as distortions, solidification cracking, porosity, cracks, chemical reactions between dissimilar materials etc. [6].

Many researchers have studied the evolution of microstructure in FSW of dissimilar materials. Moreira et al. [7] joined dissimilar aluminium alloys (AA6061 and AA6082) using FSW and reported significant changes in the microstructure of the weld region compared to the base material. Lee et al. [8] performed dissimilar FSW of cast A356 and AA6061 and reported that microstructure of SZ was mainly composed of material on RS and joint quality was dependent on location of base materials. Ahmed et al. [9] welded AA7075 and AA5083 using FSW and their results revealed that the difference in base metal properties have strong impact on recrystallization in SZ. Scialpi et al. [10] investigated dissimilar FSW of AA6082 and AA2024 and reported that microstructure of the welded joint significantly affected the micro-hardness.

Aluminium alloys 2xxx and 7xxx series are of utmost importance to the aerospace industry [11]. 2xxx series aluminium alloys are widely used in aircraft components [12] whereas 7xxx series aluminium alloys have applications in aircraft structural components and missile parts etc. [13]. AA2219 and AA7475 are widely used in aircrafts for making cryogenic tanks, upper and lower wing surfaces, body stiffness, surface floors etc. [1].

Joining of dissimilar aerospace grade aluminium alloys by FSW need to be explored for fruitful utilization of various desirable properties of aluminium alloys. Very less literature is available on FSW of dissimilar AA2219 and AA7475. Keeping this in view, an attempt has been made to investigate the microstructural evolution in FSW of dissimilar aluminium alloys (AA2219 and AA7475).

2. Experimental Procedure

2.5 mm thick aluminium alloys 2219-O and 7475-T761 are selected as base materials to be joined by using FSW. Chemical composition of AA2219 and AA7475 is presented in table 1 and table 2 respectively. AA2219 was fixed on advancing side (AS) whereas AA7475 was fixed on retreating side (RS). A high carbon die steel tool with shoulder diameter of 10 mm, pin diameter of 4 mm and pin length of 2.2 mm was employed to perform FSW. Experiments are conducted on robust vertical milling machine which was retrofitted for performing FSW.

Table 1. Chemical Composition of A2219-O (wt. %)

Elements	Al	Cu	Sn	Mn	Fe	Si	Ti	Zn	Ni	Zr	V
AA2219	91.97	6.8	0.02	0.315	0.16	0.06	0.04	0.06	0.023	0.203	0.165

Table 2. Chemical Composition of AA7475-T761 (wt. %)

Elements	Al	Cu	Mg	Mn	Fe	Si	Ti	Zn	Ni	Zr	Cr
AA2219	90.99	1.34	1.93	0.0062	0.101	0.06	0.023	5.36	0.002	0.0076	0.155

After extensive trial experimentation, welding was performed at rotational speed of 1120 rpm and traverse speed of 160 mm/min at a tool tilt angle of 2.5°.

Microstructural specimens were machined from the welded samples using Wire Electric Discharge Machine (Wire-EDM). The acquired samples were polished as per standard metallographic techniques and etched with Keller's reagent. Microstructural examination was done using Optical Microscopy (make: QS Meteorology, Chennai).

3. Results and Discussion

FSW of dissimilar AA2219 and AA7475 was performed successfully without any macro and micro defect. After FSW, three distinct zones viz. the stir zone (SZ), the thermo-mechanically affected zone (TMAZ), and the heat affected zone (HAZ) were observed at AS and RS. All these zones are distinguished on the basis of their microstructures. Mechanical properties of the welded joints depend on the microstructures [14]. Thus, the study of microstructure become important for predicting the quality of the welded joints.

Microstructures of AA7475 (RS) and AA2219 (AS) are shown in figure 2. Grain orientation of material located on RS is in the rolling direction whereas grains are randomly oriented in AS material. Fine black dots visible in BM of AA2219 are non-absorbable precipitates.

