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Application of Dragon fly Algorithm in Optimizing Fusion Zone Grain Size and Micro Hardness of Pulsed Current Micro Plasma Arc Welded of Titanium (Ti-6Al-4V) Alloy

A. Sunny Kumar[1], Prof. T.V. Hanumantha Rao[2], Prof. V.V.S. Kesava Rao[2], RT Ramakanth[3]

[1]*Department of Industrial Engineering, GITAM University, Visakhapatnam, India, sunnyeagle2020@gmail.com*
[2]*Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, Visakhapatnam, India, tvhrao.me@anits.edu.in*
[2]*Department of Mechanical Engineering, Andhra University, Visakhapatnam, India, kesava9999@gmail.com*
[3]*Department of Mechanical Engineering, Avanthi engineering college, Narsipatnam, Visakhapatnam, India,*
*Corresponding author Email: sunnyeagle2020@gmail.com

Abstract

In the present work, Titanium (Ti-6Al-4V) alloy sheet of 0.5 mm thick is butt welded using Micro Plasma Arc Welding. Welding input parameters like peak current, base current, pulse rate and pulse width are considered and output responses like fusion zone grain size and micro hardness of the welded joint are considered. Taguchi L_{25} orthogonal matrix is adopted by considering four factors and five levels of weld input parameters. Mathematical models are developed using MINITAB software considering linear function. Analysis of Variance (ANOVA) is carried out at 95% confidence level. The developed mathematical models have been optimized using Dragon fly algorithm minimize fusion zone grain size, and maximize the Micro hardness.

Key words: Titanium, Micro Plasma Arc Welding, Dragon fly algorithm.

1. INTRODUCTION

Ti-6Al-4V is one of the most important titanium alloys. It accounts for about 45% of the total weight of all titanium alloys produced and more than 80% of titanium alloys used in aerospace industry. It is also used in medical implants and in automotive, marine and chemical industries. It is α+β alloy which combines attractive mechanical properties with good workability and the best weldability of α+β alloys. Application of Ti-6Al-4V is limited to about 350°C which limits its use in high temperature applications. In the aerospace industry, Ti-6Al-4V is extensively used in the cold section of jet engines, i.e. in the fan and compressor sections [1].

Titanium alloys are readily joined with several common fusion welding processes such as tungsten inert gas welding (TIG), plasma arc welding (PAW), electron beam welding (EBW), and laser beam welding (EBW). Fusion welding processes can be characterized generally by the heat-source intensity.

From the literature it is understood that F. Karimzadeh et.al [2] investigated the effect of micro plasma arc welding (MPAW) process parameters on grain growth and porosity distribution of thin sheet Ti6Al4V alloy weldment. The MPAW procedure was performed at different current, welding speed and flow rates of shielding & plasma gas. F. Karimzadeh et.al [3] examined the effect of epitaxial growth on microstructure of Ti–6Al–4V alloy weldment by artificial neural networks (ANNs). The micro plasma arc welding (MPAW) procedure was performed at different currents, welding speeds and flow rates of shielding & plasma gas.

Pulsed current MPAW involves cycling the welding current at selected regular frequency. The maximum current is selected to give adequate penetration and bead contour, while the minimum is set at a level sufficient to maintain a stable arc [4,5]. This permits arc energy to be used effectively to fuse a spot of controlled dimensions in a short time producing the weld as a series of overlap-ping nuggets. By contrast, in constant current welding, the heat required to melt the base material is supplied only during the peak current pulses allowing the heat to dissipate into the base material leading to narrower Heat Affected Zone (HAZ). There are four independent parameters that influence the process are peak current, back current, pulse rate and pulse width.

Dragonfly algorithm (DA) is a novel swam intelligence optimization technique originating from natural behaviour of dragonflies, which depends on exploration and exploitation. The two aspects of the dragonflies for navigating, searching food and survival from enemies by creating sub-warms over different areas is used for convergence towards pareto optimal solutions and coverage of optimal solution along the objectives. The ultimate goal for a multi-response optimization method is to determine most accurate approximation of true Pareto optimal solution with uniform coverage across all objectives. The phenomena of dragonfly behaviour is well suited for designing modeling for generating optimal solutions for multi-response optimization problems [6].

In the present work Micro Plasma Arc Welding (MPAW) is used to join Ti-6Al-4V sheets of 0.5 mm thick. Welding input parameters like peak current, base current, pulse rate and pulse width are considered and output responses like fusion zone grain size and micro hardness of the welded joint are considered. The objective of the paper is to optimize welding parameters namely peak current, base current, pulse rate and pulse width in order to minimize fusion zone grain size and maximize micro hardness.

