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Influence of Arc Oscillation Amplitude on Tensile Properties of Gas Tungsten Arc (GTA) Welded AZ31B Magnesium Alloy Joints

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ABSTRACT

In this assessment, an effort has been made to study the outcome of magnetic arc oscillation amplitude on tensile and microstructural characteristics of gas tungsten arc welded AZ31B magnesium alloy joints. Arc oscillation amplitudes measuring 0.2mm-1.0mm are used to fabricate the five points. The study results proved that are oscillation amplitudes with a range of 0.6mm comparatively hold higher level of tensile properties while fabricating joints. The grains which are finer in nature and the precipitates having uniform distribution are responsible for the tensile properties being superior in the formation of the joints.

Keywords : Magnesium Alloy, Gas Tungsten Arc Welding, Arc Oscillation Amplitude, Tensile Properties, Microstructure

I. INTODUCTION

The industries such as automotive and aircraft require metals with higher strength, low density and good level of stiffness of magnesium alloys are found suitable in number of applications in these industries. As a hexagonal close-packed (hcp) metal, magnesium alloys reveal reduced ductility and cold workability owing to their inadequate slip systems mainly at room temperature, which restrict its extensive application [3,4]. Hence, there is a need for a viable process of welding which could act extremely well in a wide range of magnesium alloys applications as in necessary to join the segments which are easy to cast and change them into complex parts. Being, naturally, advantages with utilisation value, the magnesium alloys based on the gas tungsten arc is considered to be the popular, as well as, the chief method and adopted in the process of welding.

Fusion zone of gas tungsten arc welded magnesium alloy characteristically reveals coarse grains because of the widespread thermal conditions during weld metal solidification. This frequently results poorer weld mechanical properties and meager resistance to hot cracking. While it is thus highly desirable to control solidification structure in welds, such control is often very difficult because of the higher temperatures and higher thermal gradients in welds in relation to castings and the epitaxial nature of the growth process. In general, the severity of a number of weld defects can be reduced if the solidification structure is refined. In order to enhance the strength of the hot cracking resistance and to retain the mechanical properties newer methods of welding by employing the magnetic arc oscillation has been in practice. Magnetic arc oscillation technique resulted in significant microstructural refinement in weld fusion zone. The defects found in the welding process could be to great extend minimized by refining the structure of solidification.

By adopting two poles magnetic probe the column of the arc in MAO, which could refine the grain structure, to effect the oscillation in transverse towards the direction of the welding. This refinement of the grains is found to make the techniques effective and works well in the welding process, especially when the fusion zones are involved. The columns get broken when mechanical agitation is produced due to arc oscillation and dendrites being the nucleating units the rate of cooling raises and also micro structure get refined. Janaki ram did a study to find the effect of MAC on aluminium alloys and the tensile behavior with special reference to the refinement of the grains in the fusion zone. 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 [11]. Effect of mechanical arc oscillation on the grain structure of mild steel weld metal was examined by Mahajan et al. [12]. Grain refinement in magnetically stirred GTA welds of aluminum alloy was studied by Pearce et al. [13].

The available literatures are mainly focused on magnetic arc oscillation welding on aluminium alloys and steels only. 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 arc oscillation amplitude on tensile and microstructure properties of magnetic arc oscillation (MAO) welded AZ31B magnesium alloy joints and the results are presented in this paper.

II. EXPERIMENTAL WORK

The rolled AZ31B magnesium alloy plates with a thickness of 3 mm were cut into the vital size (150 × 150 mm) by machining process. The chemical composition and mechanical properties of the base metal 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. The photographs of MAO equipment and controller unit is shown in Fig, 2(a) and 2(b). Argon gas was used as a shielding gas with a constant flow rate of 20 l/min.

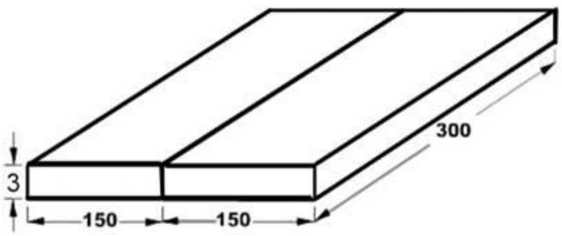
Table 1. (a) Chemical composition (wt.%) of AZ31B magnesium alloy

Al	Zn	Mn	Ni	Cr	Cu	Mg
2.60	0.67	0.27	0.012	0.008	0.017	Bal

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

0.2 % offset Yield Strength (MPa)	Ultimate tensile strength (MPa)	Elongation in 50 mm gauge length (%)	Reduction in cross section area (%)	Notch tensile strength (MPa)	Notch strength ratio (NSR)	Hardness at 0.05kg load (Hv)
160	275	14.7	14.3	253	0.92	69

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.



