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ASSESSMENT OF HEAT INPUT ON MECHANICAL PROPERTIES OF MAO WELDED AZ31B MAGNESIUM ALLOY

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ABSTRACT

In this investigation an attempt has been made to study the effect of Heat Input on tensile and microstructural characteristics of magnetic arc oscillation welded AZ31B magnesium alloy joints. Five joints were fabricated using different levels of Heat Input (290 J/mm - 379J/mm). From this investigation, it is found that the joints fabricated using a Heat Input of 334 J/mm yielded superior tensile properties compared to other joints. The formation of finer grains and higher hardness in fusion zone are the main reasons for the superior tensile properties of these joints.

Keywords: *Magnesium alloy, MAO welding, Tensile properties*

1. Introduction

Magnesium alloys have exceptional specific strength, stiffness, damping capacity, machinability, castability, and weldability, making it attractive for use in the different applications including automobile and computer parts, aerospace components, mobile phones, sporting goods, and household equipment because of their some advantageous properties [1,2] As a general means of material manufacturing, welding can be used to optimize product design and minimize the costs of production. In general, the severity of a number of weld defects can be reduced if the solidification structure is refined. Magnetic arc oscillation (MAO) is one of the effective

Techniques for refining the grain structure in the fusion zone of welds. In magnetic arc oscillation technique, the arc column is made to oscillate transverse to the welding direction using a two pole magnetic probe. Arc oscillation produces mechanical agitation in the weld fusion zone and breaks down the growing dendrite columns. As the broken dendrites act as nucleating sites and increase the cooling rate, microstructure is refined. Recently few studies were carried out on effect of magnetic arc oscillation on aluminium alloys and steels. Fusion zone grain refinement in aluminum alloy welds through magnetic arc oscillation and its effect on tensile behavior was studied by JanakiRam et al [12]. Sivaprasad et al. studied the influence of magnetic arc oscillation and current pulsing on microstructure and high temperature tensile strength of alloy 718 (Nickel based precipitation hardenable super alloy) TIG weldments [13]. However, there is no information available on the effect of magnetic arc oscillation and its parameters on magnesium alloys. By keeping this in mind, an investigation has been carried out to study the influence of heat input on mechanical properties of MAO welded AZ31B magnesium alloy joints and the results are revealed in this article.

Table 1. (a) Chemical composition (wt %) of AZ31B magnesium alloy

Al	Zn	Mn	Ni	Mg
2.60	0.67	0.27	0.012	Bal

2. Experimental Work

The rolled AZ31B magnesium alloy plates with a thickness of 3 mm were cut into the required size (150 × 150 mm) by machining process. The chemical composition and mechanical properties of the base metal

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are presented in Table 1. A square butt joint configuration, as shown in Fig.1, was prepared to fabricate the joints. The plates were mechanically and chemically cleaned by acetone before welding to eliminate surface contamination. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Square butt joints were fabricated using Magnetic arc oscillation (MAO) welding. The Magnetic arc oscillation equipment is mounted and surrounded with GTAW Torch on the seam weld and interfaced with controller, which monitors the arc oscillation frequency and amplitude. Argon gas was used as a shielding gas with a constant flow rate of 20 l/min. Current is the main parameter that 65 amp to 85 amp. Remaining parameters are MAO speed 125 mm/min. MAO Frequency 2 Hz, MAO Amplitude 0.6mm are constant.

Table 1. (b) Mechanical properties of base metal AZ31B magnesium alloy

Ultimate tensile strength (MPa)	**Notch tensile strength** (MPa)	**Hardness at 0.05kg load** (Hv)
275	253	69

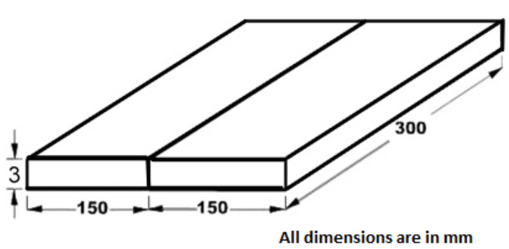


Fig. 1. Joint configuration

Five joints were fabricated using different levels of welding speeds. The other parameters such as current, oscillation frequency and amplitude were kept constant. The photographs of fabricated joints are shown in Fig 2(a). Heat input is a very important factor, which affects the bead geometry, mechanical properties and metallurgical properties of weld. Hence, heat input was also calculated and included in this study. In continuous current GTAW process the heat input per unit length is proportional to voltage and current and inversely proportional to the welding speed.

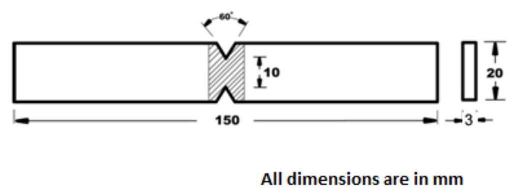
Heat input (HI) is calculated using the below Equation[10]:

$$\text{Heat Input} = \frac{I \times V \times \eta}{S}$$

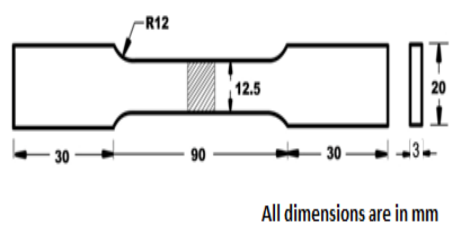
Where

I-current(amps), S-welding speed(mm/s), V-Volts,η- efficiency of the welding process.

