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EFFECT OF GMAW-P PROCESS PARAMETERS ON WELD BEAD GEOMETRY USING RESPONSE SURFACE METHODOLOGY AND ANOVA TECHNIQUE

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Abstract. *The central composite design (CCD) based on the response surface methodology (RSM) was applied to evaluate the effects of several operating parameters. The model was derived and the response surface plots were developed based on the results. The anova technique was used to test the adequacy of the empirical models and the significance of regression coefficients. Results from the viewpoint of robotic welding are presented, where were determined the best conditions of variable settings indicating the values of the proposed parameters for this kind of processes. Consequently, the response surface methodology was used to be promising technique to obtain the models of weld bead geometry for such studies.*

Keywords: *Pulsed GMAW, response surface method, weld bead geometry*

1. INTRODUCTION

Pulsed Gas Metal Arc Welding (GMAW) process is one of several types of welding processes, frequently employed in industry. It is performed either as an automated robotic process or as a manual process (Thomsen, 2006). The pulsed mode is now the target of deep investigations by the scientific community, due to the its advantages when compared to the conventional gas metal arc welding (GMAW) process. Joseph *et al*. (2003) reported that, through the supply a high current intensity, with intermittent waves, it is possible to get the spray transfer, during the high current pulses while keeping a level of average current below the spray transition current for the combination of wire and shielding gas.

The pulses allow the average current to be lower, decreasing the overall heat input and thereby decreasing the size of the weld pool and heat-affected zone (Palani and Murugan, 2007). If adequate welding parameters are chosen, the pulse is expected to provide a stable arc and little or no spatter, since no short-circuiting takes place. In this regard the selection of welding parameters in pulsed current gas metal arc welding (P-GMAW) process is comparatively more complicated as compared to that found in case of conventional gas metal arc welding (GMAW) process due to involvement of large number of simultaneously interacting parameters (Goyal *et al.*, 2009).

The quality of weld is determined by the weld bead geometry characteristics (physical parameters), that is the weld reinforcement height, weld bead width, and weld bead penetration. Also, defects such as presence of porosity, undercut, burnthrough (in the case of sheet metal welding) are not acceptable in most cases. In the case of the P-GMAW process, the bead geometry characteristics are dependent on input variables (control parameters) which are peak current, base current, peak time, base time, frequency, welding speed, wire feed speed, wire diameter, welding voltage, shielding gas composition, gas flow rate, and material composition. These control parameters affect the quality of the weld. Here for simplification the most influencing parameters peak current, base current, peak time, frequency, and wire feed speed are considered. This paper presents an empirical model to represent the metal transfer behavior in pulsed mode on weld bead geometry. The models were established from an experimental design based on response surface. Using anova technique, the comparison of means of the control parameters are done. This technique is widely used nowadays to determine the significant difference of the main control parameters considered for the experiment.

2. THE PULSED GMAW PROCESS

Pulsed GMAW is technically a modified spray transfer process. With spray transfer, drops of molten metal are continuously transferred across the arc. However, in the pulsed GMAW process, the power source rapidly switches the welding output from high peak current to low background current. Fig. 1 shows a sketch of the time dependent welding current signal. The alternating high pulse current and a lower background current comprise a waveform with an average current below the spray transition current, while maintaining spray droplet transfer qualities, improving transfer stability and out of position welding performance (Joseph *et al.*, 2003).

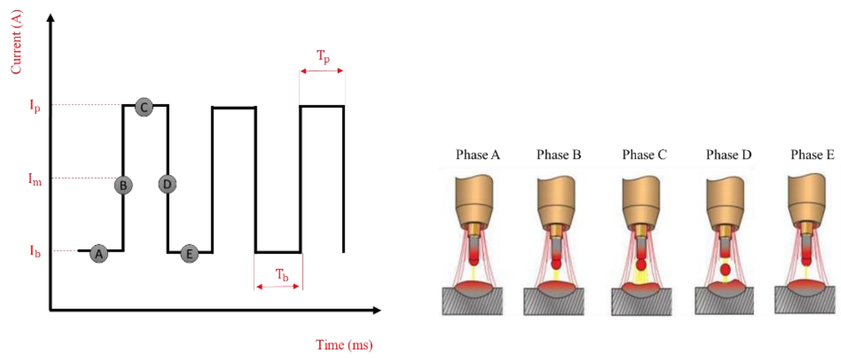


Figure 1. Schematic representation of a current-time diagram in P-GMAW (Ip = peak current; Ib = background current; tp = pulse on-time; tb = Pulse off-time; f = pulse frequency) (adapted from Jeffus, 2011)