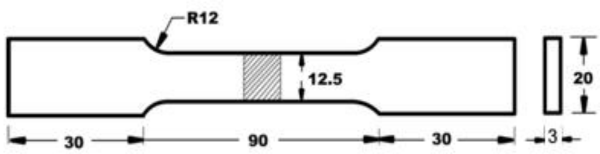
(All dimensions are in mm)

Fig. 1. Joint configuration

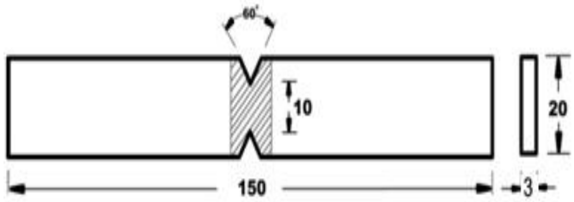
(a) MAO Equipment

(b) Controller unit

Fig. 2 Photographs of MAO Unit



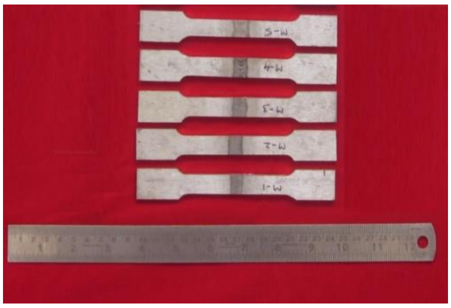
(a) Unnotched tensile specimen



(b) Notched tensile specimen

Fig. 3 Dimensions of tensile specimen

(a) Fabricated Joints



Before tensile test

After tensile test

(b) Tensile Specimens

4. Photographs of fabricated joints and tensile specimens

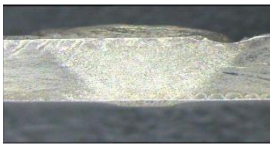
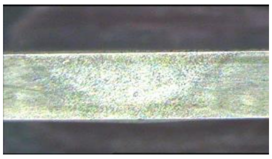
The notched specimens were prepared to assess notch tensile strength and the notch strength ratio of the weld. The tensile test was conceded out in a 100 kN, electro mechanical controlled universal testing machine (Make: FIE-Bluestar, India; Model: UNITEK-94100). The 0.2 % offset yield strength was resulting from the load-displacement diagram. The percentage elongation was also evaluated and the values are presented in Table 2. The dimensions of tensile specimen are shown in Fig. 3. The photographs of MAO joints and tensile specimens are shown in Fig.4 (a) and 4(b). A Vicker's microhardness testing machine (Make: SHIMADZU, Japan; Model: HMV-2T) was used to gauge 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 necessary size and then polished using different grade of emery sheet. A usual reagent made of 4.2 g picric acid, 10 ml acetic acid, 10 ml diluted water and 70 ml ethanol was used to expose the microstructure of the welded joints. Microstructural study was carried out by means of a light optical microscope (Make: MEIJI, Japan; Model: MIL-7100) integrated with image analyzing software (Metal Vision).

