ENGINEERING AND TECHNOLOGY IN INDIA
Volume 1 Issue 2 (October, 2010) Page : 61-67

RESEARCH ARTICLE

Accepted : *June, 2010*

A Study on effects of pulse parameters on the bead geometry of welded Aluminium Alloy 7039

PAWAN KUMAR, KISHOR P. KOLHE AND C.K. DATTA

ABSTRACT

The pulsed-current Gas Tungsten Arc (GTA) Welding process is employed for a high rate of current rise, decay and a high pulse repetitive rate, widely used in the joining of precision parts. The main aim of pulsing is to achieve maximum penetration without excessive heat built-up. The use of high current pulses is to penetrate deeply and allow the weld pool to dissipate some of the heat during a proportionately of longer arc period at a lower current. Aluminium Alloy 7039 is employed in aircraft, automobiles, high-speed trains and high-speed ships due to their low density, high specific strength and excellent corrosion resistance. The present paper depicts the application of Pulsed GTA welding for AA7039 using pure argon gas as a shielding gas with sinusoidal AC wave. In this investigation, the bead geometry and metallographic study of welded (AA7039) aluminium alloy have been carried out at various pulse currents, secondary currents, pulse frequencies and duty cycles.

Key words : Pulsed GTA Welding, Aluminum Alloy 7039, Bead Geometry, Microstructure

INTRODUCTION

The GTAW process is one of the most well established processes, which can weld all metals of industrial use and also give the best quality welds among the arc welding processes. 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. Zeytsev in1953 developed the pulsed GTAW process in the Soviet Union. GTAW is the best preferred welding process for high strength aluminium alloys due to easier adaptability and better economy. Pure tungsten electrodes, zirconiated tungsten electrodes, thoriated tungsten electrodes, ceriated tungsten electrodes, lanthanated tungsten electrodes and other tungsten alloy electrodes are used in the TIG welding process. Argon, helium, argon-helium, argon-hydrogen, helium-hydrogen, and nitrogen are used in this process as shielding gases.

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. It is a heat treatable and weldable aluminium alloy having 4.5% zinc and 2.5% magnesium. Magnesium is added for improving the mechanical properties, corrosion resistance and machinability. Zinc is usually added to improve the mechanical properties through formation of the hard intermetallic phases, such as Mg_2Zn. 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, lightweight transportable bridges, armour plate, military vehicles, road tankers, railway transport systems 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 AA5083.

Welding of aluminium and its alloys presets some peculiarities in contrast to ferrous materials, due to the physical and chemical properties of aluminium like passive oxide layer, high thermal and electrical conductivity, low fusion temperature, heat coefficient of thermal expansion, solidification shrinkage and high solubility of hydrogen and other gases in molten state. Further problems can rise when attention is focused on heat-treatable alloys, since

Kumar, Pawan, Kolhe, Kishor P. and Datta, C.K. (2010).A Study on effects of pulse parameters on the bead geometry of welded Aluminium Alloy 7039, *Engg. Tech. India*, **1** (2) : 61-67

heat, provided by welding process, is responsible for the decay of mechanical properties, due to phase transformations and softening induced in alloy [1].

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 is begun, since much heat is lost in heating the surrounding base metal. After welding has progressed a while, much of this heat has moved ahead of the arc and pre-heated the base metal to a temperature requiring less welding current than the original cold plate. If the weld is continued further 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.

AA5356 and AA5183 aluminium alloy filler wires are recommended for welding of AA7039. These filler wires are used for getting maximum strength and elongation.