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and interpass temperature, it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the heat-affected zone (HAZ). The super heating of weld pool is also a function of pulse parameters as is the wire feed rate (Palani and Murugan, 2007). The rate of heat input for a given welding condition is estimated by dividing the product of time-averaged current and voltage with the welding speed. Each pulsed GMAW wave is composed of four variables peak current, background current, pulse time and pulse frequency. The pulse parameters have significant influence on wire feed rate (Ghosh *et al.*, 2000; Palani and Murugan, 2007). Among the pulse parameters, the peak parameters have more influence on the wire feed rate (Palani and Murugan, 2007). The P-GMAW is versatile, and easily automated. Thus, it is becoming increasingly popular for use in modern robotics and automated industries. Current pulsing has been used to obtain grain refinement in weld fusion zones, which has a positive contribution to mechanical properties. Pulsed GMAW offers better arc characteristics, greatly reduced spatter, less fume generation and lower heat input than spray transfer in steady current GMAW at a given wire feed rate. The lack of any significant spatter will result in less post welding part cleanup, longer-lasting gun parts and a reduction of spatter buildup on jigs, fixtures and torch gas nozzle. The reduction in spatter means that more of the filler metal is transferred to the weld. In many applications, 98 % transfer efficiencies can be obtained, which reduces wasted filler metal (Jeffus, 2011).

2.1 Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for modeling and analyzing problems in which a response of interest is influenced by several variables (Box *et al.*, 2005). One of the most used RSM methods applied to fitting a second order model to a multivariable data is the Central Composite Design (CCD). It consists of a 2^k factorial or a 2^{k-1} fractional factorial design (k different variables tested at two levels, with the variables coded to the usual ±1 notation) extended by $2k$ axial points and N_0 central points (coded as 0) (Montgomery, 1983). A standard CCD was applied in this work to study the variables on weld bead geometry. In the experimental design developed, the center points were used to evaluate the experimental error and the reproducibility of the data. The axial points were chosen such that they would allow rotatability (Box *et al.*, 2005), which ensures that the variance of the model prediction is constant at all points equidistant from the design center. The CCD always contains axial points representing new extreme values (-α, α) for each factor in the design. According to Montgomery (1983), the value of α for the design rotatability depends on the number of points in the factorial portion of the design (N_F) and can be determined by the Eq. (1) .

$$\alpha = (N_F)^{1/4} \qquad (1)$$

Replicates of the runs at the center are very important as they provide an independent estimate of the experimental error (Box *et al.*, 2005). Meanwhile, as the number of factors, k, increases, the number of runs for a complete replicate of the design increases rapidly. In this case, main effects and interactions may be estimated by fractional factorial designs running only a minimum number of experiments. The total number of tests (***N***) required for the independent variables is shown in Eq. (2).

$$N = N_F + 2K + N_0 \tag{2}$$

were

$$N_F = L^k \quad \text{(full factorial design)} \tag{3}$$

$$N_F = L^{k-p} \quad \text{(fractional factorial design)} \tag{4}$$

In Eqs. (2), (3) and (4), L represents the number of levels for the investigation (two in the case of this study), k represents the number of process variables or factors, p independent generators and N_0 is the number of center points. The responses and the corresponding parameters are modeled using analysis of variance (ANOVA) to estimate the statistical parameters by means of response surface methods. In this study, a significance level γ = 0.05 was used, as suggested by Box *et al.* (2005). For each source of variability, a parameter called F_0 value (Fisher statistic) was computed by dividing the mean square of each variable by the mean square error. These values were compared with the equivalent F_0 values taken from a table of F-test critical values, at the selected significance level (Box *et al.*, 2005; Fisher and Yates, 1963).The levels of the independent variables, ξ_j, were coded as x_j according to the Eq. (5).

