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Optimizing pulsed GTAW process parameters for bead geometry of titanium alloy using taguchi method

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ABSTRACT

The selection of process parameters for obtaining optimal weld bead geometry of Ti-6Al-4V titanium alloy in the 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 various Ar + He (Argon + Helium) mixtures 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 this approach.

Key words : Pulse parameter, Modified taguchi method, Ti Alloy, Gas mixtures, Bead geometry

INTRODUCTION

Titanium and its alloys have been considered as one of the best engineering metals for industrial applications such as in food processing industry. This is due to the excellent combination of properties such as elevated strength to weight ratio, high toughness, excellent resistance to corrosion and good fatigue properties make them attractive for many industrial applications (Balasubramanian *et al.*, 2008). Titanium alloy grade – 5 (Ti-Al-V alloy) has gathered wide acceptance in fabrication of vessels, blades, discs, airframes, rings, fasteners, forgings and biomedical implants. Basically, GTA welding is strongly characterized by the bead geometry. This is because the bead geometry plays an important role in determining the mechanical properties of the weld. On the other hand it is widely understood that the GTA welding of titanium alloy exhibits columnar grains in the weld pool, which often results in inferior mechanical properties and may lead to hot cracking. In recent past many researchers have investigated the effect of physically disturbing the arc and thereby disturbing the molten pool by incorporating many techniques. One such technique which has been used by many investigators is pulsing current. This technique has been investigated successfully by many researchers to great success, resulting in grain refinement of fusion zone (Balasubramanian *et al.*, 2008).

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. 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). Argon – helium mixtures is 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 (Riechelt and Hoy, 1980). 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 (Leitner *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).

To study the entire process parameter with a small number of experiments, a Taguchi technique is used. In fact Taguchi technique has been designed to optimize a single quality characteristic. To consider the several quality characteristics together in the selection of process parameters, the modified Taguchi method (MTM) is used (Mohamed, 2001).

MATERIALS AND METHODS

The experiments were conducted on 2.5mm thick

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Table 1 : Chemical compositions and properties of base metal

Chemical compositions	Physical properties	Mechanical properties
Ti = 90.0 %	Density = 4.43 g/cc	Yield strength = 880 MPa
Al = 06.0 %	Melting point = 1604 – 1660^{0}C	Ultimate strength = 950 MPa
V = 4.0 %		Hardness = 349 Hv
		Elongation at break = 14.0 %

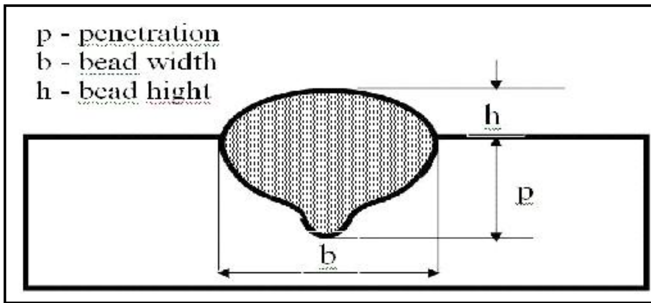

Fig. 1 : Schematic diagram of weld bead

samples of Ti alloy Gr-5 metals. These were cut into the standard sizes for bead on plate by shear and milling machine. Weld beads along the length were deposited using 2.00mm diameter filler rod of Ti alloy Gr-5 with the help of the GTAW process. A non-consumable tungsten electrode of 2.4 mm diameter was used with Ar + % He mixtures as shielded gas. The chemical composition and mechanical properties of base metal are tabulated in Table 1.

The quality of weld was based on the process parameters such as peak current in the range of 100 – 140 A, the base current in the range of 50 – 90 A, the pulse frequency in the range of 50 – 150 Hz, the pulse on time in a range of 40 – 80 % and the helium %age 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 (as shown in Fig. 1)were carried out with the help of digital varnier calliper equipped with magnifying glasses.

Selection of process parameter and their limits:

A large number of trial runs were carried out using 2.5mm-thick Titanium Gr-5 samples to find out the feasible working limits of pulsed current GTAW parameters. Different combinations of pulse current parameters with Ar + He mixtures were used to conduct the trial runs. The bead contour, bead appearance and weld quality were inspected to identify the welding parameters. From the

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	100	110	120	130	140
B	Secondary current	A	50	60	70	80	90
F	Pulse frequency	Hz	50	75	100	125	150
T	Pulse duty cycle	%	40	50	60	70	80
X	%age of He in Ar	%	10	20	30	40	50

Table 3: Experimental layout using L25 orthogonal array

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						

above analysis, following observations were made:

– If the peak current (P) < 100 A, incomplete penetration and lack of fusion were observed. At the same time, if the P > 140 A, under cut, spatters and overheating were observed.

– If background current (B) < 50 A, arc length was found to be very short. On the other hand, B > 90 A, arc became unstable and arc length was increased.

– 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.