The important process parameters which affects the bead profile are pulse current, secondary current (back ground current), pulse frequency, pulse duty cycle, welding voltage welding speed and gas flow rate. The pulse / peak current are of primary importance since it predicts the weld heat input. The pulse of higher current are found to generate a large variation of pressure in the arc. Arc pressure causes the turbulence in the weld pool, which allows the heat to penetrate deeper into the base metal. Back ground current affects the rate of cooling and solidification. Higher pulse duty cycle [Tp / (Tp + Tb)], where Tp – pulse current time and Tb – back ground current, indicates the tendency towards continuos current. The increase in pulse duty cycle causes increase in heat input resulting deeper penetration and wider weld bead. When the number of pulses is increased, the pulse time reduces. This shall reduce the radiation loss per pulse. Increase in welding voltage increases the weld width and reduces the penetration. Also welding speed plays very dominant factor in defining the geometry of the bead. With increase in welding speed, the heats per unit length decrease and hence weld width as well as penetration decreases. The typical weld bead of TIG joint, according to welding speed, shows different types of grain structures: the lower the speed (<7 mm/s) the wider the grains, what is more they result aligned in the direction of heat source motion. For the highest welding speed (>19 mm/s) a region of fine equiaxed grains grows up throughout the thickness of the weld. Gas flow rate does not affect the weld geometry significantly. Weld bead width can be controlled more efficiently by welding current than welding speed. Also bead width found to decrease with an increase in the electrode diameter to a certain extent and increase slightly with an increase of the apex angle.

The thermal behaviour of weld governed by arc characteristics significantly influences the geometry, chemistry, microstructure and stresses of weld [2]. Deep penetration in pulsed current welding is produced manly by arc pressure at peak duration and significantly long peak duration is needed for deep penetration [3]. As the pulse frequency reduces, there is a marked increase in the area of the weld. But when the pulse frequency increases, more grain boundary precipitation becomes apparent. Particularly advantageous microstructures were obtained with low pulse frequencies. If the pulse frequency was increased above certain range there was distinct deterioration in the structure characteristics [4].

Pulsed current welding is a variation of constant current welding which involves cycling of the welding current from a high level to a low level at a selected regular frequency. The high level of the peak current is generally selected to give adequate penetration and bead contour, while the low level of the background current is set at a level sufficient to maintain a stable arc. This permits arc energy to be used efficiently to fuse a spot of controlled dimensions in a short time producing the weld as a series of overlapping nuggets and limits the wastage of heat by conduction into the adjacent parent material as in normal constant current welding. In contrast to constant current welding, the fact that heat energy required to melt the base material is supplied only during peak current pulses for brief intervals of time allows the heat to dissipate into the base material leading to a narrower HAZ [5].

The evolution of microstructure in weld fusion zone is also influenced in many ways by current pulsing, principally, the cyclic variations of energy input into the weld pool cause thermal fluctuations, one consequence of which is the periodic interruption in the solidification process. As the pulse peak current decays the solid–liquid interface advances towards the arc and increasingly becomes vulnerable to any disturbances in the arc form. As current increases again in the subsequent pulse, growth is arrested and remelting of the growing dendrites can also occur. Current pulsing also results in periodic variations in the arc forces and hence the additional fluid flows that lowers temperatures in front of the solidifying interface. Furthermore, the temperature fluctuations inherent in pulsed welding lead to a continual change in the weld pool size and shape favouring the growth of new grains. It is also to be noted that effective heat input for unit volume of the weld pool would be considerably less in pulse current welds for which reason the average weld pool temperatures are expected to be low [6]. The refinement of microstructure due to the pulsed current welding results in a uniform distribution of the fine precipitates more effectively governed by its zinc pick up enhancing the amount of precipitates in the matrix [7].

Weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during weld metal solidification. This results in poor resistance to hot cracking and inferior mechanical properties. 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 [8].

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. The HAZ is the portion of the weld joint which has experienced peak temperatures high enough to produce solid-state microstructural changes but too low to cause any melting. Every position in the HAZ relative to the fusion line experiences a unique thermal experience during welding, in terms of both maximum temperature and cooling rate. Thus, each position has its own microstructural features and corrosion susceptibility. The 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 [9].

Heat input is a relative measure of the energy transferred per unit length of weld and can be significantly controlled by proper selection of pulsing conditions. Penetration is strongly influenced by pulse duty cycle. The linear relationship exists between the heat input of a weld and the maximum temperature at a given distance from weld centre line. 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 [10]. The heat input is typically calculated as follows: $H = [60EI] / 1000\,S$, Where H = Heat Input (kJ/mm), E = Arc Voltage (Volts), I = Current (Amps) and S = Travel Speed (mm/min).