FSW resulted in refinement of grains in SZ due to severe plastic deformation [6, 15] as shown in figure 3. The rotating tool moving along the joint line produces frictional heat which softens the base materials and moves them around the tool pin. Tool rotation plastically deforms the base materials due to sticking and slipping action which resulted in grain refinement caused by dynamic recrystallization of grains [16, 17]. SZ experiences high heat due to friction and plastic deformation which causes dissolution of strengthening precipitates [15]. Dissolution of strengthening precipitates reduces the strength of the SZ. However, some amount of re-precipitation might have occurred in SZ depending on the heat input and cooling rate. The temperature in SZ reaches a solid solution temperature which is sufficient for re-precipitation after cooling leading to improved joint strength [8]. The re-precipitated particles visible as white dots in AA7475 (RS) are might be $MgZn_2$ (η) [18]. Whereas in AA2219 some undissolved and coagulated Al_2Cu (θ) precipitates are present. These θ precipitates are due to high copper content in AA2219 which resulted in retention of these precipitates even though the temperature in SZ reaches the solutionizing temperature.

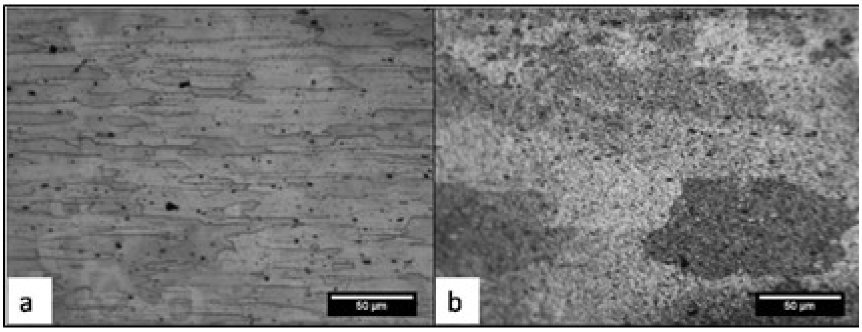

Figure 2. Microstructure of base materials: (a). AA7574 (RS), (b). AA2219 (AS)

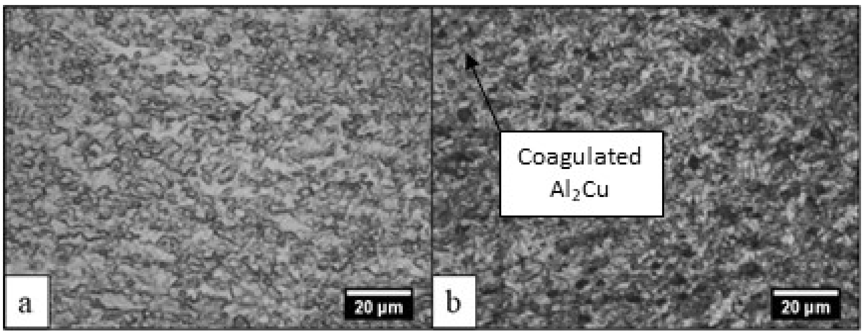

Figure 3. Microstructures of SZ: (a). RS (b). AS.

Moving away from the weld center, TMAZ is located on both AS and RS. The interface boundary between SZ and TMAZ of AS is clearly visible [9] due to higher material deformation rate at the AS of the joint as shown in figure 4. However, exceptions may be found [19] due to the difference in the flow-ability of the materials involved in the process. TMAZ experiences plastic deformation as well as thermal cycle due to mechanical stirring of tool shoulder [20]. The extent of plastic deformation and heat experienced by TMAZ is less than that in SZ. TMAZ microstructure is shown in figure 5. Grains in TMAZ are not as fine and recrystallized as observed in SZ because of partial recrystallization and significant amount of grain deformation [21]. Dissolution of GP zones and metastable phases of strengthening precipitates might have occurred in TMAZ of AS and RS due to enough heat input required for their dissolution. Coarse stable θ and η precipitates are observed at AS and RS respectively. Thermal softening causes precipitate dissolution and which lead to the degradation of mechanical properties in TMAZ. However, heat input in SZ is higher than that in TMAZ even though SZ poses better mechanical properties. This might be due to re-precipitation and grain refinement in SZ [5, 6, 9].

