Optimisation of bead geometry of pulsed GTAW process for Aluminium Alloy 7039 using Ar + He gas mixtures

[1]**Pawan Kumar,** [2]**Kishor P Kolhe,** [1]**Som Ashutosh,** [1]**C K Datta**
[1]Department of Mechanical Engineering, Delhi College of Engineering, Delhi
[2]Department of Mechanical Engineering, Agricultural University, Dapoli - Ratnagiri, India

ABSTRACT

The present paper depicts the application of pulsed gas tungsten arc welding (pulsed GTAW) for aluminium alloy (AA7039) using various Ar + He (Argon + Helium) mixtures as a shielding gas with sinusoidal AC wave. In this investigation, Taguchi method is used to formulate the experimental layout, to analyse the effect of each process parameter on the bead geometry, and to predict the optimum setting for each welding process parameter. The pulsed GTAW process is employed for a high rate of current rise and decay at a high pulse repetitive rate, which is widely used in the joining of precision parts. Zinc is usually added to improve mechanical properties through formation of hard intermediate phase, such as Mg_2Zn. 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. AA7039 is employed in aircraft, automobiles, high-speed trains and high-speed ships due to their low density, high specific strength and excellent corrosion resistance.

Key words: Pulsed GTA welding; Aluminum alloy 7039 ; Bead geometry.

INTRODUCTION

The Gas Tungsten Arc Welding (GTAW) process is frequently used in welding of aluminium alloys, because of its possible heat input control. This control can be utilized through a good selection of the process variables, which in turn results in optimizing the bead dimensions [1]. Also GTAW process is strongly characterised by the bead geometry because the bead geometry plays a very important role in determining the mechanical properties of the weld [2]. 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 thermal behaviour of weld governed by arc characteristics and the behaviour of metal transfer significantly influences the geometry, chemistry, microstructure and stresses of weld [3, 4]. Deep penetration in pulsed current welding is produced mainly by arc pressure at peak duration and significantly long peak duration is needed for deep penetration [5]. Argon helium mixtures are used to take advantages of optimum operating characteristics of each gas, superior arc ignition and stable arc characteristics of argon and higher thermal conductivity of helium. These mixtures are used to increase the heat input of the arc. Helium rich mixtures are preferred in order to achieve good cleaning action with high heat input and arc stability [6]. 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 [7].

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 shows that pulsed arc welds would be cooler and therefore exhibit less thermal distortion than conventional GTA welds of the same penetration [8]. 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. The heat input is typically calculated as follows:

$H = [60EI] / 1000\,S$,

Where H = Heat Input (kJ/mm),

E = arc voltage (Volts),

I is a Current (Amps) and S = Travel Speed (mm/min).

To study the entire process parameter with a small number of experiments taguchi techniques is used. In fact taguchi technique has been designed to optimize a single quality characteristic. To consider several quality characteristics together in the selection of process parameters, the modified taguchi method (MTM) is used [2].

EXPERIMENTAL WORK

The 6mm thick samples of AA7039 were cut into the standard sizes for bead on plate by power hacksaw cutting and shearing machine. Weld beads along the length were deposited using 3.15 mm 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 Ar and He mixture as shielded gas. The chemical composition and mechanical properties of base metal are tabulated in Table 1.

Table 1 : Chemical compositions, Physical properties and Mechanical properties of base metal process for Aluminium Alloy 7039

Chemical composition		Physical properties		Mechanical properties	
Element	% Compositions	Density	Melting point	UTS	Hardness
Al	95.8-98.6	2.70 g/cc	582-651.70c	310 MPa	75 Hv
Mg	0.8-1.2				
Si	0.40-0.80				

The quality of weld is based on the process parameters such as peak current in the range of 150-210 A, the base current in the range of 75-135 A, the pulse frequency in the range of 50-150 Hz, the pulse on time in a range of 30-90% and the helium percentage in Ar+He gas mixture ranges 10-50%. After polishing and etching of transverse cross sections of each sample, measurement of bead penetration p, bead width b and bead height h, were carried out with the help of digital Vernier calliper equipped with magnifying glasses.

