ISSN: 2319-5967
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 1, September 2012

Pulsed Parameters Optimization of GTAW Process for Mechanical Properties of Ti-6Al-4V Alloy using Taguchi Method

Pawan Kumar, C K Datta
pks_munesh@yahoo.com, ckdatta2010@gmail.com

***Abstract*— The selection of process parameters for obtaining optimal mechanical properties of Ti-6Al-4V titanium alloy with pulsed gas tungsten arc welding (GTAW) process is presented in this paper. The mechanical properties include ultimate tensile strength (UTS), microhardness and percentage elongation at break. All these characteristics were considered together in the selection of process parameters using various argon plus 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 mechanical properties. Experimental results were furnished to illustrate the approach.**

Index Terms **— GTAW, Gas Mixtures, Mechanical Properties, Pulse Process Parameters, Ti Alloy, Taguchi Method.**

I. INTRODUCTION

Titanium and its alloys have been considered as one of the best engineering metals for industrial applications. 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 [1]. 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 [2].
The important process parameters which affects the mechanical properties and bead profile of the weld are pulse current, base current, pulse frequency, pulse duty cycle, welding voltage, welding speed and gas flow rate. The thermal behavior of weld governed by arc characteristics and the behavior 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 [3]. 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 [4]. 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 [5]. 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 several quality characteristics together in the selection of process parameters, the modified taguchi method (MTM) is used [6].

ISSN: 2319-5967
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 1, September 2012

II. EXPERIMENTAL PROCEDURE

The 2.5mm thick samples of Ti alloy Gr-5 were cut into the standard sizes for tensile specimen by shear and milling machine. A non-consumable tungsten electrode of 2.4mm Φ shielded by argon plus helium gas was used to strike the arc with base metal. Filler rods (2.00mm Φ) of Ti alloy Gr-5 (same as base metal) were used for welding of this alloy for achieving the maximum strength. The chemical composition and mechanical properties of the base metal are tabulated in Table 1. Coupon plates were prepared by butt welding of the samples on Automatic Pulse GTAW TRITON 220V AC/DC welding machine. In order to remove oil, moisture and oxide layer from base metal, they were thoroughly wire brushed and cleaned with acetone. The quality of weld was based on the process parameters such as pulse 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 duty cycle in a range of 40–80 % and the helium percentage in argon plus helium gas mixture ranges 10–50%.

Tensile specimens of required dimension as per ASTM E8M were prepared from welded coupon plates and tests were carried out on 400 kN computer controlled Universal Testing Machine. The specimens were loaded at the rate of 1.5 kN per minute as per ASTM specifications, so that the tensile specimen undergoes uniform deformation and the influence of load on displacement profile was recorded. Microhardness tests were carried out on a Digital Microhardness Tester with 300gf load and 15 second dwell time incorporated with diamond indenter.

Table 1: Properties of Base Metal

<table>
<tr><td>Ti = 90.0 %</td><td>Al = 06.0 %</td><td>V = 4.0 %</td></tr>
<tr><td>Density = 4.43 g/cc</td><td colspan="2">Yield Tensile Strength = 880 MPa</td></tr>
<tr><td>Hardness, Vicker’s = 349</td><td colspan="2">Ultimate Tensile Strength = 950 MPa</td></tr>
<tr><td>Melting Point = 1604 – 1660 °C</td><td colspan="2">Elongation at break = 14.0 %</td></tr>
</table>

III. SELECTION OF PROCESS PARAMETERS AND THEIR LIMITS

The bead profile and quality of the GTA weld is greatly dependent on the joint design, welding position and proper selection of process parameters, such as current polarity, pulse current, base current, pulse frequency, pulse duty cycle, welding voltage, welding speed, arc length and shielding gas flow rate. The thermal behavior of weld is governed by arc characteristics. Welding parameters are selected on the basis of literature survey.Taguchi method has capabilities to optimize the quality characteristics through the settings of process parameters and reduce the sensitivity of the system performance to the sources of variation [7]. In fact, taguchi method had been designed to optimize a single quality characteristic. However, modified taguchi method (MTM) was used for several quality characteristics taken together into consideration for selection of process parameters [8-9]. 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 argon plus helium gas 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 above analysis, following observations were made:

