AN EXPERIMENTAL STUDY ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF DISSIMILAR ALUMINIUM ALLOY FRICTION STIR WELDS

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Abstract: Friction stir welding (FSW), a solid state joining technique is widely used for joining Aluminum alloys in marine, aerospace, automotive and many other applications of commercial importance. In the present study, dissimilar Aluminum alloy (AA 6262-T6 and AA 7075-T6) plates were FS welded by varying the weld parameters such as Tool rotational speed, weld speed and axial force with cylindrical tool pin profile. The mechanical properties (hardness and tensile strength) of the Dissimilar Friction Stir welded (DFSW) specimens were tested and compared with the base materials. The observations have been elaborated in detail along with microstructures of parent and welded specimens through Optical Microscopy and it is observed that the weld parameters have a significant effect on mechanical and micro structural properties of the welds.

Keywords: Aluminum alloys, Friction stir welding, dissimilar welds, mechanical properties and microstructure.

I. INTRODUCTION

The marine and the aeronautic industries are definitely the most Wanted, interested and focused fields of research now-a-days predominantly on joining techniques. Actually, mechanical strength and performances, corrosion resistance, residual stress state, and weight reduction are some of the most significant issues which are painstaking in the assembly of aeronautical components and also in transport industry [1]. Heat treatable wrought aluminium-magnesium-silicon alloy conforming to AA6262 is of medium strength and possess good welding characteristics over the high strength aluminium alloys and also have similar chemistry to AA6061 except small addition of lead and bismuth to enhance machinability whereas aluminium-zinc-magnesium alloy namely AA7075[2] is of high strength and possess low welding characteristics. Both the materials AA6262 and AA7075 are extensively employed in marine fittings, couplings, hinge pins, camera parts, screw machine products, automobiles and aircraft applications [3,4,5].

In contrast to many of the fusion welding processes that are routinely used for joining structural alloys, FSW is an emerging solid state joining process in which the material that is being welded does not melt and recast. FSW was invented at The Welding Institute (TWI), UK in 1991 [6-13]. FSW is a continuous, hot shear, autogenous process involving a non-consumable rotating tool of harder material than the substrate material [14, 15]. Defect-free welds with good mechanical properties have been made in a variety of aluminium alloys. When alloys are friction stir welded, solid-state phase transformations will occur during the cooling of the weld. Due to the absence of parent metal melting, the new FSW process is observed to offer several advantages over fusion welding. The material flow behavior is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters namely tool rotational speed, weld speed and axial force [16-19].

II. EXPERIMENTAL WORK

In the present study, the dissimilar Aluminum alloys AA 6262-T6 kept on the advancing side (AS) and AA 7075-T6 kept on retreating side (RS) of 6mm thick plates were friction stir welded in butt position with H13 tool steel tool of cylindrical pin diameter and shoulder diameter as 6mm and 18mm respectively.

Chemical compositions in weight percentage and mechanical properties of base metals (BMs) AA 6262 and AA 7075 at room temperature are presented in Table 1 and Table 2 in the order. Initially Square butt joint configuration was obtained by securing the plates in position using mechanical clamps. Single pass welding procedure was adopted to fabricate the joints in a direction normal to the rolling direction of the plates. An indigenously designed and developed FSW machine (15 HP; 3000 RPM; 25 kN) was used to fabricate the joints. The welding parameters considered and tool geometry are presented in Table 3.

Macro and micro structural analysis were carried out using a light optical microscope (Make: Union Opticals, Japan; Model: VERSAMET-3). The specimens for metallographic examinations were sectioned to the required dimension from the joint and polished using different grades of emery papers followed by diamond paste polishing on the disc polishing machine followed by etching with Keller's reagent to reveal the macro and microstructures.

Hardness testing was carried out using Vickers pyramid hardness testing machine (Make: Leco and LV 700) with a load of 5 kg. Hardness survey along the transverse direction of the weld was conducted at regular intervals of 2 mm from the weld centerline to the both ends.

The tensile test specimens were prepared by Electro Discharge Machining and tested according to ASTM-E8 standards on 10T, computer controlled Universal Testing Machine at an initial strain rate of $6.7X10^{-5}$ s-1 at room temperature. The tensile properties of the joint were evaluated and an average of three tested specimens was reported for each weld. All the specimens were mechanically polished before tests in order to eliminate the effect of possible surface irregularities [20, 21]. The Ultimate Tensile Strength (UTS), Yield Strength (YS), and percentage of Elongation (%E) were evaluated.

