EFFECT OF TIG AND FSW WELDING PROCESSES ON MECHANICAL PROPERTIES OF Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr ALLOY

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Abstract: In this study, friction stir welding (FSW) and Tungsten gas welding (TIG) processes were used to weld 5 mm thick Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy plates. The FSwelds and TIG welds were tested for mechanical properties (hardness, ultimate tensile strength, bending strength and impact strength) by means of vicker's hardness machine, universal testing machine and impact test machine respectively. The strength of the base material was higher, compared to the strength of the FSW and TIG welded joints. The strength of the TIG welded joint decreased, compared to the strength of the FSW welded joint. The microstructure features were also observed for base material with the aid of metallurgical microscope and compared the same with the microstructures of FSW and TIG welded joints. FSW change the material strength due to fine-grain refinement in the stir zone in Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy and therefore FS welded joint exhibited 91.6% joint efficiency followed by the TIG welded joint of 69.8%.

KEYWORDS: Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy, Friction stir welding, Tungsten gas welding, mechanical properties

1 Introduction

In the present work, a 5xxx series alloy containing 0.4%Sc and 0.1%Zr is a new light weight material chosen for the investigation. This alloy usually contains aluminium (Al), magnesium (Mg), manganese (Mn) as principal alloying constituents and traces of other metals. These alloys are work-hardenable and can be easily drawn into any shape due to high formability, exhibits high ductility, good weldability, durability, and good finishing characteristics due to Al₃Sc, Al₃Mg₂, Mg₂Si, Al₆(Fe, Mn) intermetallics [1-5]. The difficulty in adopting the traditional welding processes can be attributed mainly, new materials with low weld strength. A careful selection of the welding process for a given metal joining problem is, therefore, essential.

In the recent years, a new solid-state joining technique popularly known as Friction stir welding (FSW) was invented and patented by The Welding Institute (TWI), United Kingdom in the year 1991 [6]. The need of FSW was brought-out in the first paragraph for the reason that FSW was eco-friendly [7] and applicable for high strength to weight ratio materials and does not exhibit welding defects like porosity and hot cracks [8-16].

The present study focused to compare the FSW and TIG welding processes and their effect on mechanical and microstructure properties of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy.

2 Materials and Methods

2.1 Materials

The Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy was fabricated by stir casting melting technique using Al-4.2 wt.% Mg-0.6 wt.% Mn alloy and three master alloys (Al-10wt. %Mg, Al-2wt. %Sc and Al-5wt. %Zr). The material preparation was discussed in my previous article [16].

Table 1. The Chemical composition of fabricated alloy. (wt.%) [15].

Mg	Mn	Si	Cr	Zn	Ni	Li	Sc	Zr	Bal.
4.2 ^{+0.7} _{-0.2}	0.6 ^{+0.4} _{-0.2}	0.17 ^{+0.23} _{-0.17}	0.10 ^{+0.30} _{-0.10}	0.06 ^{+0.19} _{-0.06}	0.006 ^{+0.044} _{-0.006}	0.001 ^{+0.049} _{-0.001}	0.4 ^{+0.05} _{-0.05}	0.1 ^{+0.05} _{-0.05}	Al

2.2 Experimental methods

The plates size of 120 mm x 120 mm x 5 mm (Figure 1(c)) was cut from the cold rolled plate by water jet machine from the fabricated Al-4.2 wt.% Mg-0.6 wt.% Mn alloy and three master alloys (Al-10wt. %Mg, Al-2wt. %Sc and Al-5wt. %Zr) in rolled plates of size 150 mm x 150 mm x 5 mm thick for TIG and FSW welding processes.

Friction stir welding was carried out using 3 tonne capacity numerical controlled FSW machine with model-FSW-3T-NC. The welding was done perpendicular to the rolling direction of the plate of size 140 x 120 x 5 mm as shown in Figure 1(b). The plates were welded using the H13 tool steel with cylindrical tool pin profile. The FSW parameters such as applied load 8 kN, tool rotational speed 1200 rpm, tool traverse speed 27 mm/min were considered [17-19]. In TIG welding, the welding was done using the welding parameters such as current (160 A), Voltage (14 V), travelling speed (55 mm/min) and gas flow rate (16lpm). The model used for welding the plate of size 140 x 120 x 5 mm (Figure 1(c)) was TIG315 AC/DC model with filler wire Alloy 5356.

Fig. 1 shows the plates (a) Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy
(b) FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy
(c) TIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

The standard specimens for hardness measurement, ultimate tensile strength, bending strength and impact strength were machined from the FS welded plate and TIG welded plate.

