RESEARCH ARTICLE OPEN ACCESS

Prediction of Weld Quality of A Tungsten Inertr Gas Welded Mild Steel Pipe Joint Using Response Surface Methodology (Rsm)

[1]I.U. Abhulimen, [2]J.I. Achebo

[1]Department of Materials and Production Engineering, Faculty of Engineering and Technology, Ambrose Alli University Ekpoma, Edo State, Nigeria.[2]Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria

ABSTRACT
The weld quality of tungsten inert gas (TIG) welded joint has been investigated to identify the most economical weld parameters that will bring about optimum properties. Response surface methodology has been used in the optimization of the tungsten inert gas weld of mild steel pipes. Response surface methodology, based on the central composite face centered design was generated for the purpose of optimization of the weld quality.All the process parameters have desirability of 1. Tensile strength response for this solution have a desirability of 0.910595 and the yield strength of 0.59. Result showed that minimizing current and voltage an average tensile strength of 535.452MPa and yield strength of up to 408.74MPa can be achieved, while keeping gas flow rate and electrode diameter within the range of test. It was also deduced that tensile elongation of the TIG weld is not influenced by the process parameters selected for the purpose of this study.

KEYWORDS: Flow, Methodology, Optimization, Rate, Tungston.

I. INTRODUCTION

Oil and gas pipelines are among the biggest infrastructure projects in developing countries in recent years. Because mild steel is available in a variety of structural shapes and are easily welded into pipe, tube, tubing etc., they are used for pipelines in the oil and gas industries. Mild steel pipes and tubing are easy to fabricate, readily available, and relatively cheaper than other metals.TIG welding (Tungsten Inert Gas Welding) is also known as Gas Tungsten Arc Welding (GTAW) which uses a non-consumable electrode and separate filler metal with an inert shielding gas.TIG welding, is about the most popular welding method, which finds its applications in industrial environments. Evolving microstructure of welds in turn depends on the heating cycle arising during the welding, composition of the welded alloy, cooling condition, and the filler material.The prevailing heating cycle during welding is dependent on factors such as current, speed, electrode diameter, gas flow rate, voltage etc. making welding a multi-input, multi-output process.A common problem that has faced the pipeline engineer is the control of the process input parameters to obtain a good welded joint with the required bead geometry and weld quality with minimal detrimental residual stresses and distortion.

Response Surface Methodology (RSM)was used to obtain optimum model to predict the output quality of the weld. This was important because it explores the relationships between several explanatory variables and one or more response variables. (Box and Wilson 1951). The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response.

II. LITERATURE REVIEW

Gunaraj et al (1999) designed a response surface methodology to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses as a two or three dimensional hyper surface. Jayachandran and Murugan (2011) carried out investigations on the Influence of surfacing process parameters over bead properties during stainless steel cladding and discovered that an optimum weld cladding process yields minimum base metal dilution with higher deposition rates with the required cladding thickness in minimum number of passes.

Krishankant et al (2012) used the application of response surface modeling for determination of flux consumption in submerged arc welding by the effect of various welding parameters direct and interactive effects of process variables on the bead parameters through two dimensional and three dimensional graphs.

Kundan et al 2012, showed that tungsten inert gas welding (TIG) is one of the most important material joining processes widely used in industry. Surface Response Methodology has been developed to study the effects of input variable (i.e. current, voltage, travel speed) on output responses (i.e. reinforcement height, weld bead width, metal deposition rate). Elangovan et al, 2012 showed how an effective methodology was developed to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding by coupling response surface method (RSM) with genetic algorithm (GA). Sudhakaran et al 2012, presented a paper on the study of optimization of process parameters using particle swarm optimization to minimize angular distortion in 202 grade stainless steel gas tungsten arc welded plates. Palani and Saju 2013, Modeled and Optimized Process Parameters For Tig Welding Of Aluminium-65032 Using Response Surface Methodology and reported that Tungsten inert gas welding is one of the widely used techniques for joining ferrous and non ferrous metals.

III. METHODOLOGY

3.1 Conducting Experiments

The TIG welding and tensile test experiments were conducted at the Petroleum Training Institute (PTI) Warri using the actual values of the design matrix. While the non-destructive tests were conducted at the department of Materials and Production Engineering, Ambrose Alli University, Ekpoma. The welding and tensile test experiments were conducted at the Department of Welding and fabrication technology, Petroleum Training Institute (PTI), Warri, Delta State, Nigeria. While the hardness tests and the micro structural examinations were carried out in the department of materials and production Engineering, Ambrose Alli University Ekpoma, Edo state, Nigeria.