MATERIALS AND METHODS

The 6mm thick samples of AA7039 were cut into the standard sizes for bead on plate by power hacksaw cutting and grinding. Weld beads along the length were deposited using 3.15mm diameter filler wires of aluminium alloy 5356 (Al-5%Mg) with the help of the GTAW process. A non-consumable tungsten electrode of 2.4 mm diameter was used with high purity (99.99%) argon gas as a shielded gas. Chemical composition and mechanical properties of base metal are as follows.

Al = 93.06 – 93.06 %	Mg = 2.03 – 2.07 %	Zn = 3.692 – 3.749 %
Density = 2.74 g/cc	Melting point = 482 - 638 °C	
Hardness, Vicker's = 125	Ultimate tensile strength = 470 MPa	

Bead on plate were carried out on a pulsed GTAW machine (TRITON 220 AC/DC) with AC sinusoidal wave at various pulse currents (125A to 220 A), secondary / base currents (40A to 120A), pulse frequencies (50 to 250 Hz) and pulse duty cycles (0.1 to 0.9). Bead penetration and bead width were measured at the middle of the specimen (Fig 1). Microstructural changes have also been observed at weld zones of specimen at various pulse currents, secondary currents, pulse frequencies and pulse duty cycles.

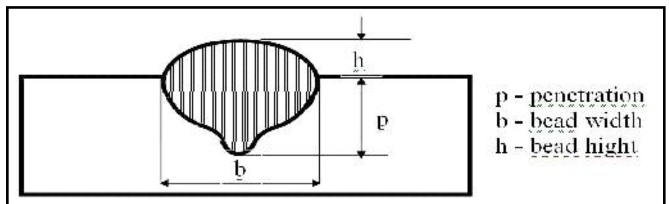

Fig. 1 : Schematic diagram of Weld bead

RESULTS AND ANALYSIS

IDuring welding, it was observed that on increasing of frequency, there was a harsh sound in the welding machine. No colour changes during welding were observed. Experimental results with microstructures of weld zone, fusion zone and heat affected zone (HAZ) are illustrated in the following figures.

The results for the penetration (P) and penetration/width (P/B) ratio with the increase in pulse currents, secondary currents, pulse frequencies and pulse duty cycles are plotted in Fig. 2 to Fig. 9, and the microstructures of the weld zone, fusion zone and heat affected zone (HAZ) are shown in Fig. 10 to 12. From the above, the following observations were made,

– In GTAW process, the reinforcement or height of the weld bead mainly depends upon the supply of fillers at time of welding. It has no correlation with the pulse parameters.

