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Optimization of Pulsed Current TIG Welding Parameters on Al-SiC Metal Matrix Composite – An Empirical Approach

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Abstract

Joining of aluminium alloys and aluminium composites are done using TIG welding, due to its economic and good quality welds among arc welding processes. During TIG welding of aluminium alloys & aluminium composites coarse grain structure formation and intermetallic formation in weld zone will result in poor mechanical properties such as reduced strength of the weld. These problems can be rectified by using the optimized pulsed current parameter of pulsed current TIG welding. Pulsed current TIG welding parameters have greater influence on weld zone and heat affected zone's microstructure & mechanical properties. To optimize the pulsed current TIG welding parameters such as peak current, base current, pulse on time and pulse frequency experiment is designed using Taguchi L_9 orthogonal array technique. From the experiment, effect of pulsed current parameters peak current, base current, pulse on time and pulse frequency on weld centre micro hardness was evaluated. Regression equation was developed using Design Expert ® statistical software to predict the weld centre micro hardness. Correlation co-efficient (r^2) showed 0.99 and error % showed less than 1% which means the regression equation developed was more consistent. Empirical model was developed to optimize the pulsed current parameters of PCTIG welding was also performed using Design Expert ® statistical software. Optimized values for pulse on time, pulse frequency, peak current and base current were 54.79%, 5.12Hz, 160A and 60A respectively. Optimized predicted value of weld centre micro hardness has been observed as 77 HV. Trial runs were performed for optimized PCTIG welding condition to check the consistency of the model, which resulted only 5% of deviation between experimental values and predicted values. This showed optimized pulsed current parameters of PCTIG welding resulted in higher micro hardness which implies that strength of the weld is increased.

Keywords: Al-SiC Composite, Micro Hardness, Optimization, Pulsed Current TIG, Regression Equation

1. Introduction

In aluminium metal matrix composite use SiC, TiB_2, TiC, B_4C are ordinarily utilized reinforcement[1]. In this above reinforcement silicon carbide used as major reinforcement for aluminium due to higher wear resistant[2], higher strength to weight ratio[3]. Stir casting procedure is mostly utilized for to produce the Aluminum Silicon Carbide (Al-SiC) composite because of its higher production rate[4]. Stir casting could be attained to by minor changes in traditional casting procedure[5]. It is the most suitable and efficient method for delivering Al-SiC composite when compared with other manufacturing process such as powder metallurgy route and spray coating process[6]. TIG welding on aluminum composite gave reduced weld strength because of higher heat generation in weld zone[7] and lesser cooling rate[8] of weld pool which brings about coarse grain structure in weld zone and residual stresses developed in heat affected zone[9]. TIG welding of Al-SiC composite, SiC is separated into Silicon (Si) and Carbon (C). This carbon joins with aluminum (Al) phase to forms (aluminum carbide) Al_4C_3 + (Silicon) Si. Al_4C_3 stage is more brittle in nature, in this manner brought about significant misfortune in weld quality[9]. Aluminum

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carbide development in TIG welding on Al-SiC composite have chance for enhanced in weld quality[10]. The issue of coarse grain microstructure amid TIG welding on aluminum combinations could be redressed by utilizing surface nucleation[11], microcooler expansion[12], circular segment swaying[13], impact of beating current system on Aluminum compound 6061 tractable conduct[14] and beating current on Aluminum amalgam 7075 exhaustion conduct[15] to acquire fine grain microstructure. Among this beating current system has wide acknowledgement, as it can be utilized continuously mechanical applications with least changes in the current[16].

In pulsed current TIG (PCTIG) welding, peak current gives satisfactory entrance and globule shape[17]. Base current keeps up stable circular segment and it utilizes the curve vitality viably. Pulse on time gives enough time to exchange the heat from weld zone and heat affected zone to base material district[18].

From the literature[19] it is clear that the optimized PCTIG welding parameters gives reduced heat input, higher cooling rate and fine grain microstructure. This improves weld strength in aluminium alloys when compared to normal continuous current TIG welding. So this shows the significance of optimizing the PCTIG welding parameters.

