Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 11, Issue, 02, pp.1034-1038, February, 2019

DOI: https://doi.org/10.24941/ijcr.33876.02.2019

ISSN: 0975-833X

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

OPTIMIZATION AND PREDICTION OF WELD PENETRATION SIZE FACTOR (WPSF), OF MILD STEEL WELDED JOINT

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ARTICLE INFO

Article History:
Received 15th November, 2018
Received in revised form
28th December, 2018
Accepted 05th January, 2019
Published online 28th February, 2019

Key Words:
RSM, WPSF, TIG, Mild Steel, Contour Plot.

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ABSTRACT

The quest for the continued improvement of weld quality cannot be over emphasized. Hence, every good manufacturer is eager to find better ways to improve product quality. Research has shown that one of the practical ways to improve on weld quality is to optimize input process parameters. The aim of this study is to optimize and predict the Weld Penetration Size Factor (WPSF)of TIG mild steel welds using Response Surface Methodology (RSM), with the purpose of achieving optimum results. In this study, several sets of experiments were carried out. The input parameters considered were the applied current, voltage, and gas flow rate. The TIG welding process was used to join two pieces of mild steel plates, after which the WPSF was measured respectively. The experimental result was analyzed using the RSM. The results obtained showed that current of 140.01 Amp, voltage of 20.00 volt, welding speed of 150.00mm/min, and gas flow rate of 12.01 L/min will produce a weld with the following optimum properties of WPSF at 2.6636mm. This solution was selected at a desirability value of 97.30%

Citation: ***Nweze, S. and Achebo, J.* 2019.** "Optimization and prediction of weld penetration size factor (wpsf), of mild steel welded joint", *International Journal of Current Research*, 11, (02), 1034-1038.

INTRODUCTION

Welding is a metal joining process that involves heating pieces of metal using electricity or a flame so that they melt and bond together (Etin-osa and Achebo, 2017). The nature of joint formed from the bonding of two parent metals greatly depends on the input parameter, if quality weld is to be achieved. Achebo and Odinikuku (2015), stated that the choice of welding input process parameters can vary the quality of the weldment. The bead geometry is specified by bead width, reinforcement, penetration size factor and reinforcement form factor. The bead geometry and shape relationships affect the load carrying capacity and number of passes needed to fill the groove of a joint (Choudhary *et al.,* 2011). Omajene et.al (2013), Palani and Murugan (2006) showed that the bead width of a weld is the maximum width of weld metal deposited that influences the flux consumption rate. According to Akkas et al (2013), Mallya and Srinivas, (1989) the bead width is in direct proportion to the arc current, welding voltage and diameter of the electrode. It is inversely proportional to the welding speed. Penetration is the maximum distance between the top of the base plate and depth of fusion. Penetration is influenced by welding current, welding speed, polarity, electrode stick out, basicity index and physical properties of the flux. According to Kumar, (2011), weld joint is considered to be sound and economical if it has a maximum penetration, minimum bead width and reinforcement. Soy *et al.* (2011), in their study discovered that the length of the arc between the electrode and molten weld metal determines the variation of the welding voltage. An increase in the arc length increases the voltage. The voltage determines the shape of the weld bead cross section and external appearance. Increasing the voltage at a constant current will result in a flatter, wider, and reduced penetration, which also leads to reduced porosity caused by rust on steels. Increase in arc voltage results to an increase in the size of droplets and thereby reduce the number of droplets. Increase in voltage enhances flux consumption, but a further increase in voltage will increase the possibility of breaking the arc and hinder normal welding process. Increase in arc voltage beyond the optimum value leads to an increase in loss of alloying elements which affects the metallurgical and mechanical properties of the weld metal. Arc voltage beyond the optimum value produces a wide bead shape that is susceptible to cracking, increase undercut and difficulty of slag removal. Lowering the arc voltage results in stiffer arc that improves penetration.

