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Experimental Study on Mechanical and Micro Structural Characteristics of Dissimilar Friction Stir Welded Joints of Heat Treatable Aluminium Alloys

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Abstract:- **This paper presents an experimental study on mechanical and micro structural characteristics of dissimilar friction stir welded joints between AA6061-T651 and AA7075-T651 aluminium alloys which are widely used in marine , automotive , aircraft and aerospace industries. Compared to fusion welding processes, friction stir welding process is a solid state joining process is suitable for joining these two alloys. Dissimilar friction stir welded joints are fabricated by varying the weld parameters such as rotational speed, welding speed and three different tool pin profiles placing the 6061 alloy in the advancing side . The mechanical properties (micro hardness and tensile strength) of the dissimilar friction stir welded specimens were tested and compared with the base metals. All the joints fractured in the heat affected zone side of 6061 alloy side correspond to the minimum values in micro hardness profiles. The experimental observations have been explained in detail along with microstructures of parent metal and welded specimens through optical microscopy and scanning electron microscopy and it is observed that the weld parameters have a significant effect on mechanical and micro structural properties of the welds.**

Keywords: **Dissimilar joining, friction stir welding, tensile strength, microstructure, microhardness, pin profiles.**

I. INTRODUCTION

Friction stir welding (FSW) process is a solid state joining technique considered to be the significant development over the past two decades which was invented and validated at the welding institute (TWI), United Kingdom in the year 1991[1]. In this process no melting occurs and the heat is generated internally by means of friction between the material-tool interface and the plastic deformation takes place without pre or post heating. Materials with different aluminum alloys can be welded together with a least alteration in mechanical properties due to no melting [2-7]. P Bahemmat et al [8] investigated the mechanical, micro and macro structural characteristics of dissimilar friction stir welding of AA6061-T6 and AA7075-T6; and reported that because of the higher strength of the SZ compared with the HAZ and the TMAZ, the specimen was not fractured in the SZ and the fracture occurred in the TMAZ–HAZ interface on the AA6061 side, which has lower hardness and strength in the weld cross-section. It is observed that very few experimental works are carried out in dissimilar FSW of aluminium alloys [9-21]. In the very few studies performed on dissimilar FSW, researchers have not yet been drawn to study about dissimilar FSW of AA6061-T651 and AA7075-T651.The present research work reports the effects of process parameters (rotational speed, welding speed and types of tool pin profile) on tensile strength were analyzed on the basis mechanical and micro structural properties of dissimilar friction stir welds.

II. EXPERIMENTAL WORK

Aluminium alloys of AA6061-T651 and AA7075-T651 are selected for to fabricate dissimilar joints using the FSW process; where T651 heat treatment consists of solution heat treated, stretched and artificially aged. The FSW machine (Hydraulic power pack motor of 2.2kW /440V with 3000 rpm maximum rotational speed; 5000 mm/min as X axis rapid traverse speed and maximum axial thrust as 50kN) used for the dissimilar welding of the above alumimium alloy plates. The tools with different pin profiles, weld set up and a typical welded plate are shown in Fig. 1(a), (b) and (c). The thickness of the both aluminium alloy plates are 6.35 mm. Chemical compositions and the mechanical properties of AA6061-T651 and AA7075-T651 are given in Tables I and II respectively. The plates are placed in a butt configuration of 100 mm length; 50 mm width and the FSW process is carried out normal to the direction of the plates. Dissimilar friction stir welding process is carried out by placing the high strength aluminium alloy AA7075-T651 at the retreating side (RS), and by placing the aluminium alloy AA6061-T651 at the advancing side (AS); since if the weaker alloy is located at the RS, the fabricated weld will become weaker than when the weaker alloy is at the RS [8].

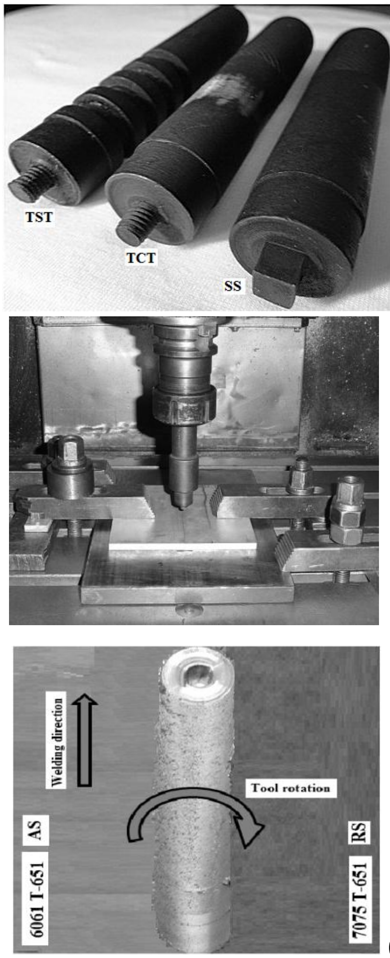


Fig.1 (a) Tool pin profiles, (b) FSW set up, (c) Typical welded plate by FSW process

