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Research paper

Study on the Effect of Pulsed Current TIG Welding Parameters on Weld Profile of Al-SiC Composite Weldments Using L_9 Orthogonal Array's Experimental Design

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Abstract:

Investigation of Al-SiC composite weldment's, weld profile such as weld depth, weld width and (D/W) ratio, during various conditions of PCTIG welding designed using L_9 orthogonal array. The experiment is designed using L_9 orthogonal array to reduce the number experiments from 81 to 9 experimental conditions. The parameters considered for PCTIG welding are peak current, base current, pulse frequency and pulse on time. Regression equation, contour plot analysis are developed. This statistical & mathematical analysis are used to find the influence of each pulsed current parameter at each level by pulsed current parameters on weld depth, weld width and (D/W) ratio during PCTIG welding of Al-SiC composite. Optimization of the pulsed current TIG welding parameters is also carried out to and the optimized predicted value is compared with experimental value. PCTIG welding parameters such as peak current of 160A, base current of 60A, pulse on time as 50% and pulse frequencyas 5Hz shows highly desired results such as high weld depth = 2.5mm, minimum weld width = 6.5mm and higher (D/W) ratio = 0.38.

Keywords: *SiC composite, PCTIG welding, weld profile, regression equation, optimization.*

1. Introduction

A composite material is characterized as a mixture of at least two different materials. Materials having exceptional features that are superior to the individual segments utilized alone[1]. The material system composed of at least two or more dissimilar constituents differing in form, insoluble in each other physically distinct[2] and chemically in homogeneous resulting in high quality properties which are much different from the constituent material properties [3]. Composite materials are usually used in light weight applications of manufacturing, aerospace and many other sectors in the forms of agglomerates, laminates, reinforcements for metals & polymer materials [4].

PCTIG welding shows the improved mechanical behavior than TIG welding. Improved mechanical properties of PCTIG welding is due to fine grain microstructure when compared to constant current TIG welding which gives coarse grain microstructure [5]. During PCTIG welding, peak current gives adequate penetration. Base current is responsible for maintaining the stable arc, pulse frequency & pulse on time give enough time to transfer heat from the arc to the weld material [6]. During base current time, the weld pool is cooled and heat has been transfered from weld zone to heat affected zone & base material region [7]. This reduces the width of the heat affected zone and thermally induced stresses [8].

Due to difference in heat input during PCTIG welding between peak current and base current, weld pool is cooled immediately and higher heat concentration on weld pool reduces [9]. This gives fine grain microstructure on weld zone [10]. Finer grain size has increased grain boundaries which results in an improved mechanical behavior for PCTIG welded specimens [11]. Major problem in welding of aluminium is hot cracking [12]. This can be minimized by reducing heat input [13] and choosing of correct filler material [14]. Here weld profile of weld depth, weld width, weld depth to weld width (D/W) ratios during pulsed current TIG welding is optimized.

2. Experimentation

Table 1: PCTIG welding parameters and levels

Parameter	Levels		
	1	2	3
Peak current (A)	140	50	160
Base current (A)	40	50	60
Pulse on time (%)	40	50	60
Pulse frequency (Hz)	2	5	10

To study the contour plots, the experiments are designed according to Taguchi L_9 orthogonal array [15]. PCTIG welding parameters and its levels for Taguchi L_9 orthogonal array are performed using ADOR CHAMPTIG 300AD welding machine shown in figure 1. Here 4 factors and 3 levels as given in the table 1 and designed for various conditions were shown based on the reference [16]. based on the procedure of the Design Expert® statistical software, the run order has been performed.

Fig. 1: PCTIG welding machine

Autogenous TIG welding is performed on Al-8% SiC composite material with a plate thickness of 5mm for the experimental conditions shown in table 2, welded samples are shown in figure 2. Macrostructures or weld profiles such as weld depth, weld width & (D/W) ratio were observed and captured using high resolution camera with 8x magnification capacity and is shown in figure 3a and 3b respectively.

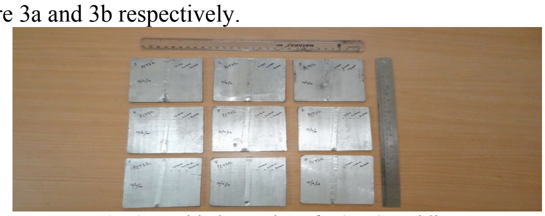

Fig. 2: Welded samples of PCTIG welding

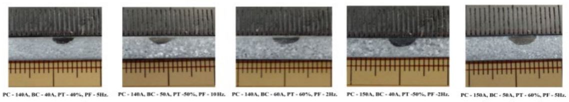

Fig. 3a: Macro structure for PCTIG welded samples (condition 1 to 5)

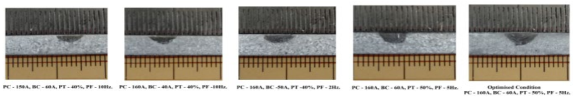

Fig.3b: Macro structure for PCTIG welded samples (condition 6 to 9 and optimized condition)

3. Observed Results from the Weld Profile

From figure 3a and figure 3b, weld depth, weld width, (D/W) ratio were measured for various pulsed current TIG welding condition and tabulated in table 2. Using these experimental values the statistical analysis such as regression equation, analysis of contour plots are developed. Using this techniques, effect of pulsed current TIG welding parameters such as peak current, base current, pulse frequency and pulse on time were studied and evaluated.