MATERIALS AND METHODS

***Materials*:** Tigwelding process was selected for this research, we used 100%Argon Shielding Gas to provide good protection of our samples against atmospheric contamination. Face Mask, Googles and Hand Gloves were the personal safety kits used for protection against welding hazards.150 pieces of mild steel plate measuring 60x40x10mm was used for the experiment. This experiment was repeated 30 times producing a total of one hundred and fifty welded joints. For each run, five specimens were used to determine the weld penetration Size factors and the average recorded respectively. Table 1 shows the weld process parameter, Figure 1 and 2 shows the TIG welding machine and the argon gas cylinder used to carry out this research respectively. The selected input parameters have the upper (+) and lower limits (-). The limits of the four welding variables are shown in Table 1. Current, welding speed, gas flow rate and voltage were the four process parameters applied to predict and optimize the response (weld penetration form factor). The central composite design (CCD) matrix was developed using the design expert software, producing 30 experimental runs. The input parameters and response make up the experimental matrix. Response surface methodology design can either be carried out using the Box-Behnken Design or the Central Composite Design. the Central Composite Design's advantages over Box-Behnken is that it allows the experimental researcher to see what effect the factors has on response if the experimental researcher goes beyond or below the chosen levels of factors. This research focus on the use of the CCD. CCD is an RSM which apart from its three level factors has axial point (also known as star point), and this axial point increases the number of levels to five levels to give the experimental design flexibility and robustness. In Central Composite Design the minimum numbers of factors it can accommodate is TwoImhansoloeva *et al.,* (2018).

Weld Penetration Form Factor Measurement: After the welding the samples, the weld penetration form factor was measured using equation (1). Figure 3 shows a sketch of the welded sample for better understanding (Mistry, 2016).

RESULTS AND DISCUSSION

In this study, thirty experimental runs were carried out, each experimental run comprising the current, voltage, welding speed and gas flow rate, used to join two pieces of mild steel plates measuring 60mm x 40mm x10mm. The weld penetration size factor, was measured. The results are shown in Table 2. The model summary which shows the factors and their lowest and highest values including the mean and standard deviation is presented as shown in Table 3; Result of Table 3 revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The minimum value of weld penetration size factor (WPSF) was observed to be 1.002mm with a maximum value of 2.990mm, mean value of 1.866 and standard deviation of 0.637. In assessing the strength of the quadratic model towards maximizing the weld penetration size factor (WPSF), one way analysis of variance (ANOVA) was done for each response variable and result is presented in Table 4. Analysis of variance was needed to check whether or not the model is significant and also to evaluate the significant contributions of each individual variable and the combined and quadratic effects towards each response. To validate the adequacy of the model based on its ability to maximize the weld penetration size factor (WPSF), the goodness of fit statistics presented in Table 5 was employed; Coefficient of determination (R-Squared) values of 0.9125as observed in Table 5 shows the strength of response surface methodology and its ability to maximize the weld penetration size factor (WPSF). Adjusted (R-Squared) values of 0.8308 as observed in Table 5 indicates a model with 83.08% reliability. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 10.314as observed in Table 5 indicate an adequate signal. This model can be used to navigate the design space and maximize the weld penetration size factor (WPSF). The optimal equation which shows the individual effects and combine interactions of the selected variables against the mesured response of WPSF is presented based on the coded variables in equation 2, equation 3 presented the actual variable.

The coded equation for:

$$WPSF = +1.03 -0.15*A -0.20*B +0.043*C -0.20*D +0.056*A*B +0.15*A*C +0.13*A*D +0.020*B*C -0.23*B*D -0.036*C*D +0.063*A^2 +0.34B^2 +0.27C^2 +0.37D^2 \quad (2)$$

Final equation in terms of actual factors:

$$WPSF = +228.87637 -3.18035*A -0.83744*B -0.99383*C - 7.26954*D+2.77875E-003*A*B+7.26500E-003*A*C +0.63981*A*D+1.96750E-004*B*C-0.022856*B*D - 3.55125E003*C*D+0.015727*A^2+3.40594E-003B^2 +2.67069E-003C^2 +0.37152D^2 \quad (3)$$

Where, A=voltage, B=current, C=welding speed, D=gas flow rate, A*B =voltage*current, A*C= voltage*welding speed, A*D= voltage*gas flow rate, B*C= current*welding speed, B*D= current*gas flow rate, C*D= welding speed*gas flow rate, A^2= voltage^2, B^2= current, C^2= welding speed^2 and D^2= gas flow rate^2