2.0 EXPERIMENTATION

Titanium (Ti-6Al-4V) sheets of 100 x 150 x 0.5 mm are welded autogenously with square butt joint without edge preparation. The chemical composition and tensile properties of Titanium (Ti-6Al-4V) sheet is given in Table .1 & .2. High purity argon gas (99.99%) is used as a shielding gas and a trailing gas right after welding to prevent absorption of oxygen and nitrogen from the atmosphere. The welding has been carried out under the welding conditions presented in Table .3. There are many influential process parameters which effect the weld quality characteristics of Pulsed Current MPAW process like peak current, base current, pulse rate, pulse width, flow rate of shielding gas, flow rate of purging gas, flow rate of plasma gas, welding speed etc. From the earlier works [9] carried out on Pulsed Current MPAW it was understood that the peak current, base current, pulse rate and pulse width are the dominating parameters which effect the weld quality characteristics. The values of process parameters used in this study are the optimal values obtained from our earlier papers [9]. Hence peak current, base current, pulse rate and pulse width are chosen and their values are presented in Table .4. Details about experimental setup are shown in Figure .1.

Fig.1 Micro Plasma Arc Welding Setup.

Table .1 (Ti-6Al-4V) (weight %)

V	Al	Fe	C	N	H	O	Ti
5.8	4.00	0.20	0.05	0.03	0.011	0.19	89.71

Table .2 Mechanical properties of Titanium (Ti-6Al-4V)

Elongation (%)	Yield Strength (MPa)	Ultimate Tensile Strength (Mpa)	VHN
14	880	950	349

Table .3 Welding conditions

Power source	Secheron Micro Plasma Arc Machine (Model: PLASMAFIX 50E)
Polarity	DCEN
Mode of operation	Pulse mode
Electrode	2% thoriated tungsten electrode
Electrode Diameter	1.5 mm
Plasma gas	Argon & Hydrogen
Plasma gas flow rate	6 Lpm
Shielding gas	Argon
Shielding gas flow rate	0.6 Lpm
Purging gas	Argon
Purging gas flow rate	0.6 Lpm
Copper Nozzle diameter	1mm
Nozzle to plate distance	1mm
Welding speed	260 mm/min
Torch Position	Vertical
Operation type	Automatic

Table .4 Process parameters and their limits.

	Levels					
Input Factor	**Units**	**1**	**2**	**3**	**4**	**5**
Peak Current	Amperes	26	28	30	32	34
Base Current	Amperes	11	13	15	17	19
Pulse rate	Pulses /Second	10	20	30	40	50
Pulse width	%	20	30	40	50	60

2.1 Measurement of Fusion Zone Grain Size

Three metallurgical samples are cut from each joint leaving the edges of defective portion of the welded length. Defective length of weld is identified visually and also by conducting dye pentrant and X-ray tests and mounted using Bakelite. Sample preparation and mounting is done as per ASTM E 3-1 standard. The transverse face of the samples are surface ground using 120 grit size belt with the help of belt grinder and polished sequentially using grade 1/0 (245 mesh size), grade 2/0(425 mesh size) and grade 3/0 (515 mesh size) sand paper. The specimens are further polished using aluminium oxide, diamond paste and velvet cloth on a disc polishing machine. The polished specimens are macro-etched using Kroll's reagent (100 ml water, 1-3 ml hydrofluoric acid, 2-6 ml nitric acid) solution to reveal the microstructure. By varying the etching time microstructure and grain size of the weld zone are revealed. The micrograph of parent metal is shown in Figure .2 and weld fusion zone is shown in Figure .3 at 100 X magnifications. Grain size at fusion zone of weld joint is measured using SEM (Make: INCA Penta FETx3, Model: 7573). Figure .4 indicates the grain size of weld fusion zone. Average values of grain size in weld fusion zone are presented in Table.5.The grain sizes are measured randomly in the weld fusion zone, where the grain size is uniform and undisturbed.