TABLE I

Chemical composition of base aluminium alloys

Base alloys	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Pb	Sn
6061-T651	97.16	0.8	0.4	0.27	0.09	0.96	0.21	0.01	0.06	0.02	0.01	0.01
7075-T651	89.76	0.05	0.1	1.3	0.03	2.69	0.2	0.01	5.78	0.06	0.01	0.01

TABLE II

Mechanical properties of base aluminium alloys

Aluminium alloys	Yield strength, (MPa)	Ultimate tensile strength, (MPa)	Tensile elongation, (%)	Micro hardness (VHN)
6061-T651	287.0	303.0	17.2	102.0
7075-T651	526.0	583.0	11.3	171.0

Trail experiments are conducted to determine the working and feasible range of process parameters. The influenced process parameters and their working range for the dissimilar FSW of AA6061-T651 and AA7075-T651 are presented in Table III. After the welding, the transverse tensile specimens are prepared with reference to ASTM E8M-04 standard.The room temperature tensile test was carried out with reference to ASTM D 557 M- 94 at a crosshead speed of 1.5 mm/min using a computer-controlled testing machine (Associated Scientific Engg. Works, New Delhi) and their ultimate tensile strength are measured from the averages of the three specimens. Vickers microhardness distribution conducted under the load of 500g.f. for 10s at 1mm neighbouring distances.

TABLE III

Dissimilar friction stir welding parameters and the selected levels

S. No	Operating parameter	Symbol	Unit	Levels		
				Low (-1)	Middle (0)	High (1)
1	Tool rotational speed	*R*	rpm	800	900	1000
2	Welding speed	*W*	mm/min	90	100	110
3	Tool pin profile	*P*	-	SS	TCT	TST

RESULTS AND DISCUSSION

3.1 Macro and micro structural observations

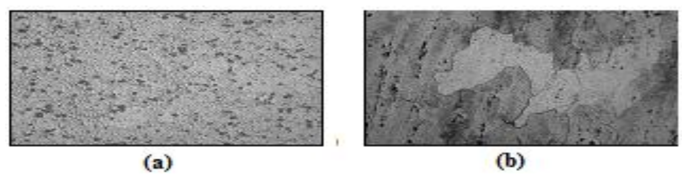


Fig. 2 Microstructure of (a) AA 6061-T651 & (b) AA 7075-T651 alloy at 100X

Fig.2 (a) shows the microstructure of AA 6061 where the particles of Mg_2Si that are evenly precipitated in aluminium solid solution. Some inter metallic's which are undissolved like Al_6 (Fe, Mn) also present in the matrix. The matrix is well solutionized and precipitation hardened. The particles of Mg_2 Al which are present can be resolved at higher magnification whereas Fig.2(b) shows the microstructure of AA7075 where the precipitation hardened matrix with the fine precipitation of Cu-Al_2 along with Mg Zn_2 and complex precipitates of $Cr_2Mg_3Al_{18}$ complete dissolution of Cu-Al_2 and reprecipitation leads to finer particles after solutionising and Age hardening. The high hardness measured shows the precipitation of the strengthening agents are complete.

Fig.3 Typical micrograph showing various regions of the FS welded plate

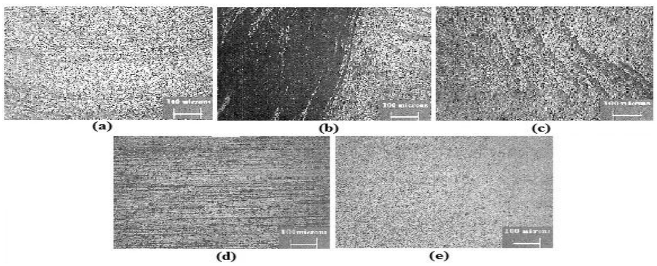


Fig.4 Optical micrographs with main distinct regions of dissimilar FS weld (a) SZ (b) TMAZ on AA7075 side (c) TMAZ on AA6061 side (d) BM AA7075 (e) BM AA6061

Fig.3 shows the micrograph of the produced weld after thoroughly etched with the keller's reagent marked as stirred zone (SZ), thermo mechanical affected zone (TMAZ) and base metal (BM). Fig.4 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 Al_2Zn precipitates and that on the right side indicates Mg_2Si precipitates. The SZ has equiaxed grains with both the precipitates. In all the specimens where the hardness distribution was measured, the AA7075 alloy was located at the RS and the AA6061alloy was in the AS; hardness was measured towards left (AA7075 side) and from center to right (AA6061 side). The Stirred zone has higher hardness compared with the HAZ and TMAZ because of the smaller grain size at this zone. The higher hardness is observed when the fracture location is at the body of the base metal or at the HAZ, which has lower hardness in comparison with the stirred zone. The fracture location of joints was in the HAZ of AA6061 side due to lower hardness value.