Regression equations were used to estimate the strength of the weld. Empirical model was developed by earlier researchers, to optimize the pulsed current welding parameters using various methods such as surface response method[20], Hooke and Jeevas algorithm[21] and Taguchi L8 orthogonal array method[22]. To study the outcome of PCTIG welding parameters like pulse on time, pulse frequency, peak current and base current on weld micro hardness, empirical models and regression equations have to be developed. To predict the weld micro hardness of Al-SiC composite same method could be followed. To formulate the empirical model and regression equation, Design Expert 7 statistical software was used.

2. Experiments

The experiments were carried out and the responses were recorded. The empirical relationships were developed to predict the weld centre micro hardness using following steps.

To know the working limits of the PCTIG welding parameters, on a 5mm plate of Al-SiC composite, number of trial runs were performed. Following results were observed from the trial runs.

- When peak current was greater than 160 A, it resulted in excessive penetration of the weld. Lack of fusion and incomplete penetration were resulted when peak current was less than 140 A.
- Unstable arc and arc wandering were observed when the base current was greater than 60 A. When the base current was reduced below 40 A, shorter arc length was formed. Thus welding cannot be performed under this condition.
- When the Pulse Frequency was less than 2 Hz, welded samples showed weld beads similar to that of constant current TIG welding. Arc glares and arc spatters were observed when pulse frequency was greater than 10Hz.
- Overheating of tungsten electrode was observed when pulse on time was greater than 60%, where as when the pulse on time was less than 40%, it resulted in poor weld bead surface appearance.

Experimental runs were decided using 4 factors and 3 levels as given in the Table 1. Using Taguchi L9 orthogonal array, 9 experiments were designed and various conditions are furnished in Table 2.

Experiments were carried out using different pulsed current parameters designed with 4 factors and 3 levels of Taguchi L9 orthogonal array as mentioned in previous section. Autogenous welding was performed on Al-8%SiC composite material with a plate thickness of 5mm using ADOR CHAMPTIG 300AD welding machine.

Micro hardness observed on weld centre, 1mm below the welded surface was measured using Shimadzu Vickers micro hardness tester.

All the experimental results were observed and recorded and is furnished in Table 2. These experimental conditions and the resulting responses were fed to Design Expert 7 software. Using this software, regression equation

Table 1. PCTIG welding parameters and levels

Parameter	Levels		
	1	2	3
Peak Current	140A	150A	160A
Base Current	40A	50A	60A
Pulse On Time	40%	50%	60%
Pulse Frequency	2Hz	5Hz	10Hz

Table 2. Experimental conditions for pctig welding and recorded responses

PCTIG Welding Conditions	Peak Current (A)	Base Current (A)	Pulse On Time (%)	Pulse Frequency (Hz)	Micro Hardness (HV)
1	160	40	60	10	61.2
2	140	60	60	2	62.9
3	150	60	40	10	65.3
4	140	40	40	5	71.3
5	150	50	60	5	67.6
6	140	50	50	10	67.2
7	160	50	40	2	60.8
8	160	60	50	5	75.1
9	150	40	50	2	63.2

and empirical model were developed, to predict the weld micro hardness of Al-SiC composite and optimize the PCTIG welding parameters.

3. Developing Empericial Model

Statistical and mathematical techniques can be used for developing empirical relationships. By these techniques the influence of parameters on response can be studied easily. It can also be used for optimizing the conditions based on desired response and also be employed for predicting the response[16]. Experimental design was done in Design Expert 7 statistical software package making using of Taguchi L9 orthogonal array. Regression equation and correlation coefficients were also developed using Design Expert 7 statistical software. Peak current, base current, pulses on time and pulse frequency are the functions of weld centre micro hardness. The empirical model developed using regression equation includes main factors and first order interaction of all factors. This can be expressed in the form of first order polynomial equation as specified in equation (1).

$$R = Z_0 + Z_2 + Z_3 + Z_4 + Z_{12} + Z_{23} + Z_{41} + Z_{24} + Z_{13} + Z_{34} \quad (1)$$

R: Response as weld centre micro hardness.
A: Peak current,
B: Base current,
C: Pulse on time,
D: Pulse frequency,
Z_0: Average response,
Z_1, Z_2,..., Z_{34}: Regression coefficients.