To assess the accuracy of prediction and established the suitability of response surface methodology using the quadratic model, a reliability plot of the observed and predicted values of the WPSF response were obtained as presented in Figures 4. The high coefficient of determination (r^2 = 0.9125) as observed in Figures 4 was used to established the suitability of response surface methodology in maximizing the weld penetration size factor. To accept any model, its satisfactoriness must first be checked by an appropriate statistical analysis. To diagnose the statistical properties of the model, the normal probability plot of the WPSF residual presented in Figure 5 were employed. The normal probability plot of student zed residuals was employed to assess the normality of the calculated residuals. The normal probability plot of residuals which is the number of standard deviation of actual values based on the predicted values was employed to ascertain if the residuals (observed – predicted) follows a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result of Figure 5 revealed that the computed residuals are approximately normally distributed an indication that the model developed is satisfactory. In addition, result of the normal probability plot of residual also indicates that the data used are devoid of possible outliers. To study the effects of combine variables on each response; weld penetration size factor (WPSF), 3D surface plots presented in Figure 6 were employed. The above Figure shows a 3 dimensional surface plot on contour plot which was employed to give a clearer concept of the response surface and the relationship between the variables on the response. As the color of the curved surface gets darker, the weld penetration size factor (WPSF) gets higher. The presence of a colored hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface. The 3D surface plot as observed in Figure 6 shows the relationship between the input variables (voltage, current, welding speed and gas flow rate)

Table 1. Welding process parameters limits

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	140	160
Gas flow rate	Lit/min	F	12	14
Voltage	Volt	V	20	24
Welding speed	cm/min	S	150	170

Table 2. Experimental result for the WPSF

Std	Run	Voltage (Volt)	Current (Amp)	Welding Speed (mm/min)	Gas Flow Rate (L/min)	WPSF (mm)
26	1	22.00	150.00	160.00	13.00	1.0324
29	2	22.00	150.00	160.00	13.00	1.0326
30	3	22.00	150.00	160.00	13.00	1.0323
25	4	22.00	150.00	160.00	13.00	1.0324
27	5	22.00	150.00	160.00	13.00	1.0325
28	6	22.00	150.00	160.00	13.00	1.0323
18	7	26.00	150.00	160.00	13.00	1.0021
23	8	22.00	150.00	160.00	11.00	2.9899
21	9	22.00	150.00	140.00	13.00	2.2015
20	10	22.00	170.00	160.00	13.00	2.0005
19	11	22.00	130.00	160.00	13.00	2.8765
24	12	22.00	150.00	160.00	13.00	2.1325
17	13	18.00	150.00	160.00	13.00	1.6534
22	14	22.00	150.00	160.00	13.00	2.0873
5	15	20.00	140.00	170.00	12.00	2.7276
4	16	24.00	160.00	150.00	12.00	1.5454
7	17	20.00	160.00	170.00	12.00	2.3843
14	18	24.00	140.00	170.00	14.00	2.3438
10	19	24.00	140.00	150.00	14.00	2.1037
6	20	24.00	140.00	170.00	12.00	1.6943
16	21	24.00	160.00	170.00	14.00	1.6371
2	22	24.00	140.00	150.00	12.00	1.9965
8	23	24.00	160.00	170.00	12.00	2.6262
3	24	20.00	160.00	150.00	12.00	2.5862
9	25	20.00	140.00	150.00	14.00	2.2322
13	26	20.00	140.00	170.00	14.00	2.4315
1	27	20.00	140.00	150.00	12.00	2.3981
11	28	20.00	160.00	150.00	14.00	1.8693
12	29	24.00	160.00	150.00	14.00	1.0677
15	30	20.00	160.00	170.00	14.00	1.0621

Table 3. RSM design summary for optimizing weld parameters

Study type Response surface Run30												
Initial Design Central composite Blocks No Blocks												
Design Model Quadratic												
Factor	**Name**	**Units**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**	**Mean**	**Std. Dev.**			
A	Voltage	Volt	Numeric	20.00	24.00	-1.00	1.00	22.000	1.789			
B	Current	Amp	Numeric	140.00	160.00	-1.00	1.00	150.000	8.944			
C	W.S	M/min	Numeric	150.00	170.00	-1.00	1.00	160.000	8.944			
D	GFR	L/min	Numeric	12.00	14.00	-1.00	1.00	13.000	0.894			
Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model	
Y1	WPSF	mm	30	Polynomial	1.002	2.990	1.866	0.637	2.984	None	Quadratic	

Table 4. ANOVA table for validating the model significance towards maximizing WPSF

