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

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Materials

ABSTRACT

Purpose: In this paper, the mechanical properties of welded joints of 6061 T6 and 5083 O aluminium alloy obtained using friction stir welding (FSW) with four rotation speed (450, 560, 710 and 900 rpm) and conventional fusion welding are studied.
Design/methodology/approach: FSW welds were carried out on a milling machine. The performance of FSW and Fusion welded joints were identified using tensile, hardness and microstructure.
Findings: Better tensile strength was obtained with FSW welded joints. The width of the heat affected zone of FSW was narrower than Fusion welded joints welded joints
Research limitations/implications: Properties FSW and Fusion Welded processes were also compared with each other to understand the advantages and disadvantages of the processes for welding applications of the Al alloy.
Originality/value: The results show that FSW improves the mechanical properties of welded joints.
Keywords: TIG; MIG; FSW

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1. Introduction

The present paper compares the influence of a fusion welding techniques (TIG and MIG) and a solid-state welding technique (FSW) on both microstructure and mechanical properties of an Al-Mg-Si alloy. In TIG welding, an electric arc is formed between consumable tungsten electrode and the workpiece. The arc provides the thermal energy to melt the work pieces as well as the filler if necessary. For Al alloys, due to their elevated thermal conductivity, the weld penetration remains very shallow: less than 3mm in 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) in 1991. 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 considering the lower heat input of the solid-state joining process and the high stability of hardening particles.

2. Experimental work

2.1. Base metal

Table 1.
Chemical composition of base metal

Element	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Al
AA 5083-O	0.05	0.10	0.40	4.90	0.40	0.40	0.15	0.25	Bal
AA6061-T6	0.04	0.15	0.35	0.8	0.15	0.4	0.15	0.25	Bal.

2.2. Filler materials

The 4xxx series alloys have Si added to reduce the melting point and to increase the fluidity in molten state.

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	-	Bal.

2.3. Experimental procedure

The plates of AA6061-T6 and AA5083-O aluminum alloy were machined to the required dimensions (150mm×75×6mm). Butt joint configuration was prepared to fabricate GTA and GMA welded joints. Single pass welding was used to fabricate the joints. AA4043 (Al-5%Si) grade filler rod and wire were used for GTA and GMA welding processes, respectively. High purity (99.99%) argon gas was the shielding gas. Butt joint configuration as shown in Fig. 1 was prepared to fabricate FSW joints. A non-consumable, rotating tool made of high speed steel was used to fabricate FSW joints. FSW is affected by process parameters such as rotational speed, welding speed and axial force. Compared to fusion welding processes, there is no porosity or other defects related to fusion. However, the hardening precipitates responsible for the good mechanical properties of heat treatable aluminum alloy are shown to be affected by this process, partly because of their low stability. The process parameters must be optimized to get defect free joints. The optimum friction stir welding process parameter for joining AA6061-T6 and 5083-O aluminum alloy are 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.

Table3.
Welding conditions and 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 reducing the residual stress in the fabricated welded joins, post weld heat treatment was performed. 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 are carried out in the 100 kN capacity electromechanical Universal Testing Machine at a displacement rate of 0.5 mm/min. The weld metal specimens are tested in the 100 kN electromechanical testing machine in the same displacement rate. Load versus displacement was recorded in X-Y axis. The 0.2 percent offset yield strength was calculated from the load stress diagram. The percentage elongation of the joint and the weld metal specimen are also estimated. Figs. 1 and 2 shows the before testing and after testing specimens respectively.

