

## DETERMINING THE MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF A STIR WELDED MAGNESIUM ALLOY

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### ABSTRACT

Friction stir welding (FSW) is relatively a solid state welding process which is popularly used in railway, aerospace, automotive, and marine industries. The purpose is for joining process of aluminium, titanium, magnesium, zinc, copper alloys, of similar and dissimilar metals and also in thermoplastics. The study was carried to grow an understanding on the microstructural properties, grain size of a friction stir welded magnesium alloy and also to evaluate the mechanical properties of the welded area. For this, a magnesium plate of 3.8mm thickness, 100mm length and breadth were welded in a CNC controlled friction stir welding machine powered by servo gears and servo motors. Metallurgical microscope was used to determine the microstructural review and the grain size of the welded area and the base metal. Rockwell hardness test had been conducted to find the hardness value of the base metal and the welded area.

**Keywords:** friction stir welding, microstructure, welding parameters, Rockwell hardness

### INTRODUCTION

Magnesium alloys present a unique feature that, it is a unique structure materials representing high specific strength and has the capability to absorb the vibrations and shocks to the material. So, magnesium is most probably used in automobile industry, aircraft manufacturing. Another unique application is, it plays a major role in concept tires and racing tires. Magnesium wheels have been widely used in racing industries. It can withstand more shock and vibrating energy from the road surface. Due to its corrosive properties, it also plays a major role in ship building industry. There is a specific name "sacrificial metal" in ship building industry, because the under platform of the ships are totally made in magnesium to avoid rusting of the metal. As it saves the ship it have got that name.

The main reason behind this vast application of magnesium is due to the friction stir welding process. Friction stir welding process works on the principle of "plastic deformation". It is a simple technique that "when the material is welded it starts to melt and it form a solid state welding. While it melts, it will be like a plastic and turns into solid. So, the welding condition will be good and perfect. In this the microstructure and the grain size of the welded area and the base metal is compared and result is given on that. Mostly, the microstructure and the hardness depends on the weld. The weld will be good if the tool is properly hardened and dimensions of the tool should be perfect. Most probably the pin length of the tool is accurately machined and its dimension is kept by considering the work piece thickness. If it is not perfect, the tool pin will pierce the work piece and a hole will be formed in the weld. Around the world, mostly aluminium alloys will be friction stir welded, here we have used 98% Mg content magnesium alloy and studied about the microstructure, grain size, and hardness of the welded area and the base metal. Tool rotational speed, welding speed and the axial load have been considered as the welding parameter. All these parameters are setted on the numerically controlled friction stir welding machine.

### EXPERIMENTAL PROCEDURE

**Material:** The plates used in this study is 98% Magnesium content plate. It is semi purest form of magnesium. The material was received in the sizes of (300 x 300 x 3.8) mm. it was produced by powder metallurgy and mechanical alloying techniques.

The material we used contains combination of 8 materials and forms the alloy. The density of the material is  $1.738 \text{ g}\cdot\text{cm}^{-3}$ . The melting point is also high that is, 923 K (650 °C, 1202 °F). So, this material can be easily stir welded and the welding condition will also be good. The chemical composition of the material is given in table 1.

**Table.1.chemical composition of the material**

Al	Zn	Mn	Si	Fe	Cu	Zr	Mg
0.017%	0.033%	1.33%	0.007%	0.055%	0.005%	0.011%	98.10%

The plates of (300 x 300 x 3.8) were cutted from the billet by wire cut electro-discharge machining (EDM) at a feed rate of 2mm/min. the wire cut EDM method will give accurate machining of edges and the surfaces of the plates. Because if the side edges and the surfaces are not properly machined, the welding quality will not be good and cracks can be developed in the welded area. The plates have been cutted into the dimension of (100 x 100 x 3.8) mm. It means that

Length – 100 mm

Breadth – 100 mm

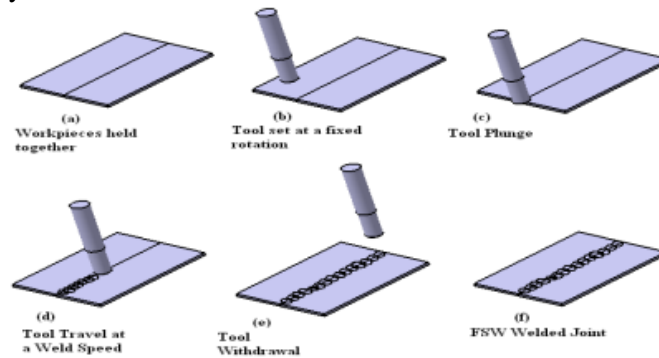
Thickness – 3.8 mm.

The plates were also surface machined. It was done using the surface grinding machine. The surfaces of the plates have been finely machined without reducing the thickness. If the thickness is reduced, the pin length of the

tool also must be reduced otherwise it will pierce into the material. So, the machining process should be done with proper care and accuracy. The tool used here was undergone to a heat treatment process where the hardness of the tool is increased. Hardening of the tool is very important because, during the welding process the tool have to withstand high temperature and pressure. For that, hardening of the tool is very important.