III. RESULTS

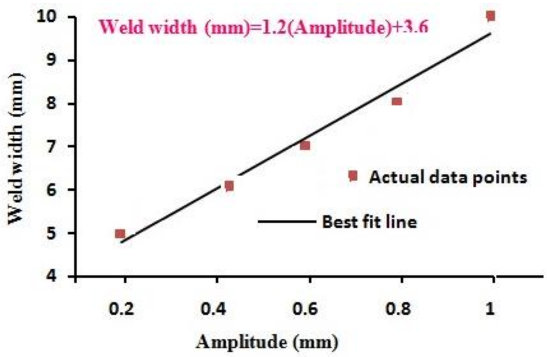
3.1 Macrostructure

The macrostructures of the joints made with various arc oscillation amplitudes ranging from 0.2 to 1.0 mm are shown in Fig 3.1. These tests proved that amplitude of 0.6 mm was most effective without any other counter effects. At higher amplitudes the arc behavior was erratic, leading to bead roughness and the surface breaking defects were observed (Janakiram et al, 1999). Amplitude increases, weld width also increases (1 mm). Due to higher amplitude, the arc is longer, so the stability of the arc may be poorer during oscillation (Koteswara rao et al, 2005). If the amplitude decreases, the weld depth is increased. The effect of amplitude on fusion zone characteristics is shown in Fig. 3.2. Whenever, the amplitude increased from lower level to higher level, depth of penetration is maintained constant in certain level, and then penetration decreases with increasing amplitude (Fig.3.2 (a)), but the weld width is increased linearly with increasing amplitude (Fig.3.2 (b)). Fig 3.2(c) shows the optimum welding conditions that satisfying all the weld quality characteristics.

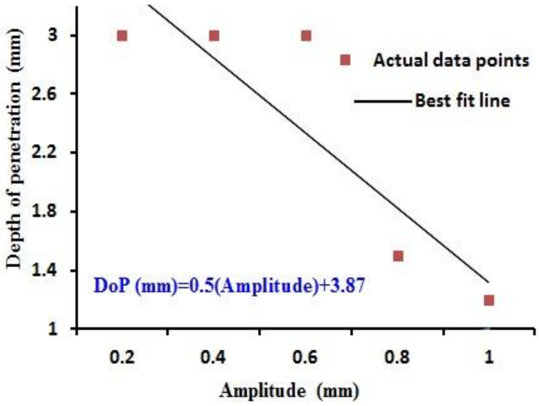
Fig 3.1 Effect of amplitude on weld bead profile

Amplitude (mm)	**Macrograph**	**Depth of penetration (mm)**	**Weld width (mm)**	**Observations**
0.2		3	5	Full penetration
0.6		3	7	Full penetration
1.0		1.8	10	Incomplete penetration

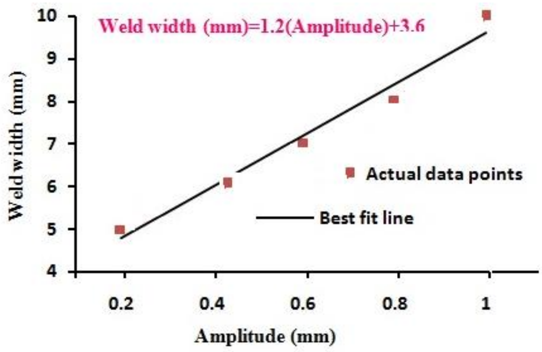
From Fig 3.2(c), one can easily find the optimum conditions to weld to magnesium alloys with proper depth of penetration. It is observed that when the amplitude increased from 0.6 mm leads to incomplete penetration of the weld region and decreases beyond that region is called burn through region



(b)



(a)



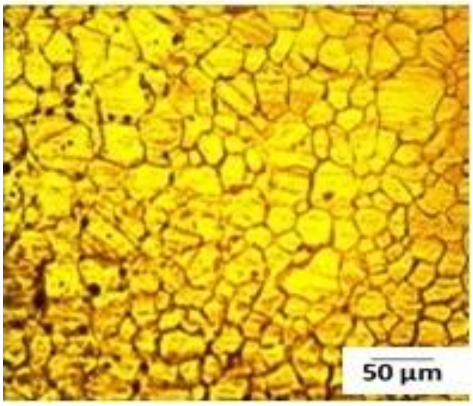
(c)

Fig 3.2 Effect of amplitude on fusion zone characteristics

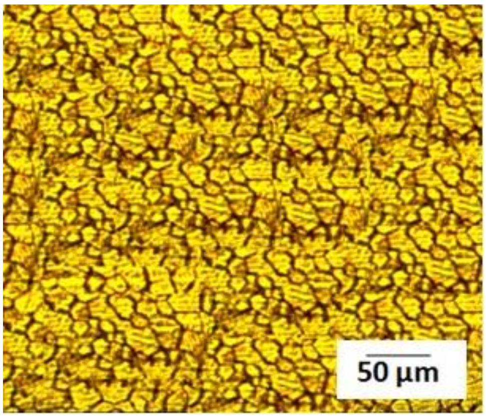
.3.2 Microstructure

The microstructures of fusion zone of all the joints are displayed in Fig 3.3. From the micrographs, it is understood that the arc oscillation amplitude has substantial influence on average grain size of fusion zone region in MAO welded AZ31B magnesium alloy. The joint made with a arc oscillation amplitude of 0.6 mm, contains finer grains (26 µm) in the fusion zone compared to other joints. Coarse grains (42 µm) were observed (Fig. 3.3 (a)) for the joint fabricated using a amplitude of 0.2 mm.