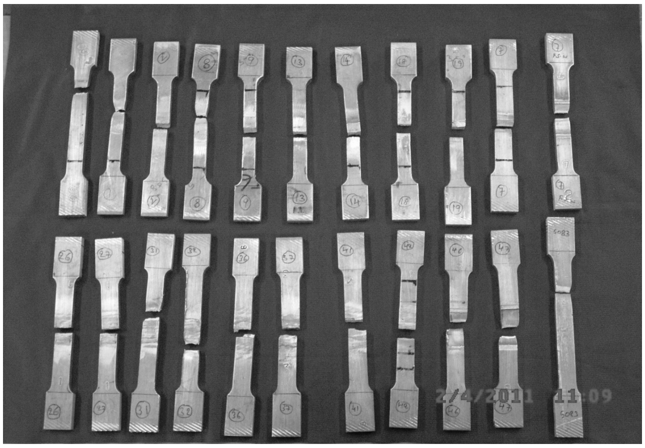

Fig. 1. Testing specimens

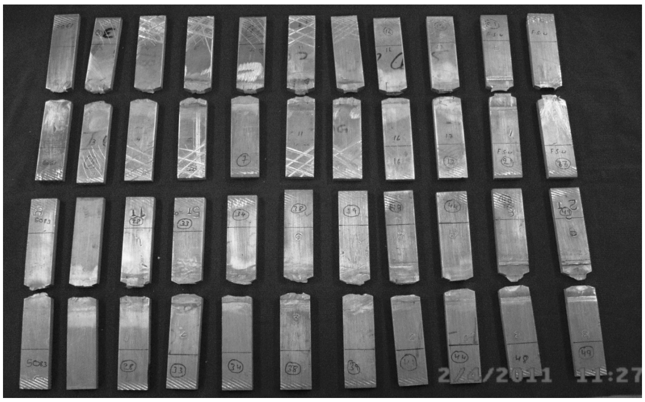

Fig. 2. After testing specimens

3.2. Micro hardness survey

Such hardness test has been made with a load as light as 1 gram, although the majority of micro-hardness tests are made with loads of 100 gram to 500 gram.. The degree of accuracy that can be attained by the surface smoothness of the specimen tested. If test load decreases, surface finish requirements become more stringent. When the load is 100 grams or less a metallographic, finish is recommended. But for this investigation applied load is 500 gram. The load is applied smoothly without impact and held in place for 15 sec. The indenter is made of diamond and is in form of a square base pyramid having an angle of 136^0 between faces. Micro-hardness is measured from the weld center to base metal on both sides. Microstructure examinations have been carried out using optical microscope to quantify various micro constituents present in the weld metals. Final polishing is done using the diamond compound (1μm particle size) in the disc-polishing machine. Samples are etched with keller's reagent. Microstructure analysis has been carried using VERSAMET-3 light optical microscope with clemax-vision image analyzing system and the optical micrographs of weld zone are recorded. Fig 11 shows the microscope with clemax image vision system.

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 Tables 3 and 4.

The Tables 5, 6 shows the comparision details about BM, CC-TIG, CC-MIG, PC-TIG, PC-MIG, FSW (Tensile Test) (Figs. 3-8).

Table 3.
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 4.
Post Weld Aging for smooth 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 5.
As Weld for notch 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.
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

