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Comparative investigation of friction stir welding and fusion welding of 6061 T6 – 5083 O aluminum alloy based on mechanical properties and microstructure

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Abstract. This paper compares, the mechanical properties of welded joints 6061 T6 and 5083 O aluminium alloys obtained using friction stir welding (FSW) at four rotation speeds namely 450,560,710 and 900 rpm and that by conventional fusion welding. FSW welds were carried out on a milling machine. The performance of FSW and Fusion welded joints were identified using tensile test, hardness test and microstructure. The properties of FSW and fusion welded processes were also compared with each other to understand the advantages and disadvantages of these processes for welding applications for Al alloys. It was seen that the tensile strength obtained with FSW was higher as compared to conventional fusion welding process. The width of the heat affected zone of FSW was narrower than Fusion welded joints. The results showed that FSW improved the mechanical properties of welded joints.

Key words: TIG, MIG, FSW.

1. Introduction

The present paper had compared the influence of fusion welding techniques namely TIG and MIG with a solid-state friction stir welding technique (FSW) on both the microstructure and mechanical properties of an Al-Mg-Sc alloy. In the TIG welding process, an electric arc forms between the consumable tungsten electrode and the work piece. This arc provides the required energy to melt the work pieces as well as the filler if necessary. For Al alloys it has been observed that due to their elevated thermal conductivity, the weld penetration remained very shallow amounting to less than 3mm for one pass. The elevated temperatures attained in fusion welding processes induce an important microstructural evolution especially concerning hardening precipitates. Friction stir welding (FSW) is a solid-state joining technology patented by The Welding Institute (TWI), U.K in 1991 [1].This process involves the advance of a rotating hard steel pin extended by a cylindrical shoulder between two contacting metal plates. Frictional heating is produced from the rubbing of the rotating shoulder with the two workpieces, while the rotating pin deforms the heated material. Compared to fusion welding processes, there is little or no porosity or other defects related to fusion. In fact, the industrial interest of this study is to evaluate the possible benefits of FSW compared to TIG, MIG keeping in mind the lower heat input of the solid-state joining process as well as the high stability of hardening particles [2]. Lightweight aluminium alloys are used widely in applications such as aerospace and transportation (ship panels, the frames of high speed railway and automobile parts) [3]. Simple artificial aging treatment was found to be more beneficial than other treatment methods to enhance the tensile properties of the friction stir-welded joints [4]. The joints obtained with FSW reduce up to 30% the involved costs compared to mechanical fastening together with a weight reduction of 10%. On the other hand, traditional welding processes present a series of disadvantages when applied to Al alloys [5].

2. Experimental details

2.1. Base metal. The base metal are AA6061 T6 and 5083 O which are heat treatable and non heat treatable aluminum alloy respectively and the compositions are given in Table 1.

Table 1
Base metal composition

Element	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Al
AA 583-O	0.05	0.10	0.4	4.9	0.4	0.4	0.15	0.25	bal
AA 6061-T6	0.04	0.15	0.35	0.8	0.15	0.4	0.15	0.25	bal.

2.2. Filler materials. The AA 4043 series alloys have Si added to reduce the melting point and to increase the fluidity in molten state.The composition of the filler metal is as per Table 2.

Table 2
Chemical composition of filler metals (Wt%)

Filler Metal	Si	Mg	Cu	Fe	Mn	Zn	Ti	Cr	Al
AA 4043	5.0	0.05	0.30	0.80	0.05	0.10	0.2	0-	Bal.

