Metallurgical Characterization of Friction Stir Welding Joints of AA6061-AA6061, AA6061-AA6082 & AA6082-AA6082 Under T6 Condition

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Abstract- *Al alloy is widely used for commercial applications in the transportation, construction and similar engineering industries. It possesses excellent mechanical properties in addition to good corrosion resistance. In this experiment, Friction Stir welding to obtain the butt joints of similar and dissimilar aluminum alloys i.e. (AA6061-6061, AA6082-6082 & AA6061-6082 under T6 condition) is carried out and NDT testing (penetrate and ultrasonic tests) to detect any weld defects present in the welded area, which reveals a good acceptance. Micro hardness and micro structure in the weld is examined. The Microstructure evaluation of AA6061 shows that the Fusion with parent metal is good, Grains are slightly elongated at the heat affected zone at similar welds, Microstructure evaluation of AA6082 similar weld shows that grains are slightly decreased at HAZ and Microstructure evaluation of AA6082 and AA6061 dissimilar weld shows that grains are slightly elongated at welded zone than a base metal AA6061 and same as a grain size of base metal AA6082. Vickers Micro hardness evaluation of AA6061-AA6061 shows that after Friction Stir welding (FSW) at parent metal Vickers Micro hardness slightly higher than weld zone. Vickers Micro hardness is high at HAZ for AA6061. Vickers Micro hardness of AA 6082-6082 at the weld region is higher than HAZ, Parent metal. Vickers Micro hardness of AA 6061-6082 at the weld region is higher than HAZ. By comparing the three welded joints Vickers Micro hardness of AA6061-AA6082 is higher than similar welds (AA6061-AA6061 & AA6082-AA6082) at welded region, at HAZ Vickers Micro hardness AA6061-A6061 is higher than the other two welded joints.*

Keywords- Friction stir welding, NDT, Micro hardness, Micro structure, Heat Affected Zone.

I. INTRODUCTION

Friction stir welding is a relatively new joining process can best compare to fusion welding process. It is considered as a solid state process, and it does not require the need for gas shielding or filler metals. FSW consists of a rotating and non consumable pin tool that is slowly plunged into the weld line until the pin tool's shoulder is in intimate contact with the work piece. As the tool rotates and moves forward along the weld line, the material at the weld line begins to heat up, forcing it to flow around the rotating tip to consolidate on the pin tool's backside. The heat source is developed mainly due to the friction and plastic deformation while placing the pin tool's shoulder in intimate contact at all times with the work piece. The work pieces must be rigidly clamped to a backing anvil in a manner that prevents them from moving and being forced apart at the abutting joint faces.