The regression coefficients depend on, the main factors and interaction of factors. Regression co-efficient were solved in Design Expert 7 statistical software, to obtain regression equations and predict the weld centre micro hardness.

Correlation Coefficient 'r^2' shows how nearer the predicted values are, to the experimental values. Correlation coefficients for regression equations are shown in Table 4. Values of correlation are having higher values and it was showing significant effect of main factors and their interactions with response. This was checked using Analysis of Variance (ANOVA).

$$r^2 = \frac{\sum\left(Y_{predicated} - Y_{average}\right)^2}{\sum\left(Y_{experimental} - Y_{average}\right)^2} \quad (2)$$

r^2: Correlation Coefficient.
$Y_{predicated}$: Predicated value of the response.
$Y_{experimental}$: Experimental value of the responses.

Calculation of correlation coefficient using predicated value and experimental value for the same experimental condition was done using equation (2).

Table 4 shows the percentage of error between experimental value and predicated value developed using

Table 3. Regression equation

Response	Regression equation	Coefficient of correlation (r^2)
Micro Hardness	R = 66.15 + (0.17*A) + (2.29*B) + (2.27*C) + (1.01*D) + (6.44*A*B) + (2.07*A*C) + (1.78*B*C)	0.99

Table 4. Percentage of error in micro hardness

PCTIG welding condition	Experimental Value (HV)	Predicated Value (HV)	Percentage of Error (%)
1	61.2	61.1	−0.09
2	62.9	62.8	−0.14
3	65.3	65.4	0.16
4	71.3	71.4	0.2
5	67.6	68.2	0.84
6	67.2	67	−0.32
7	60.8	61	0.29
8	75.1	74.8	−0.38
9	63.2	62.8	−0.57

regression equation. These values were plotted into error graph in Figure 1. Figure 1 shows the graph with experimental values and predicated value of weld centre micro hardness. From the graph it is clear that the percentage of error is below 1% between experimental value and predicated value. In Figure 1, most of the predicated values and experimental values of weld centre micro hardness coincides each other, consistent result were obtained through regression equation for weld centre micro hardness. Hence the regression models are valid within the range of pulsed current parameters.

4. Analysis of Contour Plots

Contour plots were generated using Design Expert software to study the interaction effect of pulsed current TIG welding parameters such as pulse on time, pulse frequency, peak current and base current on weld centre micro hardness. Figure 2 to Figure 10 shows contour plots which predict the weld centre micro hardness with X-axis as base current & Y-axis as peak current. Pulse on time and pulse frequency values were made constant in all graphs. Comparison of these graphs shows the effect of pulsed current parameters on weld centre micro hardness. This is explained in the following sections.

From Figure 2, micro hardness is observed as 65HV. Figure 4 shows micro hardness of 67 HV and Figure 3 shows micro hardness of 77HV. In Figure 2 to Figure 2, maximum micro hardness were found in the interval of 160A of peak current and 60A of base current. Decrease in the difference in peak current and base current leads to the decrease in weld micro hardness. Increase in pulse frequency above 5Hz, does not have any significant effect on weld micro hardness.

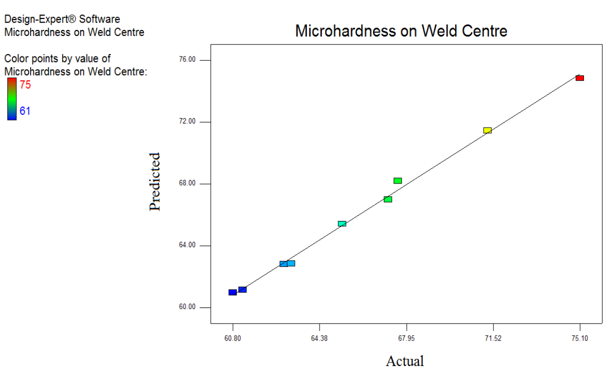

Figure 1. Predicted value vs actual value of weld centre micro hardness.