For this processe the efficiency of utilization of the heat generated was taken as 70% [15−16]. During the experiment, voltage was found as 18V was taken for the heat input calculation. The heat input values for different levels of welding speeds, are presented in Table 2. To measure the temperature during welding, a K- type chromel-alumel thermocouple was used [13]. Thermocouple was located at 10 mm from the weld centre. The hot end diameter of the thermocouple was 1.5 mm, the cold end was fixed to a thermocouple bank and was in turn connected to the DAQ Labview.



(a) Notched tensile specimen



(b) Unnotched tensile specimen

Fig.2 Dimensions of tensile specimen

The welded joints were sliced and then machined to the required dimensions according to the ASTM E8M-04 standard for sheet type material (i.e., 50 mm gauge length and 12.5 mm gauge width). Two different tensile specimens were prepared to evaluate the transverse tensile properties of the welded joints. The smooth (unnotched) tensile specimens were prepared to evaluate yield strength, tensile strength and elongation of the joints. The notched specimens were prepared to evaluate notch tensile strength and the notch strength ratio of the weld. The tensile test was carried out in a

100 kN, electro mechanical controlled universal testing machine (Make: FIE-Bluestar, India; Model: UNITEK-94100). The 0.2 % offset yield strength was derived from the load-displacement diagram. The percentage of elongation was also evaluated and the values are presented in Table 2. The photographs of MAO joints and tensile specimens are shown in Fig.2(a-c). A Vicker's microhardness testing machine (Make: SHIMADZU, Japan; Model: HMV-2T) was used to measure the hardness across the weld cross section with a 0.05 kg load for a 20 s dwell time. The specimens for metallographic examination were sectioned to the required size and then polished using different grades of emery paper. A standard reagent made of 4.2 g picric acid, 10 ml acetic acid, 10 ml diluted water and 70 ml ethanol was used to reveal the microstructure of the welded joints. Microstructural analysis was carried out using a light optical microscope (Make: MEIJI, Japan; Model: MIL-7100) incorporated with image analyzing software (Metal Vision).

Fig 2(a).Photographs of Fabricated joints

Fig 2(b).Before tensile test

Fig 2(c).After tensile test

3. Results

3.1. Macrostructure

The macrostructure of the joints made with different current are presented in Fig. 3. At lower heat input levels (i.e., current of less than 65 amp), a partial penetration was observed in the welded joints. At higher heat input levels (i.e., higher current of greater than 85 amp), a burn through of the weld and the surface breaking defects were observed. This may be the reason for the lower tensile properties of these joints. The joint fabricated the heat input of 334 J/mm (75 amp) produced a defect free joint with full penetration.

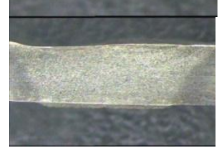
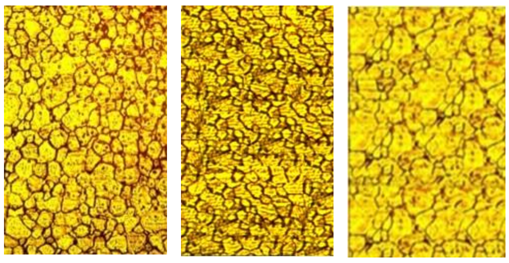
Heat Input J/mm	**Macrostructure (cross section)**	**Observations**
290		FZW - 5 mm FZD -2.8 mm Partial penetration
334		FZW - 5 mm FZD - 3 mm Full penetration
379		FZW- 10 mm FZD - 3 mm Burn through

Fig.3 Effect of Heat Input on fusion zone macrostructure

3.2. Microstructure

The microstructures of fusion zone of all the joints are displayed in Fig.4. From the micrographs, it is understood that the of heat input have appreciable influence on average grain diameter of fusion zone region in AZ31B magnesium alloy. The joint fabricated with a of heat input of 334 J/mm (75 amp), contains finer grains (26 µm) in the fusion zone compared to other joints. Coarse grains (46 µm) were observed in the joint fabricated using heat input of 379 J/mm (85 amp).



