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Experimental study of MIG welding and solid state welding for age hardenable AA 7075 aluminium alloy

U.K.Ghodwade [1], S.S.Patil [2] , Dr. C.L.Gogte[3]

[1]Assistant Professor, M.B.E.Society's College of Engineering, Ambajogai, 431517(M.S.), India,

[2] Associate professor, Center of Excellence, Metallurgy and Material Engineering Department, Marathwada institute of Technology, Aurangabad, 431028(M.S.), India

[3]Professor, Center of Excellence, Metallurgy and Material Engineering Department, Marathwada institute of Technology, Aurangabad, 431028(M.S.), India

ABSTRACT

High strength age hardenable 7xxx series aluminium alloy such as AA 7075 is commonly found in several key components of aircraft and automobiles. These alloys are difficult to join by conventional fusion welding techniques. Realizing a weld joint in such alloys without impairing the mechanical properties is difficult task. The 7xxx alloys among the Al-Zn-Mg-Cu versions provide the highest strengths of all aluminium alloys. AA 7075-T6 aluminium alloys with thickness of 3mm were butt welded using friction stir welding and metal inert gas welding (MIG). The joints were compared in terms of electrical conductivity (% IACS), a physical property of aluminium alloy used to define relationship of changes in alloy composition and metallurgy. The same joints were also assessed for hardness and micro structural properties. The results show that the solid state FSW joints have higher electrical conductivity and hardness than MIG joints. The width of heat affected zone of FSW joints is narrower than the MIG fusion welds indicating better mechanical properties. An attempt has been made to correlate the electrical conductivity and the hardness in different weld regions, and found that electrical conductivity and hardness are non linear to each other in FSW joint, but they cannot be co-related to each other in MIG welded joint.

Keywords: AA 7075, Friction stir welding, MIG welding, Electrical conductivity.

1. INTRODUCTION

One of the strongest aluminium alloys in the aerospace industry is Aluminium alloy AA 7075 due to its strength to weight ratio. [1] 7XXX series alloys are heat treatable with ultimate tensile strength of 572 MPa, although they are difficult to weld by conventional fusion welding processes.
AA 7075 has been extensively used in the following industries, aluminium alloy aircraft and aviation space shuttle, rocket propulsion for missiles, automobile industries (alloy wheel), marine engine components, and external throwaway tanks for military aircrafts.
The initial strength of AA 7075 is enhanced by the addition of alloying elements such as copper, magnesium, zinc and silicon. Since these elements singly or in various combinations show increasing solid solubility in aluminium with increasing temperature.

Table No 1: Chemical composition of AA 7075

Chemical Composition (wt %)	Cu	Si	Fe	Mn	Mg	Zn	Cr	Ti	Al
Observed Values	1.56	0.06	0.19	0.04	2.53	5.83	0.20	0.038	Bal.
Specified Range	1.2 – 2.0	0.5 Max	0.7 Max	0.3 Max	2.10 – 2.90	5.1– 6.1	0.20 – 0.28	0.20 Max	--

The selected experimental sample confirms to AA 7075 aluminium alloy grade for the above chemical parameters tested.

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Table No 2: Typical properties of AA 7075[2]

Properties	Physical	Mechanical		Thermal		Processing temperature		
Characteristic	Density	Hardness	Ultimate tensile strength	Melting point	Specific heat capacity	Annealing	Solution	Ageing
Metric	2.81g/cc	87 HRB	572 MPa	477-635^{0}C	0.96 J/g-^{0}C	413^{0}C	466-482^{0}C	121^{0}C
English	0.102lb/in^3	87 HRB	83000 psi	890-1175^{0}F	0.229 BTU/lb-^{0}F	775^{0}F	870-900^{0}F	250^{0}F

1.1 Friction stir welding:- FSW, patented by the welding institute (TWI) of UK in 1991[3], is an important manufacturing process for producing solid state welded structures, because no material is being melted. Hence, the innovative FSW is advantageous as compared to other traditional fusion welding processes as, there are no voids and cracking in the weld, no need of filler materials, no shielding gas required, clean and environment friendly process because there are no harmful effects like arc formation, radiation and release of toxic gas etc[1].

In FSW process, the plates are clamped on the bed and vertical force is applied by fixing the tool in the collet of conventional vertical milling machine. A high speed steel (non–consumable) tool is used which comprises a pin and a shoulder. The pin advances between the two contacting metal plates. Frictional heating is produced from the rubbing of the rotating shoulder with the two work pieces, while the rotating pin deforms the heated material at temperatures below the melting point.