1. 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.
2. 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.
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) < 40%, the heat input was very low which was not sufficient to melt the base metal. On the contrary, if the T > 80%, over melting of the base & filler metal and overheating of tungsten electrode was noticed.
5. If the percentage of helium in argon plus helium gas mixture (X) < 10%, the arc stability, bead penetration and bead appearance 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 experimental limiting values are tabulated in Table 2.

ISSN: 2319-5967
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 1, September 2012

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	Base 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	Percentage of He in Ar	%	10	20	30	40	50

IV. OPTIMAL SELECTION OF PROCESS PARAMETER BY MTM

Modified taguchi method (MTM) is used to find out the optimal process parameter mix to enhance the mechanical properties of the weld joint by conducting minimal experiments.

A. 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.

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						

B. Experimental Results

The experiments were conducted as per orthogonal array and results of the mechanical properties as UTS, microhardness of weld zone and percentage elongation are tabulated in Table 4. All tensile specimens fractured at weld joint, therefore their mechanical properties correspond to that of weld joint. For optimizing the process parameters, four quality characteristics were considered for a single characteristic. Hence MTM is used. Weighted response of mechanical properties was 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 mechanical properties after taking the comparative importance value of each parameter by three experts in the field of welding technology [10]. After calculation of relative importance values, the weights for UTS, microhardness in weld zone and elongation at break were selected as 0.640, 0.254 and 0.106 respectively. Weighted response is tabulated in Table 5.

C. Analysis Of Variance (ANOVA)

ANOVA is the most important tool for calculating the responsible factors which significantly affects the mechanical properties of the weld joints. For determining the significant affecting process parameters, F-test was performed. The results of ANOVA and percentage contribution by each process parameters are tabulated in Table 6. Response graph (Fig. 1) is drawn from response table (Table 7), to identify the significant level of each process parameter.

ISSN: 2319-5967
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 1, September 2012

Table 4: Experimental Results for the Mechanical Properties

S. No	UTS (MPa)	Microhardness VPN	Elongation %age	S. No	UTS (MPa)	Microhardness VPN	Elongation %age
01.	1018	368	2	**14.**	1104	368	3
02.	1153	347	2	**15.**	1244	343	6
03.	1119	336	2	**16.**	1024	351	5
04.	1107	364	3	**17.**	1135	345	6
05.	1073	353	3	**18.**	1207	326	6
06.	1129	349	4	**19.**	1179	337	3
07.	1133	342	4	**20.**	1194	330	7
08.	1103	353	5	**21.**	1168	347	3
09.	1179	331	6	**22.**	1171	346	6
10.	1079	343	4	**23.**	1068	350	5
11.	1195	358	3	**24.**	1145	347	5
12.	1102	345	6	**25.**	1169	325	7
13.	1131	329	7				

Table 5: Weighted Response for the Mechanical Properties

Expt No	Weighted Response	Expt No	Weighted Response	Expt No	Weighted Response	Expt No	Weighted Response	Expt No	Weighted Response
1.	710.15	**6.**	772.09	**11.**	814.12	**16.**	709.98	**21.**	794.69
2.	785.67	**7.**	772.52	**12.**	754.79	**17.**	774.71	**22.**	796.53
3.	762.29	**8.**	757.93	**13.**	768.12	**18.**	813.08	**23.**	736.23
4.	763.07	**9.**	797.57	**14.**	762.43	**19.**	798.73	**24.**	781.60
5.	739.30	**10.**	740.46	**15.**	839.64	**20.**	806.12	**25**	790.10

