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REVIEW ARTICLE

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Optimization of pulsed GTAW process parameters for bead geometry of aluminium alloy 6061 using Taguchi method

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ABSTRACT

The selection of process parameters for obtaining optimal weld bead geometry of aluminium alloy 6061 (AA6061) with pulsed gas tungsten arc welding (GTAW) is presented. The bead geometry includes bead penetration, bead width and bead height. All these characteristics were considered together in the selection of process parameters using Argon as a shielding gas with sinusoidal AC wave and modified taguchi method was used to analyze the effect of each welding process parameter on bead geometry properties. Experimental results were furnished to illustrate the approach.

Key words : Pulse parameters, Modified Taguchi Method, Al Alloy 6061, Bead geometry

AA6061 aluminium alloy (Al-Mg-Si alloy) has gathered wide acceptance in fabrication of food equipments, chemical containers, passenger cars, road tankers and railway transportation systems (Kumar *et al.*, 2007). 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 heat, provided by welding process, is responsible for the decay of mechanical properties, due to phase transformations and softening induced in alloy (Norman *et al.*, 1999).

Pulsed 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 pulse process variables, which in turn results in optimizing the bead dimensions (Mohamed, 2001). Also pulse 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 (Jeneey *et al.*, 2001). The important process parameters which affects the bead profile are pulse current, secondary current (base / 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 significantly influences the geometry, chemistry, microstructure and stresses of weld (Dieter, 1992; Balasubramanian and Balasubramanain, 2008). 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 (Ko and Yoo, 2001).

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 (Lietner *et al.*, 1973). 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).

Taguchi method is a powerful tool for design of high-quality systems, widely used for improving quality without increasing cost and with minimum experimentation. It provides a simple, efficient and systematic approach to optimize designs for performance, quality and cost. This method is valuable when process parameters are qualitative and discrete. The parameter design based on the Taguchi method can optimise the quality characteristics through the settings of process parameters and reduce the

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sensitivity of the system performance to the sources of variation (Tarng and Yang, 1998). In fact, Taguchi method had been designed to optimize a single quality characteristic. However, for several quality characteristics taken together into consideration for selection of process parameters, the modified Taguchi method (MTM) is used (Sundarrajan, 2009; Kumar and Sundarrajan, 2006).

Experimental procedure:

The 5mm thick samples of AA6061 were cut into the standard sizes for bead on plate by power hacksaw cutting and milling machine. Weld beads were deposited along the length using 3.15mm diameter filler wires of aluminium alloy 5183 (Al-5%Mg) using GTAW process. A non-consumable tungsten electrode of 2.4 mm diameter was used with argon as shielding gas. The chemical composition and properties of base metal are tabulated in Table 1.

Table 1 : Chemical composition and properties of base metal

Al = 95.8 – 98.6 %	Mg = 0.8 – 1.2 %	Si = 0.40 – 0.80%
Density = 2.70 g/cc		Melting point = 582 – 651.7 °C
Hardness, Vicker's = 75		Ultimate tensile strength = 310 MPa

The quality of weld is based on the process parameters such as peak current in the range of 120 - 150 A, the secondary / background current in the range of 80 -110 A, the pulse frequency in the range of 50-125 Hz and the pulse on time / pulse duty cycle in a range of 30-75%. After polishing and etching of transverse cross sections of each sample, measurement of bead penetration p, bead width b and bead height h (as shown in Fig 1.) were carried out with the help of digital varnier calliper equipped with magnifying glasses.

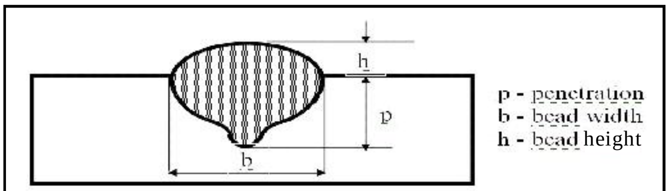

Fig. 1 : Pod exposing attachment

Selection of process parameter and their limits:

A large number of trial runs were carried out using 5mm-thick AA6061 samples to find out the feasible 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 were made:

– If the peak current (P) was less than 120 Amp, incomplete penetration and lack of fusion were observed. At the same time, if the pulse current exceeded 150 Amp, spatters and overheating were observed.

– If background current (B) was lower than 80 Amp, arc length was found to be very short. On the other hand, if the background current was greater than 110 Amp, arc became unstable and arc length was increased.

– If the pulse frequency (F) was less than 50 Hz, the bead contour and bead appearance was not of good quality. However, if the pulse frequency was greater than 125 Hz, there was a harsh sound in welding machine.

– If the pulse duty cycle was lower than 30%, the heat input was very low which was not sufficient to melt the base metal. On the contrary, if the pulse duty cycle was greater than 75%, over melting of the base and filler metal and overheating of tungsten electrode was noticed.

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

Optimal selection of process parameter by MTM:

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

Orthogonal array:

In the study, four levels were chosen for the four factors. The limiting values of the factors are tabulated in Table 2. There is 15 degree of freedom and hence L16 orthogonal array was used. The experimental layout for the experimentation is detailed in Table 3.