FSW has the potential for welding of aluminium alloys because the processing temperature occurs well below the metal's melting point, thereby eliminating the solidification defects and other undesirable chemical reactions. However, as with all welding processes. Friction welding is preferred over that of conventional fusion welding process due to the following advantages such as no fumes, no welding arc, low heat input and almost no finishing costs. AA6061 is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements[1]. Further to joints of similar alloys, FSW is being studied for welding dissimilar alloys which can be of particular interest in some industrial applications. Some works can be found in the literature,e.g. [2], but data is still scarce on the characterisation of this joint type. In this work the ability to join dissimilar alloys by FSW was studied using butt welded plates. The hardness values in nugget zones are lower than base metal but higher than thermal mechanical affected zone and heat affected zone, An increase in the hardness in nugget zone due to work hardening takes place during friction stir welding, in joints which have high ductility, the tensile fractures occurred in around the heat affected zone and thermal mechanical zone, for low ductility joints fracture in around the nugget zone on the advancing side [3]. In nugget zone long grains are seen also contain sub grains, sub boundaries and dislocations. It is strongly depends on the shape of the tool pin profile. The interface region between nugget zone and parent metal is diffuse relatively on the retreating side, but slightly sharp on the advanced side of the tool [4]. Axial thrust is highly affected by shoulder diameter slightly by tool rotation and welding speed [5]. The presence of eutectic structure of $Al3Mg_{17}(\gamma)$ and Mg in the region of stir zones of lap and butt welds observe the presence of liquid formation during friction stir welding[6]. The hardness of friction stir welding joints strongly depended on the precipitate distribution and slightly on the increases size of the grains, stress amplitude and plastic strain decreases due to increase in the welding speed [7]. The joint developed by using square pin profile tool produces higher tensile strength. Friction stir welding at higher welding speed produces voids causes poor consolidation of the metal interface [8] .Failure of friction stir welded joints occur at defective area when joints associated with defect like pin hole, failure occ urs in low hardness zone if joints are defect free [9]. Tool rotation speed has maximum contribution on heat affected zone distance and this followed by axial force and transverse speed [10]. Conical shoulder tool produce larger nugget grain size in hot welds [11] fatigue strength of the joints decreased with increase in tool rotation for a fixed tool pin diameter, fatigue strength decreases with increasing tool pin diameter for fixed tool rotation [12]. Joints fabricated using square pin profile tool defect free[13] In heat affected zone percentage of coincident site lattice boundaries increases and high angle random boundary percentage decreases this is due to increase low angle boundaries [14]. Increase tool rotation rate decreases the size and aspect ratio of Si particles in the friction stir processing of A356 [15] Increasing distance from zone boundaries of friction stir processing decreases the yield strength and tensile strength [16]. Advancing side of the weld samples has high hardness values. Massive grain and equiaxed grains are produced in post weld heat treatment [17]. During tensile test the friction stir welded AA6082-AA6082 material has grater values of load at yield, elongation at yield, yield stress, tensile strength and load at break when compared to AA6061- AA6061 and AA6061-AA6082; Load at break, elongation at break & CHT at peak of friction stir welded AA 6061-AA 6082 has grater values when compared to AA6061-AA6061 and AA6082-AA6082 under T6 condition. Mechanical testing is done and results are explained [18].

1. 1 Properties of Aluminum Alloys AA6061-T6 and AA6082-T6

N. Bhanodaya Kiran Babu et.al [19] discussed the chemical composition, physical properties of aluminum alloys. The chemical composition of AA6061 and AA6082 are tabulated in table1, the physical properties were tabulated in table 2

Table.1 Chemical composition of A6061-T6 & AA6082-T6

Elements	Mg	Mn	Fe	Si	Cu	Cr	Zn	Al
Base Metal (6061 T6)	0.8-1.2	0.0-0.15	0.0-0.70	0.4-0.8	0.15-0.40	0.04-0.35	0.0-0.25	Balance
Base Metal (6082 T6)	0.6-1.2	0.4-1.0	0.0-0.5	0.7-1.3	0.0-0.1	0.0-0.25	0.0-0.1	0.0-0.2

Table 2 Physical Properties of AA6061-T6 & AA6082-T6

Physical Property	Density (K/m ^3)	Melting Point ^{0}C	Modulus of Elasticity, Gpa	Poisson's Ratio
Base Metal (6061 T6)	2700	600	69	0.33
Base Metal (6082 T6)	2700	555	70	0.33

1.2 Non-Destructive Testing (NDT)

NDT is the way of testing without destroying the material the structural integrity, quality and reliability of components and plants can be ensuring [20]. NDT has extensive applications for condition monitoring, energy audit, Predictive maintenance etc.

A. Ultrasonic Testing- (UT): Ultra high frequency sound is introduced into the part being inspected and if the sound hits a material with different acoustic impedance some of the sounds will reflect back to the sending unit and can be presented on a visual display.

B. Penetrating Test: Liquid penetration testing is that when a very low viscosity liquid is applied to the surface of it will penetrate into fissures and voids open to the surface. Once the excess penetrate is removed the penetrate trapped in those voids will flow back out, creating an indication.

II. MATERIAL AND METHODS

2.1 Frictional Stir Welding

FSW is performed by taking three plates of AA6061 and 3 plates of AA6082 having dimension (200mmx100mm) with 5mm thickness was taken. The process includes welding of dissimilar and similar alloys as one piece (AA6061-AA6082). The selected parameters were travel speed of 50mm/min; tilt angle of 1°; rotating speed of 1120 rpm. In the similar manner welding of similar alloys as second piece (AA6061-AA6061) the selected parameters are travel speed of 50mm/min: tilt angle of 1°; rotating speed of 900 rpm.