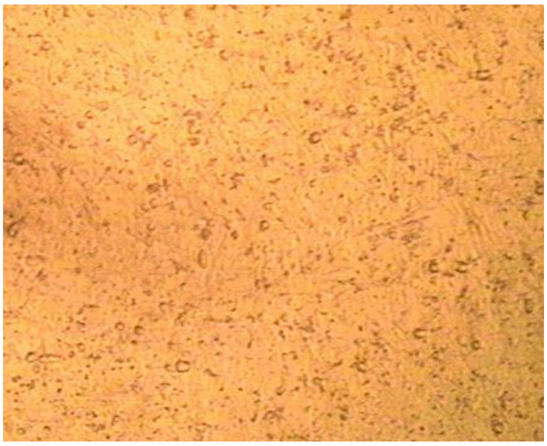

Fig.2 Microstructure at Fusion zone

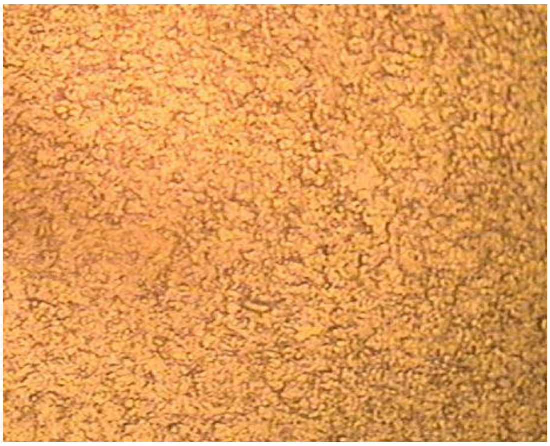

Fig.3 Grains at Fusion zone

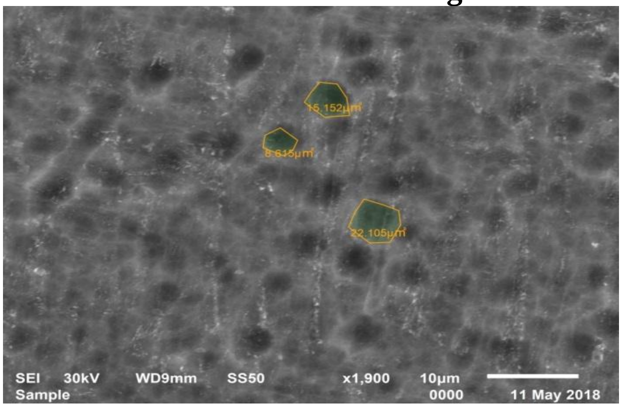

Fig .4 SEM image of fusion zone grain size

2.2 Measurement of Micro Hardness

The hardness of the weld fusion zone of the welded samples are measured using Vicker's micro hardness testing machine (Make: METSUZAWA CO LTD, JAPAN, Model: MMT-X7) by applying a load of 0.5 Kg as per ASTM E384. Average values of three readings of each sample are presented in Table .5.The variation of hardness across the weld joint is shown in Figure .5. It is understood from the Figure .5 that hardness is decreasing from the centre of the weld towards the HAZ. This is due to grain refinement taking place in the weld fusion zone, because of pulsing current used in the welding process.

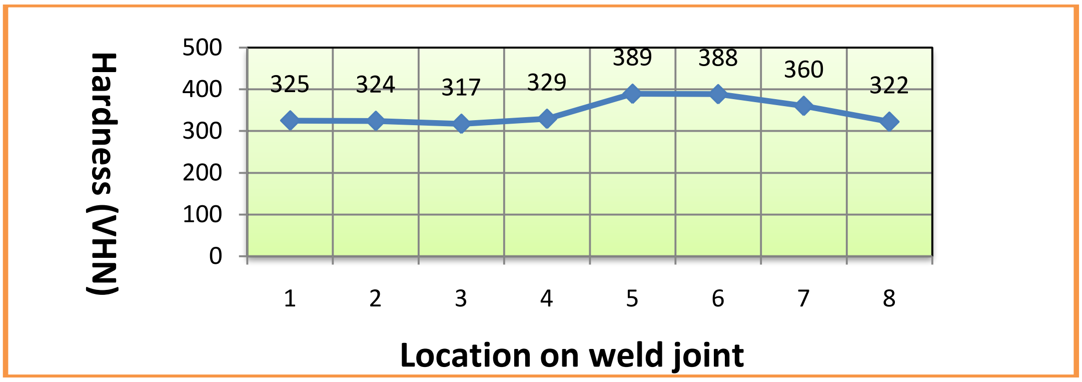

Figure .5 Variation of hardness across the weld

Where 1,2,7,8 are on Heat Affected Zone (HAZ) and 3,4,5,6 are on Fusion Zone (FZ).

