EXPERIMENTAL INVESTIGATION OF FRICTION STIR WELDING ON MAGNESIUM ALLOY

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ABSTRACT: Friction stir welding (FSW) is a modification of the traditional friction welding. It is a mechanical process whereby solid-state welding is performed using heat generated from the friction of a rotating tool. Two plates of magnesium alloy are butted together and held in place against a backing material using a clamping system. The rotating tool is then slowly plunged with a downward force into the weld joint. It remains stationary for a few seconds while enough heat is generated due to friction that the welded material will begin to flow around the tool. Once this point is reached, the tool is traversed along the joint forming the weld behind the tool as it moves along. The main benefits of friction stir welding come from the fact that the melting temperature of the work piece is not reached during the weld. The mechanical properties of welded magnesium alloys are retained and even improved when the correct welding parameters are utilized an area of valuable research as FSW is a relatively new process. By changing the parameters of the rotation speed of the tool, and the feed rate at which the tool traverses the joint in the welding process and testing of mechanical properties which to be done in different parameters.

KEYWORDS: Friction Stir Welding, Welding Magnesium Alloy

I.INTRODUCTION

A relatively new joining process, friction stir welding (FSW) produces no fumes; uses no filler material; and can join aluminum alloys, copper, magnesium, zinc, steels, ndtitanium. sometimes produces a weld that is stronger than the base material.

1.1 HOW DOES FSW WORK

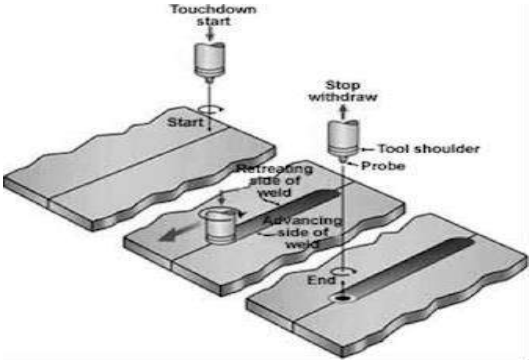


Figure 1.1 HOW DOES FSW WORK

In FSW, a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the weld joint between two pieces of sheet or plate material that are to be welded together (Figure 1). The parts must be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart or in any other way moved out of position.Frictional heat is generated between the wear-resistant welding tool and the material of the work pieces.

This heat causes the work pieces to soften without reaching the melting point and allows the tool to traverse along the weld line. The resultant plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged together by the intimate contact of the tool shoulder and the pin profile. This leaves a solid-phase bond between the two pieces.

1.2 EXPERIMENTAL PROCEDURES

Dissimilar 2024-T3 aluminum alloy and AZ31 magnesium alloy of 3mm thick plates were friction stir butt welded using a tool made of a tool steel (SKD61). The welding tool is imposed of 12mm diameter shoulder and 4mm diameter threaded probe. Figure 2 shows the schematic illustration of the tool. The tool axis was tilted by 3 degrees backward with respect to the vertical axis.

1.3 PRINCIPLES AND OPERATIONS

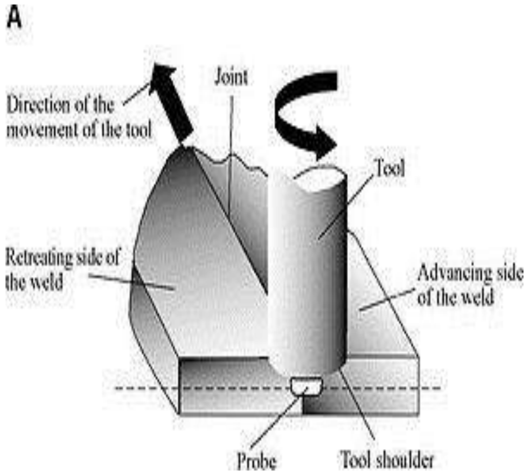


Figure 1.3 PRINCIPLE AND OPERATION-A

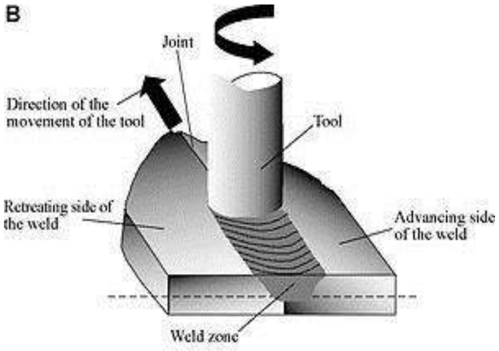


Figure 1.4 PRINCIPLE AND OPERATION-B
Schematic diagram of the FSW process:

(A) Two discrete metal work pieces butted together, along with the tool (with a probe).