– It is observed from Fig. 2 and Fig. 6, as the pulse

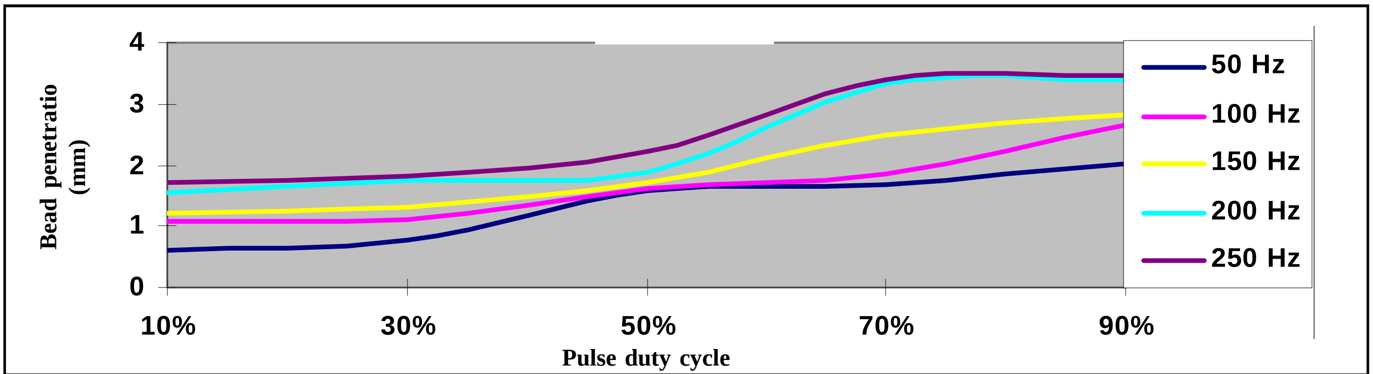

Fig. 2 : Effect of pulse duty cycle on bead penetration at various frequencies

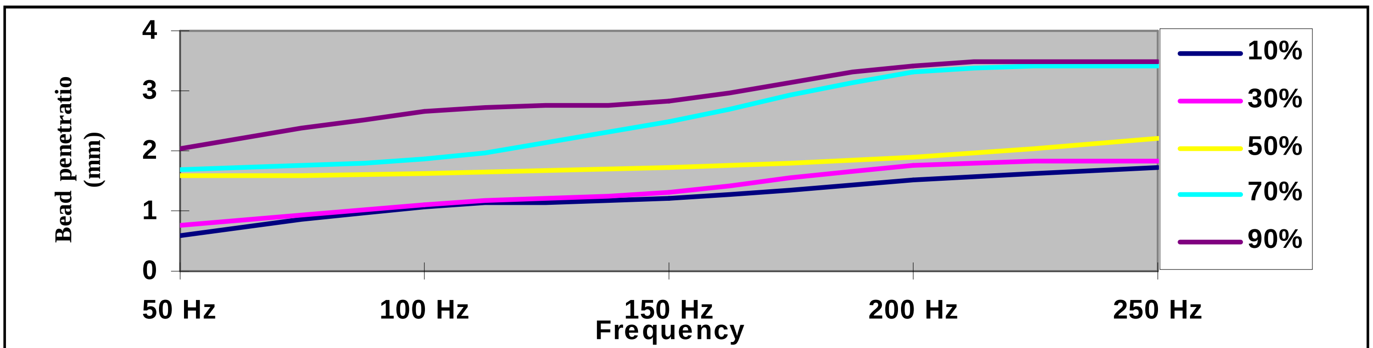

Fig. 3 : Effect of pulse frequency on based penetration at various duty cycles

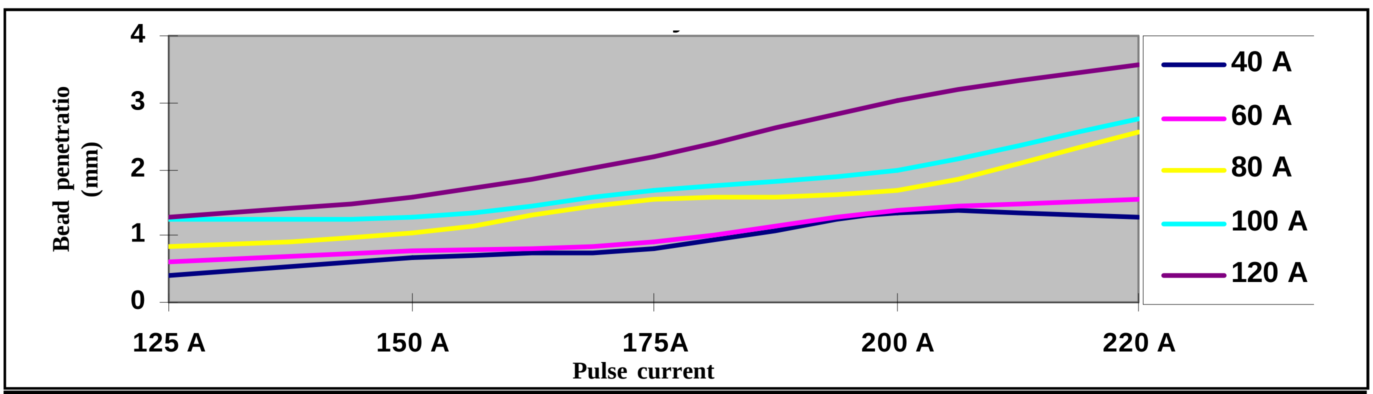

Fig. 4 : Effect of pulse current on base penetration at various secondary currents