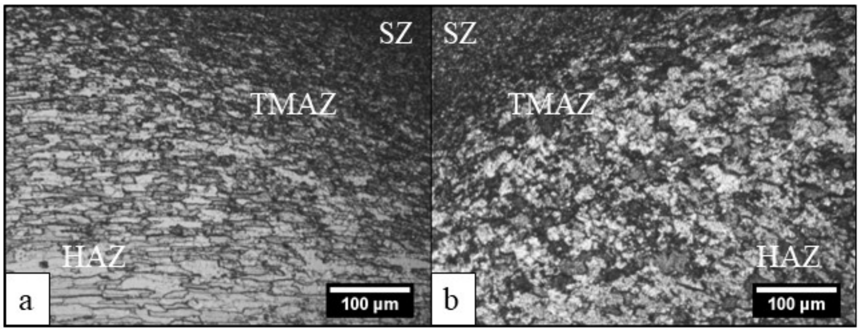

Figure 4. Microstructure of interface for traverse cross section: (a). RS (b). AS.

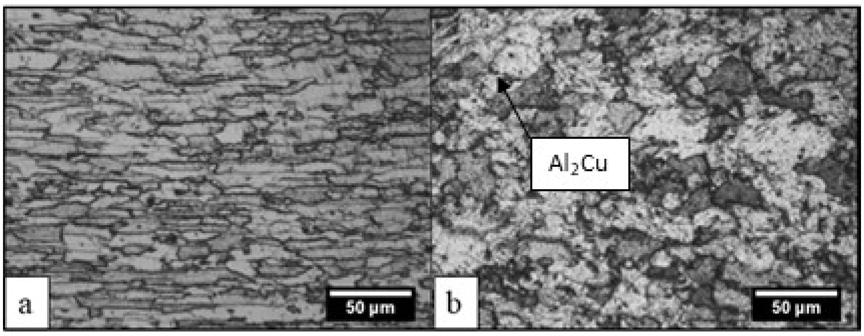

Figure 5. Microstructures of TMAZ: (a). RS (b). AS.

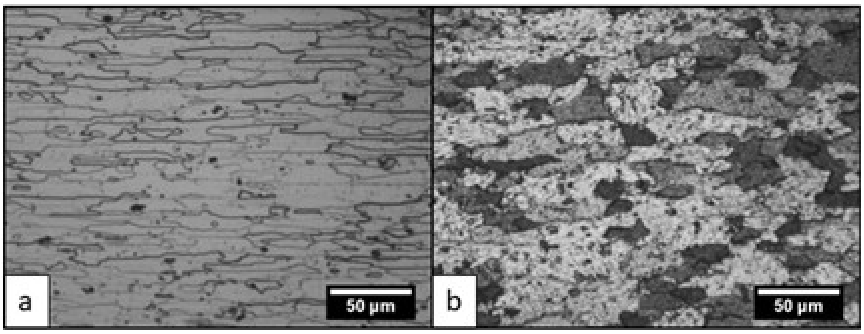

Figure 6. Microstructures of HAZ: (a). RS (b). AS.

HAZ has similar or larger grain size compared with that of base materials [10] as shown in figure 6. This region is observed between the base material and TMAZ. Coarsening of grains and precipitates is observed in HAZ because of experiencing only heat input without any plastic deformation. Also, high volume of coarse strengthening precipitates in HAZ was due to less dissolution of precipitates as shown in figure 6. As less heat is generated in HAZ which might have not sufficient for dissolving the precipitates and also traverse speed in the presence case is higher which has not given the sufficient time required for dissolution of precipitates. Lower mechanical properties of the welded joints are generally observed at either TMAZ or HAZ depending upon the heat input and temper condition of base materials. Coarse precipitates at TMAZ/HAZ interface results in lower mechanical properties [22].

4. Conclusions

Dissimilar FSW of AA2219 and AA7475 was completed successfully. Microstructures of various weld zones was evolved. Following conclusions are drawn based on the above results and discussions:

- Fine recrystallized grains are observed in stir zone.
- Dissolution of strengthening precipitates and grain growth in SZ reduces the joint strength whereas re-precipitation in SZ improves the joint strength.
- Partial recrystallization took place in TMAZ.
- Coarsening and dissolution of precipitates is observed in TMAZ whereas only coarsening of precipitates is observed in HAZ.
- Grain size increases by moving away from the SZ towards the unaffected base material.

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