An Experimental Study on the Effect of Weld Parameters on Mechanical and Micro structural Properties of Dissimilar Aluminium Alloy FS 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 square tool pin profile. The mechanical properties (hardness and tensile strength) of the Dissimilar Friction Stir welded (DFS welded) 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.

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, phase transformations that occur during the cooling of the weld are of a solid-state type. 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].

In the present study, the dissimilar Aluminum alloys AA 6262-T6 and AA 7075-T6 of 6mm thick plates were joined by FSW considering welding parameters as tool rotational speed (1000rpm, 1200 rpm and 1400rpm), weld speed (0.4 mm/sec, 0.6 mm/sec and 0.8 mm/sec) and axial force (8kN, 9kN and 10kN) with a square tool pin profile made of H13 tool steel.

EXPERIMENTAL WORK

Plates of 6mm thick of 6262-T6 and 7075-T6 Al alloys were friction stir butt welded using a tool made of H13 tool steel having 18mm shoulder diameter and the swept diameter of the square pin measuring 6mm. AA 6262 was kept on the advancing side (AS) of the tool and AA 7075 was kept on retreating side (RS).

Chemical compositions in weight percentage and mechanical properties at room temperature of base metals (BMs) AA 6262 and AA 7075 are presented in Table 1 and Table 2 respectively. Square butt joint configuration was prepared to fabricate the FSW joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was adopted to fabricate the joints. 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 comprising stirred zone (SZ), thermo mechanically affected zone (TMAZ), and base metal (BM) regions and were polished using different grades of emery papers. Final polishing was done using the diamond paste on the disc polishing machine. Specimens were etched 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 with hardness measurements at regular intervals of 2 mm from the centerline of the weld on both sides of the weld.

The tensile test specimens were prepared by Electro Discharge Machining and tested according to ASTM-E8 standards on 10tonne, 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 using three tensile specimens in each condition preparedfrom the same joint. All the specimens were mechanically polished before tests in order to eliminate the effect of possible surface irregularities [20, 21]. The specimen finally fails after necking and the load versus displacement was recorded. The Ultimate Tensile Strength (UTS), Yield Strength (YS), and percentage of Elongation (%E) were evaluated.

Table1Chemical 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 swept diameter (mm)	6
6	Pin Length (mm)	5.8

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 colored than the AA7075 one. It is clear that the microstructure of the SZ is mainly composed of the AA6262 fixed on the 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.

3.2 Hardness observations

Table 4 shows the micro hardness values in SZ, tensile test results of all the DFS welded specimens and also the position of tensile failure considering all the conditions. It is observed that out of all the

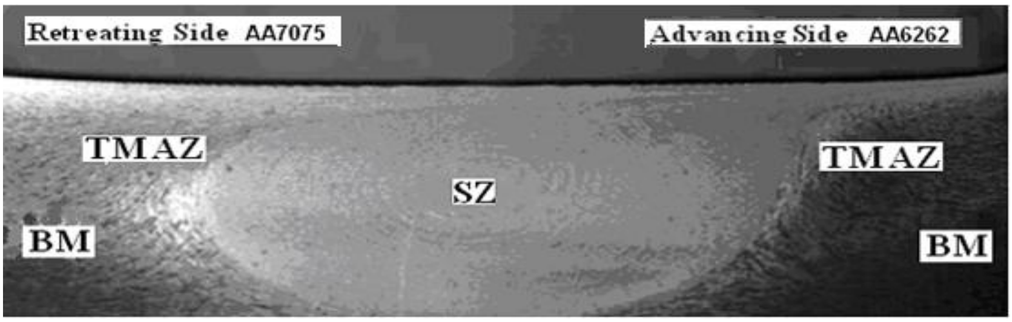

Fig.1 Typical macrograph showing various regions of the FS welded plates on AS, RS.

