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Research Paper :

Process optimization in joining aluminium alloy 7039 using TIG arc welding process

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ABSTRACT

This paper depicts an application of GTA Welding for Aluminium alloy 7039 (AA7039) using pure argon gas as a shielding agent with sinusoidal AC wave. Variations of microhardness of AA7039 from weld zone to unaffected base metal were studied at various currents and frequencies. Microstructural changes of welded AA7039 were also studied. AA7039 is a heat treatable and weldable Aluminium-4.5%, Zinc-2.5% magnesium alloy. Magnesium is alloyed with aluminium for increasing mechanical properties, corrosion resistance and easy machinability. Zinc is usually added to improve mechanical properties through formation of hard intermediate phase, such as Mg_2Zn. Gas Tungsten Arc Welding process (GTAW) was found to be the the best preferred welding process for high strength Aluminium alloy due to easier adaptability and better economy.

Key words : GTA Welding process, Aluminum Alloy 7039, Microhardness, Microstructure

A demand for lighter and stronger aluminium armour for protection against high explosive shell fragments in the early 1960s led to the introduction of AA7039. Heat treatable aluminium alloys are widely used in aircraft structural applications and are susceptible to localized corrosion in chloride environments, such as pitting, crevice corrosion, intergranular corrosion, exfoliation corrosion and stress corrosion cracking. AA7039 is employed in aircrafts, automobiles, high-speed trains and high-speed marine applications due to their low density, high specific strength and excellent corrosion resistance. It was used in the armoured hulls of M551 light tanks and XN723 IFV in USA. AA7039-T64 exhibits better performance against ball and armour piercing than 5083. Creation of this material made it possible to design and put into full scale production one of the best infantry fighting vehicles in the world–BMP–3. The aluminium armour of the vehicle ensured at least 1500 kg of weight savings as compared to a steel armoured hull of the same protection level. Many of the aluminium alloys also exhibit excellent weldability as a prime requirement for any engineering structure, where welding is a predominant fabrication route. Aluminium is an excellent conductor of heat. It requires large heat inputs when welding begins, since much heat is lost in heating the surrounding base metal. As welding progresses, much of this heat moves ahead of the arc and pre-heated base metal to a temperature requiring less welding current than the original cold plate. If the weld is continued farther on to the end of the two plates where there is nowhere for this pre-heat to go, it can pile up to such a degree as to make welding difficult unless the current is decreased. The GTAW process is one of the most well established processes, which not only weld all metals of industrial use but also gives the best quality welds among the arc welding processes. The pulsed GTAW process was developed in the Soviet Union. The advantage of this process includes the better control of heat input and penetration (Becker and Adams, 1978).

The increased numbers of variables in the pulsed GTAW process also support the possibility of increased control of the solidification process. The current and arc length are selected to adjust the weld depression and width behind the weld pool rear in order to control the full penetration state. The change in either the current or the arc length will generate variations in both the weld depression and weld width in gas tungsten arc welding (Zhang *et al.*, 1996). The basic requirements of all GTAW processes are similar, *i.e.* a power source, a hand or machine manipulated torch, a pressurized supply of a suitable inert gas or gas mixtures from cylinders and cables of correct size to conduct welding current from the power source to the torch and tungsten electrode. GTAW is the best preferred welding process for high strength aluminium alloys due to easier adaptability and better economy.

The use of non-heat treatable fillers that can resist hot cracking is more meaningful in welding 7xxx series alloys. In these alloys, as long as possible the weld metal contains 3% Mg or more, hot cracking is not a serious problem (Balasubranian *et al.*, 2007 and 2008a). Ramesh (1977) reported that pulsed current automatic TIG welding shows increased arc stability particularly at low current, and arc blow effects are eliminated. Vainarman *et al.* (1966) reported that the use of pulsed arc welding in place of conventional TIG welding increases the output by 200 – 400%, reduces consumption of argon by three to ten times, and also reduces the cost of 1 m weld deposition by three to five times. Al-Zn-Mg (AA7039) alloys have an attractive combination of high strength, low weight, and corrosion resistance. They have proved to be effective as lightweight transportable bridges, armour plate, military vehicles, road tankers, and railway transport systems (Balasubramanina *et al.*, 2008b). AA5356 and AA5183 aluminium alloy filler wires are recommended for welding of AA7039. Apart from mechanical considerations of joint design, the welding process, filler material, heat input, number of weld passes etc., influence the microstructure of the weld at the joint and in turn influence the extent of the heat affected zone and residual stresses that will built up in the base metal ion (Esterlinh, 1985). On the largest scale, a weldment consists of a transition from the wrought base metal through a HAZ and into the solidified weld metal and includes five microstructurally distinct regions normally identified as the fusion zone, the unmixed region, the partially melted region, the HAZ, and the unaffected base metal.