2.3. Experimental procedure. Plates of AA6061-T6 and AA5083-O aluminum alloy were machined to the required

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dimensions (150×75×6 mm). A butt joint configuration was prepared to fabricate GTA and GMA welded joints. Single pass welding was used to fabricate the joints with AA4043 (Al-5%Si) grade as the filler rod and wire for GTA and GMA welding processes, respectively. The shielding gas used was argon with a high purity of 99.99%. A butt joint configuration was prepared to fabricate the FSW joints. A non-consumable, rotating tool made of high speed steel was used to fabricate the FSW joints. It has been observed that FSW is affected by various process parameters such as rotational speed, welding speed and axial force but as compared to fusion welding processes; there are neither porosity defects nor any other defects as seen in the fusion process. However, the hardening precipitates responsible for the good mechanical properties of heat treatable aluminium alloy are shown to be affected by the FSW process, partly due to their low stability. The process parameters must be optimized to get defect free joints. The optimum friction stir welding process parameters for joining AA6061-T6 and 5083-O aluminium alloys are the speed of 600 rpm, 18 mm/min and 6.5 kN. Trial experiments and microstructural analysis were carried out for each mentioned process to find out the optimum process parameters. The welding conditions and optimized process parameters presented in Table 3 were used to fabricate the joints.

Table 3
Welding process parameters

PROCESS	GMAW	GTAW	FSW
Welding machine	Lincoln USA	Lincoln USA	RV Machine Tools, India
Tungsten electrode diameter (mm)	1.6	3	–
Filler rod/wire diameter (mm)	1.6	3	–
Voltage (volts)	22.07	17.35	–
Current (amps)	186	170	–
Welding speed (mm/min)	188	64	10
Shielding gas	Argon	Argon	–
Gas flow rate (lit./min)	9	9	–
Tool rotational speed (rpm)	–	–	600
Axial force (kN)	–	–	6.5
Tool pin profile	–	–	Cylindrical threaded
Tool shoulder diameter (mm)	–	–	18
Pin diameter (min)	–	–	6
Pin length (mm)	–	–	5.8

2.4. Weld aged treatment. In order to improve the mechanical properties and to reduce the residual stress in the fabricated welded joins, post weld heat treatment was performed [5]. The post-weld aging treatment was carried out at 170 °C for a soaking time of 7 h.

3. Properties evaluation

3.1. Tensile properties. The tensile tests were carried out in a 100 kN capacity electromechanical Universal Testing Machine with a displacement of 0.5 mm/min. The weld metal specimens were tested in a 100 kN electromechanical testing machine at the same displacement rate. The load versus displacement plot was recorded in X-Y axis and 0.2 percent offset yield strength was calculated from the load stress diagram. The percentage elongation of the joint and the weld metal specimen were also estimated. In Figs. 1 and 2 the tensile test specimens are showed

Fig. 1. Tensile tested specimens

Fig. 2. V notch tensile tested specimens

3.2. Micro hardness survey. Micro hardness test was performed with a light load of 1 gram, although the majority of micro-hardness tests are performed with loads ranging 100 gram to 500 gram. The degree of accuracy can be estimated by the surface smoothness of the specimen tested. As the test load decreases, surface finish requirements become more rigid. At a load of 100 grams or less a metallographic, finish is recommended. For this investigation a smooth load of 500 gram was applied using a diamond-shaped indenter in the form of a square base pyramid having an angle of 136 degrees, without impact and was held in place for 15 seconds. Micro-hardness was measured from the weld center to the base metal on both sides. Microstructure examinations were carried out using optical microscope to quantify various the micro constituents present in the weld metal. Final polishing was done using a diamond compound having a 1 μm particle size in a disc-polishing machine. Samples were etched using Keller's reagent. Microstructure analysis was carried out using VERSAMET-3 light optical microscope with Clemex-vision image analyzing system and the resulting optical micrographs of the weld zone were recorded.

4. Results and discussions

4.1. Tensile properties. The tensile properties such as Ultimate Tensile Strength (UTS), yield strength (YS) and (%) elongation, Notch Strength Ratio (NSR) and Joint Efficiency are presented in the Table 4, 5, 6 and 7. The Tables shows the comparision details about BM, CC-TIG, CC-MIG, PC-TIG, PC-MIG, FSW (Tensile Test).

