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INVESTIGATION OF MECHANICAL AND METALLURGICAL PROPERTIES OF FRICTION STIR WELDED MAGNESIUM ALLOY

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ABSTRACT

Main objective of this study is to evaluate some fundamental observations on the effect of welding processes on mechanical and microstructural behavior of magnesium alloy. Weldability of magnesium alloys has recently been investigated with a variety of processes, particularly gas tungsten arc welding, laser beam welding and friction stir welding. Even though these magnesium alloys are easily weldable by fusion welding processes, the welded joint strength is poor. Hence the FSW process parameter must be optimized to get high quality joints. In this investigation, the effect of process parameters on Friction Stir Welding of AZ63 magnesium alloy were studied. The joining of magnesium alloy by conventional methods is very difficult due to the problems such as crack formation, void formation, expulsion in the weld zone. The joining of aluminum alloy by conventional welding process can problems such as presence of segregation, blow hole, crack formation and porosities and including loss of alloying elements. These problems can be eliminated by using friction stir welding technique which offers an alternative through solid-state bonding. Samples were prepared for the mechanical testing and micro-structural characterization.

Keywords: *FSWFriction Stir welding.*

1. Introduction

Welding is a process of joining materials, usually metals and thermoplastics by causing coalescence. It is usually done by adding filler materials that forms a pool of molten material which cools and forms a strong joint. Welding is a joining process producing coalescence of materials by heating them to the welding temperature with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal on Definitions and Symbols (2010)[1]. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work-pieces to form a bond between them, without melting the work pieces.FSW is capable of joining magnesium alloys without melting and thus it can eliminate problems related to the solidification. Aluminium and magnesium alloy find wide applications in aerospace, automotive, ship building industries. Various grades of aluminium and magnesium alloy is found in the market. They were divided by alloy designation systems each series of alloy will have different chemical composition and properties. This process is primarily used on aluminum and most often on large pieces, which cannot be easily heat-treated post weld to recover temper characteristics. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. welding is widely used by Metal workers in the fabrication, maintenance, and repair of parts and structures. Welding is used extensively in all sectors or manufacturing, from earth moving equipment to the aerospace industry. While there are many methods for joining metals, welding but FSW seems to be more promising for joining magnesium alloys. Hence, in this investigation an attempt was made to find out the optimal parameter in which results of good mechanical and metallurgical properties will be found.

2. Experimental Work

In order to achieve the desired aim, the present investigation was planned in the following sequence:

- Selection of welding method
- Selection of material
- Fabrication of weld joints

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- Evaluating the mechanical and metallurgical properties

2.1 Selection of Welding Method

FSW is a solid state joining process that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the friction stir welding tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal can be joined using mechanical pressure (applied by the tool), much like joining clay. It is primarily used on aluminium, and most often on extruded alumina (non-heat treatable alloy) and on structures which need superior weld strength without a post weld heat treatment. Here the work of friction is used to mix and join materials. This process is primarily used on aluminum and most often on large pieces, which cannot be easily heat-treated post weld to recover temper characteristics. It was invented and experimentally proven by(Thomas et al 1991) [2] and a team of his colleagues at The Welding Institute TWI UK in December 1991. TWI holds a number of patents on the process, the first being the most descriptive. Friction stir welding machine is shown in the Figure 2.1.(Make: R.V. Machine Tools, India; capacity: 20kN; 3000 rpm). The rotational speed has a more significant role on the final microstructure and mechanical properties of the joints, compared to the traverse speed [3].

Figure 2.1: Friction Stir Welding Machine

2.2 Selection of Material

The development of new grades of alloys and manufacturing techniques such as welding play an important role in exploiting the new field of applications. Weldabilityof magnesium alloys has recently been investigated with a variety of processes, particularly gas tungsten arc welding, laser beam welding and friction stir welding. With arc welding processes, lack of weld penetration is generally a limitation of the magnesium alloys. FSW is capable of joining magnesium alloys without melting and thus it can eliminate problems related to the solidification. Aluminium and magnesium alloy find wide applications in aerospace, automotive, ship building industries. Various grades of aluminium and magnesium alloy

is found in the market. They were divided by alloy designation systems each series of alloy will have different chemical composition and properties. Magnesium alloyAZ63 has been selected with dimensions of 6mm thickness and 100mm length and a width of 50mm. The chemical composition and mechanical properties of the base materials are shown following Table 2.1 and Table 2.2.