Selection of process parameter and their Limits

A large number of trial runs were carried out by using 6mm-thick AA7039 samples to find out the optimum working limits of pulsed current GTAW parameters. Different combinations of pulse current parameters were used to conduct the trial runs. The bead contour, bead appearance and weld quality were inspected to identify the welding parameters. From the above analysis, following observations are made:

1. If the peak current (P) < 150 A, incomplete penetration & lack of fusion were observed. At the same time, if the P > 210 A, under cut, spatters & overheating were observed.
2. If background current (B) < 75 A, arc length was found to be very short. On the other hand, B >135 A, arc became unstable and arc length was increased.
3. If the pulse frequency (F) < 50 Hz, the bead contour and bead appearance was not of good quality. However, if the F > 150 Hz, there was a harsh sound in welding machine.
4. If the pulse duty cycle (T) < 30%, the heat input was very low which was not sufficient to melt the base metal. On the contrary, if the T > 90%, over melting of the base & filler metal and

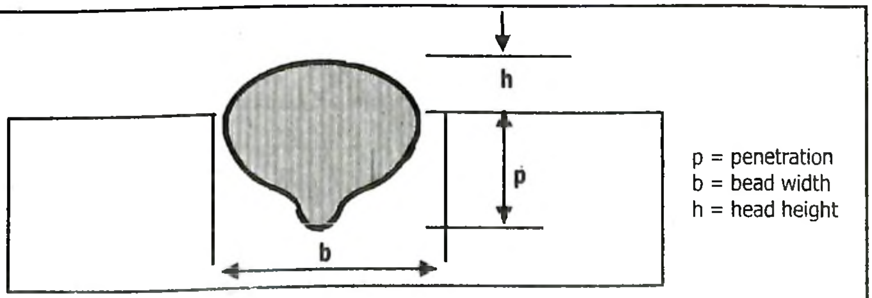


Fig. 1 : Schematic diagram of Weld Bead

overheating of tungsten electrode was noticed.

5. If the %age of helium in Ar + He gas mixture (X) < 10%, the arc stability, bead penetration and bead appeara-nce were poor. On the other hand if X > 50%, gas consumption gas mixture per kg weld deposition was very high.

The problems were overcome by choosing appropriate process parameters to have good quality welds. Process parameters and their limiting values for experimentation are tabulated in Table 2.

Table 2 : Process Parameters and their limiting Values

Symbol	Process parameter	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
P	Pulse/Peak Current	A	150	165	180	195	210
B	Secondary Current	A	75	90	105	120	135
F	Pulse Frequency	Hz	50	75	100	125	150
T	Pulse Duty Cycle	%	30	45	60	75	90
X	%age of He in Ar	%	10	20	30	40	50

Optimal Selection of Process Parameter by MTM

Modified Taguchi Method (MTM) is used to find out the optimal process parameter mix to enhance the bead geometry by conducting minimal experiments.

Orthogonal array

In the study, five levels were chosen for the five factors. The limiting values of the factors are tabulated in Table 2. There were 20 degrees of freedom and hence L25 orthogonal array was used. The experimental layout for the experimentation is detailed in Table 3.

Table 3: Process Parameters and their limiting Values

Expt No.	Levels of Process Parameters					Expt No.	Levels of Process Parameters				
	P	B	F	T	X		P	B	F	T	X
1	1	1	1	1	1	14	3	4	1	3	5
2	1	2	2	2	2	15	3	5	2	4	1
3	1	3	3	3	3	16	4	1	4	2	5
4	1	4	4	4	4	17	4	2	5	3	1
5	1	5	5	5	5	18	4	3	1	4	2
6	2	1	2	3	4	19	4	4	2	5	3
7	2	2	3	4	5	20	4	5	3	1	4
8	2	3	4	5	1	21	5	1	5	4	3
9	2	4	5	1	2	22	5	2	1	5	4
10	2	5	1	2	3	23	5	3	2	1	5
11	3	1	3	5	2	24	5	4	3	2	1
12	3	2	4	1	3	25	5	5	4	3	2
13	3	3	5	2	4						