Response 1 WPSF						
ANOVA for Response Surface Quadratic Model						
Analysis of Variance table [Partial Sum of Squares-Types III]						
Source	**Sum of Square**	**df**	**Mean Square**	**F Value**	**P-Value Prob>F**	
Model	11.09	14	0.79	11.17	<0.0001	Significant
A-Voltage	0.58	1	0.58	8.11	0.0122	
B-Current	0.95	1	0.95	13.34	0.0024	
C-WS	0.044	1	0.044	0.61	0.4452	
D-GFR	0.95	1	0.95	13.41	0.0023	
AB	0.049	1	0.049	0.70	0.4170	
AC	0.34	1	0.34	4.76	0.0454	
AD	0.26	1	0.26	3.69	0.07694	
BC	6.320E-003	1	6.320E-003	0.089	0.7694	
BD	0.84	1	0.84	11.79	0.0037	
CD	0.020	1	0.020	0.28	0.6016	
A^2	0.11	1	0.11	1.53	0.2351	
B^2	3.18	1	3.18	44.86	<0.0001	
C^2	1.96	1	1.96	27.58	<0.0001	
D^2	3.79	1	3.79	53.38	<0.0001	

and the response variable (weld penetration size factor (WPSF)). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. Finally, numerical optimization was performed to ascertain the desirability of the overall model. In the numerical optimization phase, we ask design expert to maximize WPSF while also determining the optimum value of voltage, current, welding speed and gas flow rate.

Figure 1. TIG Machine

Figure 2. Shielding gas and regulator

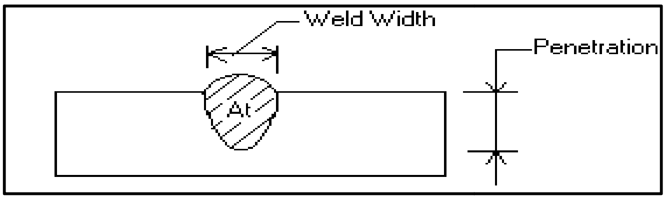


Figure 3.