1.2 Metal inert gas welding:- MIG welding was first used in the USA in the mid 1940's, is an arc welding process that uses a continuously fed wire both as electrode and as filler metal, the arc and the weld pool being protected by an inert gas shield.[4]

MIG is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metals, which heats the work piece metals, causing them to melt and join. Along with the wire electrode, a shielding gas is used through the welding gun, which shields the process from the contaminants in the air. A constant voltage, direct current power source is most commonly used with the MIG process.

Ericsson and Sandstrom (2003) investigated the influence of welding speed on the fatigue behavior of FSW, MIG and TIG process for AA 6082[5], Squillace et. Al. (2004), investigated the microstructure and pitting corrosion resistance in TIG and FSW joints for 2024-T3 alloy[6], Taban and Kaluc (2007) studied the Microstructural and mechanical properties in TIG, MIG and FSW joints for 5083-H321 Aluminium alloy[7], Moreira et.al. (2007) investigated the fatigue behavior of joints of FSW and MIG welding for AA 6061 T6 and AA 6082 T6 [8], Munoz et.al. (2008) investigated the Microstructural and mechanical properties FSW and TIG for 5XXX series aluminium alloy [9].

Though the research work of comparative study of FSW and other welding techniques have been reported, it seems that the detailed and systematic comparison between the FSW and MIG welded joints for AA 7075 has not been reported yet.

"Hence the aim of this study is to compare the electrical conductivity, mechanical and Microstructural properties of FSW and MIG welded joints for AA 7075 T6".

2. EXPERIMENTATION

The rolled plates of AA 7075 of size 150mmX60mmX3mm are supplied in the T6 condition and their composition is given in table 1, and physical properties in table 2. The two plates were fusion welded using MIG technique and solid state welded using FSW.

Butt joints for MIG welding were prepared by Argon as the shielding gas and AlSi5 as the filler material.

The plates with identical dimensions were firmly clamped in the fixture of a vertical milling machine so that the plates do not flutter away due to the welding torque and a non consumable high speed steel tool is seized in the spindle. The tool is moved in the downward direction on the welding line, where the plates are to be joined, inserted between them and prearranged a dwell time, then the feed is given, and the tool used for FSW is shown in figure 1. At the end the tool is moved upwards from the welding line, and a blow hole is left, which is the disadvantage of the FSW process. The quality of the weld was first visually inspected to both upper and bottom surfaces for weld smoothness and then examined under the optical microscope for microstructure and internal defects.

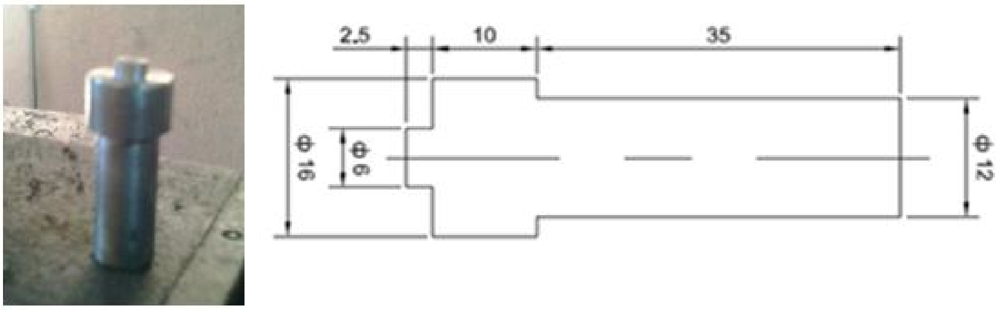

Figure1: FSW tool

3. RESULTS AND DISCUSSIONS

3.1 Electrical Conductivity:

Electrical conductivity is a measure of how well a material accommodates the movement of an electric charge. The conductivity values were reported as percent IACS. IACS is an acronym for International Annealed Copper Standard, which was established by the 1913 International Electrochemical Commission. The conductivity of the annealed copper (5.8001 x 107S/m) is defined to be 100% IACS at 20°C. All other conductivity values are related back to this conductivity of annealed copper.

Conductivity values in Siemens/meter can be converted to % IACS by multiplying the conductivity value by 1.7241 x10-6. When conductivity values are reported in micro Siemens/centimeter, the conductivity value is multiplied by 172.41 to convert to the % IACS value.