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and interpass temperature, it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ (Scott, 1999; Kim *et al.*, 1998 and Kolhe and Datta, 2007). The heat input is typically calculated as follows:

$$\mathbf{H = [60\,E\,I] / 1000\,S}$$

where, H = Heat Input (kJ/mm),
E = Arc Voltage (Volts),
I = Current (Amps) and
S = Travel Speed (mm/min)

METHODOLOGY

The experiments were performed on the Pulse GTAW TRITON 220 AC/DC process with AC sinusoidal wave at various currents (100 to 160 Amp) and frequencies (from 50 to 150 Hz) with Gas flow rate 6 litre per minute and line pressure of 2 Kg/cm^2 as shown in Fig. 1a. Bead-on-plate tests were carried out on 7 mm thick samples of AA7039 base metal. The chemical composition and physical properties of base metal are given in Table 1. AA7039 specimens were pre-etched for removing the residual deformation from the surface of the specimen. The best results from the range of different etching solutions and variety of concentrations were achieved by pre-etching the specimen with a 2% aqueous solution of sodium hydroxide. Welding was done using 3.15 mm diameter filler wires of aluminium alloy 5356 (Al-5%Mg) and the compositions and physical properties are given in Table 2. A non-consumable tungsten electrode of 2.4 mm diameter was used with high purity (99.99%) argon gas as a shielded gas. Microhardness (Vickers) was measured from the weld

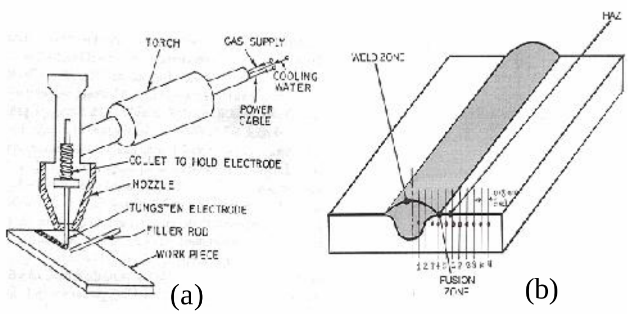

Fig. 1: **Systematic diagram of experimental setup of PULSE GTAW Welding on Aluminum Alloy 7039**

Table 1 : Chemical composition and physical properties of base metal aluminum alloy 7039

Chemical composition:

Component	Weight per cent	Component	Weight per cent	Component	Weight per cent
Al	90.45 – 90.50	Mg	2.30 -3.30	Si	Max 0.3
Cr	0.15 – 0.25	Mn	0.10 – 0.40	Ti	Max 0.10
Cu	Max 0.10	Other each	Max 0.05	Zn	3.5 – 4.5
Fe	Max 0.40	Other total	Max 0.15		

Physical properes:

Density	2.74 g/cc	Modulus of Elasticity	69.6 GPa
Hardness, Brinell	61	Shear strength	140 Mpa
Ultimate tensile strength	210 MPa	Specific heat capacity	0.88 J/g-°C
Yield tensile strength	100 MPa	Thermal conductivity	140 W/m-K
Elongation at break	22%	Melting point	482 - 638 °C

Table 2: -Chemical composition and physical properties of filler material AA 5356