Welding of similar alloy (AA6082-AA6082) are made with a selected parameters were travels at a speed of 50mm/min: tilt angle of 1°: rotating speed of 1400 rpm. The welded plates and tool used for friction stir welding is shown in Fig 1 (a) & (b).

NON Destructive Testing is done to find the weld defects in and around the welded zone after friction stir welding. Penetrate test was made to find the defects at the outer surface and Ultrasonic testing is done to find the defects at inner surface of the welded zone is shown in Fig 2. Results of the tests revealed that there were no defects in the welded zone and at the joints.

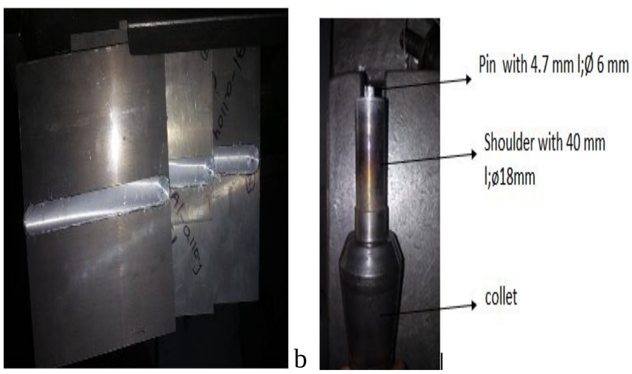


Fig1: (a) FSW plates; (b) FSW Tool

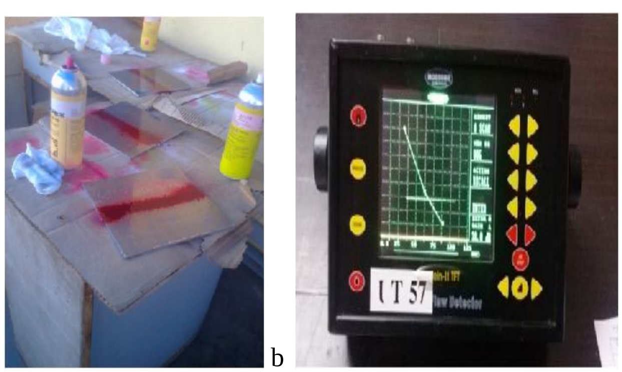


Fig2: (a) Penetrating test; (b) Ultrasonic test

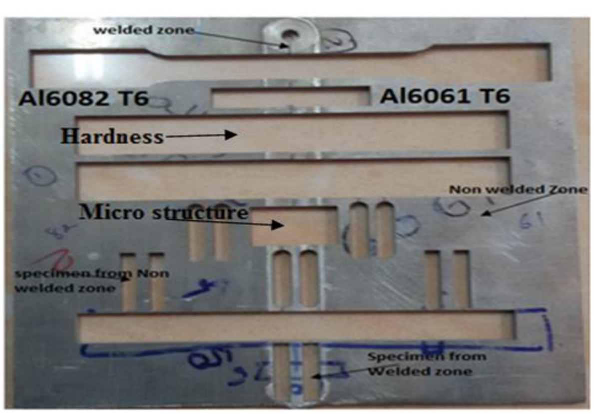


Fig.3: Friction Stir welded dissimilar joint (AA6061- AA6082) and indicating the specimens for Micro structure and Micro Hardness test.

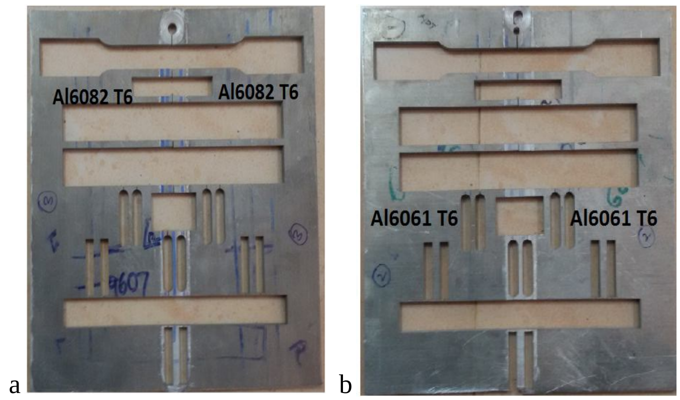


Fig 4: Friction Stir welded similar joint (a) (AA6082-AA6082); (b) (AA6061- AA6061)