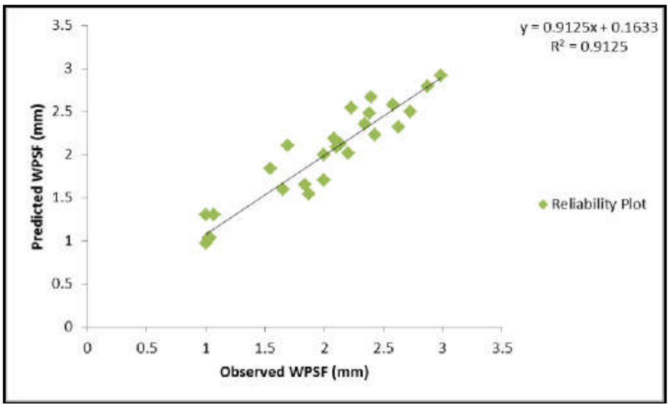


Figure 4. Reliability plot of observed versus predicted WPSF

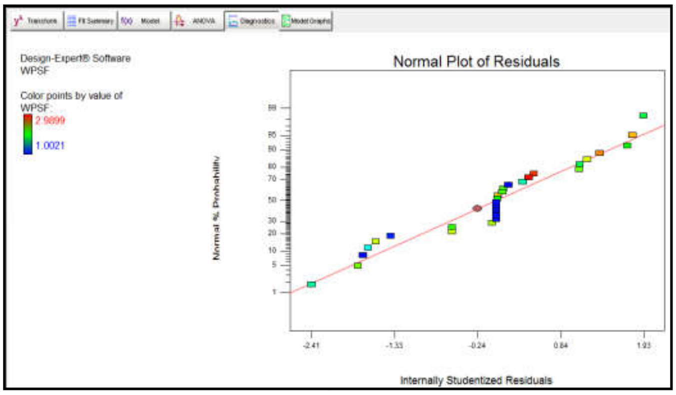


Figure 5. Normal probability plot of studentized residuals for WPSF

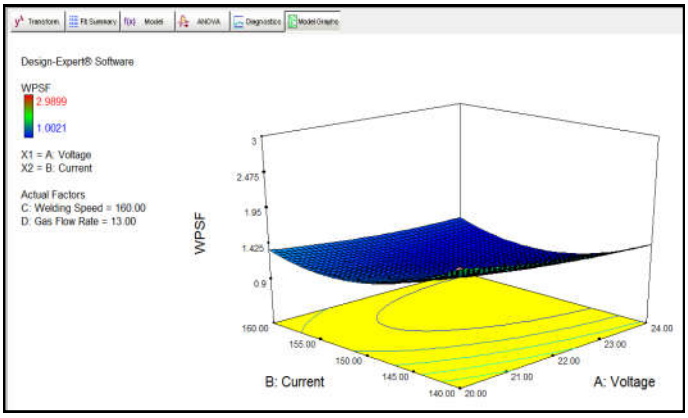


Figure 6. Effect of current and voltage on weld penetration size factor (WPSF)

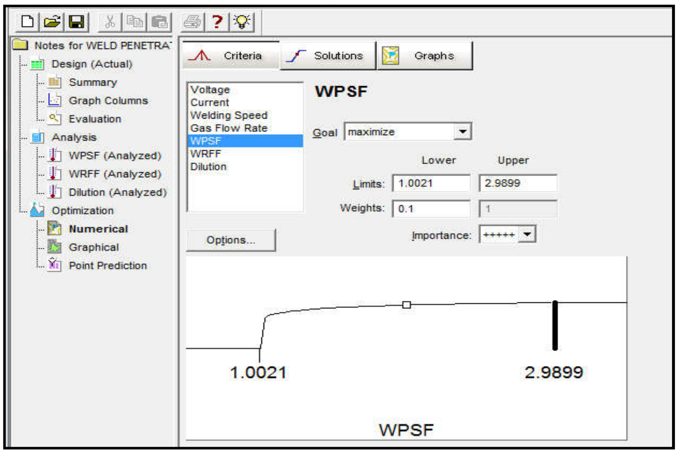
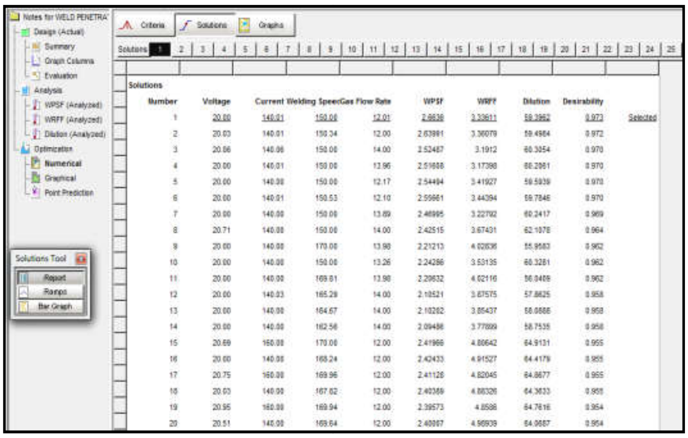


Figure 7. Interphase of numerical optimization model for maximizing WPSF



Solutions

Number	Voltage	Current	Welding Speed	Gas Flow Rate	WPSF	WRFF	Dilution	Desirability	
1	20.00	140.01	150.00	12.01	2.6636	3.33611	59.3962	0.973	Selected
2	20.03	140.01	150.34	12.00	2.63881	3.36079	59.4984	0.972	
3	20.06	140.06	150.00	14.00	2.52487	3.1912	60.3854	0.970	
4	20.00	140.01	150.00	13.96	2.51688	3.17398	60.2981	0.970	
5	20.00	140.00	150.00	12.17	2.54494	3.41927	59.5939	0.970	
6	20.00	140.01	150.53	12.10	2.59661	3.44394	59.7846	0.970	
7	20.00	140.00	150.00	13.89	2.46995	3.22792	60.2417	0.969	
8	20.71	140.00	150.00	14.00	2.42515	3.67431	62.1078	0.964	
9	20.00	140.00	170.00	13.98	2.21213	4.02636	55.9583	0.962	
10	20.00	140.00	150.00	13.26	2.24286	3.53135	60.3281	0.962	
11	20.00	140.00	169.81	13.98	2.20632	4.02116	56.0409	0.962	
12	20.00	140.03	165.29	14.00	2.10521	3.87575	57.8825	0.958	
13	20.00	140.00	164.67	14.00	2.10282	3.85437	58.0886	0.958	
14	20.00	140.00	162.56	14.00	2.09486	3.77899	58.7535	0.958	
15	20.69	160.00	170.00	12.00	2.41966	4.80642	64.9131	0.955	
16	20.00	140.00	168.24	12.00	2.42433	4.91527	64.4179	0.955	
17	20.75	160.00	169.96	12.00	2.41126	4.82045	64.8677	0.955	
18	20.03	140.00	167.82	12.00	2.40369	4.88326	64.3633	0.955	
19	20.95	160.00	169.94	12.00	2.39573	4.8588	64.7816	0.954	
20	20.51	140.00	169.64	12.00	2.40087	4.96939	64.9687	0.954	