Table 4

As Weld for smooth specimen

Joints	Peak load (kN)	Tensile strength (MPa)	Yield strength (MPa)
CC-TIG	6.90	116	–
CC-MIG	11.50	192	158
PC-TIG	10.00	166	164
PC-MIG	11.07	189	176
FSW	12.05	200	184
BM	22.56	280	234

Table 5

Post Weld Aging for smooth specimen

Joints	Peak load (kN)	Tensile strength (MPa)
CC-TIG	4.4	82.5
CC-MIG	10.00	176
PC-TIG	9.02	137
PC-MIG	8.84	163
FSW	13.64	207

Table 6

As Weld for notch specimen

Joints	Peak load (kN)	Tensile strength (MPa)	Yield strength (MPa)
CC-TIG	7.7	135	112
CC-MIG	15	215	186
PC-TIG	11.56	160	131
PC-MIG	16.8	201	180
FSW	18.4	225	195

Table 7

Post Weld for notch specimen

Joints	Peak load (kN)	Tensile strength (MPa)
CC-TIG	10.47	159
CC-MIG	12.72	193
PC-TIG	10.15	153
PC-MIG	7.866	180
FSW	14.35	218

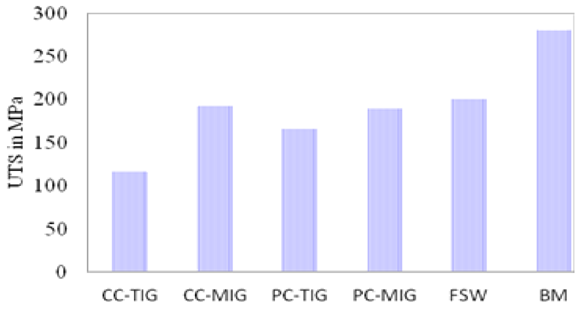

Fig. 3. UTS for As Welded

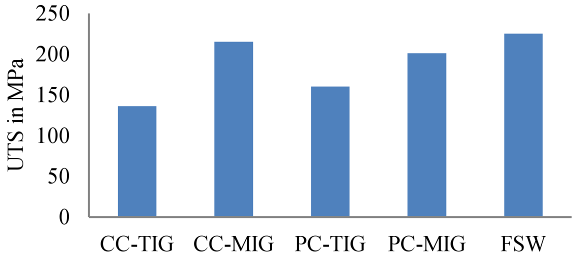

Fig. 4. UTS for PWA

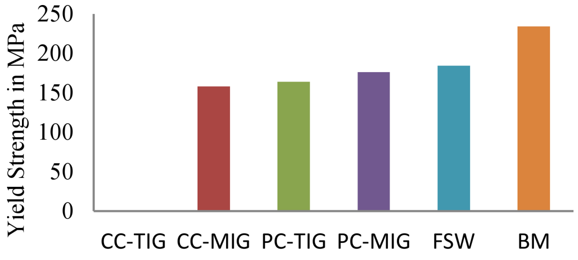

Fig. 5. Yield strength for smooth tensile specimen As Welded

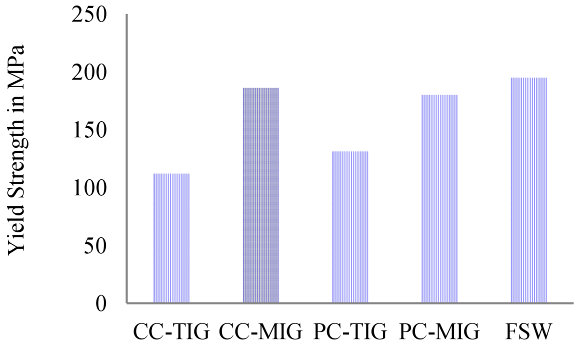

Fig. 6. Yield Strength for Smooth Tensile specimen PWA

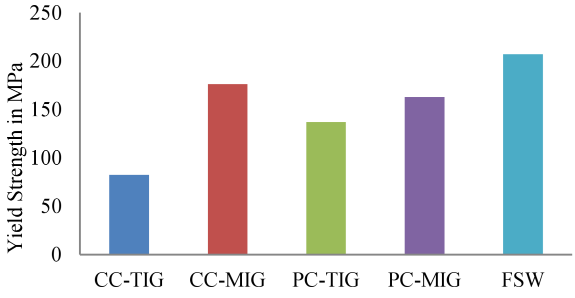

Fig. 7. Notch Tensile Strength for As Welded

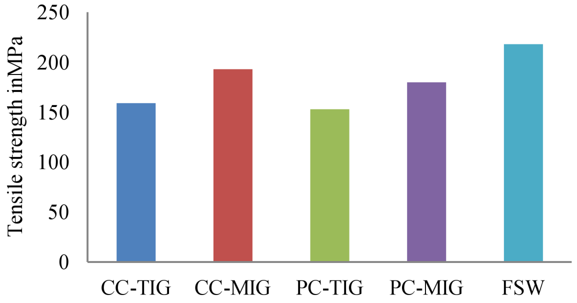

Fig. 8. Notch Tensile Strength for PWA

4.2. Hardness properties. Using Vickers micro hardness test, the hardness variation across the weld metal, to base metal region were surveyed and the average value are shown below in Figs. 9 and 10.