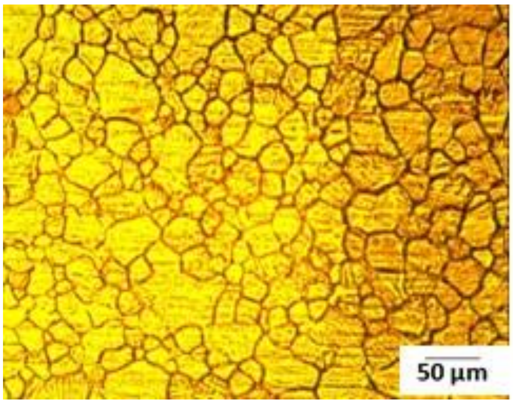
In order to simplify this work we developed a linear equation based upon the experimental results, to predict the grain size for welding of AZ31B magnesium alloy (Fig 3.3(d)). This equation is simple and one can easily find the grain size by extrapolating this curve and enables the good quality welding by referring the above depicted diagram, also it is used predict the grain size any condition when the arc amplitude is known.



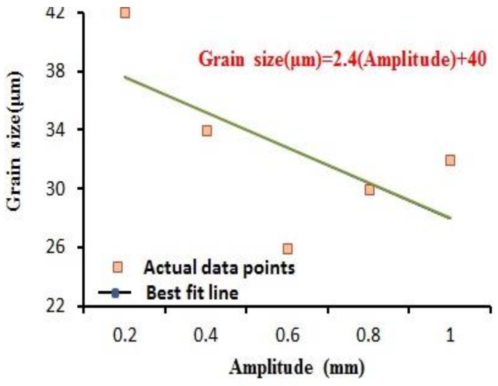
(a) Amplitude = 0.2 mm



(b) Amplitude = 0.6 mm



(c) Amplitude = 1.9 mm



(d)

Fig. 3.3 Effect of Amplitude on fusion zone microstructure

3.3 Microhardness

The microhardness plot is shown in Fig.3.4. The joint made with amplitude of 0.6 mm recorded higher hardness (68 Hv) in the fusion zone. The joint fabricated with a amplitude of 0.2 mm recorded lower hardness (59 Hv) in the fusion zone. From the Fig. 3.5 it is inferred that, when the amplitude increased from lower level to higher level, hardness also increased up to certain level and starts to decreased.