2.2 The hardness profiles can assist the interpretation of the weld microstructures and mechanical properties. Microhardness tests

were performed in order to characterize the hardness profile in the vicinity of the weld affected area. The microhardness tests were performed on a cross section perpendicular to the weld line, mid thickness across the weld zone and into the parent material, using a 1Kg load. For the analysis of microstructural changes due to the FSW process, the joints were cross-sectioned perpendicularly to the welding direction and etched with HF reagent [21]. Microstructures were acquired in different zones: transition between welded and base material, welded material and base material. Grain size analysis is done with intercept method using the software MET image X. The samples hardness and microstructure are shown in the Fig-5, 6 & 7.

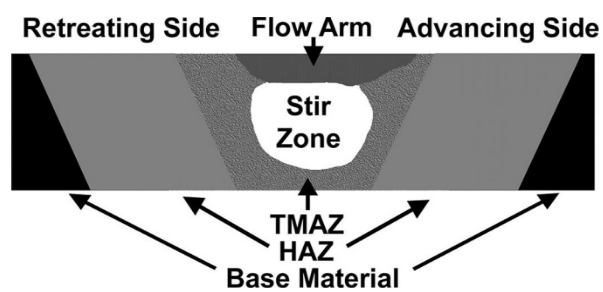


Fig.5 Different regions of FSW joint

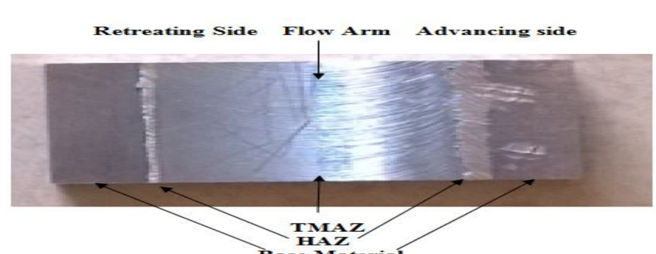


Fig.6 Different regions of FSW joint indicated on sample used for testing

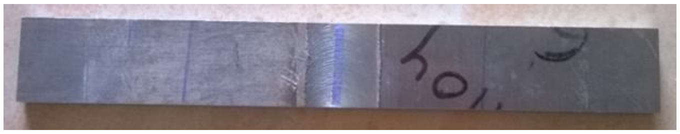
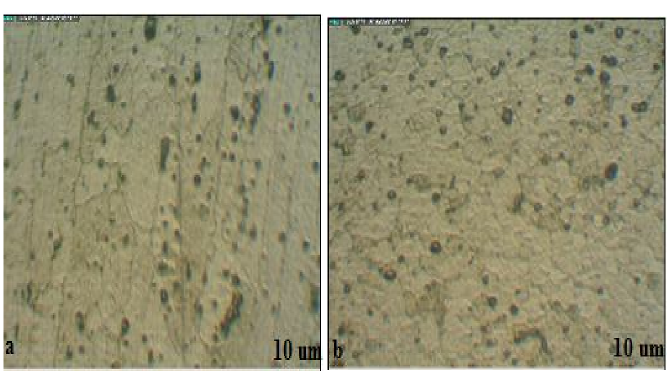


Fig.7 FSW sample used for Micro hardness test

III. RESULTS AND DISCUSSION

3.1 Microstructure Studies

Optical micrograph of AA6061 before and after Friction stir welding is shown in Fig 8. The Fig 8(a) shows optical microstructure evaluation of AA6061 shows that the Fusion with parent metal is good, Grains are slightly elongated at the heat affected zone at similar welds. The Fig. 8 (b) shows optical Microstructure evaluation of AA6061-AA6061 weld zone be observed that some fine cracks are seen and grain size is normal as base metal. The Fig. 8 (c) shows optical Microstructure evaluation of base metal AA6061 before FSW, from micrograph it can be observed that it consists of dendrites of aluminium solid solution. It also consists of coarse grains of aluminium solid solution. The Fig. 8 (d) shows optical Microstructure evaluation of AA6082-AA6061 weld zone be observed that some fine cracks are seen and grain size is normal as base metal of AA6082 and it is greater than AA6061 base metal. The Fig. 8 (e) shows optical Microstructure evaluation of AA6082 shows that the Fusion with parent metal is good, Grains are slightly decreased at the heat affected zone at similar weld compared to base metal. The Fig. 8 (f) shows optical microstructure evaluation of AA6082 shows that the Fusion with parent metal is good, from micrograph it can be observed that it consists of dendrites of aluminium solid solution. It also consists of coarse grains of aluminium solid solution. The Fig. 8 (g) shows optical Microstructure evaluation of AA6082-AA6082 weld zone be observed that some fine cracks are seen and grain size is normal as base metal. The grain sizes are shown in Table-4 and they are calculated based on ASTM E 112 standards and the grain size analysis is done by intercept method using the software MET image X.