3.2 PREPERATION OF SPECIMEN

A mild steel pipe was cut to size and the edge preparation was carried out by creating a groove of 30°on each end of the pipe in order to get a 60° groove angle with root face of 3mm. In order to achieve a very strong weld, the joints were properly cleaned with a grinder and sand paper. One careless moment can contaminate the tungsten so care was taken not to expose the tungsten, and not to touch the end of it with a finger or even a glove, as finger oils or residue on a glove can both wreck the tip of the tungsten. Argon gas with flow rates between 5 and 25 l/min was used for shielding. The purpose of using the shielding gas was to protect the weld area from atmospheric gases such as oxygen, nitrogen, carbon dioxide and water vapor. During fit-up (pipe fitting) 2.5mm was used to prepare the gap before the tackling of the pipe. The selection of the filler material is important to prevent excessive porosity. Oxides on the filler material and work piece were removed before welding to prevent contamination, and immediately prior to welding, alcohol was used to clean the surface. The prepared sample is shown in figure 3.1 below.

Fig.3.1 Sample preparation

3.3 WELDING PROCESS

To achieve the objectives of this study, the following basic steps were carefully carried out: selecting process parameters, doing an experimental design, executing the design, and measuring the output values. The chosen process parameters for this study were welding voltage, arc current, electrode size and gas flow rates. 30 run were carried out during the welding process, and a total of four different beads were achieved: 1. Root Run, 2. Hot Pass, 3. filling and 4. Capping. The final welded specimen is shown in the figure 3.2 below.

Fig.3.2 Final welded sample

3.4 MECHANICAL TESTING

The mild steel pipe of 4 mm thickness was cut into the required dimension (150 mm×50 mm) by oxy-fuel cutting and grinding. The initial joint configuration was obtained by securing the plates in position using tack welding. Single ‘V’ butt joint configuration was used to fabricate the joints using shielded metal arc welding process. All the necessary cares were taken to avoid the joint distortion and the joints were made with applying clamping fixtures. The specimens for testing were sectioned to the required size from the joint comprising weld metal, heat affected zone (HAZ) and base metal regions and were polished using different grades of emery papers. Final polishing was done using the diamond compound (1μm particle size) in the disc polishing machine. The specimens were etched with 5 ml hydrochloric acid, 1 g picric acid and 100 ml methanol applied for 10–15 s. The welded joints were sliced using power hacksaw and then machined to the required dimensions (100 mm x 10mm) for preparing tensile tests.

3.5 TENSILE STRENGTH

The un-notched smooth tensile specimens were prepared to evaluate transverse tensile properties of the joints such as tensile strength and yield strength. The specimen was mounted on both ends of the universal testing machine. The Tensile test was conducted with a 40 ton electro-mechanical controlled universal testing machine. Typically, the testing involved taking a small sample with a fixed cross-sectional area and then pulling it with a controlled, gradually increasing force until the sample changed shape and eventually fractured.

Fig. 3.4 Prepared samples for tensile tests

IV. DISCUSSION OF RESULTS

In order to investigate the influence of various factors on the TIG welding three factors (gas flow rate, current, voltage) identified in previous work as were chosen. In this study, these factors were chosen as the independent input variables. The desired responses were the tensile and yield strength which are assumed to be affected by the above three principal factors. The response surface methodology (RSM) was employed for modelling and analysing the weld parameters in the welding process.

Table 1: Design matrix

S/N	Factor	Designation	Unit	Low Level	Moderate level	High Level
1.	Gas flow rate	A	Lit/mill	25	27.5	30
2.	Current	B	Amperes	130	160	180
3.	Voltage	C	V	10.5	11.5	13.5

Table 2: Responses and design matrix

S/N	Gas flow rate	Current	Voltage	Tensile Strength	Yield Strength
1.	-1.000	-1.000	-1.000	415.841	317.44
2.	1.000	-1.000	-1.000	462.046	352.71
3.	-1.000	1.000	-1.000	508.251	387.98
4.	1.000	-1.000	1.000	462.046	352.71
5.	-1.000	-1.000	1.000	462.046	352.71
6.	1.000	1.000	1.000	508.25	387.978
7.	-1.000	1.000	1.000	462.046	352.71
8.	1.000	1.000	1.000	485.148	370.34
9.	-1.000	0.000	0.000	485.15	370.342
10	1.000	0.000	0.000	415.841	317.44
11.	0.000	-1.000	0.000	462.046	352.71
12.	0.000	1.000	0.000	462.046	352.71
13.	0.000	0.000	-1.000	462.046	352.71
14.	0.000	0.000	1.000	462.046	352.71
15.	0.000	0.000	0.000	485.15	370.342
16.	0.000	0.000	0.000	485.15	370.342
17.	0.000	0.000	0.000	485.15	370.342
18.	0.000	0.000	0.000	485.15	370.342
19.	0.000	0.000	0.000	485.15	370.342
20.	0.000	0.000	0.000	485.15	370.342

