Mechanical Properties of Aluminum 6063 Alloy Joined by Tungsten Inert Gas Welding and Friction Stir Welding Methods

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Abstract – In this investigation, the mechanical properties of aluminum 6063 alloy welded joint were studied. First welded joint was obtained by using fusion welding methods called Gas Tungsten Arc Welding (GTAW) and other one was obtained from solid state welding methods called Friction Stir Welding (FSW). This solid state welding joint of aluminum alloy 6063 was obtained by employing the conventional universal milling machine. The effect of welding processes on mechanical properties of aluminum 6063 alloy was studied based on optical microscope, tensile test, impact test and hardness test. Results obtained from these characterization tests reveals the friction stir welding provides better mechanical properties of aluminum 6063 alloy welded joint.

Index Terms – Aluminum 6063 alloy, FSW, GTAW, Tensile test, Impact test, Hardness test.

1. INTRODUCTION

Aluminum alloys possesses good combination of properties like light weight, good resistance to corrosion, good weldability, high strength to weight ratio etc., (1,2). Hence these alloys are most widely used in aerospace industries, automobile applications, marine applications. The most common welding process used for welding aluminum alloys are GTAW and Gas Metal Arc Welding (GMAW). But, the problem of welding these alloys is formation of hot cracking in fusion zone due to segregation during solidification process which leads to lessening the mechanical properties of the joints (3). This problem can be overcome by using FSW and this invented and patented by The Welding Institute (TWI) in UK during the year 1991. This green solid state joining techniques has several advantages over the fusion welding techniques, viz, no filler material, no shielding gas, no smoke or dust, also defects like porosity and hot cracking phenomenon (4). This welding technique have been applied not only for joining high strength aluminum alloys but also joining of magnesium alloys, copper alloy, steel, composite materials and dissimilar materials (5,6,7). In FSW process, a specially designed tool mounted on rotating spindle and plunged into the plates to be joined to predetermine depth level. The friction between tool and plate surface produce thermo mechanical plasticized zone and plastic deformation. Due to this, good quality of joints is produced by FSW. Lakshminarayanan et al (8) reported that FSW joints of AA6061 aluminum alloy showed superior mechanical properties compared with GTAW and GMAW joints and this is mainly due to the formation of very fine, equiaxed microstructure in the weld zone. Juan Zhao et al (9) discussed in their research work that mechanical properties of FSW welded joints are much better than those of Tungsten Inert Gas (TIG) welded joints: the strength coefficient of FSW joint is 94% and the tensile strength and yield strength of FSW joint are 19% and 31% higher than the TIG joint respectively. HE Zhen-bo et al (10) conducted experiments on Al-Mg-Mn-Sc-Zr plates using FSW and TIG welding and found that the welding coefficients are high in FSW plates than TIG welded plates. They also found that the grains in weld nugget zone of friction stir welded joints are finer that those in the molten zone of TIG welded joints. Taban and Kaluc (11) determined that double pass friction stir welded joints of 5086-H32 aluminum alloy have superior properties than that of MIG and TIG welded joints. Munoz et al (12) studied the microstructure and mechanical properties of friction stir welded and gas tungsten arc welded Al-Mg-Sc alloy and reported that the yield strength of friction stir welded and gas tungsten arc welded joints are decreased 20% and 50% respectively compared to base metal.

In this work, an attempt has been made to study the mechanical properties of GTAW and FSW joints of aluminum 6063 alloy.

2. EXPERIMENTAL WORK

2.1 MATERIALS:

The material used for the present work is an alloy of Al-Si-Mg alloy known as aluminum 6063 alloy. This alloy was machined to the required dimension of 100 x 50 x 6 mm as shown in fig.1.

Fig.1. Dimension (in mm) of joint configuration

The base material characterization tests were conducted to find out the chemical composition and mechanical properties. The chemical composition and mechanical properties of the base metal were presented in table 1 and 2 respectively.

Table 1 Chemical composition of base metal

Material	Composition (Wt. %)				
	Al	Si	Mg	Mn	Cu
AA6063 alloy	98.6	0.431	0.55	0.039	0.035

Table 2 Mechanical properties of base metal

Sl.No	Property	Values
1	Vickers hardness	84 VHN
2	Ultimate tensile strength	131 N/mm^2
3	Yield strength	73 N/mm^2
4	Impact strength	12 x 10^3 Nmm

2.2 WELDING:

(a) (b)

Fig.2- (a) FSW by milling machine (b) tool for FSW

Tool rotation speed and tool traveling speed of 1200 rpm and 60 mm/min were selected for FSW process. GTAW joints plates and FSW joints were shown in fig.3.