Figure 8. Optimal solutions of numerical optimization model

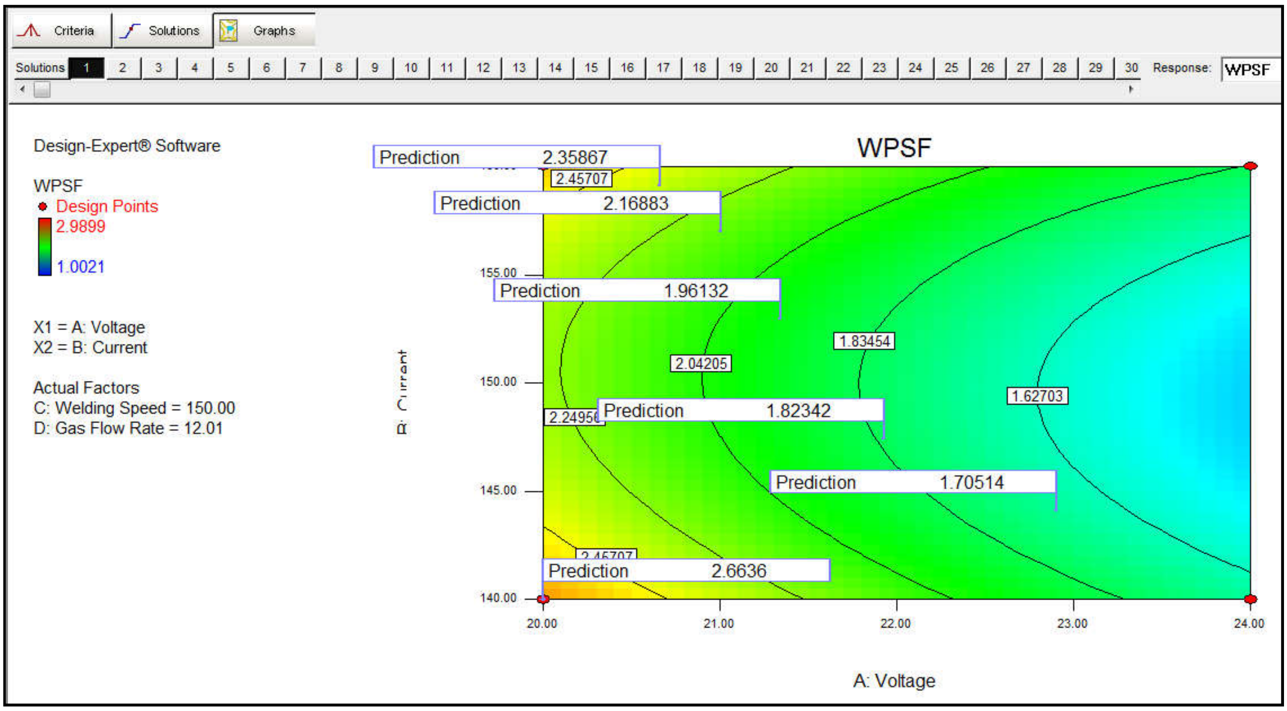


Figure 9. Predicting weld penetration size factor (WPSF) using contour plot

The interphase of the numerical optimization showing the goal of the objective function is presented in Figures 7. The interface of numerical optimization defines the objective function (minimize or maximize) as the case maybe, defines the lower and upper limit of the response with the level of importance indicated. For a maximization case, the weight leans towards the higher limit as seen above for WPSF. The numerical optimization produces about twenty (20) optimal solutions which are presented in Figure 8. From the results of Figure 8, it was observed that current of 140.01 Amp, voltage of 20.00 volt, welding speed of 150.00mm/min and gas flow rate of 12.01 L/min produced a weld material with WPSF of 2.6636mm. This solution obtained was selected by design expert as the optimal solution with a desirability value of 97.30%. Finally, based on the optimal solution, the contour plots showing the WPSF response variable against the optimized value of the input variable is presented in Figure 9. The contour plots in Figure 9 show different predictions of WPSF for different voltages =20.00 21.00, 22.00, and 23.00, to give WPSF= 2.6636, 2.16883, 1.82342 and 1.70514 respectively which shows that the RSM is also a good predicting tool.