Table 2 : Process parameters and their limiting values

Symbol	Process parameter	Unit	Level 1	Level 2	Level 3	Level 4
P	Pulse/peak current	Amp	120	130	140	150
B	Secondary current	Amp	80	90	100	110
F	Pulse frequency	Hz	50	75	100	125
T	Pulse duty cycle	%	30	45	60	75

Table 3: Experimental layout using L16 orthogonal array

Experiment No	Levels of process parameters			
	Peak current (P)	Base current (B)	Pulse frequency (F)	Pulse duty cycle (T)
1.	1	1	1	1
2.	1	2	2	2
3.	1	3	3	3
4.	1	4	4	4
5.	2	1	2	3
6.	2	2	1	4
7.	2	3	4	1
8.	2	4	3	2
9.	3	1	3	4
10.	3	2	4	3
11.	3	3	1	1
12.	3	4	2	2
13.	4	1	4	2
14.	4	2	3	1
15.	4	3	2	4
16.	4	4	1	3

Table 4 : Experimental results for the bead geometry

Sr. No	Penetration (p) mm	Width (b) mm	Height (h) mm	S. No	Penetration (p) mm	Width (b) mm	Height (h) mm
01.	0.36	8.16	2.04	09.	1.46	8.42	1.83
02.	0.47	7.98	2.50	10.	1.21	8.33	1.62
03.	0.76	8.27	2.47	11.	1.02	8.65	1.70
04.	0.97	8.32	2.74	12.	1.05	8.41	1.86
05.	0.83	8.08	1.83	13.	1.00	7.93	1.66
06.	1.63	8.15	1.85	14.	0.64	7.70	2.41
07.	1.08	8.54	1.78	15.	1.97	8.46	1.67
08.	1.57	8.15	1.86	16.	1.82	8.51	1.94

Experimental results:

The experiments were conducted as per the orthogonal array and the results are tabulated in Table 4. For optimizing the process parameters, three 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 optimisation, AHP (Analytical Hierarchy Process) was used for analysing the weights of different parameters of weld bead geometry after taking the comparative importance value of each parameter by three experts in the field of welding technology. After calculation of relative importance values, the weights for bead penetration, bead width and bead height are selected as 0.64, 0.254 and 0.106, respectively. The weightage response is tabulated in Table 5.

Analysis of variance:

Analysis of variance is the most important tool for

Table 5 : Weighted response for the bead geometry

Expt No	Weighted response	Expt no	Weighted response	Expt no	Weighted response	Expt no	Weighted response
01.	2.519	05.	2.778	09.	3.267	13.	2.830
02.	2.593	06.	3.309	10.	3.062	14.	2.621
03.	2.849	07.	3.049	11.	3.030	15.	3.587
04.	3.025	08.	3.272	12.	3.005	16.	3.532

Table 6: Results of analysis of variance						
Symbol	Welding parameter	Deg of freedom	Sum of square	Mean square	F	Contributed %age
P	Pulse current	3	0.4063	0.1354	2.374	26.89
B	Base current	3	0.3683	0.1228	2.152	24.38
F	Pulse frequency	3	0.0320	0.0107	0.187	02.18
T	Pulse duty cycle	3	0.5333	0.1778	3.116	35.29
Error		3	0.1711	0.0571		11.32
Total		15	1.5110	0.5038		

Table 7: Response table for the weld bead properties					
Symbol	Welding parameter	Level 1	Level 2	Level 3	Level 4
P	Pulse current	2.747	3.102	3.091	3.143
B	Base current	2.849	2.896	3.129	3.209
F	Pulse frequency	3.098	2.991	3.002	2.992
T	Pulse duty cycle	2.805	2.925	3.055	3.297

Table 8 : Confirmation test results				
Optimum Response	Optimal level of process parameters	Bead penetration (p) mm	Bead width (b) mm	Bead height (h) mm
Predicted	P4 – B4 – F1 – T4	2.01	8.72	2.77
Experiment	P4 – B4 – F1 – T4			

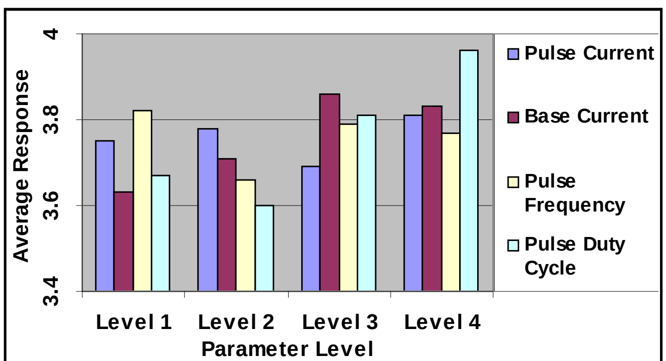

Fig. 2 : Response graph for bead geometry properties

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 indicates that pulse current, background current, pulse frequency and pulse duty cycle were the significant welding process parameters affecting the weld bead qualities. The percentage contribution by each of the process parameters are presented in Table 6. Response graph were drawn from response Table 7, to identify the significant levels of each factor.

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 4, background current at level 4, pulse frequency at level 1 and pulse duty cycle at level 4. The obtained result was verified by conducting a confirmation test based on results obtained in Table 8.

Conclusion:

This experimental study has been conducted to understand the effect of process parameters of pulsed GTAW on AA6061. On the basis of the above results it has been observed that pulse current, background current, pulse frequency and pulse duty cycle play an important role for optimising the weld bead geometries but the parameter pulse duty cycle has the maximum contribution *i.e.* 35.29%. In this investigation, the pulse current of 150 Amp, background current of 110 Amp, pulse frequency of 50 Hz and pulse duty cycle of 75% resulted the maximum values of bead geometry. The confirmation test conducted with predicted levels of factors proved to be effective and worthy.

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