TÜV Rheinland
NABCB
QM 010

SATKUL™
ENTERPRISES LTD.
An ISO 9001 : 2000

Regd. Office :
M-21, New Madhavpura Market, Shahibaug Road, Ahmedabad - 380 004, INDIA Phone : + 91 - 79 - 2562 0552, 2562 6445
Fax : + 91 - 79 - 2562 0558 E-mail : sales@satkulwelding.com Website : www.satkulwelding.com
Mumbai Office : Paras Complex, Godown No. 1/A, Survey No. 81/1-A3, Kolkhe, Panvel HO, Raigad,Maharashtra 410206.

House of Imported Welding Consumables

Sole Distributor in India
CHOSUN WELDING CO. LTD.
An ISO 9001-2000 COMPANY

APPROVALS : DNV,ABS,LR. BV, ETC...
ELECTRODES : M.S. / S.S./ L.H. / C. I. MAINTENANCE ETC.
FLUX CORED WIRES : E71T-1, E308LT-1, E316LT-1, E309LT-1, E81T1-B2, E91T1-B3 ETC...
MIG & TIG WIRES : ER70S-2,ER70S-6,ER308L,ER309L, ER316L
PAIL PACK (DRUM PACK) ALSO AVAILABLE FOR CO2-SOLID WIRES & FLUX CORED WIRES
SAW WIRE & FLUX : EL-8, EH-14, EM12K, F7A(P)0, F7A(P) 2, F7A(P) 6 ETC...

Authorised Distributor in INDIA
Oxford® ALLOYS, Inc.
Electrodes, Filler Wires & Flux Cored Wires
INCONEL, MONEL, INCOLOY HASTELLOY, STELLITE,
FERRALIUM, NITRONIC, TITANIUM, DUPLEX STEEL AND OTHER ALLOYS.

OUR ASSOCIATE :

Falcon
FALCON CABLES PVT. LTD.
An ISO 9001 : 2000 Company
M-21, New Madhavpura Market,
Shahibaug Road, Ahmedabad-380 004, INDIA
Phone : 91 - 79 - 25620552, 25626445
Fax : 91 - 79 - 25620558
E-mail : falcon@satkulwelding.com

WELDING CABLES OF SUPERIOR PERFORMANCE

MANUFACTURER OF COPPER & ALUMINIUM
TRS/HOFR WELDING CABLE

Sq mm 16-25-35-50-70-95-120

ALSO AVAILABLE
150 / 185 / 240 / 300 Sq. mm

IS 9857/1990
ISI
CM/L 7176476

DEALERS:
- CHENNAI : Clarion Enterprise : (044) 26246581 • COCHIN : Ess Square Enterprises : (0484) 2371650
- BHOPAL : J. J. Sales & Services : (0755) 2588606 • PUNE : R. S. Enterprise : 9372440995
- BARODA : Devang Enterprises : 9898123023 • NEW DELHI : Asian Trading Corporation : 9810338616
- CHANDIGARH : SVAG Engineers : (0172) 5087266 • JALGAON : Shree Datta Agencies : (0257) 2251223
- RAJKOT : Allwyn Enterprise (0281) 2225671 • VITHAL UDHYOGNAGAR : Kalash Enterprise : (02692) 236435

Attracting the best for Welding Electrode Industries, Steel Plants and Foundries

Ferro Alloys

- Ferro Boron
- Ferro Chrome (ELC/LC/EHC/HC/Nitrided)
- Ferro Manganese (ELC/LC/MC/HC)
- Ferro Molybdenum
- Ferro Niobium
- Ferro Phosphorous
- Ferro Silico Calcium
- Ferro Silico Magnesium
- Ferro Silico Manganese
- Ferro Silico Zirconium
- Ferro Silicon
- Ferro Titanium
- Ferro Tungsten
- Ferro Vanadium

Metals

- Aluminium
- Chromium Metal
- Cobalt
- Copper
- High Carbon Chromium Metal
- Iron Powder (Grade40.29/ Electrolytic)
- Manganese Metal
- Molybdenum
- Nickel
- Nitrided Manganese Metal
- Tungsten

Minerals

- Barium Carbonate
- Calcium Alginate
- Cellulose Powder
- Fluorspar
- Natural Graphite Powder
- Potassium Titanate
- Sodium Alginate
- Sodium Cryolite
- Titanium Dioxide

ISO - 9001 REGISTERED COMPANIES

JAYESH TRADING CO.