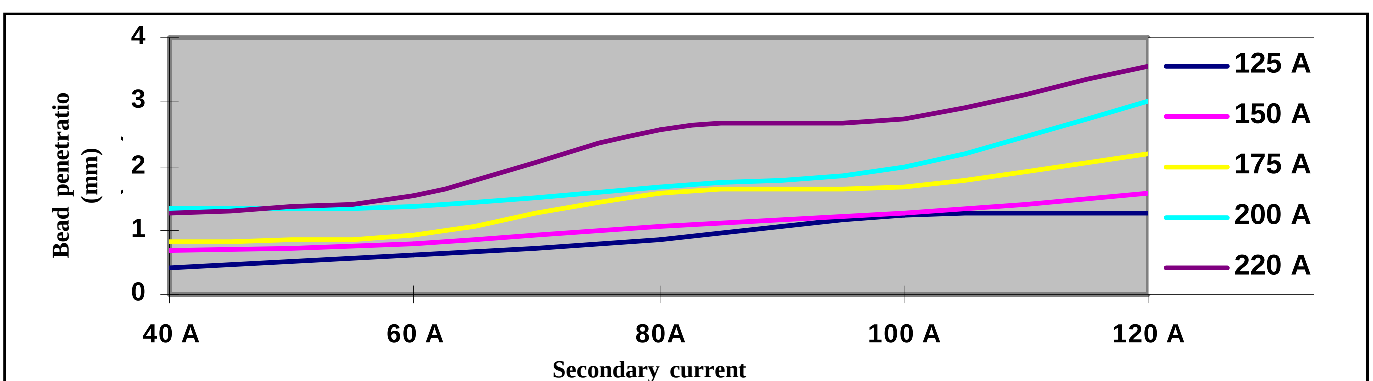

Fig. 5 : Effect of secondary current on bead penetration at various pulse current

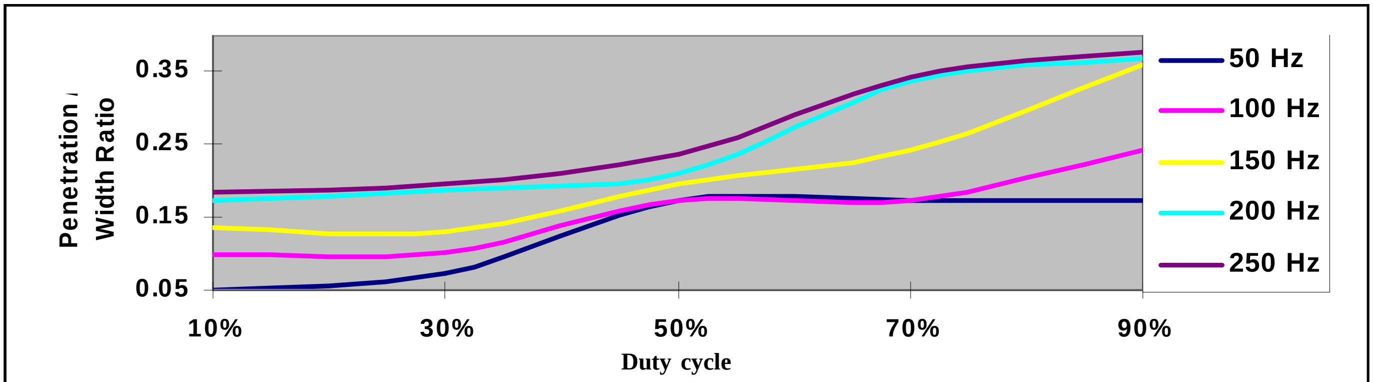

Fig. 6 : Effect of pulse duty cycle on P/B (Penetration/Width) ratio at various frequencies