$$x_j = \frac{\xi_j - [\max(\xi_j) + \min(\xi_j)]/2}{[\max(\xi_j) - \min(\xi_j)]/2} \tag{5}$$

Where $[\max(\xi_j) + \min(\xi_j)]/2$ is the value of an independent variable at the center point of its range, and $[\max(\xi_j) - \min(\xi_j)]/2$ is the step change used in the RSM design. Another advantage of coding is that the design matrix consists of vectors (columns) mutually orthogonal, which greatly simplifies the regression analysis. Many applications of regression analysis involve situations in which there are more than one regressor variable. A regression model that contains more than one regressor variable is called a multiple regression model (Montgomery, 1983). Multiple linear regression analysis is usually used to summarize data as well as study relations between variables. Typically, a second-order model of the form given in Eq. (6).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} {x_i}^2 + \sum_{i<j} \sum \beta_{ij} x_i x_j + \varepsilon \tag{6}$$

Where y is the predicted response, β_0 the constant coefficient, β_i the linear coefficients, β_{ij} the interaction coefficients, β_{ii} the quadratic coefficients and *xi*, *xj* are the coded values of input factors (independent variables) which influence the response. The above second-order response surface model can be expressed with all coefficients and process parameters are given in Eq. (7).

$$\begin{aligned} Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_{11} {X_1}^2 + \beta_{22} {X_2}^2 + \beta_{33} {X_3}^2 + \beta_{44} {X_4}^2 + \beta_{55} {X_5}^2 + \beta_{12} X_1 X_2 \\ + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{15} X_1 X_5 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{25} X_2 X_5 + \beta_{34} X_3 X_4 + \beta_{35} X_3 X_5 \\ + \beta_{45} X_4 X_5 \end{aligned} \tag{7}$$

3. METHODOLOGY

The proposed methodology for achieving the objectives was based on several stages in order to meet the requirements involved in experimental research. The phases were structured as follows: Phase 1: Preliminary studies, Phase 2: Influence of factors in the response on weld bead geometry, Phase 3: Development of experiments, Phase 4: Model building.

3.1 Preliminary studies.

Based on the literature survey, the most influencing parameters on the bead geometry are the peak current (I_p), the background current (I_b), the pulse frequency (f), the peak current time (t_p) and the wire feed speed. So these five variables were used as the experimental factors for the model. Other parameters like voltage (V), welding speed (Ws), electrode stick out, contact tube to plate distance and shielding gas type and gas flow rate are kept constant. Experiments were then carried out and the results enabled the selection of factor levels within their permissible range of variation in other to obtain welds. Table 1 shows the selected variable levels to be used for the factorial design runs.

Table 1 - Coded Values and factor levels

Peak current (X_1, A)	Background current (X_2, A)	Peak time (X_3, ms)	Pulse frequency (X_4, s^{-1})	Wire feed rate (X_5, m/min)
360 (-1)	60 (-1)	2 (-1)	190 (-1)	7.5 (-1)
375 (0)	80 (0)	2.5 (0)	200 (0)	8 (0)
390 (+1)	90 (+1)	3 (+1)	210 (+1)	8.5 (+1)

3.2 Influence of factors in the response on weld bead geometry

For get a model polynomial more satisfactory, to describe the response of interest, the central composite design (CCD) was applied to investigate the effects of the five independent variables on the response functions. The independent variables were initial peak current (X1), background current (X2), peak time (X3), frequency (X4), and wire feed rate (X5). The run corresponding to the center point was repeated six times to check the reproducibility and evaluate the experimental error of the results (Box *et al.*, 2005). The value of α for rotatable CCD is depended on the number of input parameters in this case, the number of input parameters is five, making use of Eq. (1), so the value of α is $(16)^{1/4}=2$. Therefore, the upper and lower limits of the design were coded as +2 and −2 respectively. The design matrix consists of sixteen factorial combinations, with ten axial points ($\alpha = \pm 2$) and six replication of the central points (Montgomery, 1983). A total 32 sets of experiments were carried out in this study.