Table 2.1: Chemical Composition of Base Material (% by wt)

Mg	Al	Zn	Mn	Impurities
90.91	6.90	2.08	0.04	Remaining

Table 2.2: Mechanical Properties of Base Material

Hardness HV	Tensile Strength N/mm^2	Yield Strength N/mm^2	Elongation %	Melting Point ℃
55	200	97	6	455-610

2.3 Fabrication of Weld Joints

Friction Stir welding process parameters used for the fabrication of magnesium AZ63 joints were shown in Table 2.3. Before the welding process, the prepared samples are cleaned properly with suitable chemicals, polished carefully and properly aligned. Tool made of high carbon steel with Threaded cylindrical type tool is used for joint fabrication. Square butt joint configuration was used to fabricate the joints.

The final welded plate dimensions are 100mm x 100mm x 6mm. The sample specimen is shown in Figure 2.2.

Table 2.3: Process Parameters for Welding

Sl. No.	Transverse Speed (mm/min)	Axial Force	Rotational Speed (rpm)
1	30		
2	60	5 KN	1200
3	90		

Fig. 2.2 Specimens for Welding

2.3 Evaluating the Mechanical and Metallurgical Properties

The weld samples were subjected to the mechanical properties characterization such as tensile and hardness test and microstructural analysis for Base Metal (BM), Heat Affected Zone (HAZ) and Weld Zone (WZ).

2.3.1 Tensile Test

Binlian Zou et al. [4] in his study concluded that the results of tensile tests indicate that the joint strength decreases with increasing rotational speed, while it is not affected significantly by dwell time. In engineering, tensile strength is the maximum strength a material can withstand before failure occurs. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. The fabricated joints were machined to the required dimension, according to the ASTM E8 standard. The test was carried out in electro-mechanical controlled Universal Testing Machine TUE-CN 400. Figure 2.3 shows the tensile test specimens. Higher welding speeds can produce slightly higher hardness in the stir zone [5].

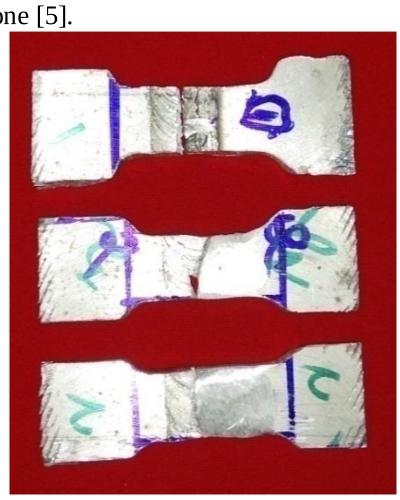

Figure 2.3: Tensile Test Specimens

2.3.2 Hardness Test

Another typical characteristic of material behaviour is the hardness of the workpiece. The hardness was measured at HAZ and mid-thickness region of the welded joint. The hardness values were measured at various places and the average was taken. The hardness test was carried out using Vickers Hardness Testing Machine which is shown in Figure 2.4.

Fig. 2.4 Hardness Testing Machine

2.3.3 Microstructure

The microstructure images reveal information about the sample including external morphology, chemical composition and orientation of grains. The specimens were cleaned, polished and etched before taking microstructure images. The emery sheets of various grades were used to polish the specimens and nitric acid was used to etch the specimen. The images were taken with magnification of 200x at BM, WZ [6]. The optical microscope is used to take microstructure images.

3. Results and Discussions

3.1 Tensile Test Results

The hardness value is found increased when the transverse speed is optimum as 30 mm/min with a rotational speed of 1200 rpm. tensile results are shown in the Table 3.1. tensile specimens after test were shown in the Figure 2.3. The comparison between the tensile strength of the welded specimen and base material for various transverse speed is given in Table 3.1 shows the tensile test results.

Table 3.1: Tensile test results for welded specimens

Sl. No	Parameter Involved		Ultimate Strength (MPa)	Joint Efficiency
	Transverse speed (mm/min)	Rotational speed (rpm)		
1.	30	1200	177.04	89%
2.	60	1200	168.25	84%
3.	90	1200	159.16	79%

Fig. 3.1 Tensile Test Specimens after Test

The Figure 3.2 shows the comparison of tensile test results between base metal and fabricated joints with different welding parameters.