Table 5: Experimental Results for Fusion Zone Grain size and Hardness

Exp No.	Peak Current (PC) (Amperes)	Base current (BC) (Amperes)	Pulse Rate (PS) (Pulses/second)	Pulse width (PW) (%)	Grain Size (Microns)	Hardness (VHN)
1	26	11	10	20	48.00	350.67
2	26	13	20	30	46.40	352.00
3	26	15	30	40	44.08	357.87
4	26	17	40	50	42.67	359.76
5	26	19	50	60	42.49	364.33
6	28	11	20	30	46.38	354.56
7	28	13	30	50	43.35	356.89
8	28	15	40	60	42.33	358.67
9	28	17	50	30	44.67	364.67
10	28	19	10	30	44.97	359.00
11	30	11	30	60	42.16	360.33
12	30	13	40	20	44.48	362.00
13	30	15	50	30	43.99	363.12
14	30	17	10	40	43.81	361.42
15	30	19	20	50	42.21	362.43
16	32	11	40	30	43.56	364.67
17	32	13	50	40	42.67	366.26
18	32	15	10	50	43.00	363.00
19	32	17	20	60	42.10	362.13
20	32	19	30	20	43.84	370.43
21	34	11	50	50	41.22	368.67
22	34	13	10	60	42.01	363.33
23	34	15	20	20	44.25	368.33
24	34	17	30	30	42.86	367.45
25	34	19	40	40	42.00	371.87

3. DEVELOPING MATHEMATICAL MODELS

A low order polynomial is some region of the independent variables is employed to develop a relation between the response and the independent variables. If the response is well modelled by a linear function of the independent variables then the approximating function in the first order model is

$$Y = b_o+\sum b_i x_i + \in \qquad (1)$$

Where b_o, b_i are the coefficients of the polynomial and $\in$ represents noise

Using MINTAB software by considering the linear model empirical models are developed

Fusion Zone Grain Size = 58.3076 - 0.2913 X_1- 0.12072 X_2- 0.0349039 X_3 - 0.0782678 X_4

Micro Hardness = 304.372 + 1.4274 X_1+ 0.738369 X_2 + 0.154694 X_3- 0.018898 X_4

where X_1, X_2 , X_3, X_4 represents the coded values of peak current, base current, pulse rate and pulse width.

Table 6: Anova Table for Grain size and Hardness

ANOVA TABLE FOR FUSION ZONE GRAIN SIZE							
Source	DFSeq	SS	Adj SS	Adj MS	F	P	%C
PC	1	16.9711	16.9711	16.9711	84.397	0.0000	27.2
BC	1	4.1587	2.9037	2.9037	14.440	0.0011	6.68
PR	1	7.8408	6.0685	6.0685	30.178	0.0002	12.6
PW	1	29.1836	29.1836	29.1836	145.128	0.0000	46.9
Error	20	4.0218	4.0218	0.2011			6.46
Total	24	62.1760					
S = 0.448428 R-Sq = 93.53% R-Sq(adj) = 92.24%							

ANOVA TABLE FOR MICRO HARDNESS							
Source	DFSeq	SS	Adj SS	Adj MS	F	P	%C
PC	1	407.494	407.494	407.494	181.674	0.0000	60
BC	1	107.370	108.627	108.627	48.429	0.0001	16
PR	1	117.903	119.201	119.201	53.143	0.0000	17.3
PW	1	1.701	1.701	1.701	0.7591	0.39414	0.25
Error	20	44.860	44.860	2.243			6.60
Total	24	679.329					
S = 1.49767 R-Sq = 93.40% R-Sq(adj) = 92.08%							

3.1 CHECKING THE ADEQUACY OF THE DEVELOPED MODELS

The adequacy of the developed models is tested using the ANOVA. As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (F-table value 2.027) value at a desired level of confidence of 95%, then the model is said to be adequate within the confidence limit. ANOVA test results are presented in Table .6 for grain size and micro hardness. From table 5.6 it is understood that the developed mathematical models are found to be adequate at 95% confidence level. Coefficient of determination'R^2' for the above developed models is found to be about 0.91.

4. OPTIMIZING USING DRAGON FLY ALGORITHM

Multi-objective dragonfly algorithm (MODA) depends on static and dynamic swarming capabilities like separation, alignment, cohesion, attraction towards food source (i.e. towards optimality), distraction outwards enemies (i.e. non-movement towards non-optimality) using the below given formulae considered from Seyedali [6]. The main objective of any swarm is survival, so all of the individuals should be attracted towards food sources and distracted outward enemies. Considering these two behaviours, there are five main factors in position updating of individuals in swarms as shown in table 7[6].