3.3 Development of experiments

An inverter welding power source was used for depositing beads using pulsed current GMAW process. Commercial grade Stargold *Clean* 96% Ar and 4% CO2 is used as shielding gas. The gas flow rate is 15 L/min for steady arc. Metal-cored wire 410NiMo MC, with a diameter of 1.2 mm is used to deposit bead on- plate welds. Base material, *1020 steel* with flat-plate shaped, 6 mm thickness, 200 mm length, 50 mm width. Constant contact tip to work distance (16mm) is maintained throughout the welding operation. The welding torch is at 90˚ to the work surface.

The experiments were conducted as the design matrix, and the weld bead specimens were prepared as the aforementioned steps to measure the sizes of weld bead geometry. Test specimens are cut from the weld beads at the middle of the plates. Models were prepared for macrography analysis through cross section, subsequently sanded and polished using standard procedure. Specimens are then etched with 2% NITAL solution for 20 s. The weld bead characteristics, weld width (W), bead height (H), and penetration (P) is measured with a Tool profile projector Mitutoyo PJ-A3000. The dimensioned macro image of one of the bead on plate welds is given in Fig. 2.

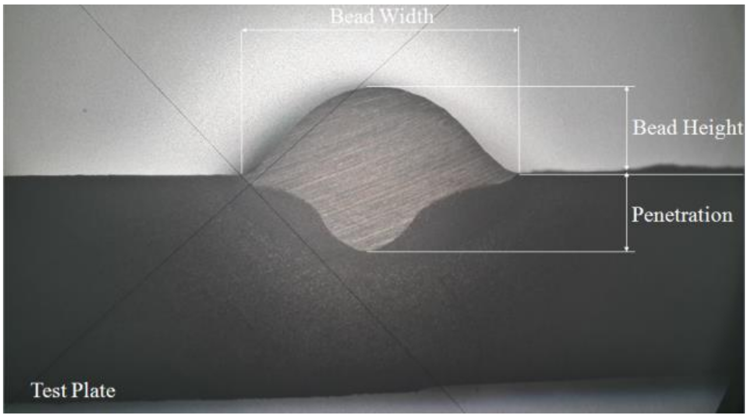


Figure 2. Schematic representation of weld bead geometry parameters measured in GMAW-P

3.4 Model building

Knowing the values for the factors and the response (dependent variable = weld bead geometry), it proceeded to make the model response surface, consisting of obtaining mathematical equations that relate the answers to the factors. Statistical software Design-Expert version 9.0.5 (STAT-EASE, Inc., Minneapolis, USA) was used to establish the central composite design matrix as shown in Table 2. Analysis of variance was conducted to determine the significance of model and regression coefficients. The quality of polynomial equation was judged by determination coefficient (R^2), and its statistical significance was checked by Fischer's F-test. The response surface and contour plots of the model-predicted responses were utilized to assess the interactive relationships between the significant variables.