3.2 Micro hardness variation studies for the dissimilar joint

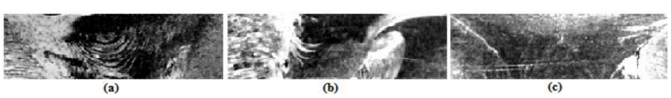


Fig.5 Macro image of transverse cross section at 20X (a) TCT tool with 900 rpm & 100 mm/min (b) TST tool with 900 rpm & 90 mm/min (c) SS tool with 900 rpm & 110 mm/min

The hardness at the center of the FSW zone was marked and hardness was measured towards left and from center to right. Fig.5(a-c) shows the typical macro images of the transverse cross section for three different process parameters with three different pin profiles Taper cylindrical threaded (TCT), Taper square threaded (TST) and Simple Square (SS). In all three specimens where the hardness distribution was measured, the AA7075 alloy was located at the RS and the AA6061alloy was in the AS; hardness was measured towards left (AA7075 side) and from center to right (AA6061 side). The Stirred zone has higher hardness compared with the HAZ and TMAZ because of the smaller grain size at this zone. The higher hardness is observed when the fracture location is at the body of the base metal or at the HAZ, which has lower hardness in comparison with the stirred zone. The fracture location of all the above three joints was in the HAZ of AA6061 side due to lower hardness value. The fracture mechanism of these two alloys is dimple fracture. From the Fig.6, it is found that dimple fracture mechanism was occurred with some degree of ductility in mixing these two alloys.

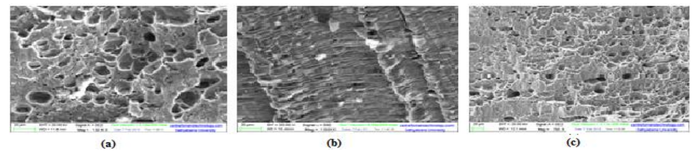
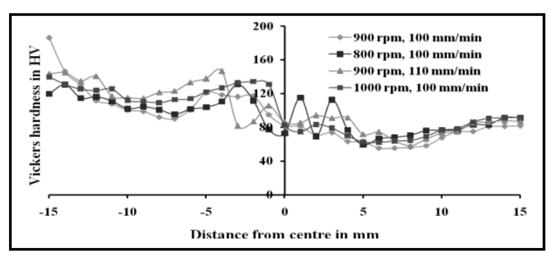
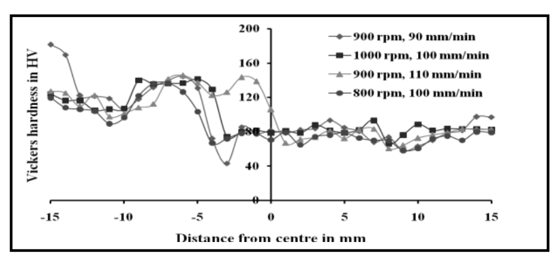


Fig.6 SEM photographs from the weld cross section at SZ (a) TCT tool with 900 rpm & 100 mm/min (b) TST tool with 900 rpm & 90 mm/min (c) SS tool with 900 rpm & 110 mm/min

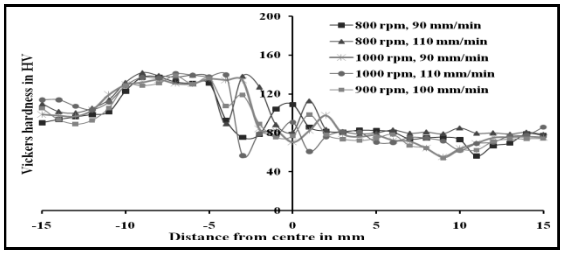
The micro hardness profiles for different process parameters with three different pin profiles Taper cylindrical threaded (TCT), Taper square threaded (TST) and Simple Square (SS) versus distance from the weld centre are depicted in Figs (7-9). For all the cases, the hardness decreases by increasing the distance from the weld centre. The micro hardness studies reveal that the change of micro hardness at the TMAZ-HAZ interface on the AA6061-T651 side is smoother than for AA7075-T651. Also it was observed the hardness distribution in the HAZ and TMAZ in the 6061-T651 side for all the welding speeds is same irrespective of rotational speeds; whereas this variation was much higher in the 7075-T651 side. This may be due to the thermal cycle in the HAZ of the weld which is more influenced due to over-aging of strengthening precipitations of AA7075-T651 than in AA6061-T651.The slope of the hardness variation variations curve, goes down by decreasing the distance from the weld centre. The micro hardness curve becomes smoother after a certain point and it is closer to the weld centre as the weld speed decreased and also the size of HAZ decreases when the welding speed increases.