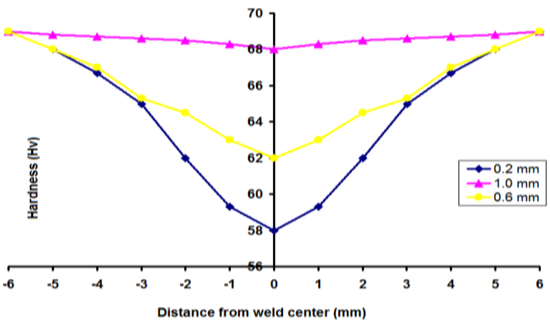


Fig 3.4 Hardness profiles

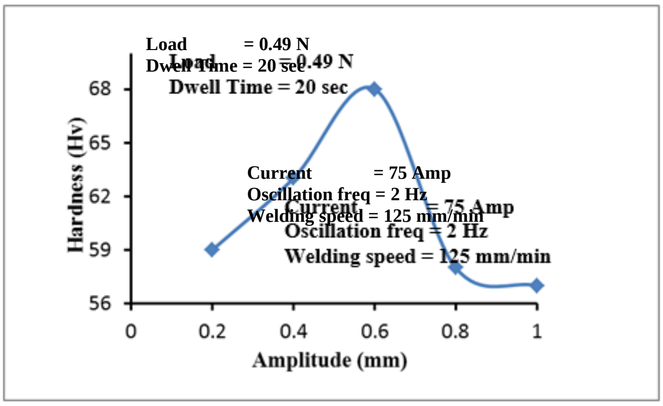


Fig 3.5 Effect of arc amplitude on fusion zone hardness graph

3.4 Tensile Properties

The transverse tensile properties of the joints made using different amplitudes were evaluated and the tensile strength values are shown in Table 3.1. The joint made with amplitude of 0.6 mm exhibits higher yield strength (192 MPa), tensile strength (248 MPa) and elongation (7.6 %). The joint fabricated with a amplitude of 1.0 mm exhibited lower yield strength (168 MPa), tensile strength (210 MPa) and elongation (6.8 %) and the joint fabricated with a amplitude of 0.2 mm exhibited the yield strength of 169 MPa, tensile strength of 212 MPa and elongation of 7.0 %.

The notch strength ratio is the ratio between the tensile strength of the notched specimen at maximum load (NTS) to the ultimate tensile strength of the unnotched specimen. The notch strength ratio (NSR) is less than unity (< 1) for all the joints. This suggests that the AZ31B magnesium alloy is sensitive to notches and they fall into the ‘notch brittle materials’ category. The NSR is 0.92 for the unwelded parent metal and PCGTAW causes a reduction in the NSR of the weld metal.

The joint fabricated with a amplitude of 0.6 mm, exhibited notch strength ratio of 0.75. The joint fabricated with a amplitude of 0.2 mm, exhibited notch strength ratio of 0.77, and the joint fabricated with a amplitude of 1.0 mm, exhibited notch strength ratio of 0.76.

Joint efficiency is the ratio between the tensile strength of the welded joint and the tensile strength of the unwelded parent metal. The joint fabricated with amplitude of 0.6 mm exhibited a maximum joint efficiency of 91 % and the joint fabricated with a amplitude of 0.2 mm exhibited the joint efficiency of 77%. The joint fabricated with a amplitude of 1.0 mm exhibited a minimum joint efficiency of 76 %.

Table 3.1 Effect of Amplitude on transverse tensile properties of the joints

Arc Amplitude (mm)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation in gauge length of 50 mm(%)	Notch tensile strength (MPa)	Notch strength ratio (NSR)	Joint efficiency (%)
0.2	169	212	7.0	165	0.77	77
0.4	180	225	7.3	176	0.78	82
0.6	192	248	7.6	188	0.75	91
0.8	182	228	7.1	179	0.78	83
1.0	168	210	6.8	161	0.76	76

IV. DISCUSSION

From the Table 3.1 and Fig. 4.6, it is observed that, the amplitude has predominant effect on tensile strength, fusion zone hardness and fusion zone grain size of magnetic arc oscillation welded AZ31B magnesium alloys joints. The measured peak temperature values and cooling rates are shown in table 4.2. The effect of amplitude on temperature profile is shown in Fig. 4.7.

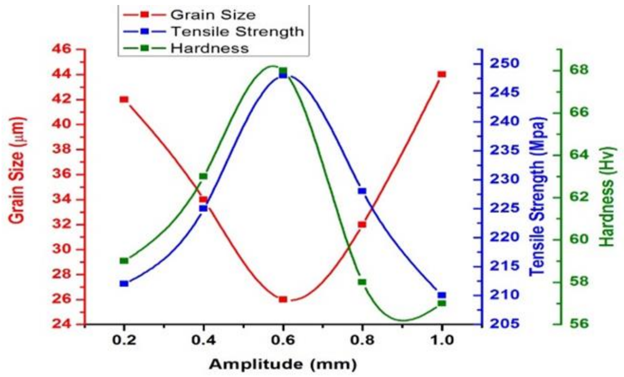


Fig 4.6 Effect of arc amplitude on grain size, microhardness and tensile strength

The effect of arc amplitude from 0.2 mm to 1.0 mm has been evaluated in this study, It is observed that arc amplitude plays an important role in generating the equiaxed grains. Among the investigated arc amplitude between 0.2 mm to 0.6 mm, are found to be effective in altering grain structure.