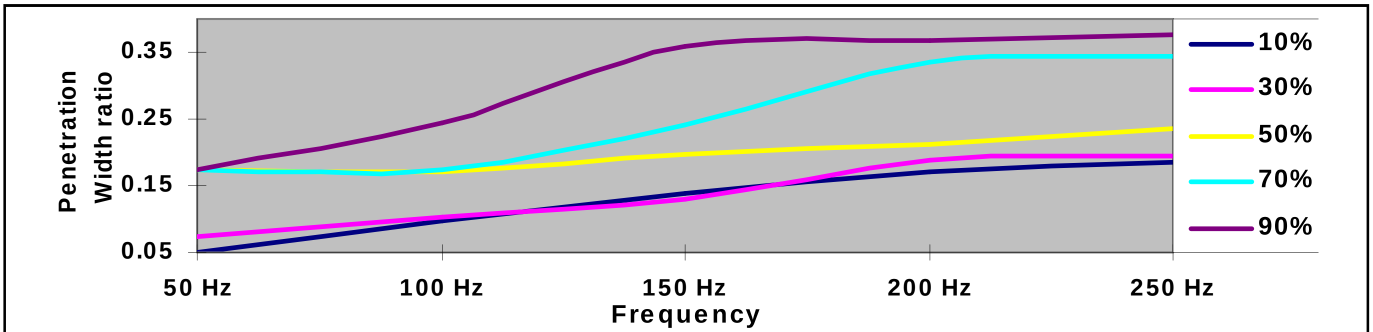

Fig. 7 : Effect of pulse duty frequency on P/B (Penetration/Width) ratio at various duty cycles

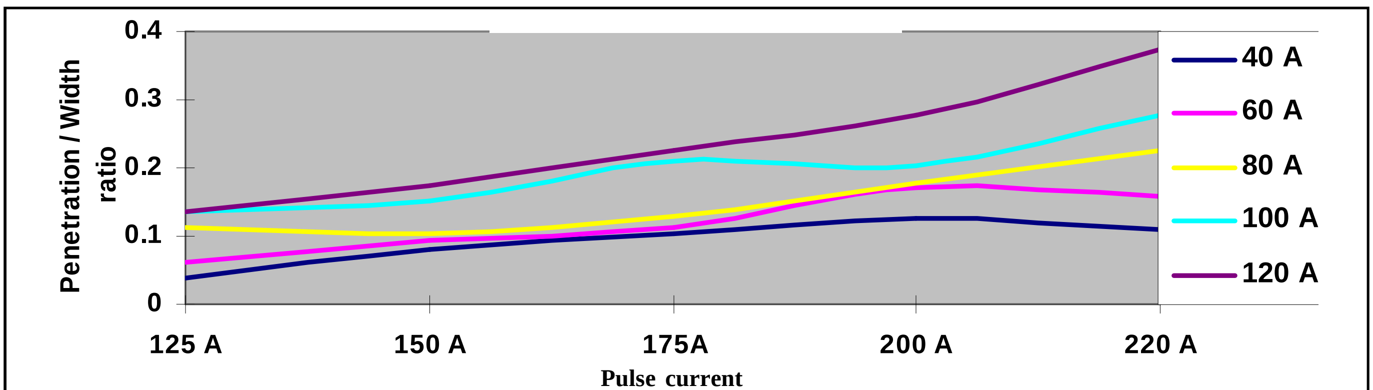

Fig. 8 : Effect of pulse current on P/B (Penetration/Width) ratio at various secondary currents