(B) The progress of the tool through the joint, also showing the weld zone and the region affected by the tool shoulder.

II.RESULTS AND DISCUSSION

2.1 CHEMICAL ANALYSIS FOR MAGNESIUM ALLOY

In this project, 6 mm thick Magnesium alloy plates were used for friction stir butt-welding trials. The chemical composition of the Mg-alloy plate used in this study is given in Table 1. Table 2 shows the mechanical properties of the plate used. Friction stir welding of the plates was conducted using a friction welding machine.

Properties		**Conditions**	
		T (°C)	**Treatment**
Density ($\times 1000$ kg/m^3)	7.76	25	-
Poisson's Ratio	0.27-0.30	25	-
Elastic Modulus (GPa)	190-210	25	-

Material specification: Mg. Alloy AZ31B Rolled plate

Si%	Cu%	Zn%	Mn%	Al%	Mg%
0.08	0.05	0.72	0.03	2.87	Remainder

Table 2.1 Chemical Analysis for Magnesium Alloy

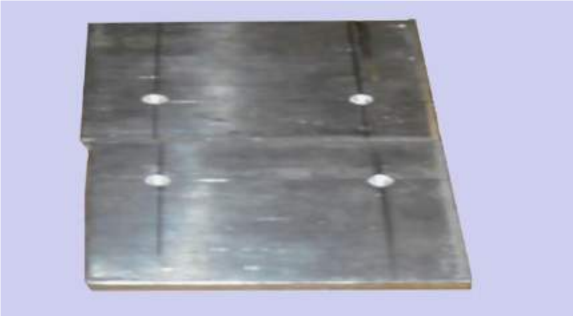


Figure 2.1 MAGNESIUM ALLOY PLATE

Mechanical Properties

Table 2.3 MECHANICAL PROPERTIES

Thermal Properties

Properties		**Conditions**	
		T (°C)	**Treatment**
Thermal Expansion (10^{-6}/ºC)	10.4	20- 100 more	-
Thermal Conductivity (W/m-K)	28.6	215 more	-

Table 2.4 THERMAL PROPERTIES

2.2 THERMAL TESTING ON WELDING MAGNESIUM ALLOY

Thermal Stability

The plates were fixed to the backing table, and then instrumented with 4 thermocouples, Even though the weld length was rather short, the recorded thermal cycle shows that thermal stability has been reached 30 mm from the beginning of the weld (thermocouple T5, T6), In order to attain the necessary plasticity, a higher heat input is needed at the beginning of the weld. This is obtained by reaching the welding speed through a ramp (continuous increase of welding speed up to the actual value). A slower speed at the beginning guaranties a higher heat input, and the right plasticity to start the weld, therefore the first thermocouples register higher temperatures than the others do. This observation is supported by the fact that all the thermocouples recorded. The thermal profiles recorded on 100mm long welds produced for a subsequent project, confirmed these results

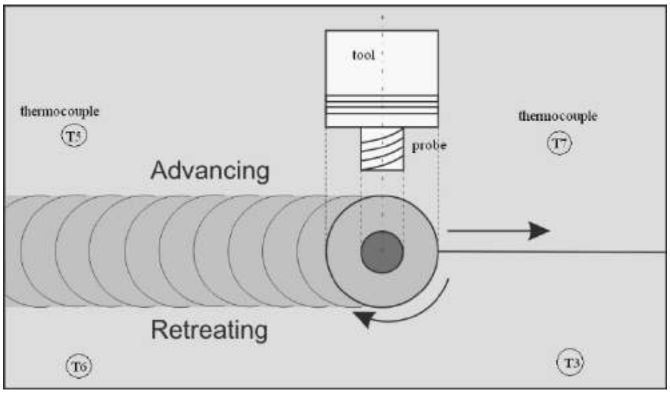


Figure 2.2 THERMOCOUPLES SETUP

Thermocouples recorded heat affected zone starting on FSW

Time (sec)	Advancing side T5 (°c)	Retreating side T6 (°c)
0	36	36
15	84	88
30	91	99
45	102	101
0	104	98
75	96	91
90	87	82