Component	Weight %	Component	Weight %	Component	Weight %
Al	92.90 – 95.30	Mg	4.50 - 5.50	Si	Max 0.25
Cr	0.05 – 0.20	Mn	0.05 – 0.20	Ti	0.06 – 0.20
Cu	Max 0.10	Other each	Max 0.05	Zn	Max 0.10
Fe	Max 0.40	Other total	Max 0.15		
	Density			2.64 g/cc	

A – Weld Zone B – Fusion Zone C – Heat Affected Zone

centre line to the unaffected base metal with a load of 200 Kgf as shown in Fig. 1b. Microhardness testing is an indentation method for measuring the hardness of a material on a microscopic scale. A precision diamond indenter was impressed into the material at load. The impression length, measured microscopically and the test load were used to calculate a hardness value.

RESULTS AND DISCUSSION

The weld beads were prepared at 100, 120, 140 and 160 Amp currents at various frequencies as 50, 75, 100, 125 and 150 Hz. During welding, it was observed that at lower current, the welding speed was less and as the current was increased, the welding speed also increased. There was a harsh sound in the welding machine on increasing the frequency and no colour change during welding were observed. The microhardness for different samples was plotted at an interval of 0.8 mm starting from the weld centre up to the unaffected base metal. Experimental results with microstructures of base metal, weld zone and HAZ are illustrated in the Fig. 2, 3, 4 and 5. The results for the microhardness with the increase in frequency at different currents are plotted in Fig. 2, 3, 4 and 5, and the microstructures of the base metal, weld zone and heat-affected zones are shown in Fig. 6, 7 and 8. From the above investigation the following observations were made,

The low microhardness of the weld zone can be attributed due to the low hardness of the fillers.

It was observed that as we move from the weld zone towards the unaffected base metal, the microhardness increases from 95 VHN to 130 VHN (approx). The microhardness increases due to the small grain size in the fusion zone.

At 6 to 8 mm (approximately) from the weld zone, the microhardness drops and then again increases gradually till it becomes constant at the unaffected base metal. The drop in the microhardness (which is approximately 15 VHN) is due to grain coarsening and precipitation hardening in the HAZ.

It is also observed that as we increase the current and frequency, the drop in the microhardness shifts away