In order to estimate the regression coefficients, a number of experimental design techniques are available. In this work, central composite face centered design (Table 2) was used which fits the second order response surfaces very accurately. Central composite face centered (CCF) design matrix with the star points being at the center of each face of factorial space was used, so α= ±1. This variety requires three levels of each factor. CCF designs provide relatively high quality predictions over the entire design space and do not require using points outside the original factor range. The upper limit of a factor was coded as +1, and the lower limit was coded as –1. All the coefficients were obtained applying central composite face centered design using the Design Expert statistical software package. After determining the significant coefficients (at 95% confidence level), the final model was developed using only these coefficients and the final mathematical model to estimate tensile strength is given:

Tensile Strength =+471.29 -14.4* A * B -14.44 *B*C
Yield Strength =+359.76-11.02 *A*B-11.02*B*C

Table 3: Anova results for tensile strength

Source	**Sum of squares**	**Df**	**Mean square**	**F value**	**P Value**	**Prob > F**
Model	3335.76	2	1667.88	3.65	0.0480	Significant
AB	1667.88	1	1667.88	3.65	0.0730	
BC	1667.88	1	1667.88	3.65	0.0730	
Residual	7765.94	17	456.82			
Lack of Fit	7765.94	12	647.16			
Pure Error	0.000	5	0.000			
Cor Total	11101.69	19				
Standard deviation	21.37		R-Squared	0.3005		
Mean	471.29		Adj R-Squared	0.2182		
Coefficient of variation	4.54		PRESS	11407.76		
Adeq Precision	6.977					

Assessing tensile strength model adequacy

The adequacy of the developed model was tested using the analysis of variance(ANOVA) technique and the results of second order response surface model fitting in the form of analysis of variance (ANOVA) are given in Table 3. The determination coefficient(R^2) indicatesthe goodness of fit for the model. In this case, the value of the determination coefficient (R^2=0.3005) indicates that about70% of the total variations are not explained by the model. The value of adjusted determination coefficient (adjusted R^2=0.2182) is also low but is closer to the R^2value, which indicates a significance of the model. Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 6.977 indicates an adequate signal indicating that the model can be used to navigate the design space.The value of probability ＞F in Table3 for model is less than 0.05, which indicates that the model is significant. The normal probability plot of the residuals for tensile strength shown in Fig. 4.1 reveals that the residuals are falling on the straight line, which means the errors are distributed normally(Correia et al., 2005). All the above consideration indicates an excellent adequacy of the regression model.

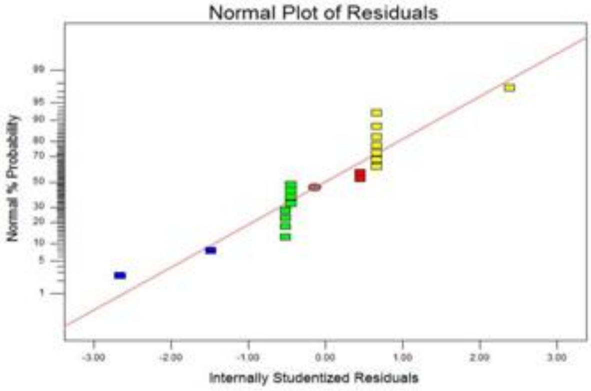

Figure 4.1: Normal Probability plot of residuals for tensile strength model

Assessing yield strength model adequacy

The adequacy of the developed model was tested using the analysis of variance(ANOVA) technique and the results of second order response surface model fitting in the form of analysis of variance (ANOVA) are given in Table 3. The determination coefficient(R^2) indicatesthe goodness of fit for the model. In this case, the value of the determination coefficient (R^2=0.3005) indicates that about70% of the total variations are not explained by the model. The value of adjusted determination coefficient (adjusted R^2=0.2128) is also low but is closer to the R^2 value, which indicates a significance of the model. Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 6.978 indicates an adequate signal indicating that the model can be used to navigate the design space.The value of probability ＞F in Table 3 for model is less than 0.05, which indicates that the model is significant. The normal probability plot of the residuals for yield strength shown in Fig.4.2 reveals that the residuals are falling on the straight line, which means the errors are distributed normally (Correia et al., 2005). All the above consideration indicates an excellent adequacy of the regression model.