Table 2: Results of weld profile

Condition	1	2	3	4	5	6	7	8	9
Weld depth (D)	2	1.5	1.5	1.5	2	1.5	2	2.5	2
Weld width (W)	6.5	6	5.5	4.5	6	5	6	6.5	6
D/W Ratio	0.31	0.25	0.27	0.33	0.33	0.3	0.33	0.38	0.33

4. Developing Regression Equation

4.1 Developing the Empirical Relationship

Empirical relationship is developed by using collection of statistical and mathematical techniques. By this technique the effect of parameters on response can be understood and used to optimize the parameter & levels based on weld profile and it can also be used to predict the weld profile by developing the empirical relationship [16].

Peak current, base current, pulse frequency and pulse on time were function of responses such as weld depth & weld width. The empirical relationships are developed between response and factors as regression equation which is expressed as mathermatical equaction based on the factors and their interaction effect.
Here in regression equation (R) denotes the response such as weld depth and weld width. Peak current is represented by A, B denotes base current, C represents pulse on time and pulse frequency was denoted as D.

$$R = Z_0 + Z_1(A) + Z_2(B) + Z_3(C) + Z_4(D) + Z_{12}(AB) + Z_{23}(BC) + Z_{34}(CD)$$

Here Z_0 was average response and Z_1, Z_2,........, Z_{34} are the regression coefficient which depends on the main factors and interaction of factors that can be calculated in Design Expert® statistical software, regression equations are developed to predict weld profile such as weld depth and weld width and are shown in table 3.

Table 3: Regression equation and correlation coefficient

Response	Regression equation (R)	Correlation coefficient (r^2)
Weld depth	R = 1.89 + (0.47*A)-(0.06*B) + (0.24*C) + (0.03*D) + (0.15*A*B) + (0.05*A*C) + (0.11* B*C)	0.98
Weld width	R = 5.74 + (0.45*A) + (0.24*B) + (0.35*C)-(0.37*D)-(0.13*A*B) + (0.15*A*C)-(0.27* B*C)	0.98

4.2 Checking the Adequacy of the Empirical Relationship

Coefficient of correlation (r^2) shows how close the predicted value was nearer to the experimental value. Correlation coefficient for the regression equation are shown below and values of correlation coefficients have higher values and is checked using analysis of variance (ANOVA) and it showed significant effect of main factors and their interactions

$$r^2 = \frac{\sum (Y_{predicted} - Y_{actual})^2}{\sum (Y_{experimental} - Y_{mean})^2}$$

4.3 Validation of the Empirical Relationship.

From the error graphs, (%) of deviation between experimental values to predicted values are found minimum. Correlation co-efficient (r^2) found nearly 0.98 for both weld depth and weld width regression equations. This correlation co-efficient shows the evidence for validate the empirical model developed within the range of pulsed current parameters.

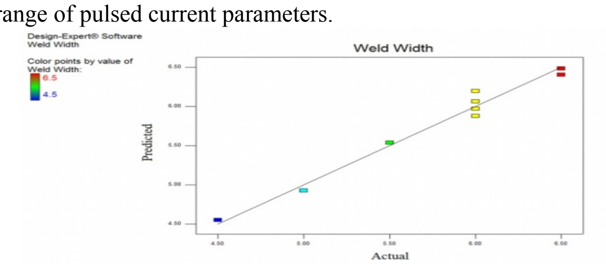

Fig. 4a: Experimental value vs. predicted value for weld width

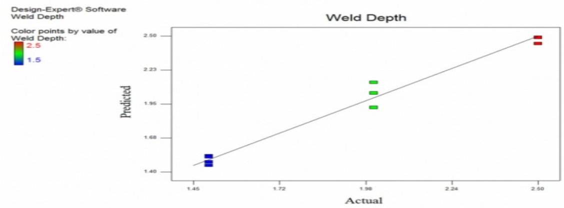

Fig.4b: Experimental value vs. predicted value for weld depth

5. Analysis of contour plots

5.1 Weld Depth

Figure 5a, 5b and 5c showed that the weld depth of 2.21mm, 2.26mm, and 2.23mm, when the pulse on time is 50% and pulse frequency values are changing from 2Hz, 5Hz and 10Hz respectively. It is infered that pulse frequency is not having much influence on weld depth. From the figure 5d, minimum weld depth obtained during, pulse on time of 40% with pulse frequency of 5Hz showed a weld depth of 1.91mm. With the pulse on time of 60% and pulse frequency of 5Hz, the weld depth is 2.63mm and is shown in figure 5e. From the figures 5a-5e, it is clear that maximum weld depth is achieved during peak current of 160A and base current of 60A. Increase in pulse on time from 40% to 60% showed increased weld depth. This shows that the increase in heat input results in increased weld depth.

