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Study of Heat Input for GTA Welded Aluminium Alloy 7039

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***Abstract*— Aluminium Alloy 7039 is an Al-Mg-Zn alloy employed in aircraft, automobiles, armored fighting vehicles and high speed trains due to their low density, high specific strength and excellent corrosion resistance. In this paper, the effects of heat input on Gas Tungsten Arc (GTA) welded Aluminium Alloy 7039 have been studied at various combinations of pulse parameters with sinusoidal AC wave. Also the effect of heat input on the microstructure, heat affected zone (HAZ) width, grain size and other mechanical properties of the weld joint has been studied.**

***Index Terms*— AA7039, GTAW, Heat Input, Microstructure of welded joints.**

I. INTRODUCTION

Aluminum alloys find wide applications in aerospace, automobiles, railway vehicles, bridges and high speed ships due to its light weight and higher strength to weight ratio [1]. Aluminium alloy 7039 has 4% Zn and 2.8% Mg as major alloying elements [2]. Other elements, such as Mn, Cr and Ti, are added in lesser amounts to enhance mechanical properties, corrosion resistance and for grain refinement. Two filler alloys, 5039 and 5356, are generally used in welding 7039. Alloy 5356, which was used in this study, has the advantage of better elongation, ease of welding and less tendency to develop cracking when welding thick sections and therefore is widely used in armor applications.

Welding of aluminium is generally performed either by gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW). Lots of difficulties are associated with this kind of joining process, mainly related to the presence of a oxide layer, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage and, above all, high solubility of hydrogen in the molten state. Further problems occur when attention is focused on heat-treatable alloys, since heat, provided by the welding process, is responsible for the decay of mechanical properties, due to phase transformations and softening.

Pulsed GTAW process is frequently used for welding of aluminium alloys as heat input during welding can be precisely controlled. Pulse process variables are controlling factor for heat input, which in turn leads to grain refinement in fusion zone, width reduction of HAZ, segregation of alloying elements and residual stresses [3, 4]. Improved mechanical properties of weld are achieved by using current pulsing due to the grain refinement occurring in the fusion zone. The main aim of pulsing is to achieve maximum penetration without excessive heat built-up.

A linear relationship exists between heat input of a weld and maximum temperature at a given distance from the weld centre line. It shows that pulsed arc welds are cooler and exhibit less thermal distortion than conventional GTA welds of the same penetration [5]. Heat input is typically calculated as follows: $H = [60EI]/1000$, where H = Heat Input (kJ/mm), E = Arc Voltage (Volts), I = Current (Amps) and S = Travel Speed (mm/min).

A weldment basically consists of five micro structurally distinct regions normally identified as fusion zone, unmixed region, partially melted region, HAZ and unaffected base metal. The HAZ is the portion of weld joint which experiences peak temperatures high enough to produce solid-state microstructural changes but they are too low to cause any melting. Every point of the weldment in the HAZ relative to the fusion line is subjected to unique thermal experience during welding, in terms of both maximum temperature and cooling rate. Thus, each point has its own microstructural features and corrosion susceptibility. Partially melted region extends usually one or two grains into the HAZ relative to the fusion line. It is characterized by grain boundary liquation, which may result in liquation cracking. An increase in the pulse frequency refines grain structure of weld metal using pulses of short duration. At a given frequency, long pulse duration produces coarser grain structure than shorter pulse duration. Further increase in the peak current leads to coarseness of grain structure [6]. Dong Min et al [7] show that with an increase of the heat input, the grains both in the fusion zone and the HAZ were coarsen and the width of the HAZ was increased for TIG welded AZ61 magnesium alloy plates.

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This paper gives the results of an investigation to determine the effect of heat input during GTAW on the following properties obtained from the microstructural analysis for butt welds of Al alloy 7039: 1) Microstructure, 2) Heat Affected Zone (HAZ) width, 3) ASTM Grain Size Number, 4) Microhardness (VHN)

II. EXPERIMENTAL PROCEDURE

In this study, 5Al alloy 7039 GTA welded 5.0 mm thick samples were undertaken. These samples were welded with AA5356 filler rods. The chemical compositions of the base metals and filler rod are shown in Table 1. Samples were machined to the required dimensions (300 x 150 x 5 mm) and edges were prepared for butt welding. Welding of the samples was carried out using an automatic Pulse TIG welding machine (TRITON 220V AC/DC). Samples were welded at the parameters shown in Table 2. Specimens were separated out from the transverse section of the weld joint and polished using a standard metallographic procedure, which consisted of molding, polishing and etching. Specimens were etched with Keller's reagent. The following welding conditions were maintained constant during the welding:

a) Electrode : Tungsten with 2% Zirconium
b) Electrode size : 2.4 mm diameter
c) Shielding gas : 30% helium + 70% argon
d) Shielding gas flow rate : 8 Litre /min
e) Filler diameter : 3.15 mm
f) Welding speed : 4.16 mm/sec
g) Electric voltage : 16.8 V
h) AC Balance % : 0 (sinusoidal)