Table 4: Anova results for yield strength

Source	Sum of squares	Df	Mean square	F value	P Value	Prob > F
Model	1943.84	2	971.92	3.65	0.0479	significant
AB	971.92	1	971.92	3.65	0.0730	
BC	971.92	1	971.92	3.65	0.0730	
Residual	4524.16	17	266.13			
Lack of Fit	4524.16	12	377.01			
Pure Error	0.000	5	0.000			
Cor Total	6468.00	19				
Standard deviation			16.31		R-Squared	0.3005
Mean			359.76		Adj R-Squared	0.2182
Coefficient of variation			4.53		PRESS	6645.78
Adeq Precision			6.978			

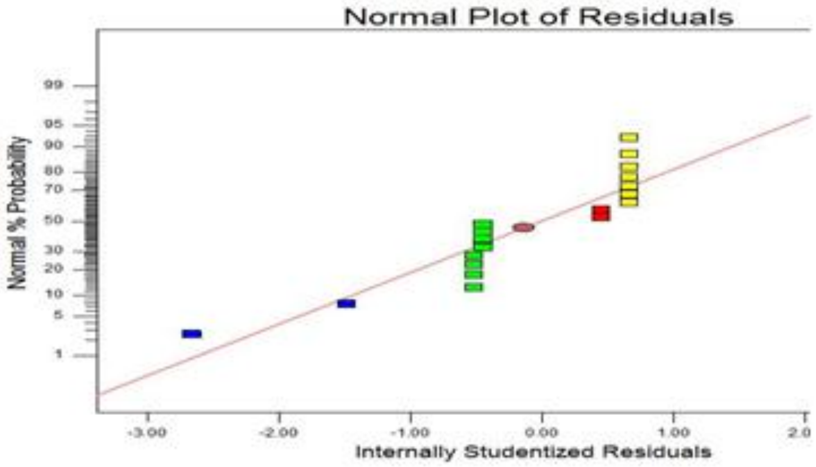