Table 2.5 THERMO COUPLE HEAT AFFECTED ZONE ON FSW

Graph for time vs temperature

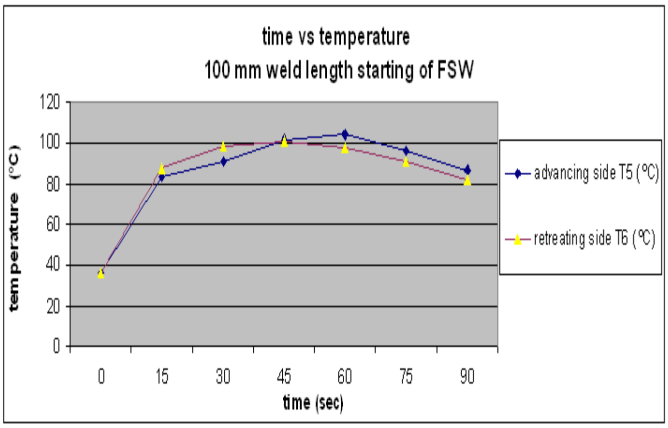
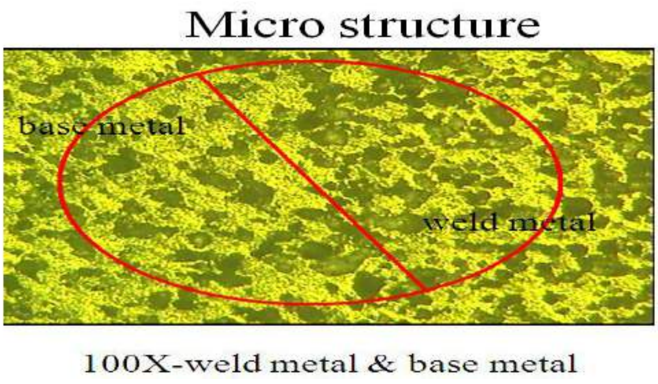


Figure 2.3 TIME VS TEMPERATURE

2.3 MICROSTRUCTURE ANALYSIS

A tool rotational speed of 1400 rpm was chosen for these trials. The plates were joined employing three different traverse speeds, 60 mm/min. The joint performance was determined by conducting optical microscopy, micro hardness measurements and mechanical testing (e.g. tensile and hardness tests).

The metallographic specimens extracted from the joints were mounted in polyester at room temperature to avoid the micro structural alterations which might take place during hot-mounting. A detailed micro structural observation was conducted for each welded plate using optical microscopy to determine the presence of any weld defect.



2.4 MICRO HARDNESS TEST

Vickers micro hardness measurement method was employed with a load of 5kgf (loading time being 10 seconds) for micro hardness measurements.

Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by

the square mm area of indentation.

Thickness mm	Width mm	CSA mm²	Tensile Load N	Tensile strength N/mm²	Position of fracture
6	7	42	6049	144.02	Weld metal

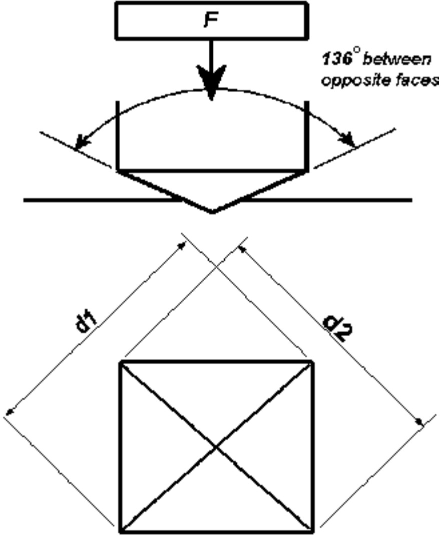


Figure 2.4 DIAMOND INDENTER

2.5 VICKERS HARDNESS CALCULATIONS

F= Load in kgf.
d = Arithmetic mean of the two diagonals, d1 and d2 in mm.
HV = Vickers hardness.

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported 72HV/5, which means a Vickers hardness of 43, was obtained using a 5 kgf force. Several different loading settings give practically identical hardness numbers on base materials and weld materials.

Base metal:

d = Long diagonal length (mm)	F = force	Hardness (HV)
0.461	5 kgf	82HV
0.464	5 kgf	81HV

Table 2.6 BASE METAL

Weld metal: (weld line)

d = Long diagonal length (mm)	F = force	Hardness (HV)
0.530	5 kgf	72 HV
0.534	5 kgf	71 HV

Table 2.7 WELD AREA

2.6 Graph for distance from the weld centre VS hardness

Tabulation for Distance VS Hardness

Table 2.8 DISTANCE VS HARDNESS

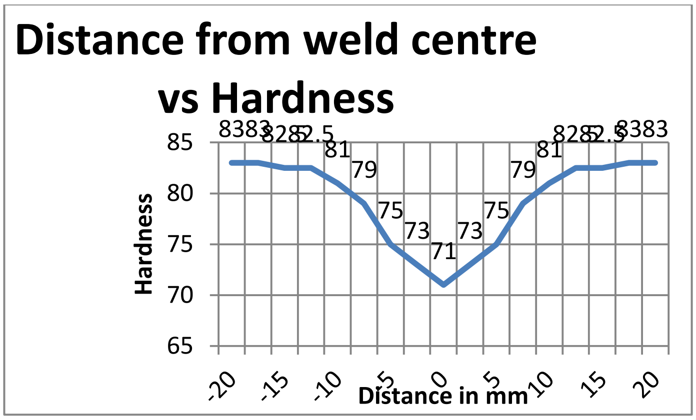


Figure 2.5 GRAPH FOR WELD CENTRE VS HARDNESS

2.7 TENSILE STRENGTH TEST ON WELDED MAGNESIUM ALLOY

Furthermore, minimum three tensile specimens prepared according to EN 895 were tested for each condition to determine the mechanical performances of the joints obtained as explained in detail in an earlier publication.