Fusion welding process like GTAW and solid state welding process like FSW have been applied to the base metal. Single pass welding was used to fabricate the square butt joints. GTAW welds joints were produced using tungsten electrode of 3 mm diameter with aluminum 6063 alloy filler rod and commercial argon gas was used as shielding gas. Welding current and arc voltages were 180 amps and 24 v respectively.

The FSW joints were made by using universal vertical milling machine as shown in fig.2. The welding process was performed with specially designed tool of high carbon high chromium steel with 20 mm diameter shoulder and 6 mm diameter

(a) (b)

2.3 CHARACTERIZATION TESTS:

The welded joints were cut by using wire Electric Discharge Machining (wire-EDM) according to American Society for testing materials (ASTM E8M-04) as shown in fig. 4 in order to evaluate the yield strength, ultimate tensile strength.

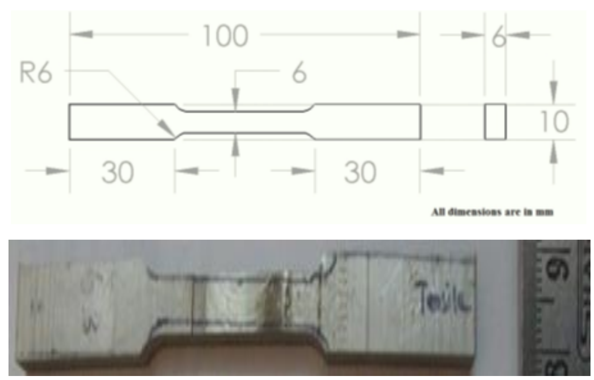


Fig. 4 Tensile test specimens

Vicker's micro hardness tester was used for measuring hardness of the weld metal with a 0.5 kg load with a dwell time of 10 sec.

Charpy specimens were prepared from the welded joints as per the ASTM E23-07a standard. The dimension of the specimen is 55 x 10 x 5 mm with a notch of 1 mm depth, 45° and 0.25 mm root radius was prepared. Then, this specimen is loaded in an impact testing machine to find out the impact strength.

The effect of welding process on grain was determined using optical microscope. The welded specimens, after sectioning and polishing, were etched with a solution containing 15ml HCl, 10 ml HF and 90 ml water, cleaned with water, cleaned with concentrated HNO_3 and rinsed with water again. Microstructural analysis on the sectioned specimens is carried out mainly to compare the grain size of specimen welded with GTAW and FSW.

3. RESULTS AND DISCUSSION

3.1 TENSILE PROPERTIES

The tensile properties of the base metal, GTAW joint and FSW joints of AA6063 alloy were evaluated and presented in the table 3.

Table 3 Tensile properties of AA6063 joints

Sl.No	Types of joints	Yield strength (N/mm²)	Ultimate tensile strength (N/mm²)	Welded joint coefficient
1	Base metal of AA6063 alloy	73	131	-
2	GTAW joint of AA6063 alloy	39	66	50.4%
3	FSW joint of AA6063 alloy	57	104	79.4%

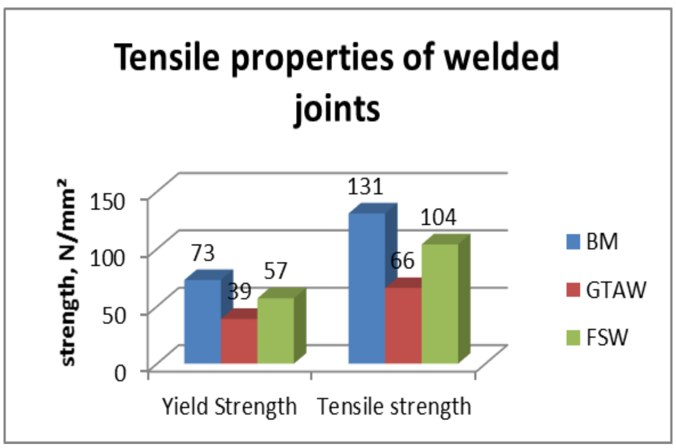


Fig.5 Tensile properties of welded joints

The yield strength and tensile strength of base metal are 73 N/mm² and 131 N/mm² respectively. But the GTAW shows a yield strength and tensile strength of 39 N/mm² and 66 N/mm² respectively. But, FSW shows a yield strength and tensile strength of 57 N/mm² and 104 N/mm² respectively. From this it is clear that the yield strength and tensile strength of FSW joint are greater than the GTAW joints. Hence, FSW process exhibited higher strength values.