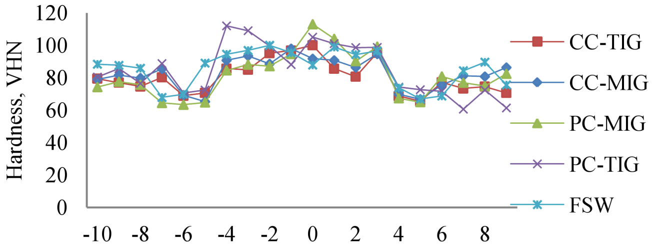

Fig. 9. Hardness Variation for As Welded

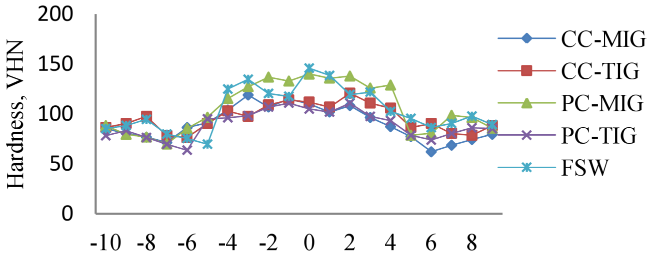

Fig. 10. Hardness Variation for PWA

5. Results and discussions

5.1. Tensile properties. The tensile tests showed that the FSW joints exhibited superior tensile properties performance as compared to MIG and TIG welded joints [6]. The reasons for the better tensile performance of the FSW joints can be attributed to the superior mechanical properties in the weld region. When the combination of operating parameters increase the plastic flow of material and frictional heat generated, then there is a corresponding decrease in the tensile elongation of the joints is observed [7]. Due to the heat input the welding zone and HAZ were affected by the tensile properties. In MIG welding process the fracture occurred in the HAZ. The tensile properties would not affect the welding zone, due to the high welding strength. While TIG welding has shown very poor tensile properties due to less welding strength.Post weld aging treatment showed appreciable improvements in the tensile properties for smooth and notch specimens. Pulsed current multipass TIG welding of 5083-O & 6061-T6 alloy section improved the tensile properties of the weld as compared to the welds produced by constant current TIG welding.