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	5880.84	1470.21	2.760	**24.48**
B	Base Current	4	4234.40	1058.60	1.987	17.63
F	Pulse Frequency	4	5608.92	1402.23	2.632	23.35
T	Pulse Duty Cycle	4	2177.37	0544.34	1.022	09.07
X	%age of He in Ar	4	3987.85	0996.96	1.872	16.60
Error		4	2130.74	0532.69		08.87
Total		24	24020.12			

Table 7: Response Table for the Mechanical Properties

Symbol	Welding parameter	Level 1	Level 2	Level 3	Level 4	Level 5
P	Pulse Current	752.10	768.11	**787.82**	780.52	779.83
B	Base Current	760.21	776.84	767.53	780.68	**783.12**
F	Pulse Frequency	764.53	786.47	**787.33**	755.17	774.88
T	Pulse Duty Cycle	760.97	757.17	772.32	**796.60**	781.32
X	%age of He in Argon	772.81	**800.11**	770.19	781.19	744.09

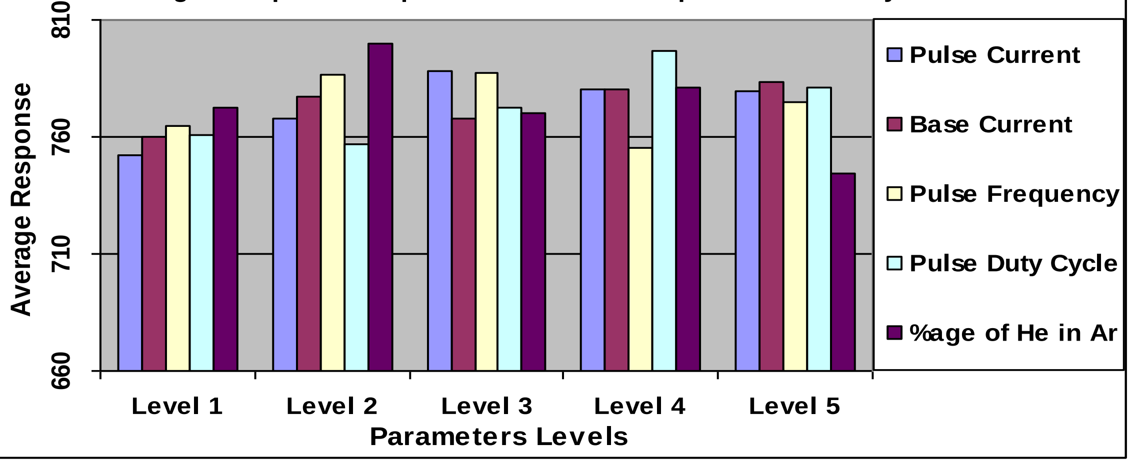

Fig 1: Response Graph for Mechanical Properties of Ti Alloy Gr - 5

D. Confirmation Test

Optimal level of process parameters was predicted using response graph and ANOVA. Process parameters and their levels which affect mechanical properties are pulse current at level 3, base current at level 5, pulse frequency at level 3, pulse duty cycle at level 4 and percentage of Helium in Argon at level 2. The obtained results were verified for the improvement in multiple quality characteristics by conducting a confirmation test based on results obtained in Table 8.

Table 8: Confirmation test results

Optimum Response	Optimal level of process parameters	UTS (MPa)	Microhardness VPN	Elongation Percentage
Predicted	P3–B5–F3-T4–X2			
Experiment	P3–B5–F3-T4–X2	1247	372	7

V. Conclusion

This experimental study has been conducted to understand the effect of process parameters of pulsed GTAW on Ti-6Al-4V Ti alloy. On the basis of the above results it had been observed that the selected process parameters plays an important role for optimising the mechanical properties of the weld joints, but pulse current had the maximum contribution i.e. 24.48% because pulse parameters with argon-helium gas mixtures produces better weld with deep penetration which directly improves the mechanical properties of weld joints. In this investigation, the pulse current of 120 A, base current of 90 A, pulse frequency of 100 Hz, pulse duty cycle of 70% and 20% of helium in argon plus helium gas mixture resulted in the maximum values of the mechanical properties of the weld joints. The confirmation test conducted with predicted levels of factors proved to be effective and worthy.