Electrical conductivity is a very useful property since values are affected by chemical composition and the stress state of crystalline structures. Therefore, electrical conductivity information can be used for checking of proper heat treatment of metals, and inspecting for heat damage in some materials.

The surface was polished to approximately 1.5µm prior to electrical conductivity and hardness measurements. The conductivity measurements were taken and the graph was plotted as electrical conductivity in %IACS against distance from weld centre in mm as shown in Fig.2

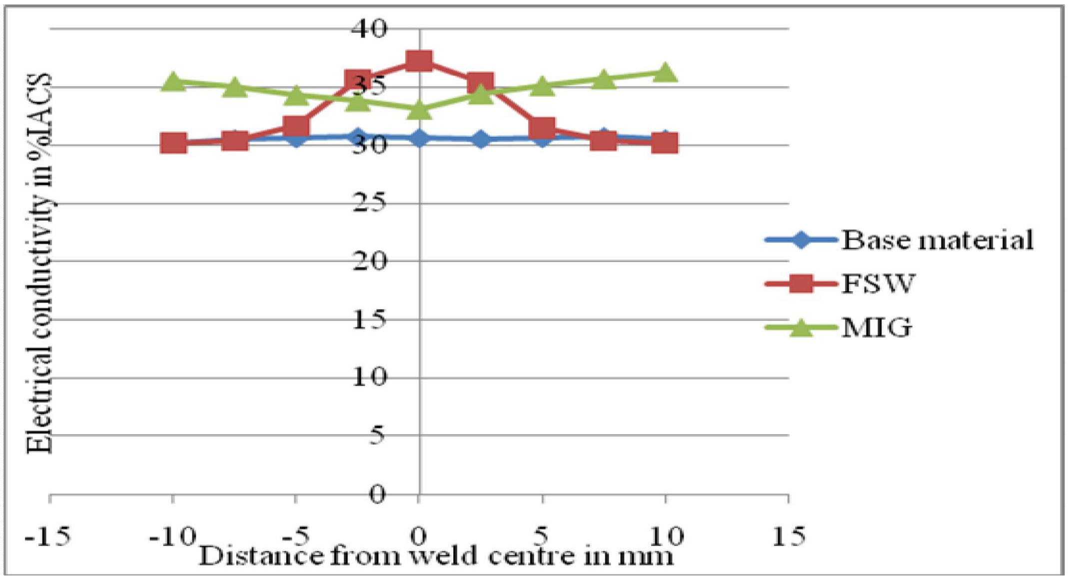

Figure 2: Electrical conductivity curves for the Base metal, FSW and MIG welded joints

Variation of electrical conductivity was observed in FSW joints from the weld centre to the base metal indicating the changes in the microstructure in different zones of welded joint, whereas the electrical conductivity for the MIG welded joints was almost constant throughout the welded joint, showing similar microstructural properties throughout the welded joint.

3.2 Rockwell hardness (HRB):

The Rockwell Hardness test is a hardness measurement based on the net increase in depth of impression as a load is applied. For soft materials such as copper alloys, soft steel, and aluminum alloys a 1/16" diameter steel ball is used with a 100-kilogram load and the hardness is read on the "B" scale.

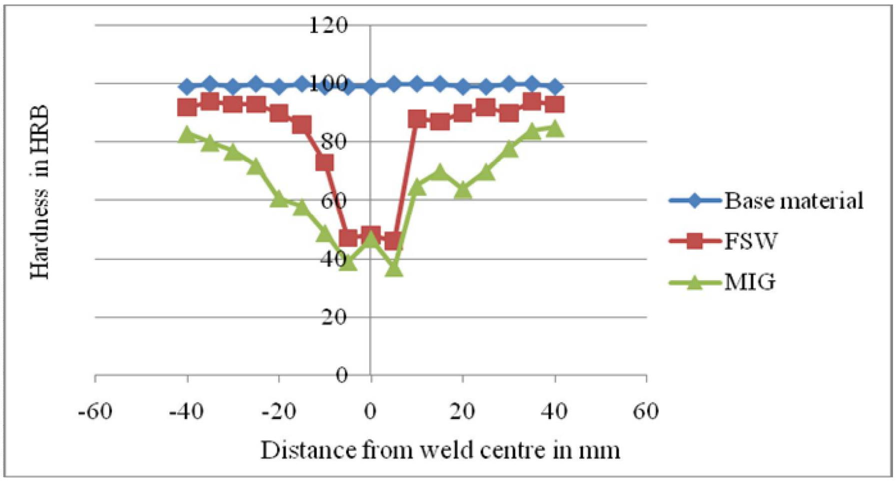

Figure 3: Hardness profiles for the Base metal, FSW and MIG welded joints

The hardness measurements were noted and the graph was plotted as hardness in HRB against distance from weld centre in mm as shown in Figure 3. The MIG Welded joints showed a large hardness drop in the weld compared with FSW, which is due to the high heat input into the weld zone.