(a)



(b)



(c)

3.3 Tensile strength observations

Table IV

Mechanical properties of dissimilar friction stir welded specimens

S.No	Rotational speed (rpm)	Welding speed (mm/min)	Pin profile	UTS (MPa)	Vicker's Hardness (VHN)	Failure position
1	800	90	SS	154.01	103.85	SZ
2	800	100	SS	170.03	110.11	HAZ of 6061
3	800	110	SS	170.01	111.32	HAZ of 6061
4	800	90	TCT	174.08	113.24	HAZ of 6061
5	800	100	TCT	186.03	112.98	HAZ of 6061
6	800	110	TCT	183.06	112.36	HAZ of 6061
7	800	90	TST	150.1	100.98	SZ
8	800	100	TST	160.1	105.48	SZ
9	800	110	TST	153.05	102.96	SZ
10	900	90	SS	170.05	111.78	HAZ of 6061
11	900	100	SS	182.07	112.23	HAZ of 6061
12	900	110	SS	179.12	109.47	HAZ of 6061
13	900	90	TCT	195.04	113.81	HAZ of 6061
14	900	100	TCT	205.08	114.22	HAZ of 6061
15	900	110	TCT	198.02	113.13	HAZ of 6061
16	900	90	TST	178.01	107.3	HAZ of 6061
17	900	100	TST	184.08	108.12	HAZ of 6061
18	900	110	TST	175.04	108.33	HAZ of 6061
19	1000	90	SS	151.09	101.23	SZ
20	1000	100	SS	160.06	106.21	SZ
21	1000	110	SS	152.07	102.12	SZ
22	1000	90	TCT	184.12	110.73	HAZ of 6061
23	1000	100	TCT	188.1	111.95	HAZ of 6061
24	1000	110	TCT	178.1	110.35	HAZ of 6061
25	1000	90	TST	172.06	104.23	HAZ of 6061
26	1000	100	TST	175.1	104.95	HAZ of 6061
27	1000	110	TST	161.08	102.65	SZ

Table IV shows the micro hardness values in SZ in addition to the tensile test results of all the dissimilar friction stir welded specimens including the tensile failure position. It is observed that of all the welded plates, the plate welded with 900rpm tool rotational speed, 100mm/min welding speed and TCT tool shows better micro hardness value at the SZ and higher tensile strength. It is observed that most of the specimens failed in the HAZ region of the AA6061 side and a few of them failed in SZ region. The joints fabricated with 900rpm tool rotational speed, 90mm/min welding speed and TST tool showed low tensile strength. Tensile strength increases with increase in rotational speed up to 900rpm, after that it decreases. The tensile strength first increases to a maximum value and afterwards show a decrease with increasing the rotational speed at a given welding speed or tool pin profile of the friction stir welded joints. Generally the tensile strength is poor at lower rotational speeds due to inadequate tool stirring action. With the increase of rotational speed for a certain range the strain hardening effect induced by tool stirring action increases tensile strength but the tensile strength lowers significantly with an increase of rotational speed to a rather high value due to excess heat input results in re-precipitation, reduction in dislocation density and coarsening of strengthening precipitates. The variation in tensile strength value at different rotational speed for a tool pin profile is due to the variation of material flow and frictional heat generated. For a given rotational speed or tool pin profiles, the increase of welding speed increases the tensile strength to a certain value, and further increase of welding speed results in the decrease in the tensile strength of the friction stir welded joints .All the three different tools yield lower tensile strength at the lowest welding speed of 90 mm/min.

IV. Conclusions

- The friction stir welding process used successfully to join dissimilar aluminium alloys (AA6061and AA7075).
- Better mechanical properties (hardness and tensile strength) were obtained with the FSW plate fabricated with 900 rpm tool rotational speed, 100mm/min welding speed with TCT tool compared to all other conditions.
- The Stirred zone has higher strength compared with the HAZ and TMAZ because of the smaller grain size at this zone. The higher hardness values are observed when the fracture location is at the body of the base metal or at the HAZ, which has lower hardness value in comparison with the stirred zone. The fracture location of the joints was in the HAZ of AA6061 side due to lower hardness value. The reason for the lower value can be attributed to the poor fusion of the two plates.

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