Table 2. Design matrix with responses

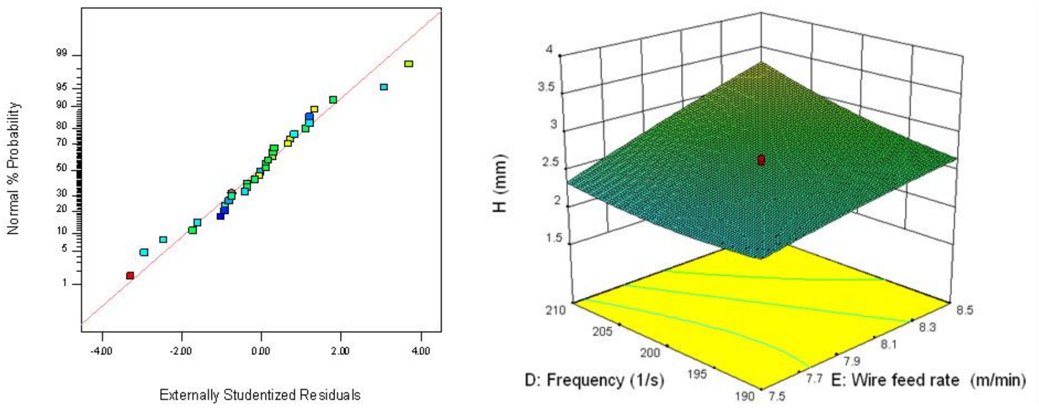
Experiment	Run	Coded variables					Response parameters		
		X1	X2	X3	X4	X5	H (mm)	W (mm)	P (mm)
32	1	375	75	2,5	200	8	2,562	8,159	2,074
26	2	375	75	2,5	200	9	3,332	8,627	2,746
29	3	375	75	2,5	200	8	2,622	7,743	2,09
12	4	390	90	2	210	7,5	2,251	6,235	2,098
21	5	375	75	1,5	200	8	2,199	6,536	1,84
28	6	375	75	2,5	200	8	2,636	8,021	1,784
24	7	375	75	2,5	220	8	3,258	8,524	2,714
31	8	375	75	2,5	200	8	2,443	8,063	2,071
23	9	375	75	2,5	180	8	2,626	7,276	2,182
14	10	390	60	3	210	7,5	2,596	7,644	2,157
16	11	390	90	3	210	8,5	3,852	9,213	3,452
19	12	375	45	2,5	200	8	1,759	4,597	1,487
11	13	360	90	2	210	8,5	3,112	8,49	2,57
27	14	375	75	2,5	200	8	2,623	7,816	2,072
5	15	360	60	3	190	7,5	2,1	5,628	1,76
4	16	390	90	2	190	8,5	2,523	7,496	2,099
9	17	360	60	2	210	7,5	2,162	5,817	1,81
8	18	390	90	3	190	7,5	2,192	5,909	1,834
6	19	390	60	3	190	8,5	2,618	7,276	2,175
7	20	360	90	3	190	8,5	2,266	7,323	1,893
15	21	360	90	3	210	7,5	2,035	5,432	1,708
3	22	360	90	2	190	7,5	1,899	6,536	1,6
30	23	375	75	2,5	200	8	2,668	7,24	2,359
20	24	375	105	2,5	200	8	2,195	5,915	1,836
10	25	390	60	2	210	8,5	3,24	8,954	3,332
1	26	360	60	2	190	8,5	2,551	6,983	2,121
17	27	345	75	2,5	200	8	2,173	6,565	1,819
13	28	360	60	3	210	8,5	2,324	6,307	1,94
25	29	375	75	2,5	200	7	1,677	6,536	1,422
18	30	405	75	2,5	200	8	3,267	8,163	2,694
22	31	375	75	3,5	200	8	3,129	7,897	2,584
2	32	390	60	2	190	7,5	2,596	7,193	2,157

4. RESULTS

Using central composite design, the experiments with different combination of peak current, background current, peak time, frequency and wire speed rate were performed. Result was analyzed using analysis of variance as appropriate to the experimental design used. The P value was used as a tool to check the significance of the model and each coefficient; along with these statistics, it can be concluded that the parameter appears to be more important when reported at lower p-value. Additionally, since the estimated p-values of the parameters are lower than the significance level, which is 0.05, for this purpose. The results of ANOVA for the H model, W model and P model are shown in Tables 3, 4 and 5, respectively. These results show that all the models are significant and adequate. The ANOVA for the model of bead height is listed in Table 3. From the ANOVA for response surface model for weld width, the model F-value of 7.10 implied that the model was significant. Values of Prob > F less than 0.05 indicated that the model terms were significant. In this case, the principal effect peak current (X1), frequency (X4), wire speed rate (X5) and the first-order interaction effect (X4X5) were significant model terms whereas background current (X2), peak time (X3) and the interaction terms (X1X2, X1X3, X1X4, X1X5, X2X3, X3X4, and X3X5) were all insignificant to the response. Second-order of frequency (X4X4) could affect bead height.