5.2. Microstructure. The optical micrographs of the fusion zone/nugget region of all the joints are displayed in Fig. 10. From the micro graphs, it can be seen that the grain structure was columnar for CCTIG welds and fineaxed for PCTIG welds. The structure becomes increasingly coarser and columnar for CCMIG welds.This deformation leads to the formation of very fine equiaxed recrystalized grains in the friction stir processed zone.Various dislocations with network structure were observed in the recrystalized grains. A high density of dislocations with network structure were observed in many grains. FSW process imparts a large degree of plastic deformation to the work piece by the mechanical stirring action of a rotating tool. This deformation leads to the formation of very fine equiaxed recrystalized grains with in the friction stir processed zone while various dislocations with network structure were observed in the recrystalized grains. Due to a high density of dislocations with a network structure observed in many grains. The tensile properties of FSW joints are superior as compared to MIG and TIG welded joints due to thermo mechanical processing taking place during the friction stir welding [8]. Horizontal profiles of vickers hardness in the weld are indicated in Figs. 9 and 10. In Friction Stir Weldments, there is considerable softnening through out the weld zone, as compared to the base material [9, 10]. The mi-

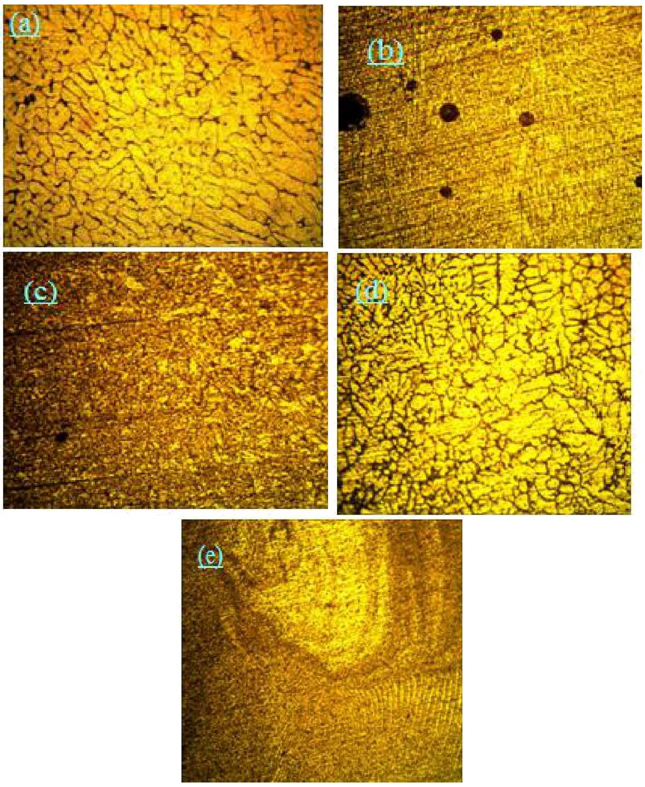

Fig. 11. Optical Micrograph images of Weld Zone (a) CC –MIG (b) CC-TIG (c) PC-MIG (d) PC-TIG (e) FSW

nimum hardness is located around 8 mm from the weld center towards 5083-O side.Hardness is relatively high in the weld regions of all the joints compared to heat affected zone (HAZ) and base metal (BM). The hardness value was found to be low in the weld region of CCMIG when compared to other welding processes. The post weld aging treatment enhanced the hardness of weld region in the joints [11].

6. Conclusions

The mechanical and metallurgical properties of TIG, MIG and Friction Stri Welded joints dissimilar AA 5083-O and 6061-T6 were evaluated in detail, a comparison was made and the following conclusions were derived from the investigation.The tensile properties of welded joints AA 5083-O and 6061-T6 aluminium alloy joints were influenced by welding process and post weld aging treatment with a reasonable increase in tensile properties been noted for post weld aged joints as compared to welded joints. Even though, the PWHT procedure was time consuming and costly, it was advantageous for the welds due to improvements in tensile properties. Grain refinement with a fine distribution of precipitates showed much better strength and ductility in FSW joints.FSW joints show comparatively excellent mechanical properties when compared to TIG and MIG joints.Micro Hardness was found to be relatively lower in the Heat affected zone and higher in the weld region. The micro hardness values were found to be high in the weld region of FSW joints as compared to MIG and TIG welded joints.Moreover, the joints fabricated by FSW process exhibited superior mechanical and metallurgical properties compared to other conventional welding processes.

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