3.3 Co-relation between electrical conductivity and hardness

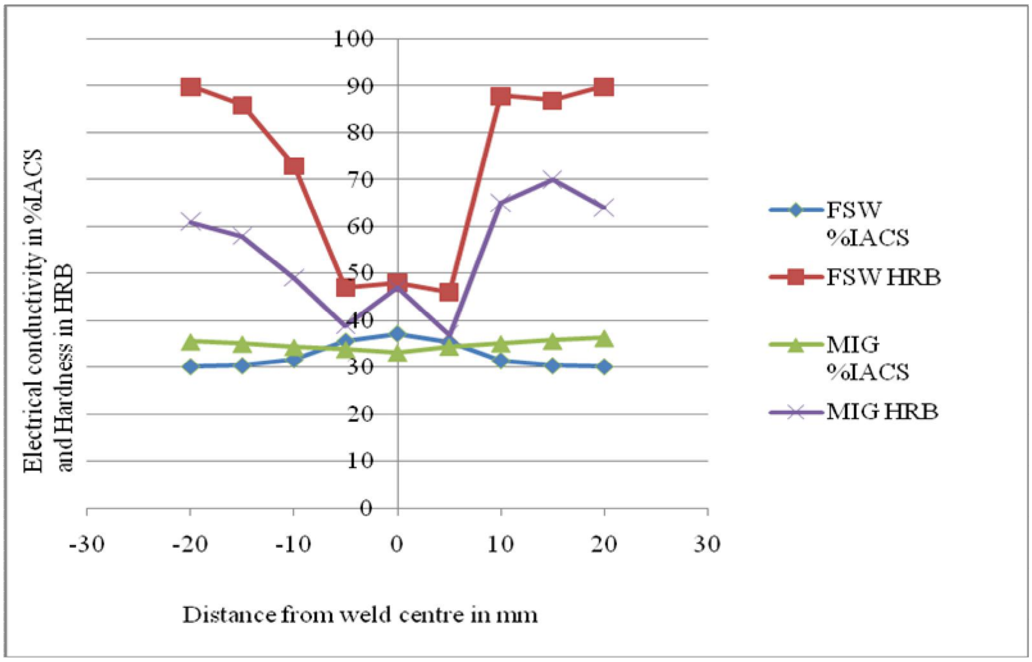

Figure 4: Electrical conductivity v/s hardness for FSW & MIG joints

In FSW, electrical conductivity and hardness showed a reciprocal effect, i.e. an increase in one produced a decrease in the other and vice versa. In MIG, the Electrical conductivity is almost constant throughout the welded joint and has a large hardness drop. Therefore, electrical conductivity and hardness are non linear to each other in FSW joint, but they cannot be co-related to each other in MIG welded joint.

3.4 Microstructure*:* Sample preparation: For optical microstructure inspection the cross-section of weld zone was polished and then etched by Keller's reagent consisting of 95 ml distill water, 2.5 ml HNO3, 1.5 ml HCL and 1 ml HF.

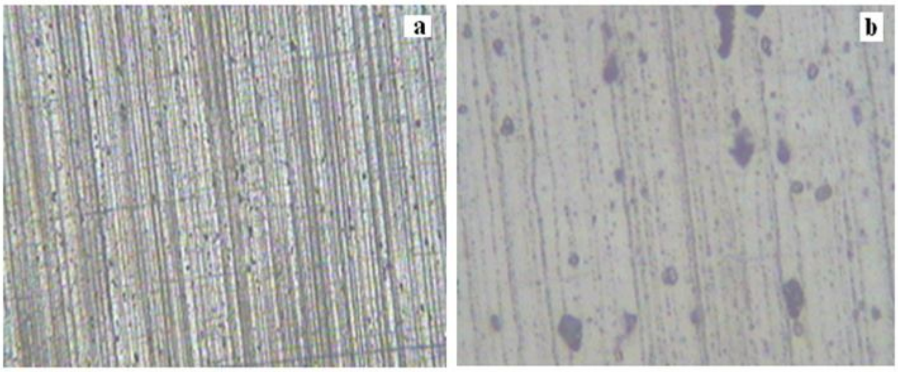

Figure 5: Microstructure of base metal (a. Magnification 100x, b. Magnification 500x)