Table 1: Chemical Composition of Base and Filler Metal (Weight %)

Alloy	Al	Mg	Zn	Others
7039	93.0	2.80	4.00	Rest
5356	95.2	4.8	-	

Table 2: Pulse GTA Welding Parameters

Process Parameters	Unit	Sample				
		1	2	3	4	5
Pulse Current	A	150	150	180	195	210
Base Current	A	105	135	75	105	90
Pulse Frequency	Hz	100	150	100	50	50
Pulse Duty Cycle	%	60	90	90	75	90

III. TESTING AND ANALYSIS

The microstructures of the specimens were studied under optical microscope (GX51 N-233U, Olympus). Image analysis of micrographs of the weld metal was carried out using image analyzing software .The calculation of heat input for the pulse current welding process can be done by mean current using the relationship. $Im = [I_p t_p + I_b t_b]/t_T$ on heat input equation, where Im is mean current, I_p is pulse current, t_p is time on peak current, I_b is base current, t_b is time on base current, t_T is total time. The heat input for various samples are tabulated in the Table 3.

Table 3: Heat Input of Samples

Sample No	Tp sec	Tb sec	I mean (A)	H (J/mm)
1	0.006	0.0040	132.0	31.9
2	0.006	0.0007	148.4	35.9
3	0.009	0.0010	169.5`	41.0
4	0.015	0.0050	172.5	41.8
5	0.018	0.0020	198.0	48.0

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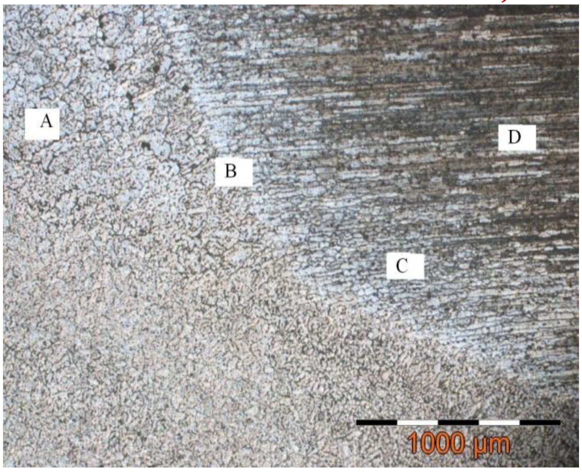

Fig 1: Microstructure of welded AA7039 (50x)
A–WZ, B–FB, C–HAZ and D-Unaffected BM

Fig 2a: Microstructure of Sample1 (100x)

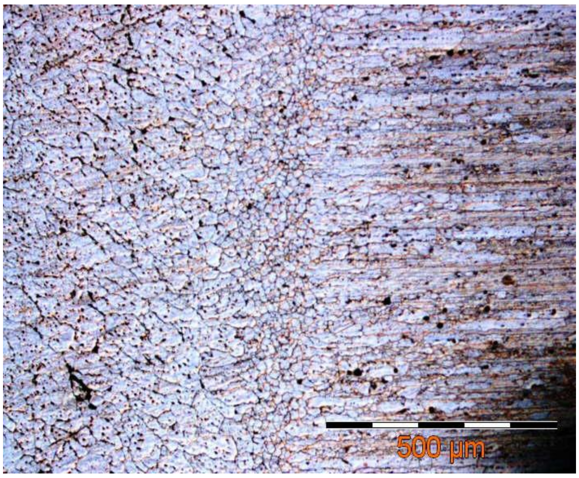

Fig 2b: Microstructure of Sample 2 (100x)