The microhardness of the welded joints of size 30 x 10 x 5 mm was measured across the transverse section on the surface of the weld center using diamond indenter with a 5kgf applied force using MVN-50PC 115-0618 vicker's microhardness tester. Tensile tests were performed as per ASTM E8 standards with constant crosshead speed by using TUE-C-600 model universal testing machine. The width of the specimen is 12 mm and the thickness of the specimen is 5 mm [18]. The bend test is done using TUE-C-600 model universal testing

machine to evaluate the bend strength of the alloy. The energy absorbed by the alloy was obtained from charpy impact tests were conducted according to the ASTM E23 standard using impact testing machine 98/1081, V notch type with notch angle 45°, 2mm depth of notch and specimen size 10 x 5 x 55 (mm). The microstructure of the weld joints was investigated as per ASTM E407:2015 standard on the orientation of the specimen cross-section using kellers reagent etchant with 100X magnification by means of optical microscope [19].

3 Results and discussion

3.1 Effect of welding processes on Mechanical properties

The results of the tests on the mechanical properties of the Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr, FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr and TIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy are shown in Table 2.

Table 2 Mechanical Properties

Alloy Type	H	UTS	IS	BS
	VHN	(MPa)	KJ/m ²	(MPa)
Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	139	260.40	2.5	3480
FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	111	238.54	11.25	3325
TIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	94	157.86	3.8	3215

3.2 Effect of welding processes on Hardness

At the weld center the micro hardness values of FSW and TIG welded joints are the lowest compared to non-welded alloy which is caused due to softening of the material at the central part of the welded specimens. The micro hardness of the TIG welded joint is lower than the FSW welded joint.

3.3 Effect of welding processes on Tensile strength

It can be seen that the improvement in the mechanical properties of the FSW welded joint compared to TIG welded joint. The obtained tensile strength of FSW joint is 238.54 MPa and TIG welded joint is 157.86 MPa, where as non-welded alloy's strength is 260.40 MPa. FSW change the material strength due to fine-grain refinement in the stir zone in Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr and therefore FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr exhibited 91.6% of joint efficiency and 69.8% of joint efficiency in TIG welded alloy.

3.4 Effect of welding processes on Impact strength

The highest impact strength (11.25KJ/m²) obtained for FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy due to fine grains in the stir zone produces tiny dimples, which led to improved strength. This strength is obtained by calculating the ratio of actual energy observed to its cross-sectional area.

3.5 Effect of welding processes on bending strength

The lowest bending strength observed in TIG welded alloy and high bending strength achieved in non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy. It is also observed that the bending strength increased with the increase of tensile strength.

3.6 Effect of welding processes on Microstructure

The optical micrograph of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy is shown in Figure 2(a). The fragmentation of Al₃Mg₂ and Al₃Sc_{1-x}Zr_x intermetallic and the average grain size vary from 15

to 25 μ m with the distribution of dendritic structure and spherical particles. Figure 2(b) represent the microstructure of the FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr consists of fine grains in the stirred zone with an average grain size less than 2 μ m. This reduction in grain size depends on FSW parameters.

Fig. 2 Optical Micrograph (a) Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

(b) FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr (c) TIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

Figure 2(c) shows the microstructure of TIG welded alloy which consists of very fine interdendritic network with finely dispersed intermetallic particles in the matrix of aluminium solid solution. The microstructural change in TIG welded joint and FSW welded joint is occurred due to the high and low temperatures in the weld centers respectively.

CONCLUSIONS

- Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloys were successfully fabricated by stir casting technique.
- Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy achieved the mechanical properties, i.e., Hardness (139 VHN), Ultimate tensile strength (260.4 MPa), Bending strength (3480 MPa), Impact strength (2.8KJ/m²) and % elongation is 7.4.
- Friction Stir Welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy achieved the mechanical properties, i.e., Hardness (118.98 VHN), Ultimate tensile strength (238.54 MPa), Bending strength (3325 MPa), Impact strength (11.25 KJ/m²) and % elongation is 4.9 was obtained.

- Friction Stir Welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy achieved the mechanical properties, i.e., 85.5 % Hardness, 91.6% Ultimate tensile strength, 95.5 % Bending strength, 24.8 % Impact strength and % elongation is 66.2% was obtained when compared to that of non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy .
- TIG welded alloy Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy achieved the mechanical properties, i.e., Hardness (94 VHN), Ultimate tensile strength (157.86 MPa), Bending strength (3215 MPa), Impact strength (3.8 KJ/m²) and % elongation is 4.6 was obtained.
- TIG welded alloy Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy achieved the mechanical properties, i.e., 32.3 % Hardness, 39.3% Ultimate tensile strength, 7.6 % Bending strength, 24.8 % Impact strength and % elongation is 66.2% was obtained when compared to that of non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy .

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