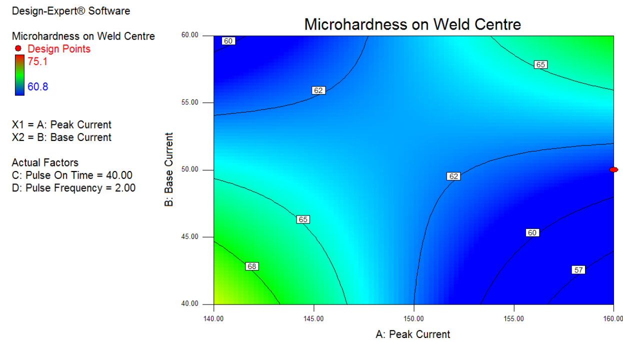

Figure 2. Micro hardness – (pulse on time – 40%, pulse frequency - 2Hz).

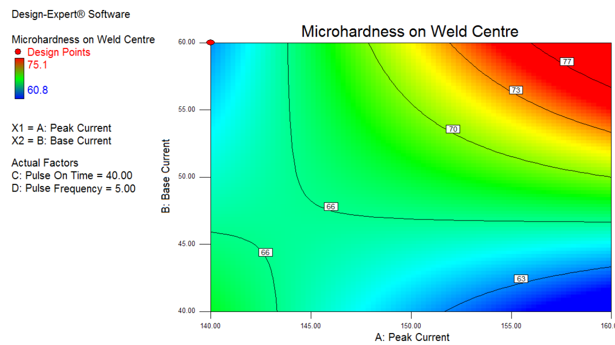

Figure 3. Micro hardness – (pulse on time – 40%, pulse frequency – 5Hz).

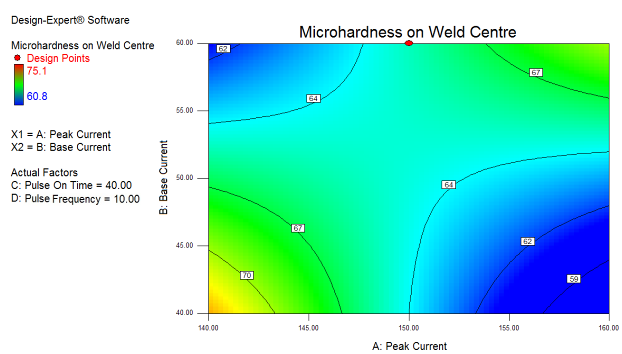

Figure 4. Micro hardness – (pulse on time – 40%, pulse frequency – 10Hz).

In Figure 5, with pulse on time of 60% and pulse frequency of 2Hz shows micro hardness of 71HV, Figure 6 shows the micro hardness of 73 HV for pulse on time – 60% & pulse frequency 5Hz. Figure 7 shows micro hardness of 72HV for pulse on time of 60% with pulse frequency as 10Hz. Maximum weld micro hardness as depicted in Figure 5 to Figure 7, were found in the interval of 160A of peak current and 60A of base current. Lower

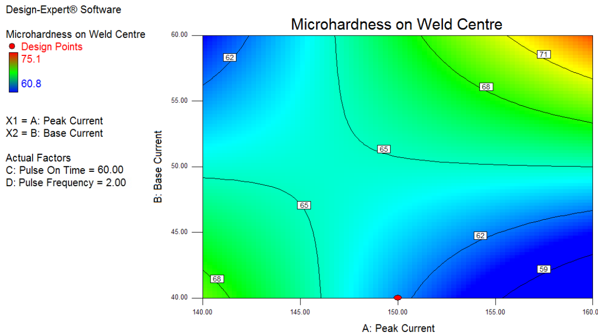

Figure 5. Micro hardness – (pulse on time – 60%, pulse frequency - 2Hz).