The weld bead morphologies depend on the arc amplitude. At lower amplitude, the refinement of weld metal is not appreciable, which leads to formation of grains coarsening in the fusion zone (Bridar et al, 2012). The average grain size of fusion zone is about 42 μm. The microhardness values recorded in the joint made with 0.2 mm shows that it is lower than that of joint made with 0.6 mmin the fusion zone, an appreciable increase in grains size of the fusion zone is the reason for lower hardness values, and moreover the tensile strength of the joint is lower than that of joint made with the arc amplitude of 0.6 mm. During tensile test, all the specimens were invariably failed at fusion zone. This is consistent with the hardness profile shown in Fig 3.4.

Amplitudes higher than the optimum (1.0 mm), i.e at higher amplitudes the arc behavior was erratic, leading to bead roughness and burn through was observed. Probably for a longer arc the stability may be poorer during oscillation. The highest peak temperature (430oC) was recorded for these joint. This leads to slower cooling rate (2.6 ºC/s) and subsequently formed coarser grains in fusion zone (average grain size of fusion zone is about 44 μm), the tensile strength of the joint is lower than that joint fabricated with an arc amplitude of 0.6 mm. The formation of coarser and elongated grains in the fusion zone and lower hardness are the reasons for the lower tensile strength (210 MPa) of these joints.

The forces due to the external magnetic field augment the indigenous Lorentz forces in the weld pool and thus increase fluid flow and reduce temperature gradients. In addition, the arc oscillation changes the shape of the weld pool continuously, and thus the direction of maximum thermal gradient at the solidifying boundary also changes with time. This leads to a situation in which, instead of a few favorably oriented grains growing over long distances, newer grains become favorably oriented with respect to the instantaneous direction of maximum thermal gradient leading to grain refinement (Sivaprasad et al., 2009). The temperature (341 oC) was recorded for the joint made with the amplitude of 0.6 mm. Further it is also observed that faster cooling rate of 1.6ºC/s was observed for this joint, than the joint made with amplitude of 1.0 mm, which leads to formation of finer grains in the fusion zone. The average grain size of fusion zone is about 30 μm. The refinement of solidification structure is seen to have exercised beneficial effect on the yield (192 MPa) and tensile strengths (248 MPa) of the AZ31B MAO welded magnesium alloy. The reason for this trend of microhardness in the fusion is relatively higher thermal gradients and subsequently has fine grained microstructure (Bridhar et al, 2012). Grain refinement also led to an improvement in tensile properties of the joints.

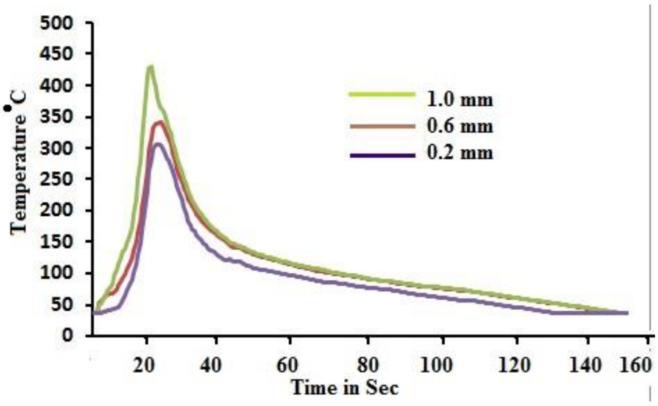


Fig.4.7 Effect of Amplitude on Temperature profile

Table 4.2 Measured Peak temperature values

Experiment No.	Amplitude (mm)	Measured peak temperature at 10 mm from the weld centre line (^{O}C)	Cooling rate ($^{O}C/s$)
1	0.2	305	3.3
2	0.6	341	1.6
3	1.0	430	2.6

V. CONCLUSIONS

From this investigation, the following important conclusions are derived:

(1) The arc oscillation frequency has significant influence on the grain size and hardness of fusion

zone and subsequently on the tensile properties of GTAW joints of AZ31B magnesium alloy.

(2) The five welded joints fabricated varying the arc oscillation frequency between 0.2-1.0 mm, the joint fabricated using a oscillation frequency of 0.6 mm, shows superior tensile properties than their counterparts.

(3) The formation of finer grains in the fusion zone, higher hardness of fusion zone, and uniformly distributed precipitates in fusion zone are found to be the reasons for the superior tensile properties of the joint fabricated using a arc oscillation frequency of 0.6 mm than other joints.

VI. ACKNOWLEDGMENTS

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