Table 3. Analysis of variance (ANOVA) for response surface model for bead height.

Source	Sum of squares	Degree of freedom	Mean square	F-value	p
Model	7,12648	20	0,35632	7,10	0,001
X1	1,30994	1	1,30994	26,10	0,000
X4	0,69757	1	0,69757	13,90	0,003
X5	2,64219	1	2,64219	52,65	0,000
X4X4	0,1936	1	0,1936	3,86	0,075
X4X5	0,33478	1	0,33478	6,67	0,025
Residual	0,55204	11	0,05019	-	-
Lack of fit	0,51917	6	0,08653	13,16	0,006
Pure error	0,03286	5	0,00657	-	-
Correlation total	7,67852	31	-	-	-
S=0,240	R^2= 92,81%	R^2(aj)= 79,74%			



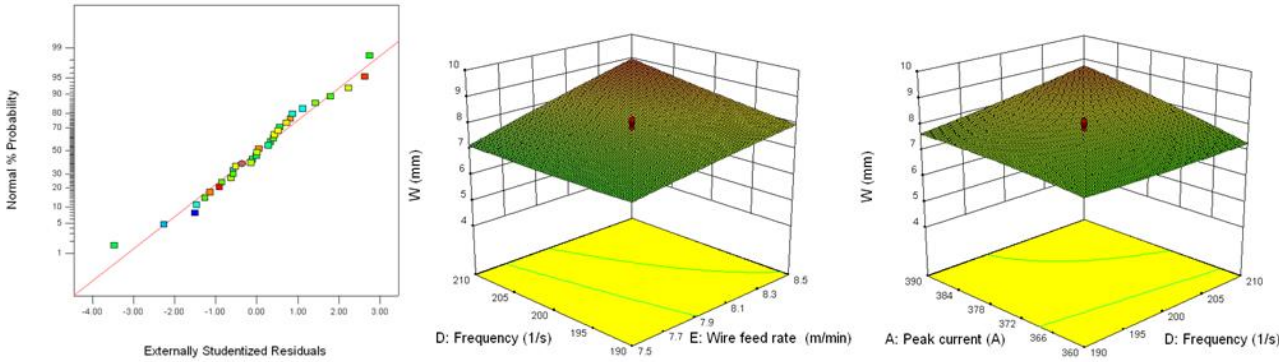
(a) (b)

Figure 3. (a) Normal probability plot of residuals; (b) 3D plots of the effect of the factors on bead height.

The ANOVA for the model of weld width is listed in Table 4. From the ANOVA for response surface linear model for bead height, the model F-value of 6.93 implied that the model was significant as well. In this case, X1, X4, X5 and the first-order interaction effect (X1X4, X4X5) were significant model terms whereas background current (X2) and peak time (X3) term is insignificant to the response.

Table 4. Analysis of variance (ANOVA) for response surface model for weld width.

Source	Sum of squares	Degree of freedom	Mean square	F-value	p
Model	35,59690	20	1,7798	6,93	0,001
X1	4,6807	1	4,6807	18,22	0,001
X4	1,6255	1	1,6255	6,33	0,029
X5	10,4426	1	10,4426	40,64	0,000
X1X4	1,3201	1	1,3201	5,14	0,045
X4X5	1,0112	1	1,0112	3,94	0,073
Residual	2,82640	11	0,2569	-	-
Lack of fit	2,27230	6	0,3787	3,42	0,099
Pure error	0,55400	5	0,1108	-	-
Correlation total	38,42330	31	-	-	-
S=0,507	R^2= 92,64%	R^2(aj)= 79,27%			