Table1.Chemical composition (wt %) of BM's

Elements	Si	Cu	Mn	Mg	Zn	Al
AA6262	0.640	0.262	0.096	0.88	0.048	Bal
AA7075	0.104	1.560	0.063	2.32	5.950	Bal

Table 2. Mechanical properties of BM's

Material	UTS (MPa)	YS(MPa)	%E	Hardness(VHN)
AA6262-T6	346	319	22.8	108
AA7075-T6	589	471	20.8	195

Table 3. Welding Parameters and Tool geometry

S.No	Process Parameters	Values
1	Tool rotational Speed(rpm)	1000,1200, 1400
2	Weld Speed(mm/sec)	0.4,0.6, 0.8
3	Axial Force (kN)	8,9,10
4	Tool shoulder diameter (mm)	18
5	Tool Pin diameter (mm)	6
6	Pin Length (mm)	5.8

III. RESULTS AND DISCUSSIONS

3.1Macro and Microstructural observations

The FSW joints were successfully produced. The obtained joints shown no porosity or other defects in both top and root weld surface in all the welding conditions. Fig.1 shows the macrograph of the produced weld after thoroughly etched with the Keller's reagent marked as "SZ", "TMAZ" and "BM". From the different etching response of each material the AA6262 Al alloy appeared darker in colour than that of AA7075. It is clear from the microstructure that SZ is mainly composed of AA6262 which is fixed on AS than AA7075 fixed on RS.

The SZ is the region that experienced the highest strain and undergoes recrystallization. Its microstructure is due to the mechanical action of the tool probe that generates a continuous dynamic recrystallization process. The higher temperature and the severe plastic deformation during the welding in the SZ result in a new equiaxed fine grain structure.

Fig.2 shows the Optical microstructures of the BM's and that of the welds at SZ and TMAZ. The left-hand side micrograph of the BM region indicates that microstructure consists of Mg_2Si precipitates and that on right side indicates Al_2Zn precipitates. The SZ has equiaxed grains with both the precipitates. The appreciable variation in grain size and distribution of strengthening particles in TMAZ region was observed on both AS and RS compared to SZ, which is due to various reasons such as FSW parameters, tool geometry, work piece composition & temperature, vertical pressure and active cooling