JAYESH INDUSTRIES LIMITED

*above products are available in Lumps/Chips/Powder form.

®

JAYESH GROUP

A Name that Ensures Trust

605-9, Krushal Commercial Complex, Above Shoppers Stop, G.M. Road, Amar Mahal, Chembur (W), Mumbai - 400 089. India
Tel : +91 22 6703 9991 / 4074 9990 / 2526 0983, Fax : +91 22 6703 9990 / 2526 0986 Toll Free : 1800 22 9997
Email: info@jayeshgroup.com / contact@jayeshgroup.com Website : www.jayeshgroup.com

RESULTS

The experiments were conducted as per the orthogonal array and the results were tabulated in table 4. For optimizing the process parameters, four quality characteristics have to be considered for a single characteristic. The weighted response of bead geometry properties is obtained by adding weights to the responses as a single quality characteristic. In this optimization, the weights for bead penetration, bead width and bead height are selected as 1/3 (assuming equal weightage). The weighted response is tabulated in Table 5.

Table 4 : Experimental results for the bead geometry

S. No	Penetration (p) mm	Width (b) mm	Height (h) mm	S. No	Penetration (p) mm	Width (b) mm	Height (h) mm
01.	0.54	7.07	1.45	14.	1.12	10.58	1.99
02.	0.80	7.93	1.23	15.	1.67	9.40	2.01
03.	2.00	9.78	1.74	16.	1.71	9.86	1.83
04.	1.76	9.55	1.56	17.	1.42	9.04	2.42
05.	2.03	10.09	1.76	18.	1.33	8.76	1.87
06.	0.61	7.82	1.59	19.	1.78	9.42	2.28
07.	0.91	8.09	1.48	20.	1.19	9.45	1.83
08.	1.23	9.12	1.97	21.	1.42	10.06	1.91
09.	1.63	9.56	1.12	22.	1.84	9.81	1.87
10.	1.49	9.98	2.13	23.	1.56	8.52	1.63
11.	1.66	9.61	1.82	24.	2.35	10.68	1.42
12.	0.69	9.13	1.74	25.	1.29	8.05	2.09
13.	1.06	9.69	1.89				

Table 5 : Weighted response for the bead geometry

Expt No.	Weighted Response	Expt No.	Weighted Response	Expt No.	Weighted Response	Expt No.	Weighted Response	Expt No.	Weighted Response
1.	3.02	6.	3.34	11.	4.36	16.	4.47	21.	4.46
2.	3.39	7.	3.49	12.	3.85	17.	4.29	22.	4.51
3.	4.51	8.	4.11	13.	4.21	18.	3.99	23.	3.90
4.	4.29	9.	4.10	14.	4.56	19.	4.49	24.	4.82
5.	4.63	10.	4.53	15.	4.36	20.	4.16	25	3.81

Analysis of variance

Analysis of variance is the most important tool for calculating the responsible factors which significantly affects the bead geometry properties. For determining the significant affecting process parameters, F-test was performed. The results of ANOVA are tabulated in Table 6 and response graph in Fig 2. The %age contribution by each of the process parameters are presented in Table 6. Response graph are drawn from response Table 7, to identify the significant levels of each factor.