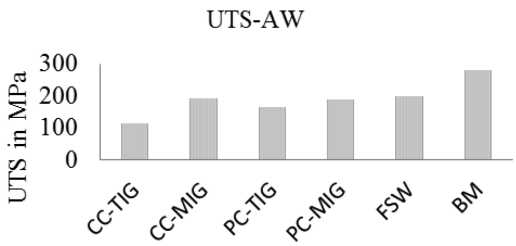

Fig. 3. UTS for as welded

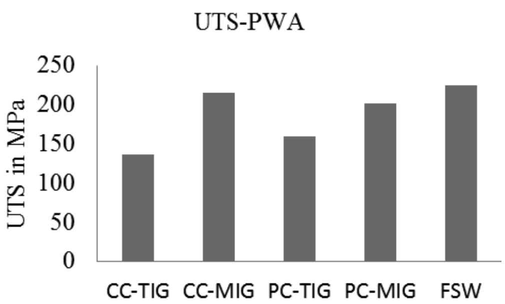

Fig. 4. UTS for PWA

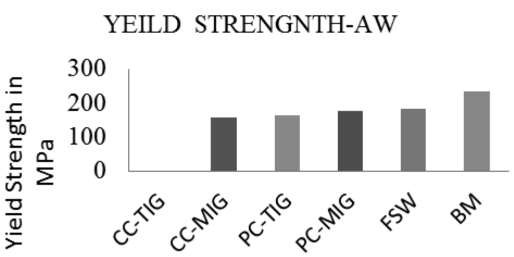

Fig. 5. Yield strength for smooth tensile specimen as welded

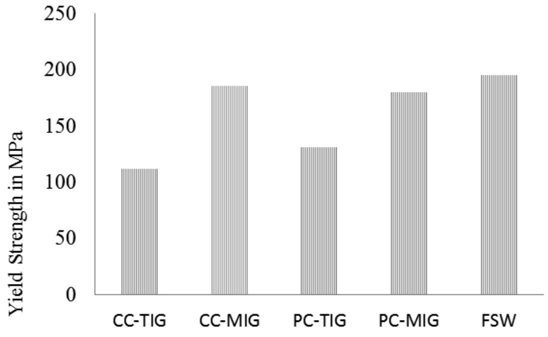

Fig. 6. Yield strength for smooth tensile specimen PWA

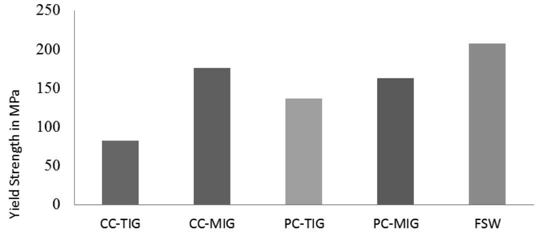

Fig. 7. Notch tensile strength for as welded

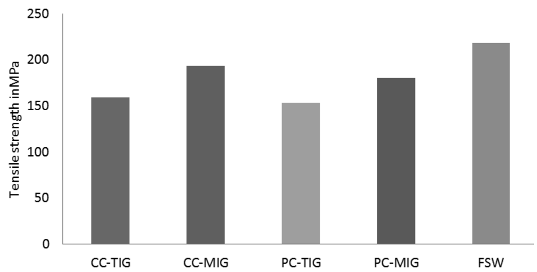

Fig. 8. Notch tensile strength for PWA

4.2. Hardness Properties

Using vickers micro hardness, the hardness variation across the weld metal, to base metal region are surveyed and the average value are shown in Figs. 9, 10.