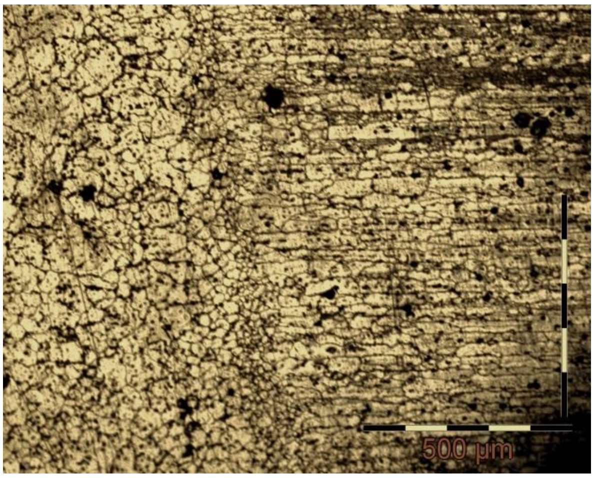

Fig 2c: Microstructure of Sample 3 (100x)

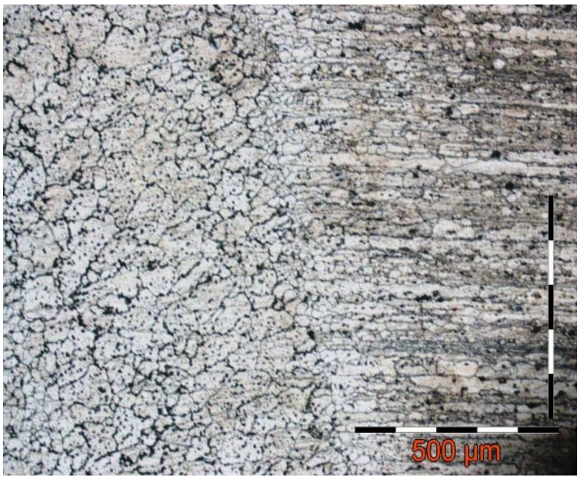

Fig 2d: Microstructure of Sample 4 (100x)

Fig 2e: Microstructure of Sample 5 (100x)

1) Microstructural Study: The microstructure of welded AA7039 is shown in Fig 1, in which weld zone (WZ), fusion boundary (FB), HAZ and unaffected base metal (BM) is clearly visible. The grains in weld zone are coarser

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due to as cast nature of the weld and fine equiaxed grains are present at the fusion boundary. HAZ has large columnar grains near fusion boundary and the size reduces towards the unaffected base metal. Fig 2a to 2e shows the microstructures of samples 1 to 5. With the help of image analyzer system, HAZ width and ASTM grain size number were calculated from microstructures (Fig 2a to 2e) of samples. The microstructural quantity known as the ASTM micro grain size number (n), is defining by the following relationship: $N = 2^{n-1}$, where N is the number of grain per square inch at 100x.

Table 4: HAZ Width and Grain Size of Samples

Sample No	HAZ Width (μm)	ASTM Grain Size No (Weld Zone)
1	1028.90	21.20
2	1248.54	21.90
3	1269.06	20.50
4	1325.04	18.28
5	1618.37	18.08