Conclusion

In this study Mathematical model for weld penetration size factor, using TIG welding process with four input process parameters (voltage, current, welding speed and gas flow rate) has been developed. The results obtained showed that current of 140.01 Amp, voltage of 20.00 volt, welding speed of 150.00mm/min, and gas flow rate of 12.01 L/min will produce a weld penetration size factor (WPSF) of 2.6636mm. This solution was selected at a desirability value of 97.30%. Welding speed and gas flow rate are found to have a great influence on weld penetration size factor as compared to current and voltage at a moderate level. The results of this study will help reduce the cost of expensive and time wasting analytical methods employed during welding operation, and it will help fabrication industries to maximize the quality of their products.

REFERENCES

Achebo, J. and Odinikuku, W. 2015. Optimization of Gas Metal Arc Welding Process parameters using Standard Deviation (SDV) and Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA). Journal of Minerals and Materials Characterization and Engineering. 3. 298-308.

Collins Eruogun Etin-osa and Joseph Ifeanyi Achebo 2017. Analysis of Optimum Butt Welded Joint for Mild SteelComponents Using FEM (ANSYS). American Journal of Naval Architecture and Marine Engineering2017; 2(3): 61-70http://www.sciencepubli shinggroup. com/j/ ajnamedoi: 10.11648/j.ajname.20170203.12

Deepak Kumar Choudhary , Sandeep Jindal and N.P.Mehta 2011. To study the effect of welding parameters on weld bead geometry in SAW welding process. Elixir Mech. Engg. 40 (2011) 5519-5524

Joshua Emuejevoke Omajene, Jukka Martikainen, Paul Kah 2014. Effect of welding parameters on weld bead shape for weldsdone underwater. International Journal of Mechanical Engineering and Applications 2014; 2(6): 128-134 ISSN: 2330-0248

Kumar, V. 2011. Modeling of Weld Bead Geometry and Shape Relationships in Submerged Arc Welding Using Developed Fluxes. Jordan Journal of Mechanical and Industrial Engineering Vol. 5, No.5, pp. 461-470.

Mallya U. D. and Srinivas, H. S. 1989. "Bead Characteristics in Submerged Arc Strip Cladding," *Welding Journal*, pp. 30-36, 1989.

Mistry, P.J. 2016. Effect of Process Parameters on Bead Geometry and Shape Relationship of Gas Metal Arc Weldments. *International Journal of Advanced Research in Mechanical Engineering & Technology*, Vol. 2, issue 2, pp. 24-27.

Nicholas Afemhonkike Imhansoloeva, Joseph Ifeanyi Achebo, Kessington Obahiagbon, John Osadolor Osarenmwinda, Collins Eruogun Etin-Osa. (2018). Optimization of the Deposition Rate of Tungsten Inert Gas Mild Steel UsingResponse Surface Methodology. Scientific Research Publishing. vol.10, pp784-804

Nuri Akkas, DurmuG Karaye, Sinan Serdar Ozkan, Ahmet OLur, and Bayram Topal (2013). Modeling and Analysis of the Weld Bead Geometry inSubmerged Arc Welding by Using Adaptive NeurofuzzyInference System. Hindawi Publishing Corporation Volume 2013, Article ID 473495, 10 pageshttp://dx.doi.org/10. 1155/2013/473495

Palani P. K. and Murugan N. 2006. "Development of Mathematical Models for Prediction of Weld Bead Geometry in Cladding by Flux Cored Arc Welding," International Journal of Advanced Manufacturing Technology, vol. Vol. 30, pp. 669-676, 2006.

Ugur Soy, Osman Iyibilgin, Fehim Findik, Cemil Oz and Yasar Kiyan, 2011. Determination of welding parameters for shielded metal arc welding. Scientific Research and Essays Vol. 6(15), pp. 3153-3160

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