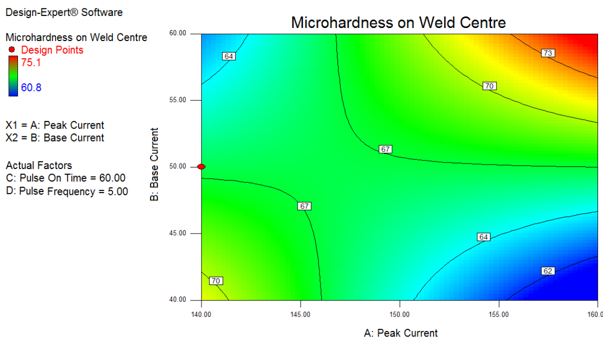

Figure 6. Micro hardness – (pulse on time – 60%, pulse frequency – 5Hz).

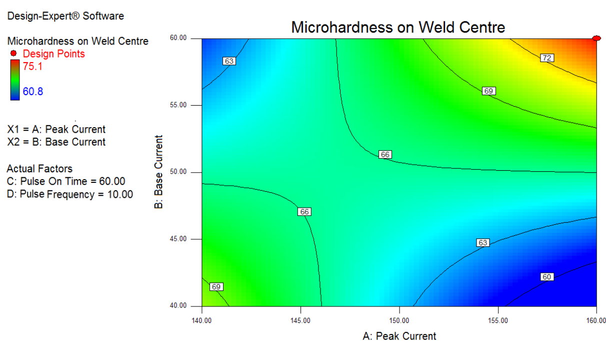

Figure 7. Micro hardness – (pulse on time – 60%, pulse frequency – 10Hz).

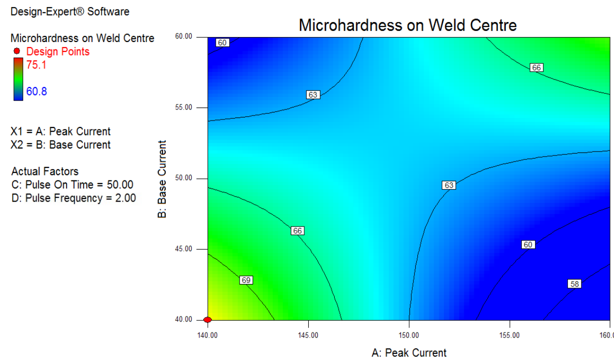

Figure 8. Micro hardness – (pulse on time – 50%, pulse frequency – 2Hz).

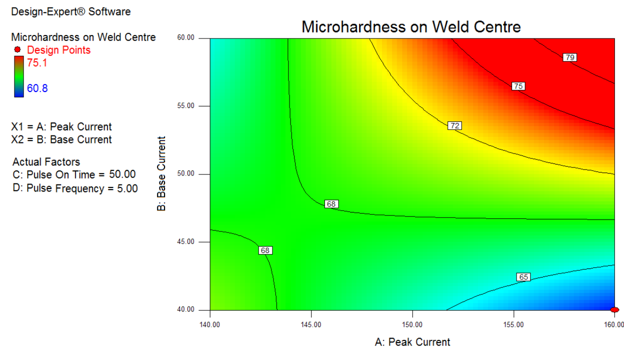

Figure 9. Micro hardness – (pulse on time – 50%, pulse frequency – 5Hz).

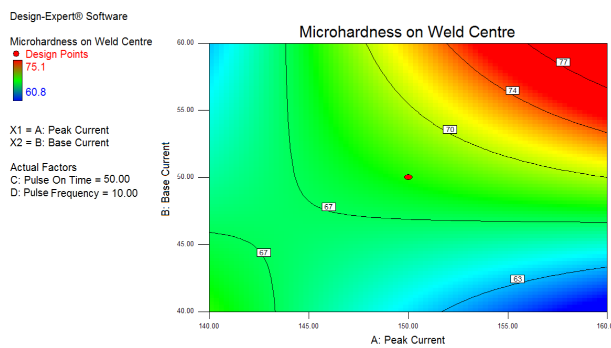

Figure 10. Micro hardness – (pulse on time – 50%, pulse frequency – 10Hz).

the difference in peak current and base current, leads to decrease in weld micro hardness and vice versa.