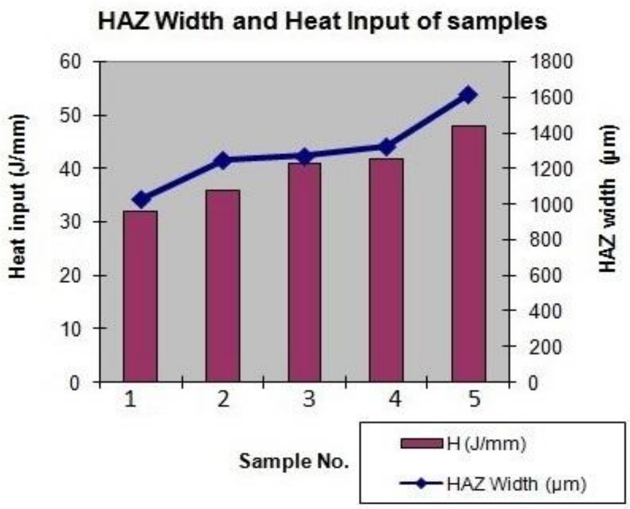

Fig 3: Variation of HAZ Width and Heat Input of Samples

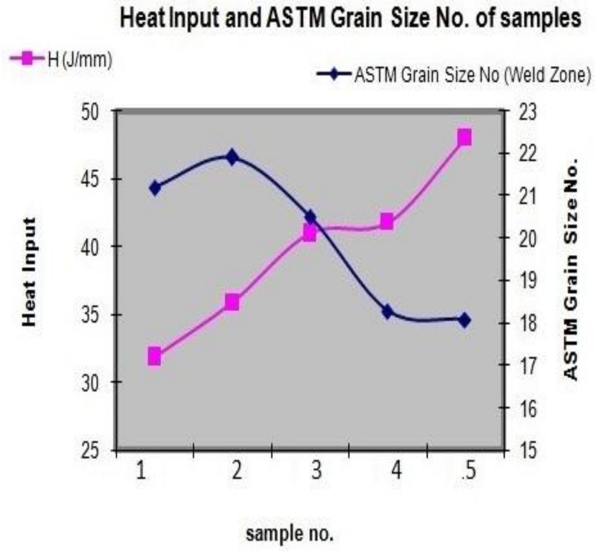

Fig 4: Variation of Heat Input and ASTM Grain Size Number of samples

The effect of heat input on HAZ width and ASTM grain size number were shown in Fig 3 and 4. The data available from Table 4, Fig 3 and 4 clearly shows as heat input increases the HAZ width and ASTM grain size also increases. Fig 5 and 6 shows the variation of grain size from weld centre to unaffected base metal for samples 1 to 5. Here ASTM grain number is smallest in weld zone and increases at fusion boundary since it is having finer grains.

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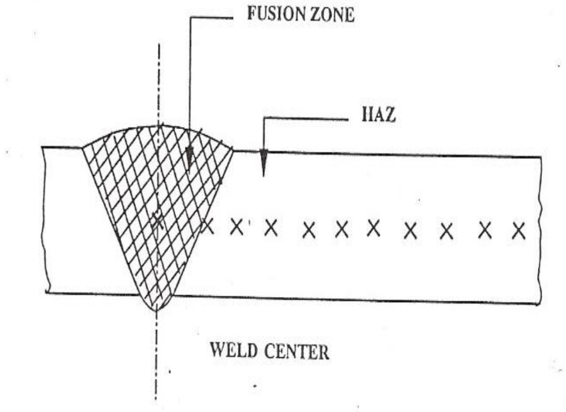

Fig 5: Schematic Diagram for Measurement of Grain Size and Micro hardness

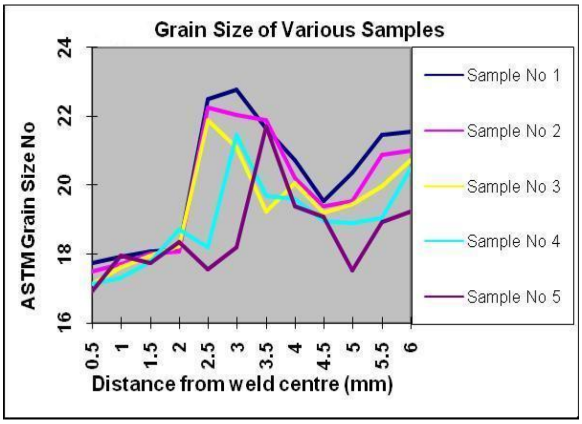

Fig 6: Grain Size Number of Samples from the Weld Centre

2) Micro hardness Study: Microhardness (Vickers) was measured from the weld centre line to the unaffected base metal with a load of 200 gf as shown in Fig 5. Microhardness testing is an indentation method for measuring the hardness of a material on a microscopic scale. A precision diamond indenter is impressed into the material at load. The impression length, measured microscopically and the test load are used to calculate a hardness value. The variations of microhardness from the weld centre were given in Fig 7.