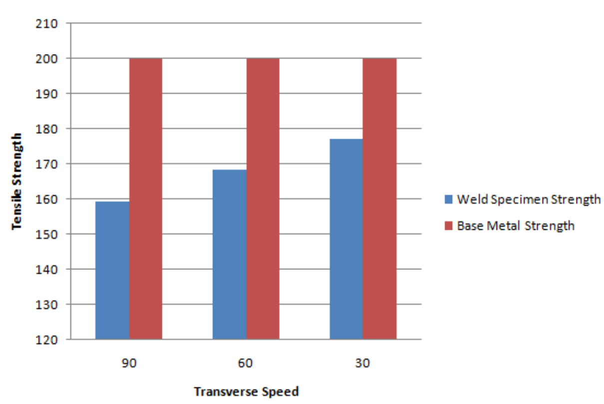

Fig. 3.2 Tensile Test Result

3.2 Hardness Test Results

The hardness test results were observed in base metal, HAZ and WZ. It shows that the hardness value of weld region is higher than that of HAZ with maximum hardness of 49HV and minimum hardness of 39HV. The Vickers hardness results are shown in Table 3.2 and Figure 3.3

Table 3: Vickers Hardness Values (HV) of Welded Specimens

Sl.No	Transverse Speed (mm/min)	Weld Zone	Heat Affected Zone	Base Metal
1	30	49	43	55
2	60	46	41	54
3	90	42	39	55

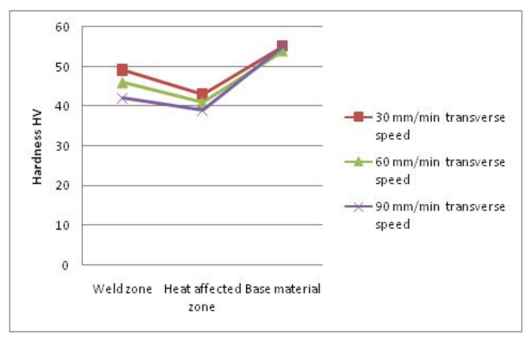

Fig. 3.3 Graph Showing Hardness Test Result

3.3 Microstructure

The microstructure images shows the finer grains in the weld region were achieved an transverse speed of 30 mm/min. At 30 mm/min transverse speed, grain growth was observed due to high heat input. The microstructure images taken at base metal and welded specimen with 30 mm/min were shown in the Figure 3.4 and Figure 3.5.

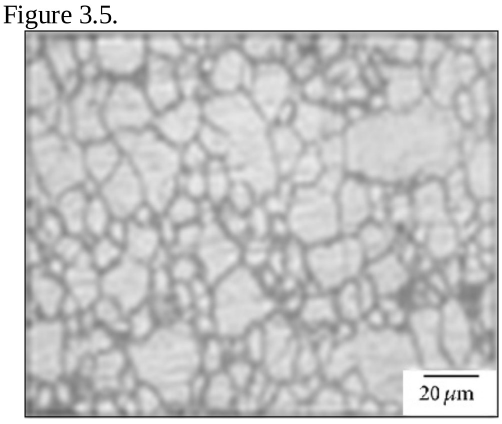

Fig. 3.4 Micrographs of Base Metal

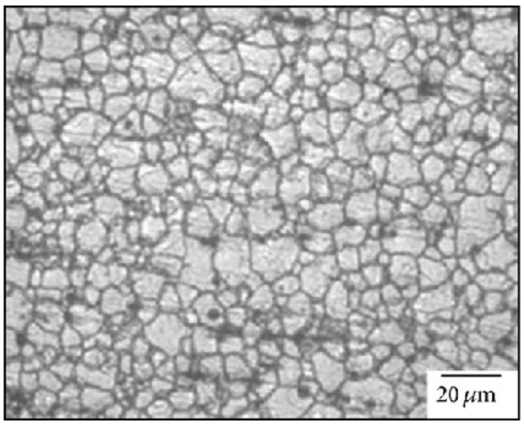

Fig. 3.5 Micrographs of specimens welded at transverse speed of 30 mm/min

4. Conclusions

The effect of friction stir welding on magnesium alloy with various process parameters has been analyzed. From the investigation the following important conclusions are derived.

1. The welded specimen prepared with 60 and 40 mm/min transverse speed has found defect due to insufficient heat input.
2. The joint fabricated with 1200 rpm and 30 mm/min transverse speed has no macro level defects. This is due to optimum heat input in this condition.
3. Moreover, the joint fabricated with 1200 rpm and 30 mm/min transverse speed has higher tensile strength compared to other joints.
4. This is due to higher hardness in the weld region and relatively finer grain size in the stir zone.

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