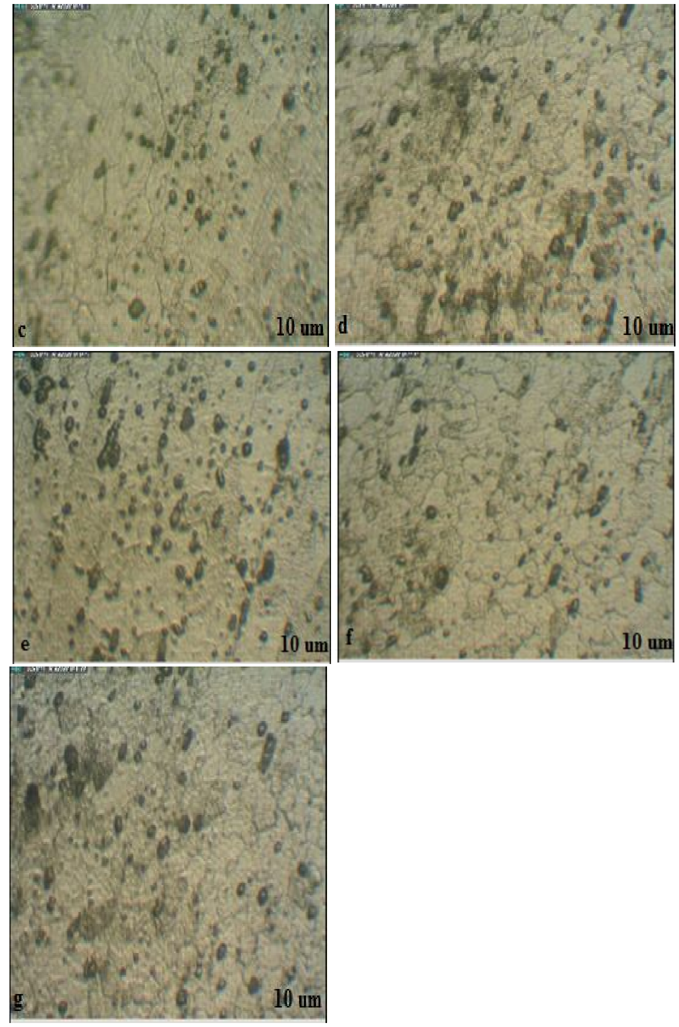


Fig-8 Optical Microscope showing Micro Structure of AA6061-AA6061, AA6082-AA6082 & AA6082-AA6061
a) 6061-6061 Heat affected zone at 400X rep
b) 6061 6061 weld zone at 400X rep c) 6061 Base at 400X rep
d) 6082-6061 weld zone at 400X rep e) 6082-6082 Heat affected zone at 400X rep f) 6082 Base at 400X rep
g) 6082-6082 weld zone at 400X rep

Table -4 Grain size analysis

Figure	Field measured	Analyzed Area	Standard	ASTM Grain Size	Intercepts	Mean Int. length (um)
a	1	.5005 sq mm	ASTM E 112	4.5	103	68.7
b	1	.5005 sq mm	ASTM E 112	4.	93	76.1
c	1	.5005 sq mm	ASTM E 112	4.	84	84.2
d	1	.5005 sq mm	ASTM E 112	5.	126	56.1
e	1	.5005 sq mm	ASTM E 112	4.5	102	69.4
f	1	.5005 sq mm	ASTM E 112	5.	118	60
g	1	.5005 sq mm	ASTM E 112	5.	136	52