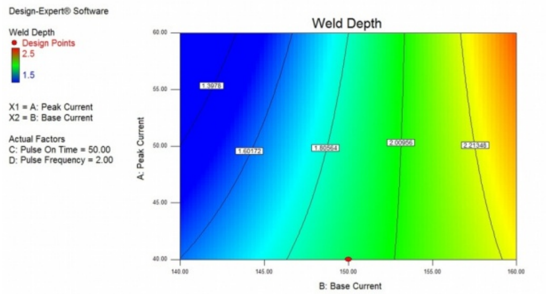

Fig. 5a: Weld depth-(Pulse on time-50% & pulse frequency-2Hz)

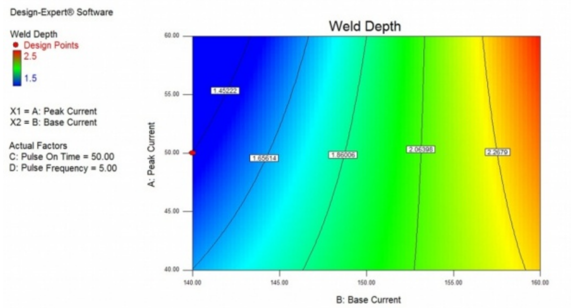

Fig. 5b: Weld depth-(Pulse on time-50% & pulse frequency-5Hz)

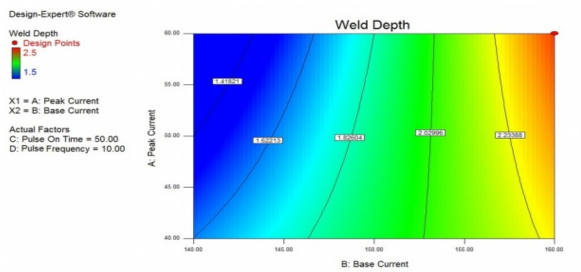

Fig. 5c: Weld depth-(Pulse on time-50% & pulse frequency-10Hz)

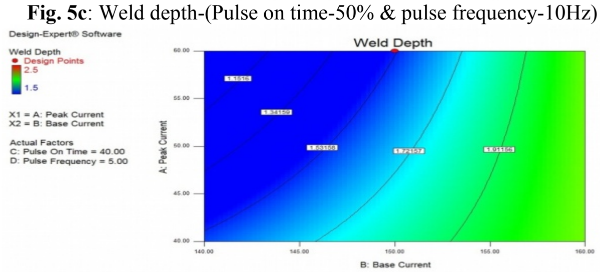

Fig. 5d: Weld depth-(Pulse on time-40% & pulse frequency-5Hz)

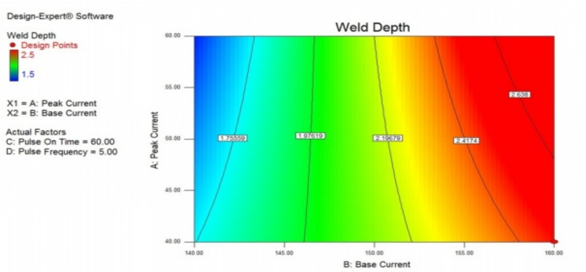

Fig. 5e: Weld depth-(Pulse on time-60 & pulse frequency-5Hz)

5.2 Weld Width

Figure 6a shows the maximum weld width of 6.45mm for pulse on time of 50% and pulse frequency of 2Hz. Weld width for pulse frequency values of 5Hz and 10Hz with a pulse on time of 50% are 5.71mm and 6.17mm respectively, as shown in figure 6b and 6c. Weld width is found to be 5.43mm and 6.24mm for pulse on time of 40% and 60% with a pulse frequency of 5Hz and is depicted in figure 6d and 6e. All the above weld width values are obtained at maximum peak current of 160A and base current of 60A. Pulse frequency of 5Hz shows minimum weld width, increase or decrease in pulse frequency other than 5Hz, showed increased in weld width. From figure 6a-6e it is clear that weld width is directly proportional to the heat input.