– If the pulse duty cycle (T) < 40 per cent, the heat input was very low which was not sufficient to melt the base metal. On the contrary, if the T > 80 per cent, over melting of the base and filler metal and overheating of tungsten electrode was noticed.

– If the percent of helium in Ar + He gas mixture (X) < 10 per cent, the arc stability, bead penetration and bead appearance were poor. On the other hand if X > 50 per cent 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 experimental limiting values are tabulated in Table 2.

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 is 20 degree of freedom and hence L25 orthogonal array was used. The experimental layout for the experimentation is detailed in Table 3.

RESULTS AND DISCUSSION

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 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 (Saaty, 1980). 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 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, pulse duty cycle and %age of He in (Ar + He) gas mixtures are the significant welding process parameters affecting the weld bead qualities. The %age contribution by each of the process parameters are presented in Table 6. Response graph

Table 4: Experimental results for the bead geometry

Sr. No.	Penetration (p) mm	Width (b) mm	Height (h) mm	Sr. No.	Penetration (p) mm	Width (b) mm	Height (h) mm
1.	0.41	6.06	0.96	14.	0.91	7.74	1.18
2.	0.43	6.19	1.01	15.	0.88	7.02	1.08
3.	0.49	7.77	1.03	16.	0.82	8.18	1.72
4.	0.62	7.93	1.52	17.	0.77	7.68	1.06
5.	0.61	8.56	1.33	18.	0.92	7.67	1.52
6.	0.71	8.64	1.39	19.	0.98	6.62	1.25
7.	0.79	8.58	1.74	20.	0.73	6.80	1.30
8.	0.81	7.97	1.08	21.	0.86	8.17	1.44
9.	0.63	7.31	1.33	22.	1.02	8.14	1.22
10.	0.82	7.62	1.68	23.	0.81	7.63	1.44
11.	0.77	7.12	1.26	24.	0.87	7.14	1.14
12.	0.67	8.16	1.48	25.	0.99	6.64	1.06
13.	0.74	7.08	1.08				

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.	1.904	6.	2.796	11.	2.435	16.	2.789	21.	2.778
2.	1.956	7.	2.869	12.	2.658	17.	2.560	22.	2.850
3.	2.397	8.	2.657	13.	2.386	18.	2.698	23.	2.609
4.	2.574	9.	2.402	14.	2.670	19.	2.440	24.	2.491
5.	2.706	10.	2.640	15.	2.461	20.	2.332	25	2.434

Table 6 : Results of analysis of variance

Symbol	Welding parameter	Deg. of freedom	Sum of square	Mean square	F	Contributed %age
P	Pulse current	4	0.0935	0.0234	2.292	06.70
B	Base current	4	0.2436	0.0609	5.971	17.46
F	Pulse frequency	4	0.2929	0.0732	7.178	20.99
T	Pulse duty cycle	4	0.2156	0.0539	5.283	15.46
X	%age of He in Ar	4	0.5085	0.1271	12.463	36.45
Error		4	0.0408	0.0102		02.93
Total		24	1.3949	0.3487	33.187	

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	2.307	2.673	2.522	2.564	2.632
B	Base current	2.541	2.579	2.549	2.515	2.515
F	Pulse frequency	2.552	2.452	2.505	2.622	2.566
T	Pulse duty cycle	2.381	2.452	2.571	2.676	2.618
X	%age of He in argon	2.415	2.385	2.583	2.588	2.729

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	P2–B2–F4-T4–X5	1.04	8.71	1.77
Experiment	P2–B2–F4-T4–X5			

are 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 2, background current at level 2, pulse frequency at level 4, pulse duty cycle at level 4 and %age of He at level 5. 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 T alloy Gr-5. On the basis of the above results it had been observed that pulse current, background current, pulse frequency and pulse duty cycle plays an important role for optimising the weld bead geometries

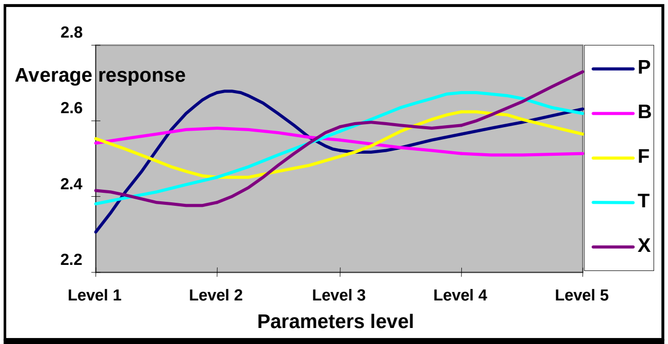

Fig. 2 : Response graph for bead geometry properties

but the parameter, %age of He in Ar + He gas mixture had the maximum contribution *i.e.* 36.45%. In this investigation, the pulse current of 110 A, background current of 60 A, pulse frequency of 125 Hz, pulse duty cycle of 70% and 50% of He in Ar + He gas mixture resulted in 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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