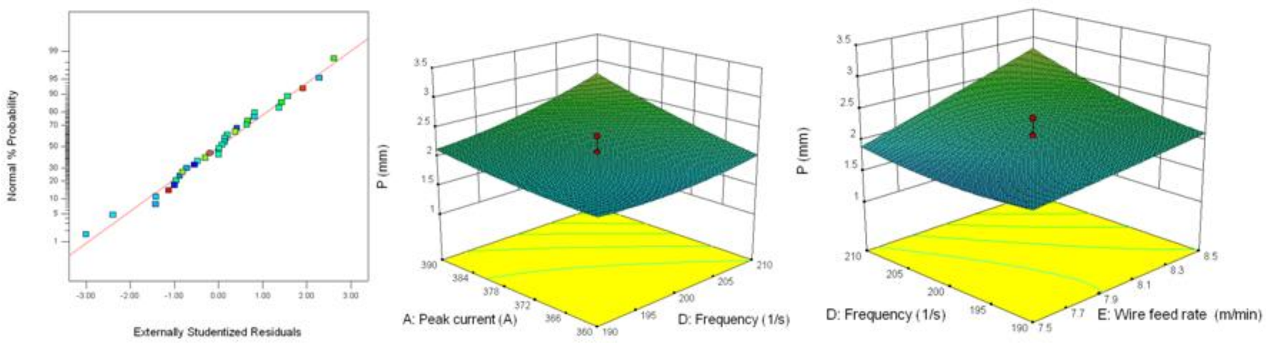
(a) (b) (c)

Figure 4. (a) Normal probability plot of residuals; (b) and (c) 3D plots of the effect of the factors on bead width.

The ANOVA for the model of penetration is listed in Table 5. From the ANOVA for response surface linear model for penetration, the model F-value of 5.95 implied that the model was significant as well. In the same way, main effects of wire feed rate (X5), frequency (X4), peak current (X1), second-order of frequency (X4X4), as well as the interaction effects of (X1X4, X4X5) are statistically significant for the response. On the other hand, other factors such as background current (X2) and peak time (X3) indicate insignificant amount, and proving that the coefficients are substantially distinctive compared to zero, as the measurements of p-values are noticeably higher.

Table 5. Analysis of variance (ANOVA) for response surface model for weld penetration.

Source	Sum of squares	Degree of freedom	Mean square	F-value	p
Model	6,29853	20	0,31493	5,95	0,002
X1	1,33154	1	1,33154	25,17	0,000
X4	0,84135	1	0,84135	15,90	0,002
X5	2,10341	1	2,10341	39,76	0,000
X4X4	0,27764	1	0,27764	5,25	0,043
X1X4	0,28082	1	0,28082	5,31	0,042
X4X5	0,41727	1	0,41727	7,89	0,017
Residual	0,58192	11	0,05290	-	-
Lack of fit	0,41629	6	0,06938	2,09	0,217
Pure error	0,16562	5	0,03312	-	-
Correlation total	6,88044	31	-	-	-
S=0,230	R^2= 91,54%	R^2(aj)= 76,17%			



(a) (b) (c)

Figure 5. (a) Normal probability plot of residuals; (b) and (c) 3D plots of the effect of the factors on bead penetration.

The regressions obtained after analysis of variance gives on weld bead geometry as a function of the different variables peak current (X1, A), background current (X2, A), peak time (X3, ms), frequency (X4, s^{-1}) and wire speed rate (X5, m/min). All terms regardless of their significance were included in the followings second-order polynomial Equations:

$$\begin{aligned}Y_H = 2.599 + 0.234\xi_1 + 0.034\xi_2 + 0.063\xi_3 + 0.171\xi_4 + 0.332\xi_5 + 0.026{\xi_1}^2 - 0.160{\xi_2}^2 + 0.012{\xi_3}^2 \\ + 0.081{\xi_4}^2 - 0.03{\xi_5}^2 - 0.025\xi_1\xi_2 + 0.103\xi_1\xi_3 + 0.074\xi_1\xi_4 + 0.034\xi_1\xi_5 + 0.092\xi_2\xi_3 \\ + 0.1194\xi_2\xi_4 + 0.131\xi_2\xi_5 + 0.027\xi_3\xi_4 + 0.024\xi_3\xi_5 + 0.145\xi_4\xi_5\end{aligned} \quad (8)$$