The ratio between the tensile strength of a welded joint and the base metal is called welded joint coefficient. The welded joint coefficient for a GTAW joint is 50.4%, while the welded joint coefficient of FSW joints is 79.4%.

3.2 HARDNESS

The hardness across the weld cross section was measured using a Vicker's hardness tester and the average values are given the table 4.

Table 4 Hardness survey of AA6063 joints

Sl.No	Types of joints	Hardness value (VHN)
1	Base metal of AA6063 alloy	84
2	GTAW joint of AA6063 alloy	53.5
3	FSW joint of AA6063 alloy	61.5

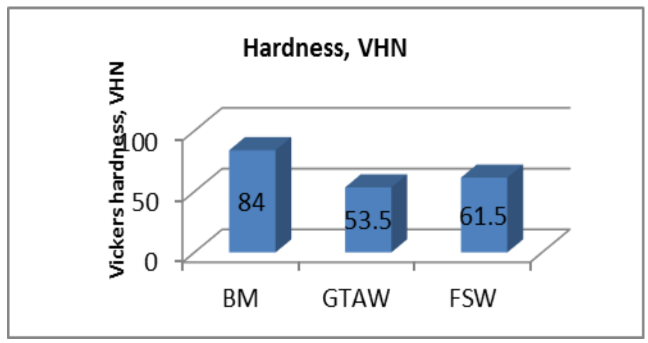
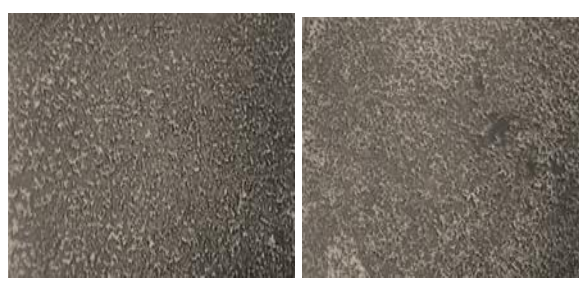


Fig.6 Hardness value of welded joints

The hardness of the base metal is 84 VHN. But, the hardness of GTAW joint is 53.5 VHN which indicates that hardness is reduced by 30.5 VHN due to heat generated during welding process. However, the FSW process increases the hardness value to some extent in the weld metal region and the hardness value is 61.5 VHN which is relatively higher than the GTAW joint. Hence, FSW joint exhibit higher hardness value due to fine grain size induced by tool motion (Fig.7).



(a) (WM, 100μm) (b) (WM,100μm)

Fig.7 (a) Microstructure of GTAW joint (b) FSW joint

3.3 IMPACT STRENGTH

The impact strength of the welded specimen was measured using a charpy impact test machine and these values are presented in the table 5.

Table 5 Impact strength of AA6063 joints

Sl.No	Types of joints	Impact strength (Joules)
1	Base metal of AA6063 alloy	12
2	GTAW joint of AA6063 alloy	8
3	FSW joint of AA6063 alloy	14

The impact strength of the base metal is 12 Joules. But, the impact strength of GTAW joint is 8 Joules which indicates that impact strength is reduced by 4 Joules. However, the FSW process increases the impact strength slightly and the value is 14 Joules which is higher than the GTAW joint. Hence, FSW joint exhibit higher impact strength due to fine grain size induced by tool motion (Fig.7).

4. CONCLUSION

In this investigation, conventional GTAW process and green solid state FSW processes were successfully applied to join AA6063 alloy. The mechanical properties like yield strength, ultimate tensile strength, hardness and impact strength have been studied. The following conclusions have been drawn.

- The tensile strength and hardness of the welded joints are less than the base metal due to heat generation during welding process.
- Compare to GTAW joints, the joints produced by FSW process exhibited better strengths.
- The hardness is also relatively high in FSW joint compare to GTAW joint.
- FSW joint exhibited good impact strength than the GTAW joint.
- FSW process produced fine grain size due to stirring action of the tool compare to GTAW process.

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