Table 6 : Results of analysis of variance

Symbol	Welding parameter	Deg of freedom	Sum of square	Mean square	F	Contributed percentage
P	Pulse Current	4	0.710	0.1775	0.7346	14.38
B	Base Current	4	1.105	0.2763	1.1428	22.37
F	Pulse Frequency	4	0.582	0.1455	0.6020	11.78
T	Pulse Duty Cycle	4	1.062	0.2656	1.0985	21.50
X	%age of He in Argon	4	0.513	0.1283	0.5308	10.39
Error		4	0.967			19.58
Total		24	4.939			

Table 7 : Response table for the weld bead properties

Symbol	Welding parameter	Level 1	Level 2	Level 3	Level 4	Level 5
P	Pulse Current	3.97	3.91	4.27	4.28	4.30
B	Base Current	3.93	3.91	4.14	4.45	4.29
F	Pulse Frequency	4.12	3.90	4.27	4.10	4.34
T	Pulse Duty Cycle	3.81	4.28	4.10	4.12	4.42
X	%age of He in Argon	4.12	3.93	4.37	4.13	4.21

Confirmation Test

The optimal level of process parameters were predicted by using the response graph and ANOVA. The process parameters and their levels which affect the weld bead geometry are pulse current at level 5, background current at level 4, pulse frequency at level 5, pulse duty cycle at level 5 and percentage of He at level 3. The obtained results were verified by conducting a confirmation test based on results obtained in table 8.

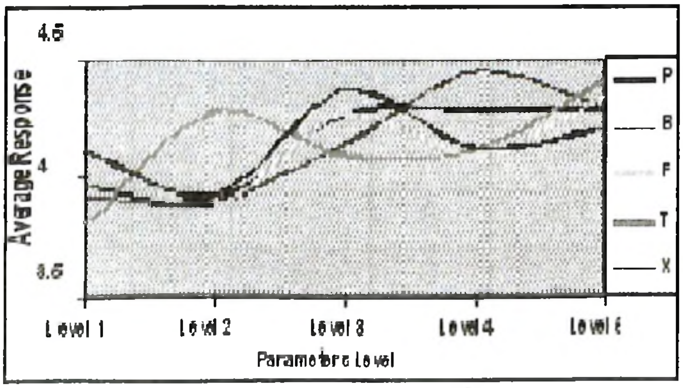


Fig 2 : Response graph for Bead Geometry Properties

Table 8 : Confirmation test results

Optimum Response	Optimal Process Parameters	Bead Penetration (P) (mm)	Bead Width (b) mm	Bead heigh (h) mm
Predicted	P5 -B4 - F5 - T5 - X3			
Experiment	P5 -B4 - F5 - T5 - X3	2.32	11.55	2.87

DISCUSSIONS

The weld beads were prepared at 100, 120, 140 and 160 Amp currents at various frequencies like 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 increases, the welding speed was also increased. There is a harsh sound in the welding machine on increasing the frequency and no colour changes 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. The results for the microhardness with the increase in frequency at different currents are plotted in fig 3 to fig 6, and the microstructures of the base metal, weld zone and heat-affected zones are shown in fig. 7. From the above investigation the following observations are made,

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

(b) It is 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.

(c) 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.

(d) It is also observed that as we increase the current & frequency, the drop in the microhardness shifts away from the weld centre towards the unaffected base metal. This is due to the increase in heat input as currents and frequencies are increases.