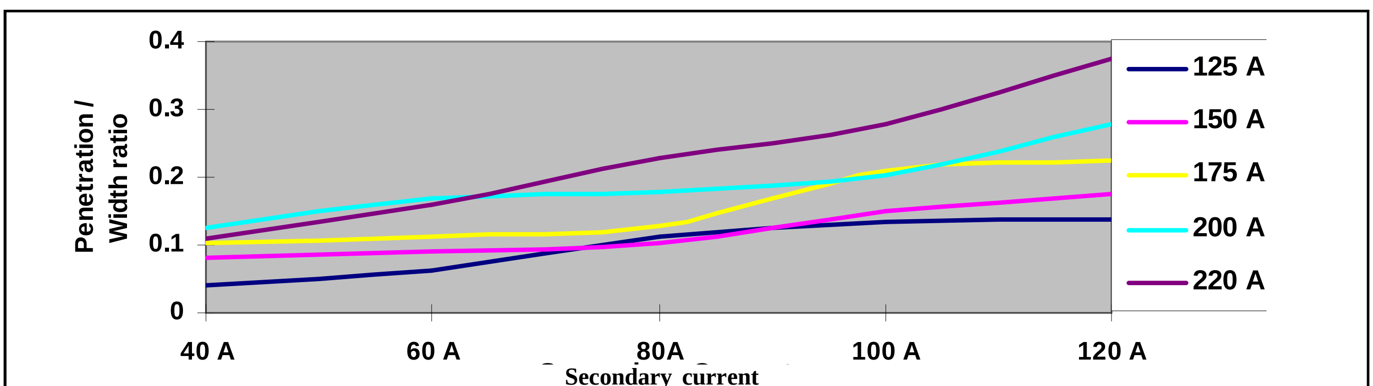

Fig. 9 : Effect of secondary current on P/B (Penetration/Width) ratio at various pulse currents

duty cycle increases from 10% to 90% at various pulse frequencies, there is an increase in penetration and penetration / width ratio due to increase in the duration of pulse current.

– From Fig. 3 and Fig. 7, it is observed that as the pulse frequency increased from 50 to 250 Hz at various pulse duty cycles, there was also an increase in penetration and penetration / width ratio due to increase in repetition of pulse current.

– Also it is observed from Fig. 4 and Fig. 8, as the pulse current increased from 125 Amp to 220 Amp at various secondary / base currents, there was an increase in penetration and penetration / width ratio due to increase in the amplitude of the pulse current.

– From Fig. 5 and Fig. 9, it is observed that as the secondary current increased from 40 Amp to 120 Amp at various pulse currents, there was also an increase in penetration and penetration / width ratio due to increase in the amplitude of the secondary current.