$$\begin{aligned}Y_W = 7.812 + 0.442\xi_1 + 0.145\xi_2 + 0.01\xi_3 + 0.26\xi_4 + 0.66\xi_5 - 0.1{\xi_1}^2 - 0.62{\xi_2}^2 - 0.13{\xi_3}^2 + 0.04{\xi_4}^2 \\ - 0.04{\xi_5}^2 - 0.33\xi_1\xi_2 + 0.21\xi_1\xi_3 + 0.29\xi_1\xi_4 + 0.02\xi_1\xi_5 + 0.076\xi_2\xi_3 + 0.029\xi_2\xi_4 \\ + 0.323\xi_2\xi_5 + 0.07\xi_3\xi_4 + 0.04\xi_3\xi_5 + 0.25\xi_4\xi_5\end{aligned} \quad (9)$$

$$\begin{aligned}Y_P = 2.071 + 0.235\xi_1 + 0.021\xi_2 + 0.026\xi_3 + 0.187\xi_4 + 0.3\xi_5 - 0.05{\xi_1}^2 - 0.1{\xi_2}^2 - 0.04{\xi_3}^2 + 0.1{\xi_4}^2 \\ - 0.006{\xi_5}^2 - 0.03\xi_1\xi_2 + 0.05\xi_1\xi_3 + 0.132\xi_1\xi_4 + 0.07\xi_1\xi_5 + 0.12\xi_2\xi_3 + 0.09\xi_2\xi_4 \\ + 0.068\xi_2\xi_5 + 0.015\xi_3\xi_4 + 0.029\xi_3\xi_5 + 0.161\xi_4\xi_5\end{aligned} \quad (10)$$

The R^2 value for Eq. (8) was 0.912, the R^2 value for Eq. (9) was 0.936 and 0.916 for Eq. (10). This indicated that 92.81%, 92.64% and 91.54% of the total variation on weld width, bead height, and penetration, respectively, was attributed to the experimental variables studied. The R^2 value also indicates that only 7.19%, 7.36% and 8.46% of the total variation was not explained by the model. The standard deviations for the three models were 0.224, 0.507 and 0.230, respectively, for Equations (8), (9) and (10). The closer the R^2 value to unity and the smaller the standard deviation, the better the model will be as it will give predicted value which is closer to the actual value for the response. This indicated that the predicted value for Y_W would be more accurate and closer to its actual value, compared to Y_H and Y_P. From the statistical results obtained, it was shown that the above models were adequate to predict the weld width, bead height, and penetration within the range of variables studied. The absolute value of the coefficients of each variable reflecting the importance of the same in terms of their effect on welds bead geometry. In this case, the wire feed rate it has a very marked effect on weld bead geometry, followed by frequency pulse and peak current. Response surface in Figs. 3, 4 and 5 allow to observe that, the higher the excess current is, the higher the feed rate is, which, agree to bibliography review. The three-dimensional plots and their respective contour plots were obtained based on the effect of the levels of the factors. Three-dimensional response surfaces shown in Figs. 3, 4 and 5 were generated using Eqs. (8), (9) and (10), respectively, to visualize the interaction effects on bead height, weld width and weld penetration.

5. CONCLUSION

From the statistical results obtained, it was shown that the above models were adequate to predict the weld width, bead height, and penetration within the range of variables studied. The absolute value of the coefficients of each variable reflecting the importance of the same in terms of their effect on welds bead geometry, whereby all the responses had R^2 of above 0.9. In this case, the wire feed rate it has a very marked effect on weld bead geometry, followed by frequency pulse and peak current. The models were calculated using response surface methodology based on central composite design. Wire feed rate had a significant positive effect on most of the important weld bead parameters, results indicate that the wire feed rate increases as the peak parameters is increased.

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7. RESPONSIBILITY NOTICE