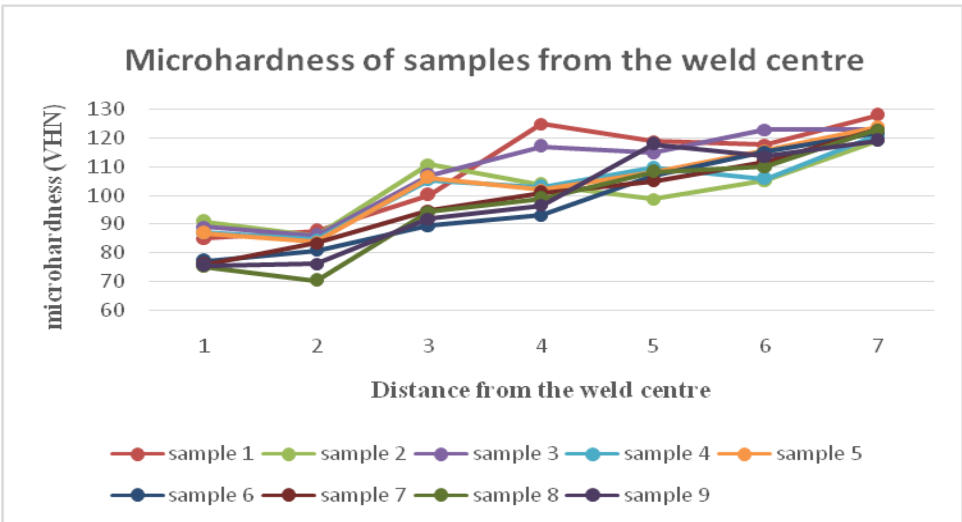

Fig 7: Microhardness of Samples from the Weld Centre

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IV. DISCUSSION

Microstructures: Welds in heat treatable alloys generally exhibit four microstructural zones as explained in Fig 1 [8]. The weld zone was a mixture consisting of melted base plate and 5356 filler metal with an as-cast dendritic cell structure. The cell size in the cast metal did not vary significantly in the various weldments. The fusion zone, an area in which inter-granular melting occurred, a butted the weld metal and contained portions of the original parent structure with partially melted and re-solidified eutectic at the grain boundaries resulting from heating to temperatures between the liquidus and solidus. The resolution HAZ is the area where temperatures were below the solidus of the alloy but high enough to dissolve the precipitates that were originally present in the parent plate. Temperatures in this area during welding were 600^0F or higher, resulting in partial or complete solution heat treatment. The microstructure varied from fine precipitates, associated principally with the grain boundaries, to coarse precipitates dispersed throughout the grain matrix. Alloy 7039 begins to overage at temperatures above 320^0F; and the precipitate agglomerates and coarsens. This is accompanied by a reduction in mechanical properties which is usually attributed to loss of coherency between the precipitate and its matrix. Beyond the over aged zone the parent material structure was unaffected by the heat of welding.
Grain size: From Fig 6 and Table 4, weld zone of all samples are occupied by coarse due to as-cast nature of microstructure, which has low hardness (almost 40% less than the parent metal) and lack strengthening phases. The grain in the centre of weld is of largest size due to the slow cooling rate at centre and this size reduces towards the fusion boundary. As heat input increases, the width of weld zone becomes wider and generates coarse grains, which is very much unfavorable for both mechanical properties of weld joint as well as strength.
Heat Input: The rate of heat input per inch of weld in arc welding is proportional to the welding voltage and current and inversely proportional to the welding speed. Most of the heat of welding will be dissipated by conduction through the adjacent metal, although a small amount will be lost by radiation and convection to the surrounding environment. From Table 4 it is sure that higher heat input generates wider HAZ due to high thermal conductivity of the base metal. In heat treatable aluminium alloys, microstructure distribution of HAZ exhibits a complicated distribution due to temperature variations. Parent material properties appear to be unaffected in locations where temperature during welding does not exceed 400^0F. Metal heated in the $400\text{-}600^0$ F temperature range undergoes hardness reductions which are not restored by natural or artificial post-weld aging. This is HAZ softening zone. Metal heated to 600^0F and above shows the greatest reduction in hardness immediately after welding, but its hardness is almost fully restored by post-weld natural or artificial aging. Wider HAZ is also unfavorable for the mechanical properties of the weld joint, due to presence of coarse grains.
Microhardness: There is a general correlation between hardness and tensile strength for aluminum alloys having similar chemical composition. Therefore, microhardness in the HAZ provided a convenient and simple means of studying the effect of heat input during welding on strength. There were mainly three regions in which microhardness shows significant change, the weld zone; fusion boundary and HAZ. From Fig 7, we can see that weld zone is having very low microhardness for all samples. As it moves from the weld centre microhardness increases at fusion boundary due to fine grains as it gets lesser time for solidification and then decreases at HAZ due to coarser elongated grains. Microhardness varies at a range of 75 VHN to 127 VHN from weld centre to parent metal. Also it was observed that the fall in microhardness moves away from weld centre from sample 1 to 5. This shows clearly the effect of heat input on microhardness.

V. CONCLUSION

From the above results we can conclude that:
a) Mechanical properties of the weld zone depend on the grain size. The unfavorable mechanical properties of the weld joints are due to coarse grains.
b) High heat input generates wider weld zone and HAZ, which reduces the joint strength and weld hardness.
c) Metal heated in the $400\text{-}600^0$F temperature range undergoes hardness reductions which are not restored by natural or artificial post-weld aging. Therefore minimum heat input, which can be controlled by optimum process parameters, should be used in welding of aluminium alloys.

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