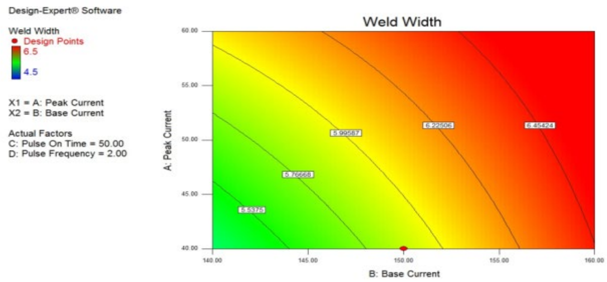

Fig. 6a: Weld width-(Pulse on time-50% & pulse frequency-2Hz)

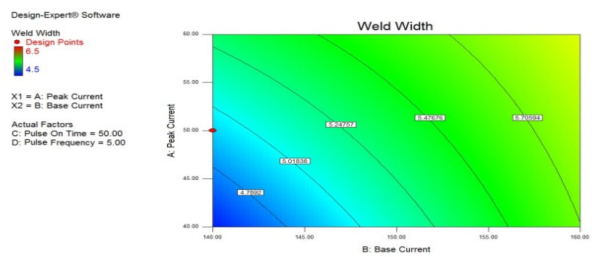

Fig. 6b: Weld width-(Pulse on time-50% & pulse frequency-5Hz)

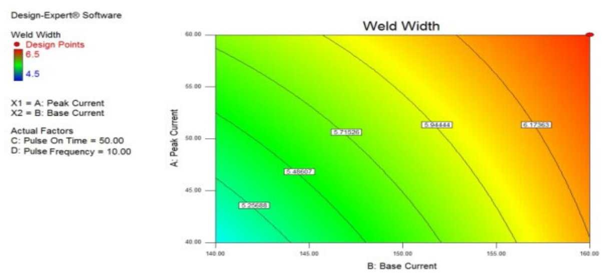

Fig. 6c: Weld width-(Pulse on time-50% & pulse frequency-10Hz)

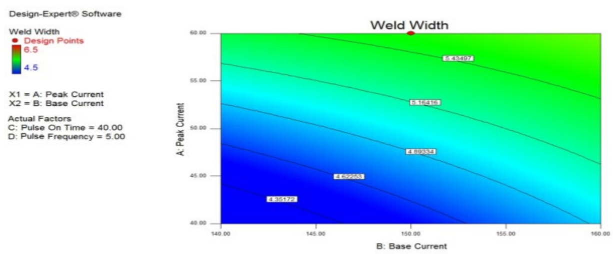

Fig. 6d: Weld width-(Pulse on time-40% & pulse frequency-5Hz)

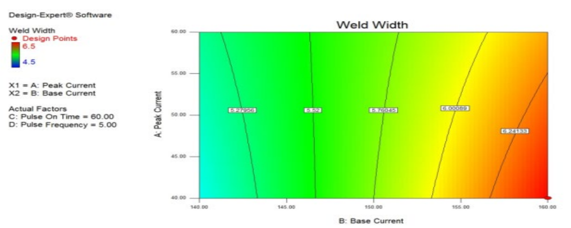

Fig. 6e: Weld width-(Pulse on time-60% & pulse frequency-5Hz)

6. Optimized Pulsed Current Parameters

From the above experimental data and from regression equations obtained from the responses of weld depth & weld width, optimized pulsed current parameter condition is obtained. This optimized pulsed current parameter condition provides the maximum weld depth and minimum weld width conditions when applied in Design Expert® statistical software package.

Table 4: Optimized predicted value vs. actual experimental value

Description	Optimized condition	Actual condition
Peak current	160A	160A
Base current	60A	60A
Pulse on time	54.79%	50%
Pulse frequency	5.19Hz	5Hz
	Predicted value	**Experimental value**
Weld depth	2.57mm	2.5mm
Weld width	6.54mm	6mm

From table 4, optimized condition of pulsed current parameter for TIG welding using Design Expert® statistical software is compared with actual condition of pulsed current TIG welding. The predicted values weld depth and weld width of optimized condition are in good agreement with the actual condition.

7. Conclusion

Regression equation developed using Design Expert ® statistical software package to predict the weld depth & weld width and the obtained correlation co-efficient value of 0.98 for both weld depth & weld width shows that the regression equation & the mathematical model developed are adequate. Analysis through contour plot shows the effect of pulsed current parameters. It is inferred that increase in peak current from 140A to 160A leads to increase in weld depth and weld width. Pulse frequency of 2Hz & 10Hz is not having much significant effect on weld depth and weld width. Pulse on time from 40% to 50% results in increase in weld depth but for 60% pulse on time increase in weld width is observed. From this it is inferred that weld depth increases for increase in pulse on time and stabilizes at higher % pulse on time leading to increase in weld width.

8. Acknowledgements

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