Figure 6: Microstructure of FSW joint ([a]. at base metal zone, [b]. Heat affected zone, [c]. Welding zone of the joint)

Figure 7: Microstructure of MIG joint ([a]. at Base metal zone, [b]. Heat affected zone, [c]. Welding zone of the joint)

Microstructures of all the joints were examined at different zones with the optical microscope.
The base metal contains fine grains which are elongated & fine grains throw in high hardness & high strength. Because of temperature rise up to 400^0C, during the FSW, some precipitates dissolve in the matrix, stirring continues and hence a finer and more uniform precipitate distribution.
In weld region of MIG, due to melting of alloy, dendritic structure with many equiaxed grains are available, this may be due to the fast heating of base metal and fast cooling of molten metal because of the welding heat input.

3.4.1Macrographs of MIG and FSW joints

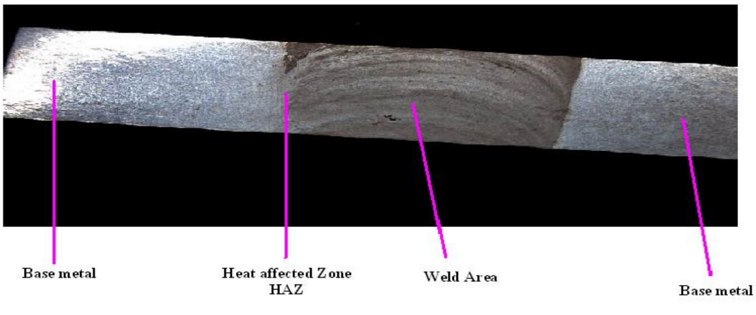

Figure 8: Macro graph of FSW joint

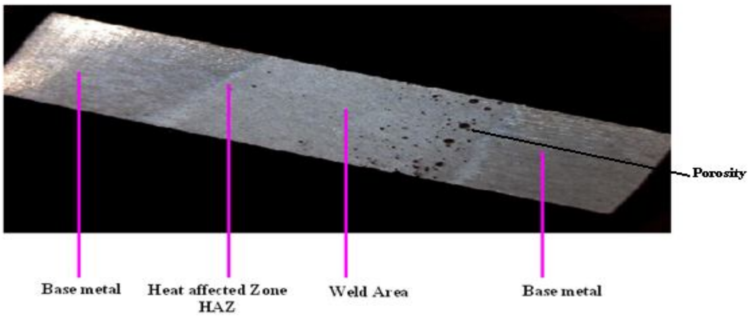

Figure 9: Macro graph of MIG joint

The heat affected zone is marginally wider in the MIG welded joints than the friction stir welded joints. And in MIG welding micro porosity is observed but which is absent in friction stir welding process.

4. CONCLUSIONS

The conventional MIG welding process and innovative friction stir welding (FSW) processes were successfully applied to join AA 7075 T6 aluminium alloy. The electrical conductivity, hardness distributions and micro structural properties of the joints have been studied in the present work. Following conclusions can be drawn:

1. Variation of electrical conductivity was observed in FSW joints from the weld centre to the base metal whereas the electrical conductivity for the MIG welded joints was almost constant throughout the welded joint.
2. The MIG welded joints have a large hardness drop as compared to FSW.
3. Non linear correlation of electrical conductivity and hardness was observed in FSW and no relation can be found in MIG joints.
4. Microstructures of all the joints were examined at different locations. The base metal contains fine grains which are elongated. The fusion zone of MIG welded joints contain dendritic structure. The weld region of Friction stir welded (FSW) joint is mainly composed of onion ring structures in the nugget zones with fine and equiaxed grains.
5. The heat affected zone is marginally wider in the MIG welded joints than the Friction stir welded joints.
6. In MIG welding, micro porosity is observed but which is absent in Friction stir welding process.
7. Friction stir welding being eco friendly metal joining process which is the need of the hour should be implemented to avoid environmental related problems.

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AUTHOR

Umesh Kashinath Ghodwade completed the B.E. in Mechanical engineering from Visvesvaraya Technological University, Belagavi, Karnataka & M.E. in Manufacturing Engineering from Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra, and presently working as an Asst. Prof. in Mechanical engineering department of M.B.E.Society's College of Engineering, Ambajogai, Beed, Maharashtra.