### Experimental Setup

The magnesium plates were friction stir butt welded using a three axis FSW machine powered by servo motors and servo gear boxes. The FSW tool of HS13 material having 20 mm shoulder diameter, 6mm pin diameter, and 3 mm pin length was used for the welding process. The hardness of the tool was 65HRC. The total tool length was 72 mm as it should be easy to hold in the tool holder.



**Fig 2.1: welding process**

Friction stir welding trials have been conducted with 0° tilt angle. Different tool rotational speeds were considered from 700 rpm to 1100 rpm and the welding speed from 60 mm/min to 100 mm/min had been considered as the welding parameters. Also axial load of 10, 12, 14, 16, 18 KN had been considered as the parameter.

**Table II: welding parameters considered**

AXIAL LOAD	TOOL ROTATIONAL SPEED	WELDING SPEED
10 KN	800 RPM	60 mm/min
12 KN	900 RPM	70 mm/min
14 KN	1050 RPM	80 mm/min
16 KN	1100 RPM	90 mm/min
18 KN	1100 RPM	100 mm/min

These were the parameters considered during the welding process.



**Fig 2.2: Experimental setup**

### RESULTS AND DISCUSSIONS

**Microstructure Review:** The microstructure test was conducted in a metallurgical microscope. The test was conducted on the welded area and the base metal.

**Specimen 1: Tool rotational speed – 1100 rpm, welding speed – 100 mm/min**



**Fig 3.1: base metal microstructure**



**Fig 3.2: welded area microstructure**

In this, the base metal has a fine Mg-Al-Mn eutectic particles in a matrix of magnesium solid solution.

The welded area has obtained nugget structure. Nugget means "bird's nest" form. So, it means the welded area is closely packed and strong enough. The weld condition is very good and there is no air gaps, cracks seen in the joint. This specimen was welded in a high tool rotational speed and welding speed. The axial load give was 18 KN.

### Specimen 2:

**Tool rotational speed – 900 rpm, welding speed – 70 mm/min**



**Fig 3.3: base metal microstructure**



**Fig 3.4: welded area microstructure**

In this also, the base metal has a fine Mg-Al-Mn eutectic particles in a matrix of magnesium solid solution.

The welded area does not show a proper structure. There are cracks, air gaps seen in the welded area. It is a low speed welding, where the tool rotational speed was 900 rpm and the welding speed was 70 mm/min.

### 3.2 Hardness Test

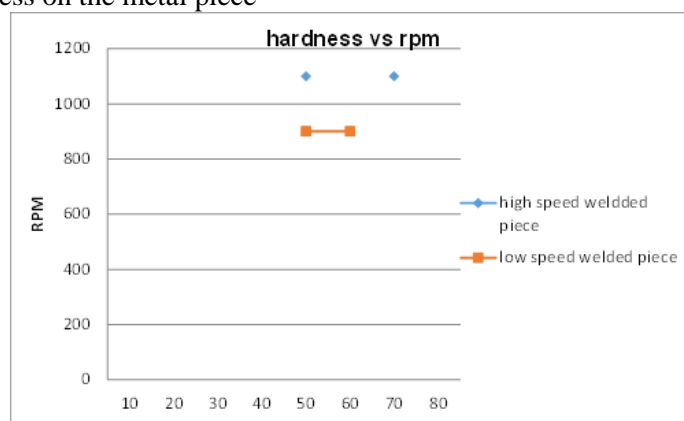
Hardness test was conducted on a Rockwell hardness test machine. For that 1/8" indenter ball was used made of steel. Rockwell hardness test is the most used in United States of America. The readings were noted on an analog meter.

**Table.3.hardness test readings**

Type Of Weld	Base Metal Hardness Reading (Hrd)	Welded Area Hardness Reading (Hrd)
Plain Plate	48	52
Low Speed (900 Rpm, 80mm/Min)	49	56
High Speed (1100 Rpm, 100mm/Min)	49	69

The readings were taken on the two samples between the welded area and the base metal area. 2kg of load was given on the metal. The table shows that the hardness value is more in the welded area compared to the base metal area. As it's an analog meter hardness tester the hardness value cannot be accurately noted, approximate values are noted. The welded area hardness value lies between 55 HRD to 70 HRD. While, the base metal hardness value lies on 48 HRD. HRD is a unit for Rockwell hardness value based on the indenter ball material we use. As we use, steel as the material the hardness unit is denoted as "HRD".

This graph shows the hardness on the metal piece



**Graph 3.1 Hardness Vs Tool Rotational Speed**

**Grain Size:** The grain size was reviewed during the microstructure test. It was based on the ASTM chart.

**Result for Grain Size:** The result shows that for base metal, the grain size no is 11.5 – 14.0 at cross section as per ASTM chart by comparison method. In same specimen the welded area had the grain size no 9.5 – 14.0 at cross section as per ASTM chart by comparison method. For specimen 2, the base metal grain size no ranges from 9.0 – 14.0 at cross section as per ASTM chart. In that specimen, the welded area has the grain size no 11.0 – 14.0 at cross section as per ASTM chart by comparison method.

## CONCLUSION

The final conclusion is that, the specimen which is welded at low speed had obtained a bad welding quality. But the specimen welded at high speed had obtained a good quality of weld comparing to other specimens. It is due to, as the thickness of the material is low (3.8 mm), it should be welded at high speed. The high thickness material can be welded properly even at low speed. The hardness value is also high compared to the base metal area in the welded area.

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