Acknowledgment

The author wishes to thank Vehicles Research and Development Establishment (VRDE), Ahmednagar for providing all the facilities for carrying out the experiments, and the scientists / staff of VRDE for their support and assistance in undertaking this work.

REFERENCES

[1] V. Balasubramanian, V.Jayabalan and M. Balasubramanain, “Effect of current pulsing on tensile properties of titanium alloy”, Journal of Material & Design, vol. 29, pp. 1459–1466, 2008.

[2] V. Balasubramanian, V.Jayabalan and M. Balasubramanain, “Process parameter optimization of the pulsed current argon tungsten arc welding of Ti alloy”, Journal of Material Science & Technology, vol. 24, no. 3, pp. 423-426, 2008.

[3] S. H. Ko and C. D. Yoo, “Effects of surface depression on poll convention & geometry in stationary GTAW”, Welding Journal, vol. 80, no. 2, pp. 39s–45s, 2001.

ISSN: 2319-5967
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 1, September 2012

[4] W. R. Reichelt and M. G. Hoy, "Effect of shielding gas on GMA welding", Welding Journal, vol. 59, no. 5, pp. 147s–155s, 1980.

[5] R. E. Leitner, H. Mcelhinney and E. I. Pruitt, "An investigation of Pulsed welding variables", Welding Journal, vol. 52, no. 9, pp. 405s–410s, 1973.

[6] A. A. Mohamed, "Optimization of weld bead dimensions in GTAW of Al-Mg alloy", Materials and Manufacturing Processes, vol. 16, no. 5, pp. 725–736, 2001.

[7] Y. S. Tarng and W. H. Yang, "Optimization of the weld bead geometry in GTA welding by the taguchi method", Advance Manufacturing Technology vol. 14, pp. 549–554, 1998.

[8] A. Kumar and S. Sundarrajan, "Optimization of pulsed TIG welding process parameters on mechanical properties of AA5456 Al alloy weldments", Materials and Design, vol. 30, pp. 1288–1297, 2009.

[9] A. Kumar and S. Sundarrajan, "Selection of welding process parameters for the optimum butt joint strength of an Al alloy", Materials and Manufacturing Processes, vol. 21, 779–782, 2006.

[10] T. L. Saaty, "The Analytical Hierarchy Process" – Mc-Graw Hill, New York, 1980.

AUTHOR BIOGRAPHY

Pawan Kumar is working as Scientist in VRDE Ahmednagar since Dec 2007. He has done B.E (Mechanical Engg) from Nagpur University in 1995 with Ist Div, M.E (Production Engineering) from Delhi College of Engg, Delhi in 2004 with Ist Div and pursuing Ph.D (Welding Technology) from Delhi College of Engg, Delhi (Thesis submitted). He is Life Member & Chartered Engineer of "The Institution of Engineers (I)" Kolkata and Life Member of "The Indian Institute of Welding" Kolkata. He has published 24 research papers out of which 09 papers are in International Journal. He has also worked as Assoc Professor in Krishna Institute of Engg & Tech, Ghaziabad for 8.5 years and also has 4 years industrial experience. In VRDE, he has developed Shock Resistant Seat for Mine Protected Vehicles.

C K Datta has around 40 years of teaching experience in reputed Engineering Colleges. He has worked as Professor & Head in Mechanical Engg Department of Delhi College of Engg, Delhi and developed a good welding research laboratory there. He has done B.E (Mechanical Engg) with Ist Div. He has also done M.E and Ph.D from IIT, Kharagpur. He is Fellow Member of "The Indian Institute of Welding (IIW)" Kolkata and Ex-President of IIW, Delhi Branch. He has published many research papers in International and National Journals. He has also guided many M.E and Ph.D Thesis. Many times he has been worked as Expert Member in selection / promotion boards of reputed organizations like DRDO, CSIR, NITs and various Government Engg Colleges.