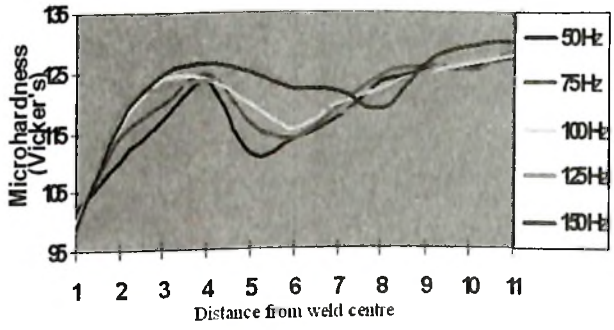


Fig. 3
Variation of Micro-hardness at 100 amp current for Aluminum Alloy 7039

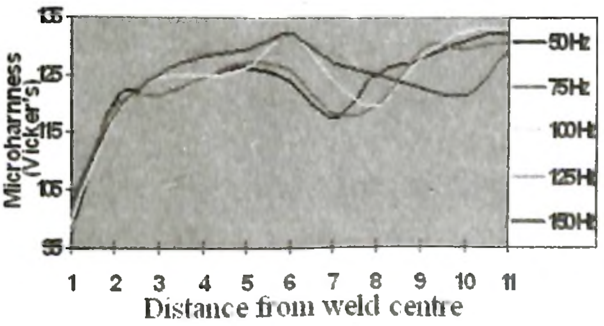


Fig. 4
Variation of Micro-hardness at 120 amp current For Aluminum Alloy 7039

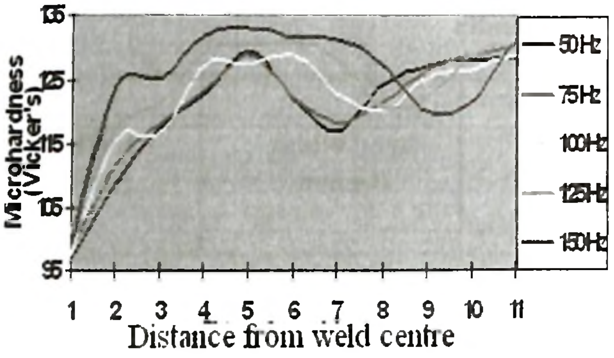


Fig. 5
Variation of Micro-hardness at 140 amp current for Aluminum Alloy 7039

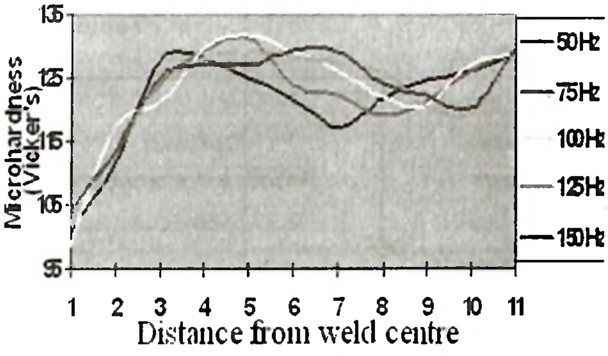
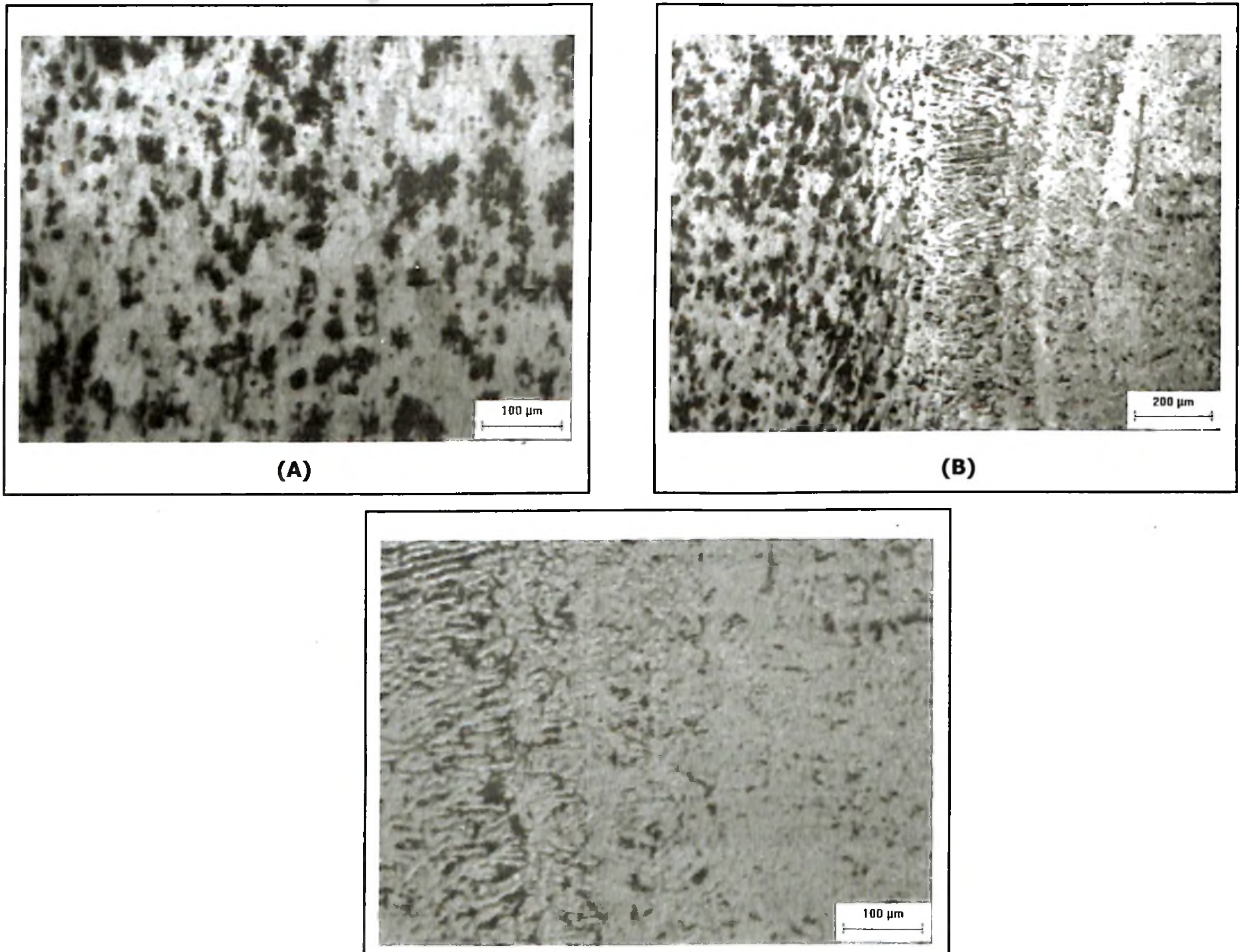