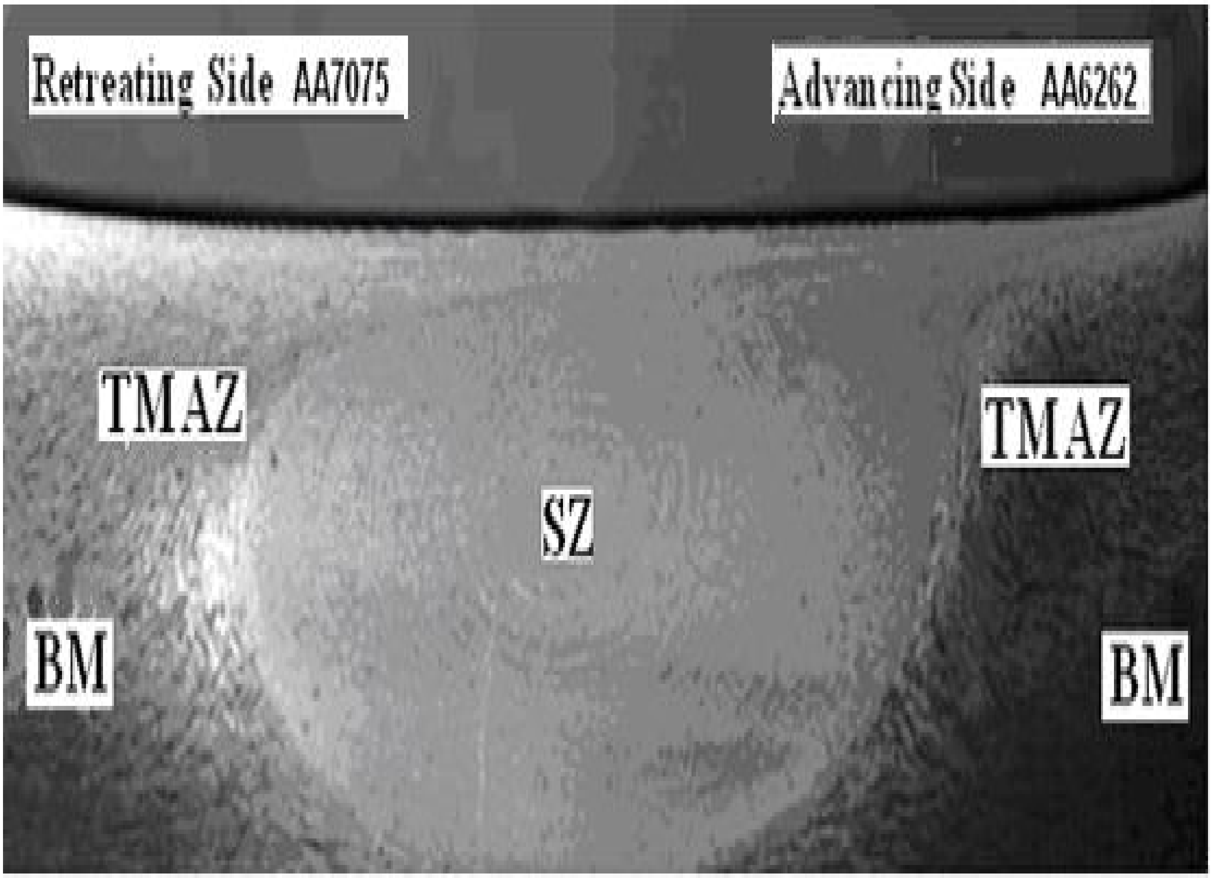

Fig 1. Typical macrograph showing various regions of the FS welded plates on AS and RS.

3.2 Hardness observations

Table 4 shows the micro hardness values in SZ in addition to the tensile test results of all the DFSW specimens including the tensile failure position. It is observed that out of all the DFSW plates, the plate welded with 1200 rpm tool rotational speed, 0.6mm/sec weld speed and 9 kN axial force showed better micro hardness value at the SZ. Fig 3 shows the effect of tool rotational speed on the hardness variation across the weld line of the DFSW plate with 0.6mm/sec weld speed and 9 kN axial force as it showed better hardness value. It is observed that the plates welded with 1200 rpm tool rotational speed shows better results compared to the other two tool rotational speeds and also the hardness in the region of tool pin interaction with the plates is found to be higher than the hardness of AA6262 BM whereas lower than that of AA7075 BM. Hardness gradually decreases to the TMAZs on both the sides of SZ and then increases towards the ends (BMs) of the DFSW plate.

3.3 Tensile Observations

Traverse tensile properties of DFSW joints fabricated using cylindrical tool pin profile with all possible conditions were evaluated. Three specimens from each weld were tested and average of which is reported in Table 4. The results show that Tool rotational speed is having significant influence on tensile properties of the welded specimens and also it is observed that most of the specimens failed in the HAZ region of retreating side i.e. AA6262 side and a few of them failed in SZ region. The joints fabricated with 1200 rpm tool rotational speed, 0.6 mm/sec weld speed and 9kN axial force showed high tensile strength, where as joints fabricated using1000 rpm tool rotational speed with 0.8 mm/sec weld speed and 8kN axial force showed low tensile strength.