Table 7: Mathematically equations using dragon fly algorithm

Description	**Formulae**
Separation is calculated as:	$s_i = -\sum_{j=1}^{N}(X - X_j)$ (2)
Alignment is calculated as:	$A_i = \frac{\sum_{j=1}^{N} V_j}{N}$ (3)
Cohesion is calculated as:	$C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X$ (4)
Attraction towards a food source is calculated as:	$F_i = X^+ - X$ (5)
Distraction outwards an enemy is calculated as:	$E_i = X^- + X$ (6)
where X is the position of the current individual, Xj shows the position jth neighboring individual, Vj shows the velocity of jth neighboring individual, N is the number of neighboring individuals, X+ shows the position of the food source and X- shows the position of the enemy.	
The step vector shows the direction of the movement of the dragonflies	$\Delta X_{i+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t$ (7)
The Position Vectors are calculated as:	$X_{t+1} = X_i + \Delta X_{t+1}$ (8)
Pareto dominance is determined as:	$\forall i \in \{1,2,.....k\},[f(x_i) \geq f(y_i)] \wedge [\exists i \in 1,2,....k : f(x_i)]$

Pareto optimality is determined as:	$\not\in \vec{y} \in X \mid F(\vec{y}) \succ F(\vec{x})$ (10)
Pareto optimal set is determined as:	$P_s := \{x, y \in X\} \exists F(y) \succ F(x)$ (11)
Pareto optimal objective front/set is determined as:	$P_f := \{F(x) \mid x \in P_s\}$ (12)
where t is the current iteration, and s, a, c, f, and e are weights of separation, alignment, cohesion, food and enemy factors respectively, w is inertia weight (w=0.9-iteration*((0.9-0.2)/max_iter)) and radius within a dragonfly flies r= (ub-lb)/4+((ub-lb)*(iteration/max_iter)*2) [6].	
Probability for each segment is:	$P_i = \frac{Ni}{c}$ (13)

The behaviour of dragonflies is assumed to be the combination of these five corrective patterns in this paper. To update the position of artificial dragonflies in a search space and simulate their movements, two vectors are considered: step (DX) and position (X). The step vector is analogous to the velocity vector in PSO, and the DA algorithms developed based on the framework of the PSO algorithm. The step vector shows the direction of the movement of the dragonflies and defined as follows that the position updating model of artificial dragonflies is defined in one dimension [7-8]

5.1. Computations and Results

Data assumed for processing of MODA in MATLAB:

a. Number of process parameters=4 (peak current, base current, pulse rate and pulse width) and linear objective functions of fusion zone grain size and micro hardness

b. Lower bound (lb) = [26A, 11A, 10 Pulses/sec, 20%] and Upper bound (ub) = [34A, 11A, 50 pulses/sec, 60%] for peak current, base current pulse rate and pulse width respectively.

c. Number of artificial dragon flies (N) = 1000

d. Maximum iterations (Max_iter) = 500

e. Maximum archive size (Max_arch) = 50

f. Number of objectives = 2

Executing the MODA code in MATLAB, the optimal combination of welding parameters obtained and their response values for fusion zone grain size and micro hardness are shown table 8. The optimal combination of fusion zone grain size and Micro hardness are generated as 40.89 microns and 366.89 VHN respectively.

Table. 8. Optimized pulsed current MPAW parameters for Grain size and Hardness

Welding Parameters	Dragon Fly algorithm	Experimental Values
Peak Current(amperes)	34.25	34
Base current(amperes)	18.65	19
Pulse rate(pulses/second)	38.12	40
Pulse width (%)	37.56	40
Fusion zone Grain size	40.89	42.00
Micro Hardness	366.89	371.87

6. Conclusion

Empirical relations are developed to predict fusion zone grain size and micro hardness of pulsed current micro plasma arc welded titanium (Ti-6Al-4V) alloy using taguchi Method. The developed model can be effectively used to predict fusion zone grain size and micro hardness values of pulsed current micro plasma arc welded joints. From the experiments conducted the minimum grain size of 42.00 microns and maximum hardness of 371.87 VHN are obtained for the input parameter combination of peak current of 34 Amperes, base current of 19 Amperes, pulse rate of 40 pulses/second and pulse width of 40%. From dragon fly algorithm the minimum value of grain size obtained is 40.89 microns and maximum hardness obtained is 366.89 VHN for the input parameter combination of peak current of 34.25 Amperes, base current of 18.65 Amperes, pulse rate of 38.12 pulses/second and pulse width of 37.56 %. The values of grain size and hardness obtained experimentally and predicted using dragon fly algorithm are within the limit.

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