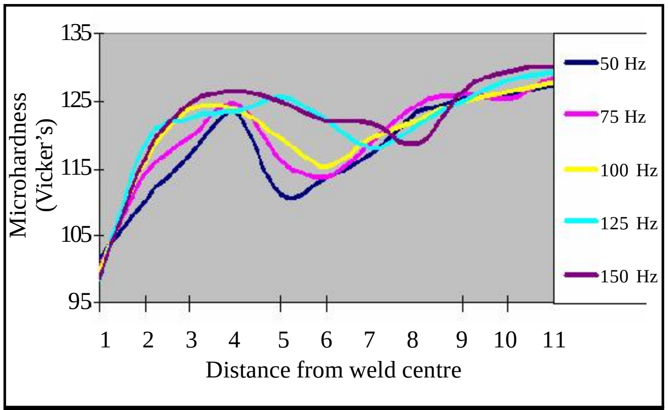

Fig. 2 : Variation of Micro-hardness at 100 amp current for Aluminum alloy 7039

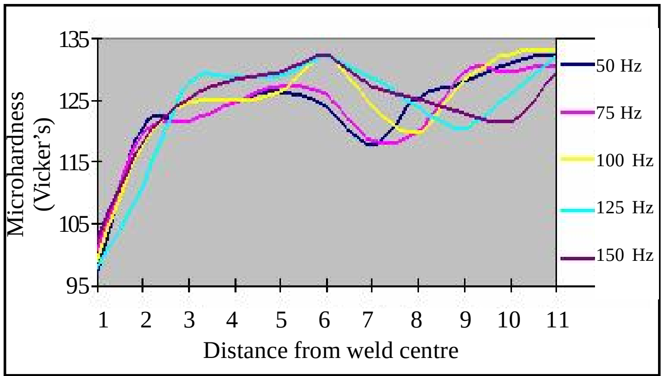

Fig. 3: Variation of Micro-hardness at 120 amp current for Aluminum alloy 7039

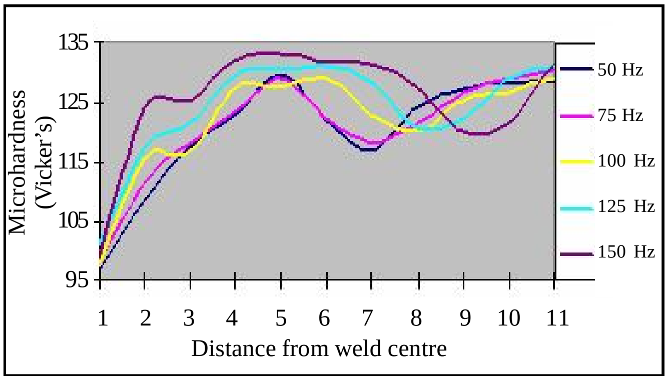

Fig. 4: Variation of Micro-hardness at 140 amp current for Aluminum alloy 7039

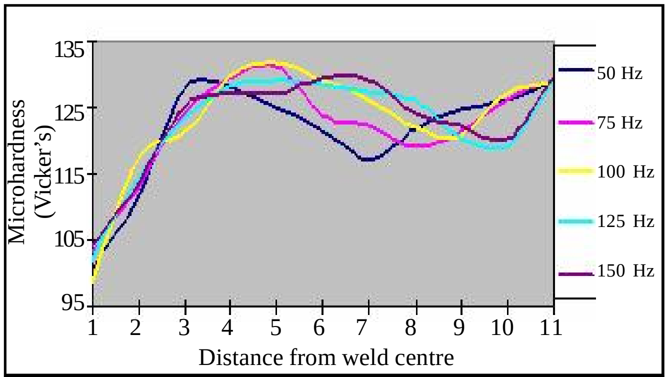

Fig. 5: Variation of Micro-hardness at 160 amp current for Aluminum alloy 7039

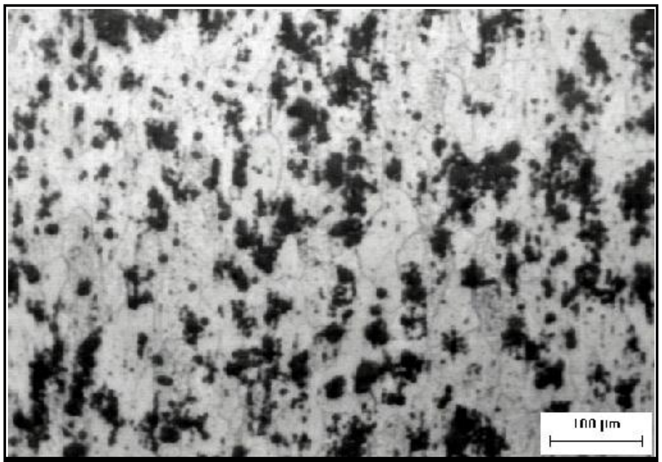

Fig. 6: Microstructure of Aluminum alloy 7039 base metal

from the weld centre towards the unaffected base metal. This is due to the increase in heat input as currents and frequencies are increases.