3.2 Hardness Test

Table 5 shows the results of Vickers Micro hardness test conducted for FSW of AA6061- AA6061, AA6082-AA6082 and AA6082-AA6061 at a load of 1Kg at equal distances from the center of the welded zone to the left and right side i.e at different zones (parent metal, Heat affected zone and weld zone). The Fig 9 shows the Micro hardness graph, in the graph for the AA6061-AA6061 sample the hardness of base metal and HAZ is higher than the value at a welded zone. For AA6082-AA6082 sample the Micro hardness at weld zone is higher than the HAZ and base metal hardness is higher than the weld zone as shown in the graph. For AA6082-AA6061 sample the Micro hardness at weld zone is higher than the HAZ and base metal hardness is higher than the weld zone.

From Table-5 and Fig-9 while comparing the weld zone of the similar and dissimilar FSW joints, AA6082-AA6061 has higher Micro-hardness value than the other two, the second highest value is for AA6061-6061 similar joint sample and the lowest value is for the third joint. Micro hardness observation at HAZ is higher for AA6061-AA6061 than other two and second higher value is for AA6082-AA6061 and the lowest value is for third joint. When moving from the left side of the welded zone the FSW sample of AA6061-AA6061 observes higher value and AA6082-AA6082 observes lower value. When moving from the right side of the welded zone the FSW sample of AA6082-AA6082 observes higher value and AA6082-AA6061 observes lower value.

Table: 5 Vickers Microhardness of AA6061-AA6061, AA6082-AA6082 & AA6082-AA6061

Sam ples	Distance	25	50	66	75	84	125	150
6082/ 6082	Hardness	74.88	81.31	67.89	76	72.66	89.989	89.98
6061/ 6061		88.04	91.42	80.42	79.667	74.78	82.47	83.74
6082/ 6061		83.35	87.1	76.88	79.74	75.89	76.41	79.94

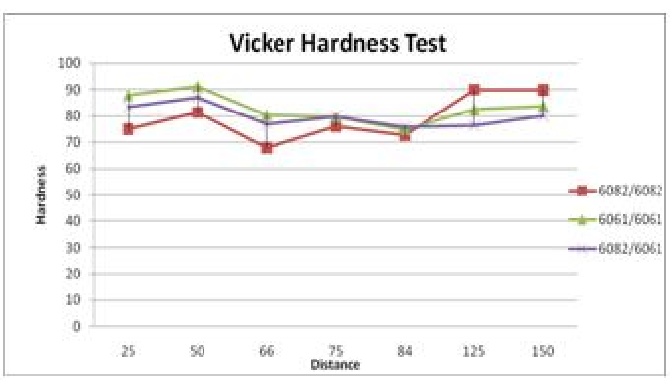


Figure 9 Vickers Microhardness of AA6061-AA6061, AA6082-AA6082 & AA6082-AA6061

IV. CONCLUSIONS

AA6061-AA6061, AA6082-AA6082 and AA6082-AA6061 was successfully friction stir welded. Microstructural characteristics, such as Microhardness and Micro structure were examined in the present study and also compared between both aluminium alloys of similar and dissimilar welded joints. The following conclusions are made.

1. The microstructure of AA6061-AA6061 shows that fusion with parent metal is good, grains are slightly elongated at heat affected zone, some fine cracks are seen in the weld zone. For AA6082-AA6082 in the parent metal fine dendrites of aluminium solid solution coring is seen at grain boundaries. Grains are severely elongated at HAZ. Fine cracks are seen within the weld zone. For AA6082-AA6061weld is good and at weld zone the grain size is slightly decreased than base metal grains size.
2. Vickers Micro hardness of AA6061-AA6061, AA6082-AA6082 & AA6082-AA6061 at weld zone is lesser than the base metal. While comparing Vickers Micro hardness at weld zone of similar & Dissimilar joints (AA6061-AA6061, AA6082-AA6082 & AA6082-AA6061), AA6082-AA6061 has a higher value.
3. When moving from the left side of the welded zone the FSW sample of AA6061-AA6061 observes higher value and AA6082-AA6082 observes lower value. When moving from the right side of the welded zone the FSW sample of AA6082-AA6082 observes higher value and AA6082-AA6061 observes lower value.

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