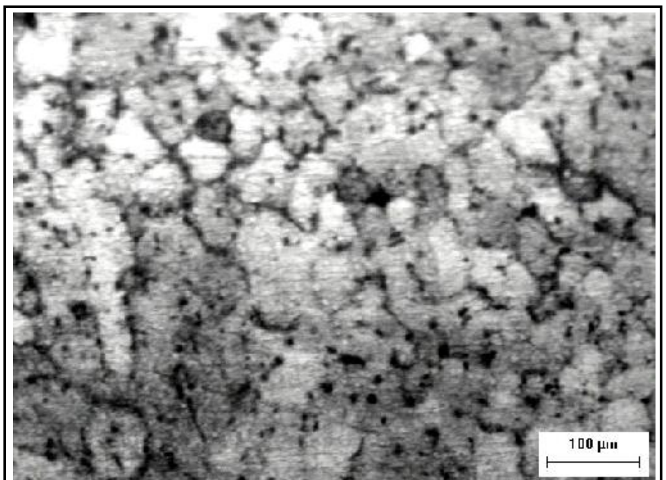

Fig. 10 : Microstructure of weld zone

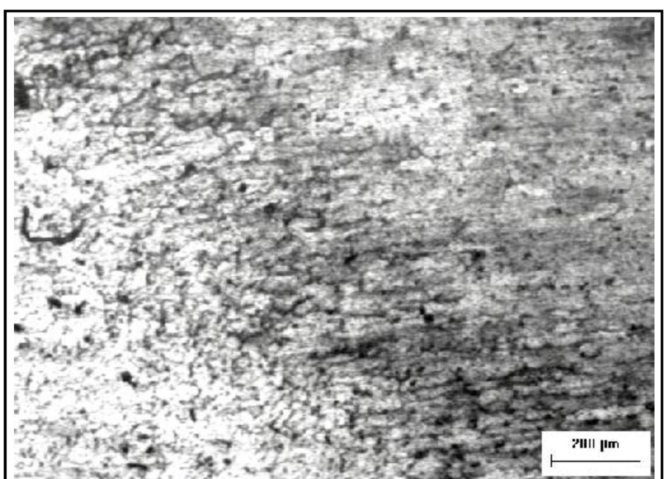

Fig. 11 : Microstructure of fusion zone

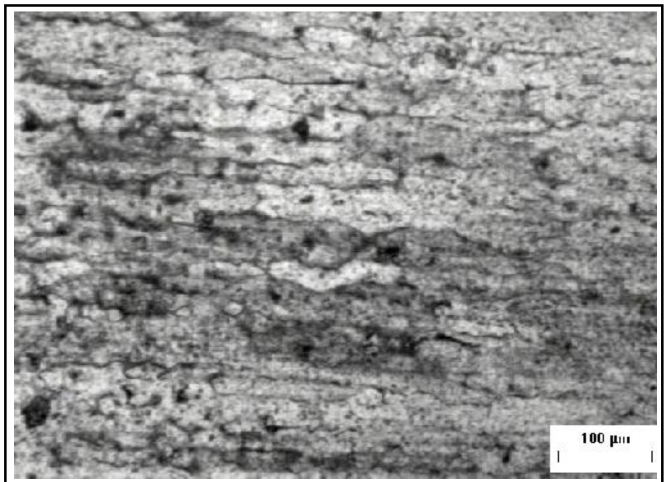

Fig. 12 : Microstructure of heat affected zone

– It is observed from the metallurgical microstructure of weld zone (Fig. 10) that average ASTM grain size was 5.8 and the grains were equiaxed. At the fusion zone or interface (Fig. 11) the grains were mixture of equiaxed and columnar grains and in HAZ (Fig. 12), the grains were observed to be fully columnar.

Conclusions:

In this paper, the effect of pulse currents, secondary currents, pulse frequencies and pulse duty cycles on the bead geometry of GTA Welded AA7039 has been studied. From this investigation it is observed that the penetration and penetration / width ratio increased with increase in the heat input *i.e.* pulse currents, secondary currents, pulse frequencies and pulse duty cycles.

REFERENCES

ASM International handbook (2006). Corrosion of Weldments (#05182G)".

Balasubramanian, V., Ravishankar, V, and Reddy, G.M. (2007). Effect of pulsed current & post weld aging treatment on tensile properties of argon arc welded high Al alloy, *Materials Sci. & Engg,* **459** (1-2) : 19-34.

Balasubramanian, V., Ravishankar, V. and Reddy, G.M. (2008). Effect of pulsed current welding on fatigue behavior of high strength aluminium alloy joints, *Materials & Design,* **29** (2) : 492 - 500.

Janaki Ram, G.D., Mitra, T.K. and Shankar, V. (2003). Microstructural refinement through inoculation of Type 7020 Al–Zn–Mg alloy welds and its effect on hot cracking and tensile property. *J. Mater Process Technol.*,**142** : 174 to 181.

Jenney, C.L. and O'Brien, A. (2001). AWS welding handbook, Vol. 1 9th Ed.

Ko, S.H., Choi, S.K. and Yoo, C.D. (2001). Effects of surface depression on poll convention and geometry in stationary GTAW, *Welding J.*, **80**(2) : 39-s – 45-s.

Madhusudhan Reddy, G., Gokhale, A.A. and Prasad Rao, K. (1998). Optimization of pulse frequency in pulsed current gas tungsten arc welding of aluminium – lithium alloy sheets, *J. Material Sci, & Technol.*, **14** : 61–66.

Norman, A.F., Drazhner, V. and Prangnell, P.B. (1999). Effect of welding parameters on the solidification microstructure of autogenous TIG welds in an Al–Cu–Mg–Mn alloy, *Mater. Sci. Eng.*, **A259** : 53–64.

Singh, D.K., Issler, L., Ghosh, P.K. and Breazu, M. (1991). Mechanical properties of TIG welded Al-Zn-Mg alloy. *Indian Welding J.*, **24** (4) : 36-45.

Scott Funderburk, R. (1999). *Key concepts in welding engineering*, Welding Innovation Vol XVI, No. 1.

Address for correspondence :
PAWAN KUMAR
Department of Mechanical Engineering,
Delhi College of Engineering, DELHI, INDIA
Email : pks_munesh@yahoo.com

Authors' affiliations :
KISHOR P. KOLHE AND
Department of Mechanical Engineering,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli, RATNAGIRI (M.S.) INDIA
Email : kishore_kolhe@rediffmail.com

C.K. DATTA
Department of Mechanical Engineering,
Delhi College of Engineering, DELHI, INDIA

****