290 J/mm	334 J/mm	379 J/mm
Grain Size	**Grain Size**	**Grain Size**
24μm	**26μm**	**46μm**

Fig.4 Effect of Heat Inputon fusion zone microstructure

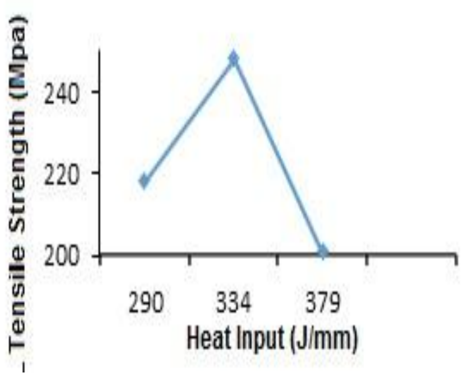


Fig 5 Effect of Heat Input on Tensile strength

3.4. Temperature profile

The heating and cooling rate for the various current are shown in Fig.6. The cooling rate for the joint made with the current of 65 amp, 75 amp, and 85 amp was determined and it is presented in Table.2. From the fig 6. it is observed that, the highest temperature of 390°C was recorded for the joint made with current of 85 amp. The lowest temperature of 270°C was recorded for the joint made with current of 65 amp.

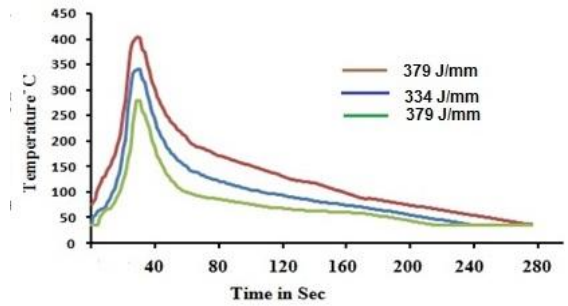


Fig 6 Heat input on Temperature profile

Table 2 Measured peak temperature values

Exp No.	**Heat Input**J/mm	**Measured peak temperature at 10 mm from the weld centre line** (°C)	**Cooling rate** (°C/s)
1	379	403	1.4
2	334	341	1.6
3	290	280	1.9

4. Discussion

From the results, it is observed that the current has predominant effect on tensile properties of magnetic arc oscillation welded AZ31B joints of magnesium alloys. The tensile strenght for the joint made with the current of 65 amp, 75 amp, and 85 amp was determined and it is presented in Table.3. The highest peak temperature (390°C) was recorded for the joint made with the heat input of 379 J/mm (85 amp). Further it is also observed that for higher heat input the cooling rate is slower (1.2 ºC/s), which leads to formation of coarser grains in the fusion zone. The average grain size of fusion zone is about 46 μm. It is known that an increase in heat input will result in slow cooling rate. Moreover, the slower the cooling rate during solidification, the longer the time available for grain coarsening. The higher heat input produces, coarse and elongated grains in fusion zone is the reason for lower hardness values. Moreover the tensile strength of the joint is lower than that of joint made with the heat input of 334 J/mm (75 amp). If the current is greater than 75 amp, the reduction in tensile properties was observed. At higher heat input (379 J/mm) the surface breaking defects were observed.

Also the formation of coarser and elongated grains in the fusion zone and lower hardness are the reason for the lower tensile strength (201 Mpa) of these joints

Table 3 Effect of Heat Input on traverse tensile properties of the joints

Heat Input (J/mm)	**Ultimate tensile strength** (MPa)	**Joint efficiency** (%)
290	**218**	**79**
334	**248**	**91**
379	**201**	**73**

The lowest peak temperature (270°C) was recorded for the joint made with the heat input of 290 J/mm (65 amp). Further it is also observed that for lower heat input the cooling rate is faster (1.7 ºC/s), which leads to the formation of finer grains in the fusion zone. Over the solidification range for AZ31 magnesium alloy (390ºC to 270ºC), with an increased cooling rate, the solidification time is suppressed and a finer weld metal microstructure is produced.

In contrast, the decrease in current leads to decrease in heat input. This leads to faster cooling rate and subsequently formed finer grains in fusion zone. It can also be noted that the precipitates concentration in the fusion zone are more, as the heat input is increased [10]. This is mainly due to the decreased cooling rate with increasing heat input.

If the current is less than 65 amp the lack of penetration is achieved (Fig.4). This may be due to lower heat input. The heat is not sufficient to melt all the metals in the fusion zone. This is the one of the reasons for lower tensile strength (218 MPa) of these joints. The joint fabricated with a current of heat input of 334 J/mm (75 amp) contain finer grains in the fusion zone (average grain size is about 26 µm) and recorded higher hardness (68 Hv) in fusion zone compared to other joints. The heat input of 334 J/mm produced defect free joint with full penetration. It can be attributed to the presence of finer grains compared to the other joints is the main reason for the higher hardness in this joint [7]. The reason for higher hardness in the fusion zone is relatively faster cooling rate due to steeper thermal gradients and consequently has fine grained microstructure. Grain refinement led to an improvement in fusion zone tensile properties. The maximum tensile strength was achieved for the joint made with a current of 75 amp

5. Conclusions

Of the five welded joints, the joint fabricated with heat input level of 334 J/mm, showed superior tensile properties due to optimum current of 75 amp than their counterparts. The formation of finer grains in the fusion zone and higher hardness in fusion zone, are the main reasons for the superior tensile properties of the above joint.

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