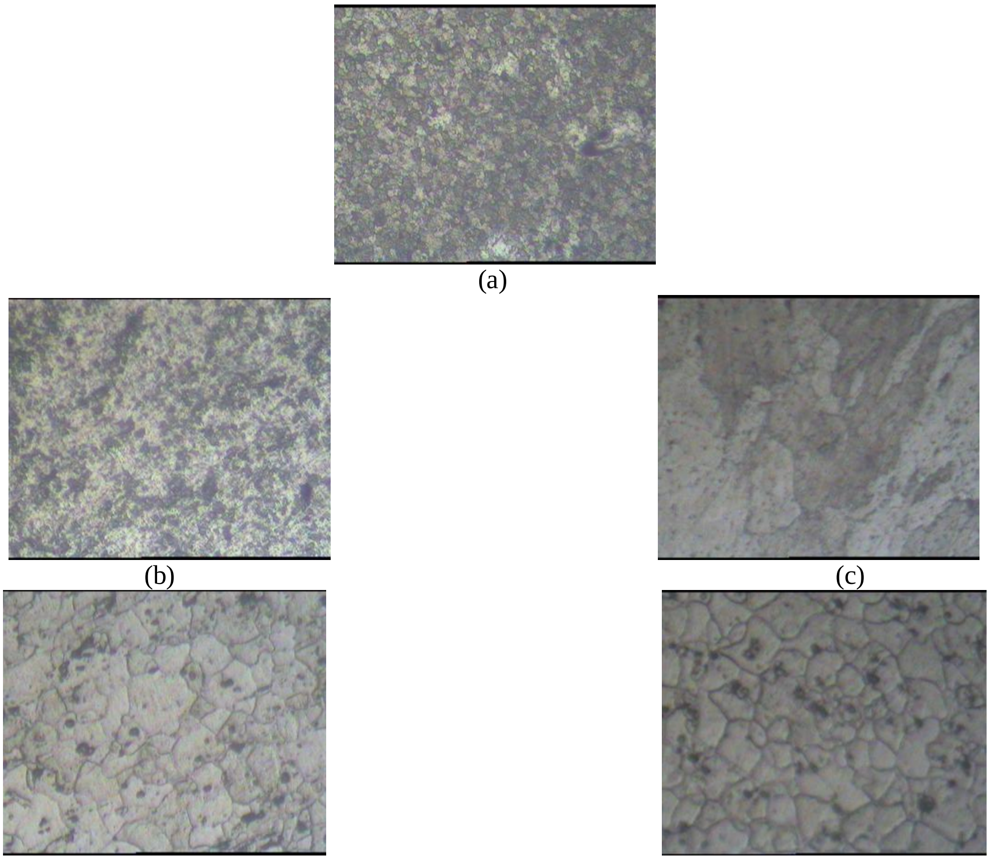

Fig. 2 Optical micrographs with main distinct regions of a dissimilar FS weld: (a) Stirred Zone (SZ) (b) TMAZ on AA6262 side (c) TMAZ on AA7075 side (d) Base metal AA6262 and (e) Base Metal AA7075.

DFS welded 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 DFS welded 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 DFS welded plate.

Table 4. Mechanical properties (Tensile and Hardness) 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	240.53	195.11	9.25	120.9	SZ
2	1400	0.4	9	248.43	207.87	12.06	128.16	HAZ of 6262
3	1400	0.4	10	247.04	201.25	10.14	125.16	HAZ of 6262
4	1400	0.6	8	243.87	203.85	9.37	123.83	SZ
5	1400	0.6	9	252.85	214.89	13.17	129.8	HAZ of 6262
6	1400	0.6	10	248.47	209.65	11.53	128.25	SZ
7	1400	0.8	8	239.05	194.53	7.84	118.86	SZ
8	1400	0.8	9	245.93	202.28	10.27	126.14	HAZ of 6262
9	1400	0.8	10	241.93	199.86	9.84	123.37	SZ

10	1200	0.4	8	244.39	198.69	9.61	122.92	HAZ of 6262
11	1200	0.4	9	251.89	212.09	12.47	132.1	HAZ of 6262
12	1200	0.4	10	249.47	206.32	10.52	128.73	HAZ of 6262
13	1200	0.6	8	249.79	207.58	9.53	126.58	HAZ of 6262
14	1200	0.6	9	256.73	218.22	13.38	134.4	HAZ of 6262
15	1200	0.6	10	252.31	213.69	11.82	131.8	HAZ of 6262
16	1200	0.8	8	240.51	199.97	8.02	119.98	SZ
17	1200	0.8	9	248.08	207.29	10.62	129.05	HAZ of 6262
18	1200	0.8	10	244.97	203.84	10.07	125.46	HAZ of 6262
19	1000	0.4	8	232.67	189.81	8.18	112.83	SZ
20	1000	0.4	9	239.78	195.66	11.53	119.61	SZ
21	1000	0.4	10	237.7	193.01	9.18	114.1	SZ
22	1000	0.6	8	237.43	197.93	8.11	115.26	SZ
23	1000	0.6	9	243.93	204.9	11.98	122.17	HAZ of 6262
24	1000	0.6	10	241.85	201.22	10.08	119.98	HAZ of 6262
25	1000	0.8	8	230.47	185.41	6.86	109.76	SZ
26	1000	0.8	9	237.63	196.52	9.14	116.85	SZ
27	1000	0.8	10	234.86	191.65	8.95	113.74	SZ

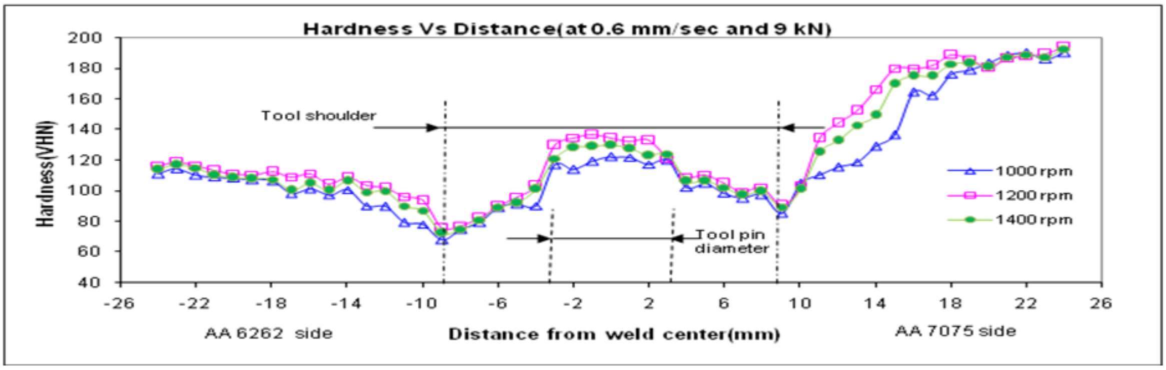

Fig.3 Hardness variation at 0.6mm/sec feed rate, 9kN axial force

3.3 Tensile Observations

Traverse tensile properties of DFS welded joints fabricated using square tool pin profile with all possible conditions were evaluated. Three specimens were tested for each condition and average of these 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 highest tensile strength, where as joints fabricated using1000 rpm tool rotational speed with 0.8 mm/sec weld speed and 8kN axial force showed lowest tensile strength.

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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