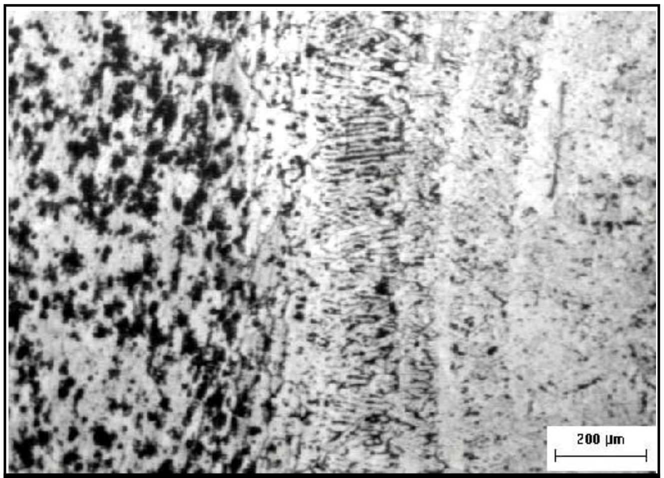

Fig. 7: Microstructure of base metal, HAZ and weld metal of Aluminum alloy 7039

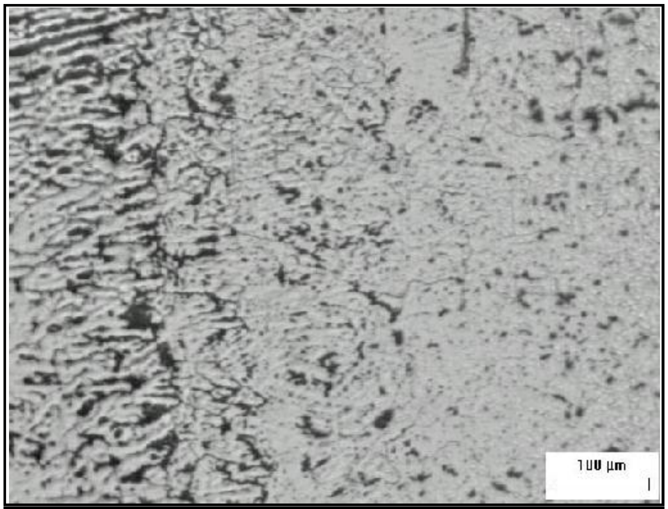

Fig. 8: Microstructure of HAZ and weld metal of Aluminum alloy 7039

Common methods for cleaning aluminium surfaces for welding

	Type of cleaning	
Compounds removed	Welding surfaces only	Complete piece
Oil, grease, moisture, and dust. (Use any method listed)	Wipe with mild alkaline solution and dry. Wipe with hydrocarbon solvent, such as acetone or alcohol Wipe with proprietary solvents. Dip edges, using any of above.	Vapor degrease Spray degrease Steam degrease Immerse in alkaline solvent Immerse in proprietary solvents
Oxides (Use any method listed)	Dip edge in strong alkaline solution, then water, then nitric acid Finish with water rinse and dry. Wipe with proprietary deoxidizers. Remove mechanically, such as by wire-brushing, filing, or grinding. For critical applications, scrape all joints and adjacent surfaces immediately prior to welding	Immerse in strong alkaline solution, then water, then nitric acid Finish with water rinse and dry Immerse in proprietary solutions

Recommended filter metals for various aluminium alloys

Base Metal	Recommended Filler Metal[1]	
	For maximum as-welded strength	For maximum elongation
EC	1100	EC 1260
1100	1100, 4043	1100, 4043
2219	2319	(2)
3003	5183, 5356	1100, 4043
3004	5554, 5356	5183, 4043
5005	5183, 4043, 5356	5183, 4043
5051	5356	5183, 4043
5052	5356, 5183	5183, 4043, 5356
5083	5183, 5356	5183, 5356
5086	5183, 5356	5183, 5356
5050	5356, 5183	5183, 5356, 5654
5052	5554, 5356	5356
5083	5356, 5554	5554, 5356
5086	5556	5183, 5356
6061	4043, 5183	5356[3]
6063	4043, 5183	5356[3]
7005	5356, 5183	5183, 5356
7039	5356, 5183	5183, 5356

Notes:

1. Recommendations are for plate of "0" temper.
2. Ductility of weldments of these base metals is not appreciably affected by filler metal. elongation of these base metals is generally lower than that of other alloys listed.
3. For welded joints in 6061 and 6063 requiring maximum electrical conductivity use 4043 filler metal. However, if both strength and conductivity are required, use 5356 filler metal and increase the weld reinforcement to compensate for the lower conductivity of 5356.

Source: adapted from New Lessons in Arc Welding The Lincoln Electric Company, 1990

Conclusions:

In the study of effect of current and frequency on welded AA7039 it was observed that the microhardness reduces in the particular area of the heat affected zone due to grain coarsening and precipitation hardening. Also, the drop in the microhardness shifts away from weld centre towards the unaffected base metal due to the increase in heat input as current and frequency are increased.

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