Figure 8 shows the micro hardness of 65HV for pulse frequency of 2Hz. From Figure 10, micro hardness of 72HV was observed for pulse frequency of 10Hz. Figure 9 shows the maximum micro hardness of 75A with pulse frequency of 5Hz. All the above maximum micro hardness was observed with 50% of pulse on time; peak current of 160A and base current of 60A have the higher weld micro hardness. Here also, decrease in the differences in peak current and base current leads to decrease in weld micro hardness. Pulse frequency greater than 5Hz does not have significant increase in weld centre micro hardness.

Using regression equation, weld centre micro hardness was optimized. Pulsed current TIG welding parameters

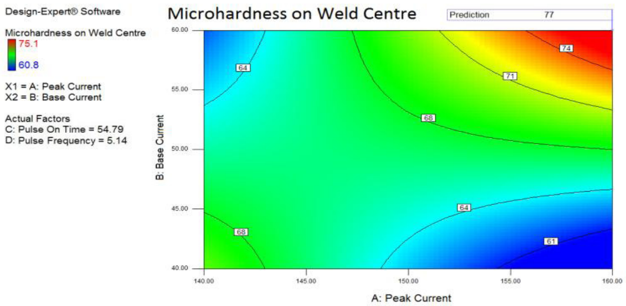

Figure 11. Micro hardness – (optimized condition).

Table 5. Optimised value vs experimental value

Description	Optimized Condition	Actual Condition		
Peak Current (A)	160	160		
Base Current (A)	60	60		
Pulse On Time (%)	54.79	50		
Pulse Frequency (Hz)	5.12	5		
	Predicted Value	Experiment Value		
	Desirability = 0.99	Trail 1	Trail 2	Trail 3
Micro hardness (HV)	77	75.1	73.6	74.2

such as peak current, base current, pulse on time and pulse frequency were developed using Design Expert statistical software. Optimized condition result was observed and depicted in Figure 11. Three trial runs were performed in the optimized pulsed current TIG welding condition with pulse on time of 50% and pulse frequency of 5Hz. This is due to the limitation of PCTIG welding machine specification. PCTIG welding parameters and weld centre micro hardness from trial runs are tabulated in Table 5.

From Table 5, it shows that the consistent result was obtained from the optimized condition developed using regression equation. Figure 11 shows increase in peak current and base current as 3:1 ratio with pulse on time as 50-55% and pulse frequency 5-6Hz showed higher weld micro hardness.

5. Conclusion

Regression equation was developed to predict the weld centre micro hardness of Al-8% SiC composite, welded using PCTIG welding. PCTIG welding parameters like pulse on time, pulse frequency, peak current and base current were closely studied. Using regression equation, empirical model was developed to obtain, optimized results for the PCTIG parameters. The resultant optimized values for pulse on time, pulse frequency, peak current and base current were 54.79%, 5.12Hz, 160A and 60A respectively. Optimized predicted value of weld centre micro hardness has been observed as 77 HV. Trial runs were performed for optimized PCTIG welding condition to check the consistency of the model, which resulted only 5% of deviation between experimental values and predicted values. This deviation is due to the change in value of pulse on time of 50% instead of 54.79% and pulse frequency of 5Hz instead of 5.12Hz.

The effect of each PCTIG welding parameters and interaction between two or more parameters on weld centre micro hardness were studied. Key findings of the study of PCTIG welding on Al-8%SiC composite 5mm thick plate were,

- Peak current & base current should be 160A & 60A respectively,
- Pulse on time is recommended to be 50% to 55%,
- Recommended pulse frequency to be 5Hz.

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