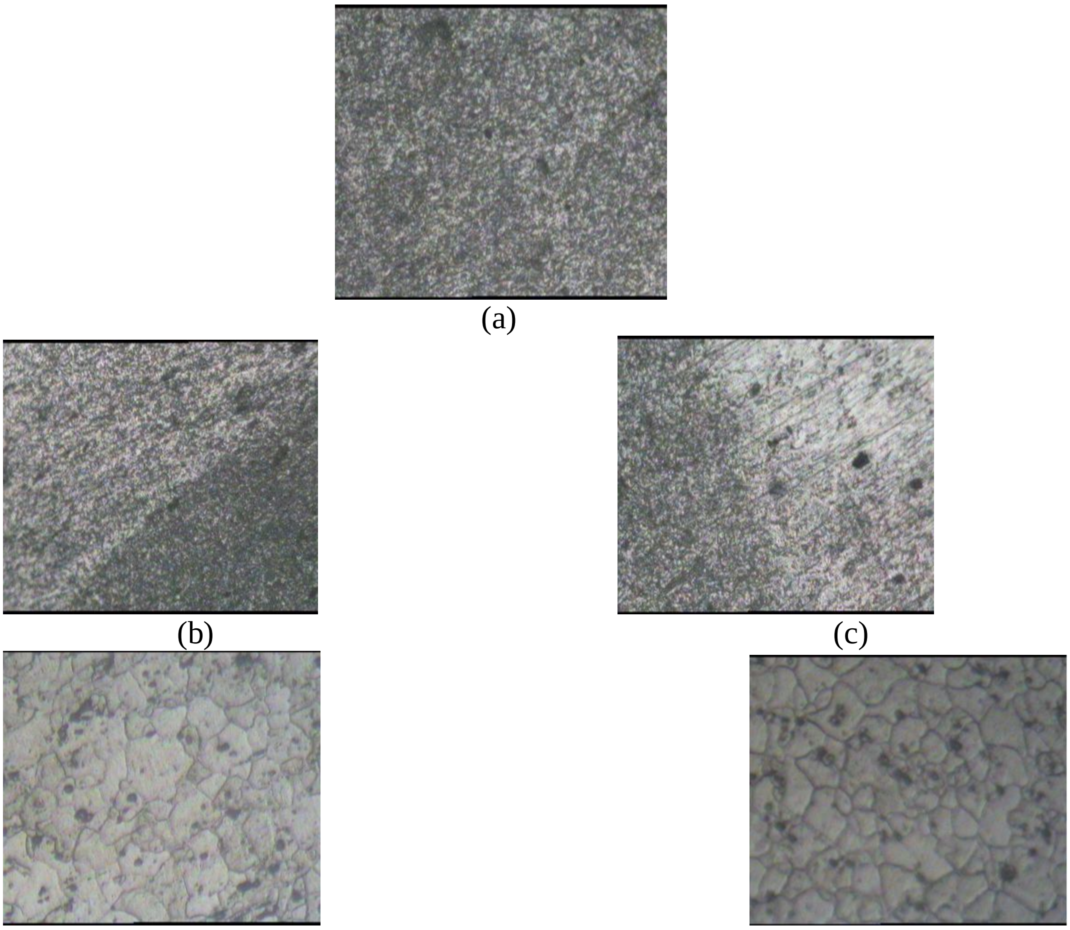

Fig. 2 Optical micrographs with main distinct regions of the DFSW: (a) SZ (b) TMAZ on AA6262 side (c) TMAZ on AA7075 side (d) BM AA6262 and (e) BM AA7075.