Fig. 6
Variation of Micro-hardness at 160 amp current for Aluminum Alloy 7039



(A)

(B)

(C)

Fig 7(a,b,c): Microstructure of Base Metal, HAZ and Weld Metal of Aluminum Alloy 7039

CONCLUSION

On the basis of the above experimental results it had been proved that pulse current, background current, pulse frequency, pulse duty cycle and percentage of He in (Ar + He) gas mixtures plays significant role for optimising the weld bead geometries. In this investigation, the pulse current of 210 A, background current of 120 A, pulse frequency of 150 Hz, pulse duty cycle of 90 per cent and 30 per cent of He in Ar + He gas mixture resulted the optimum values of bead geometry. The confirmation test conducted with predicted levels of factors proved to be worthy.

It is 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.

REFERENCES

1. Mohamed, A.A. Optimisation of weld bead dimensions in GTAW of Al-Mg alloy. Materials and Manufacturing Processes, vol 16 no. 5, 2001, pp 725 736.
2. Balasubramanian, M. and Balasubramanain, V. Process parameter optimisation of the Pulsed GTAW of Titanium alloy. Journal of Material Science and Technology, vol 24 no 3, 2008, pp 423 426.
3. Ko, S. H. and Yoo, C.D. Effects of surface depression on poll convention & geometry in stationary GTAW. Welding journal, vol 80 no 2, 2001, pp 39-s to 45-s.
4. Reichelt, W. R. and Hoy, M.G. Effect of shielding gas on GMA welding. Welding Journal, vol 59 no 5, 1980, pp 147-s to 155-s.
5. Janakiram, G.D.and Shankar, V. Microstructural refinement through inoculation of Type 7020 AlZnMg alloy welds and its effect on hot cracking & tensile property. Journal Material Process Technology, vol 142, 2003, pp 174 to 181.
6. Leitner, R.E., Mcelhinney, H. and Pruitt, E.I. An investigation of Pulsed welding variables. Welding Journal, vol 52 no 9, 1973, pp 405-s to 410-s.
7. Jenney, C. L. and O'Brien, A. AWS welding handbook, vol 1, 2001, 9th Ed.
8. Radaj, Dieter. Heat effects of welding, Springer-Verlag. Berlin, 1992, 1st Ed.