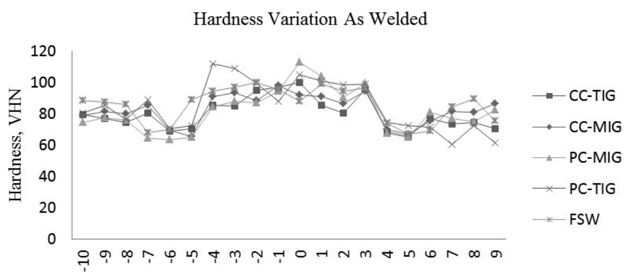

Fig. 9. Hardness variation for as welded

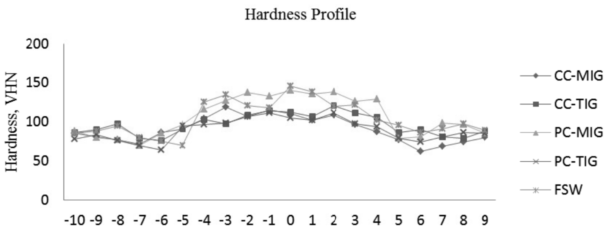

Fig. 10. Hardness variation for PWA

5. Discussions

5.1. Tensile Properties

From the tensile tests results (Figs 3-10) it is understood that the FSW joints are exhibiting superior tensile properties performance compared to MIG and TIG welded joints. The reasons for the better tensile performance of the FSW joints are the superior mechanical properties of the weld region.Ideal microstructure in the weld region.FSW process the welding zone would affected by the tensile fracture. Due to the heat input the welding zone and HAZ is 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. TIG welding has shown very poor tensile properties due to less welding strength.Post weld aging treatment has shown better improvement in the tensile properties for smooth and notch specimens. Pulsed current multipass TIG welding of 5083-O and 6061-T6 alloy section improved the tensile properties of the weld 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. 11. From the micro graphs, it can be observed that the grain structure was columnar for CCTIG welds and fineaxed for PCTIG welds. The structure increasingly coarser and columnar for CCMIG welds.This deformation leads to the formation of very fine equiaxed recrystalized grains with in the friction stir processed zone.Various dislocations with network structure observed in the recrystalized grains.A high density of dislocations with network structure 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. Previous reasearchers have reported that This deformation leads to the formation of very fine equiaxed recrystalized grtains with in the friction stir processed zone.various dislocations with network structure observed in the recrystalized grains.A high density of dislocations with network structure observed in many grains.Hence, the tensile properties of FSW joints is superior as compared to MIG and TIG welded joints due to thermo mechanical processing taking place during friction stir welding. Horizontal profiles of vickers hardness in the weld are indicated in the Fig 11. In Friction Stir Weldments, there is considarable softening through out the weld zone, compared to the base material. The minimum 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 is low in the weld region of CCMIG when compared to other welding process. The post weld aging treatment has enhanced the hardness of weld region of all the joints.

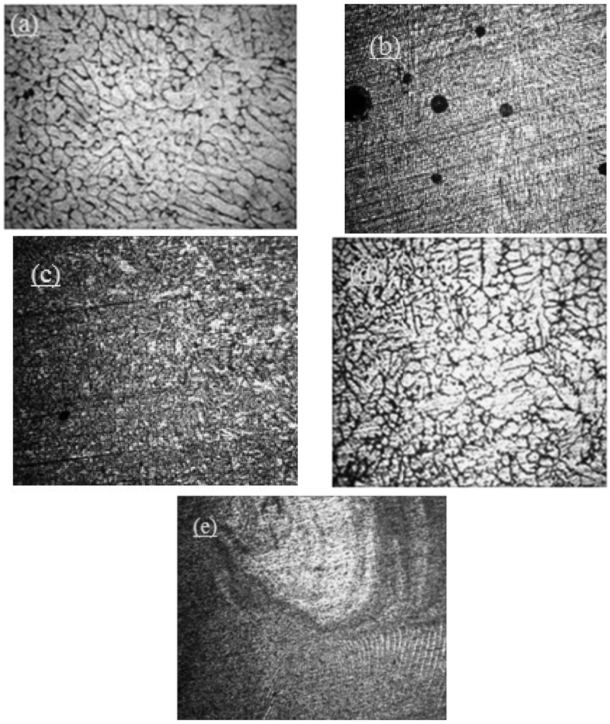

Fig. 11. Optical micrograph images of weld zone (a)CC -MIG (b) CC-TIG (C) PC-MIG (d) PC-TIG (E)FSW

6. Conclusions

The mechanical and metallurgical properties of TIG, MIG and Friction Strir Welded joints dissimilar AA 5083-O and 6061-T6 are evaluated in detail and compared and following conclusions derived from the investigation.The tensile properties of welded joints AA 5083-O and 6061-T6 aluminium alloy joints are influenced by welding process and post weld aging treatment.A reasonable increase in tensile properties has been attained for the post weld aged joints as compared to as welded joints. Even though, the PWHT procedure is time consuming and costlier, it is advantageous to apply for the welds due to above improvements in tensile properties. Grain refinement with fine distribution of precipitates shows better strength and ductility in FSW joints. FSW joints show comparatively excellent mechanical properties when compared to TIG and MIG joints. Micro Hardness is relativley lower in the Heat affected zone and higher in the weld region. The micro hardness values are high in the weld region of

FSW joints 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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