The results were compared with those obtained from the base plate specimens. Moreover, two nonstandardbending specimens (20 mm wide and 200 mm long) were also extracted from each welded plate.

Figure 2.6 WORK PIECE SETUP IN UNIVERSAL TESTING MACHINE

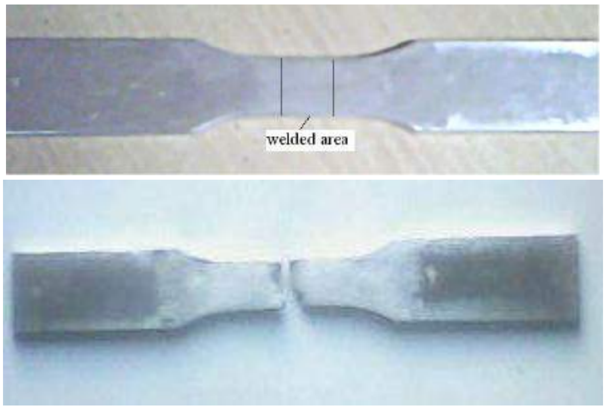


Figure 2.7 TENSILE SPECIMEN

Tabulation for load and tensile strength values

Load (KN)	Tensile strength N/mm^2
0	0
1	23.8
1.5	35.7
2	47.6
2.5	55.5
3	71.4
3.5	83.3
4	95.2
Load (KN)	Tensile strength N/mm^2
4.5	107.1
5	111.0
5.5	130.9
6	142.8
6.049	144.0

Table 2.9 LOAD VS TENSILE STRENGTH

2.8 Graph for load VS tensile strength

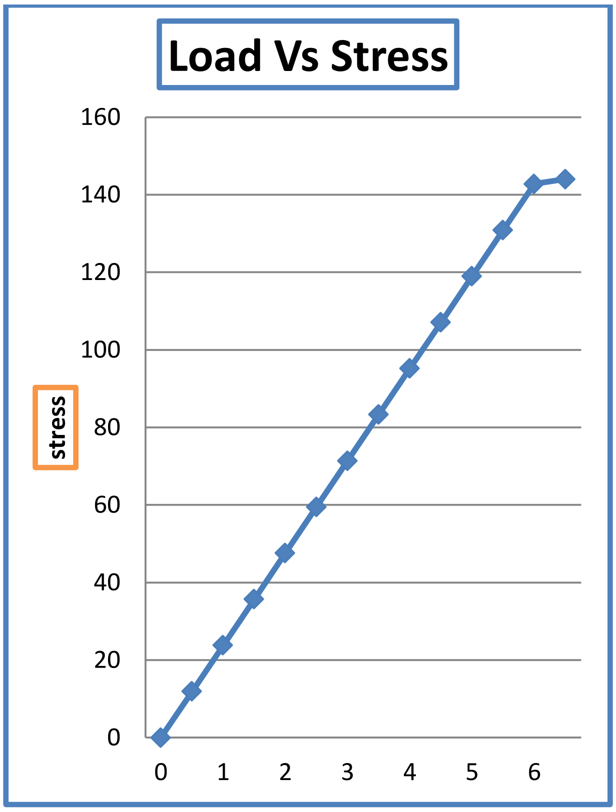


Figure 2.8 GRAPH FOR LOAD VS TENSILE STRENGTH

III.CONCLUSIONS

The Magnesium alloy can be friction stir welded in Vertical Milling Machine, but a softened region composed of the weld and HAZ evidently occurred in the joints. The degree of softening of the joints is significantly affected by the welding parameters such as welding speed and rotation speed. The optimum FSW parameters can be determined from the relations between the tensile properties and the welding parameters, and the maximum tensile strength of the joints is equivalent to 80% of that of the base material.

Hardness drop was observed in the weld region. That softening was most evident in the heat affected zone on the advancing side of the welds that corresponded to the failure location in tensile tests. An initial stage of a tunnel defect was found at the intersection of weld nugget and thermo-mechanically affected zone.

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