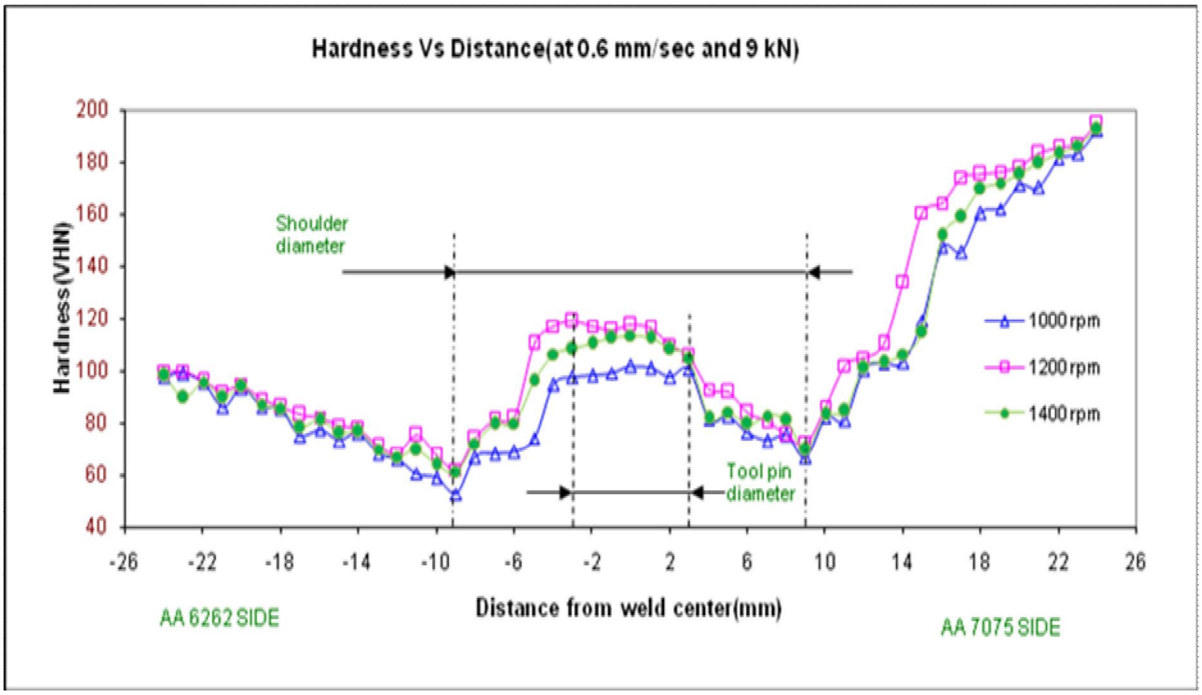

Fig.3 Hardness variation at 0.6mm/sec feed rate, 9kN axial force

Table 4. Mechanical properties of Dissimilar Friction Stir Welded specimens

S.no	Tool rotat-ional Speed, rpm	Weld speed, mm/sec	Axial force kN	UTS MPa	YS MPa	%E	Vicker's hardness	Failure position
1	1400	0.4	8	221.69	181.55	6.58	106.95	SZ
2	1400	0.4	9	225.86	189.2	9.81	111.9	HAZ of 6262
3	1400	0.4	10	223.4	180.86	7.95	109.4	HAZ of 6262
4	1400	0.6	8	227.95	183.32	6.58	101.57	SZ
5	1400	0.6	9	236.36	193.01	9.93	113.72	HAZ of 6262
6	1400	0.6	10	229.51	186.92	8.69	111.18	SZ
7	1400	0.8	8	215.02	174.98	5.79	105.8	SZ
8	1400	0.8	9	221.36	182.42	8.08	110.8	HAZ of 6262
9	1400	0.8	10	218.87	178.86	7.61	108.67	SZ
10	1200	0.4	8	225.75	184.57	7.57	108.6	HAZ of 6262
11	1200	0.4	9	228.01	192.98	10.86	115.2	HAZ of 6262
12	1200	0.4	10	226.52	188.06	8.79	112.84	HAZ of 6262
13	1200	0.6	8	229.86	192.03	8.24	110.4	HAZ of 6262
14	1200	0.6	9	238.82	202.05	11.26	117.35	HAZ of 6262
15	1200	0.6	10	232.01	196.63	10.06	114.7	HAZ of 6262
16	1200	0.8	8	218.14	182.34	6.71	107.93	SZ
17	1200	0.8	9	224.55	190.27	9.05	114.57	HAZ of 6262
18	1200	0.8	10	221.95	187.77	8.48	111.07	HAZ of 6262
19	1000	0.4	8	218.44	174.98	6.19	95.61	SZ
20	1000	0.4	9	221.29	179.31	9.32	99.5	SZ
21	1000	0.4	10	219.63	176.09	7.83	98.37	SZ
22	1000	0.6	8	221.94	178.25	6.35	96.14	SZ
23	1000	0.6	9	229.44	187.01	9.65	99.05	HAZ of 6262
24	1000	0.6	10	223.37	182.48	8.58	98.97	HAZ of 6262
25	1000	0.8	8	209.95	168.57	5.63	93.78	SZ
26	1000	0.8	9	215.83	178.49	7.91	96.81	SZ
27	1000	0.8	10	211.75	175.79	7.54	95.12	SZ

CONCLUSIONS

- The Friction stir welding used successfully to join dissimilar aluminium alloys (AA6262 and AA7075).
- Better mechanical properties (hardness and tensile strength) were obtained with the FSW plate fabricated with 1200 rpm tool rotational speed, 0.6 mm/sec weld speed and 9kN axial force compared to all other conditions.
- The SZ region shows a new equiaxed fine grain structure compared to the base metals.

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