Figure 4.2: Normal Probability plot of residuals for yield strength model

4.1 Analysis of results

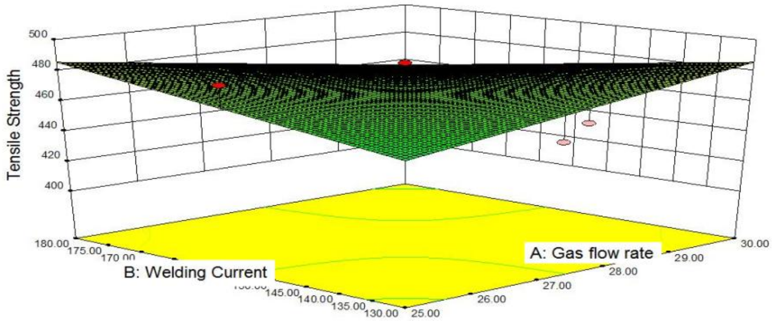

Figure 4.3: Variation of Tensile strength with welding current and gas flow rate

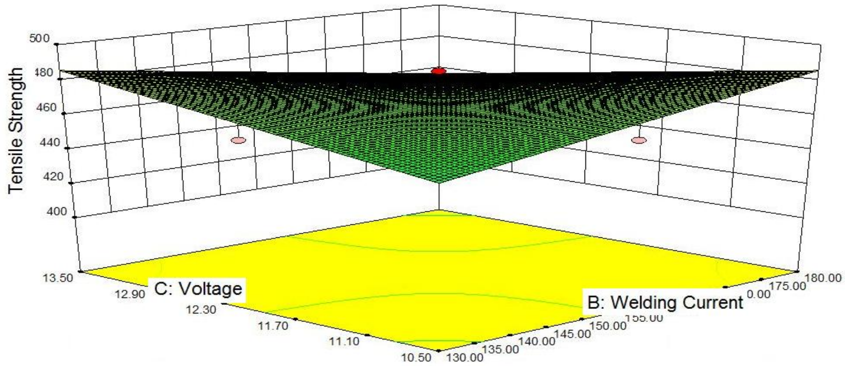

Figure 4.4: Variation of Tensile strength with welding current and voltage

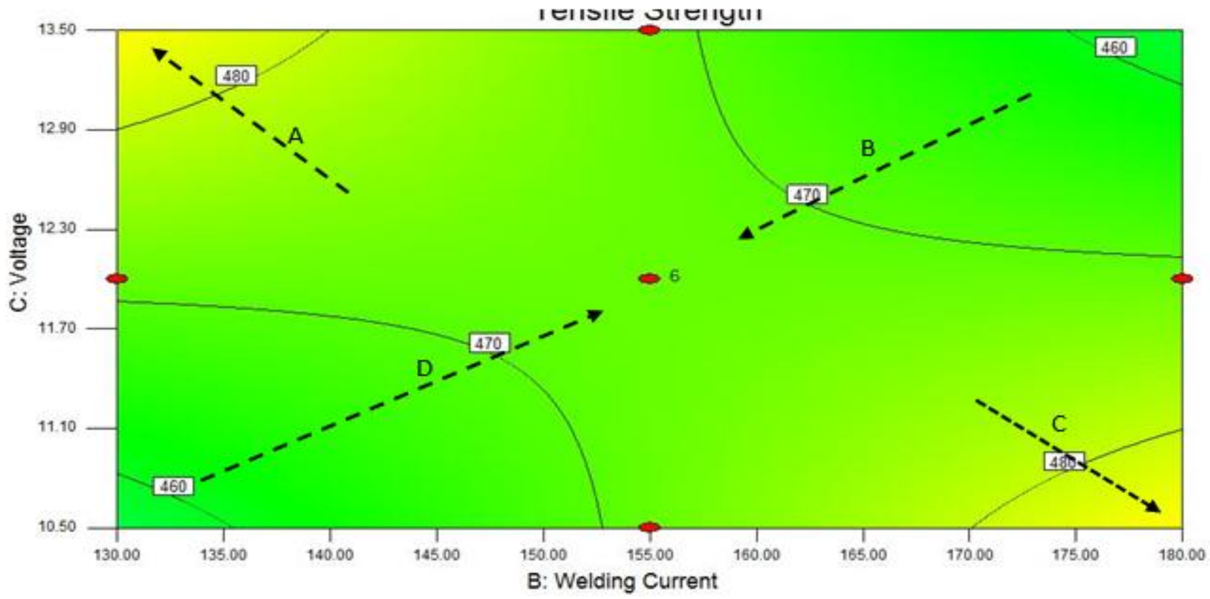

Figure 4.63: Contour plot of tensile strength in terms of current and voltage

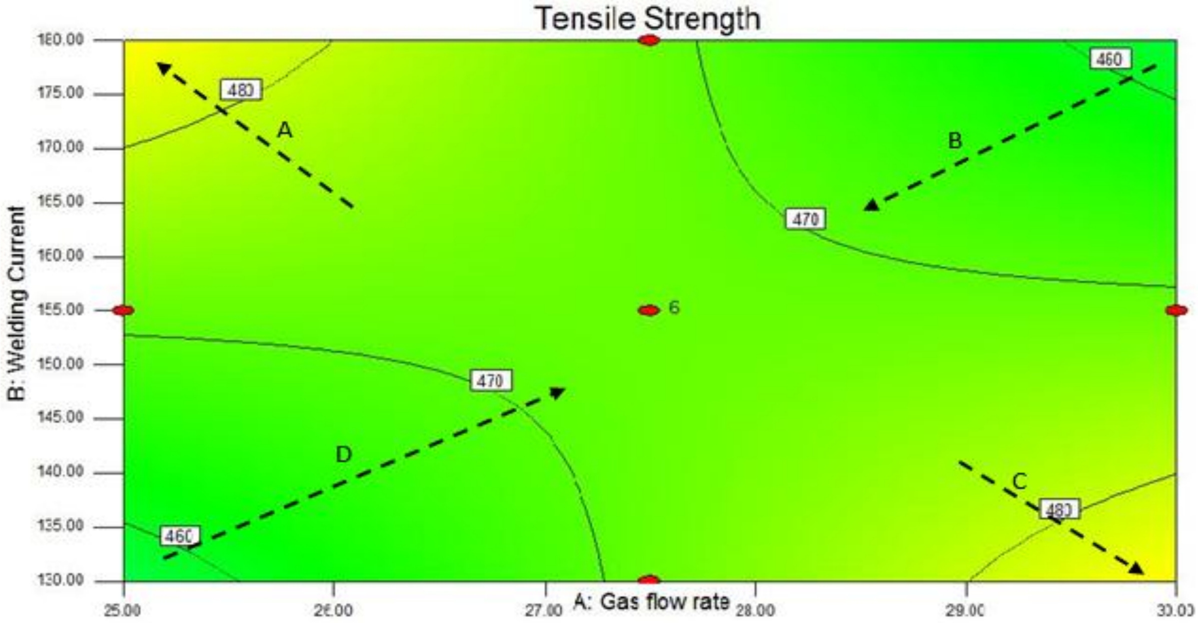

Figure 4.64: Contour plot of tensile strength in terms of current and gas flow rate

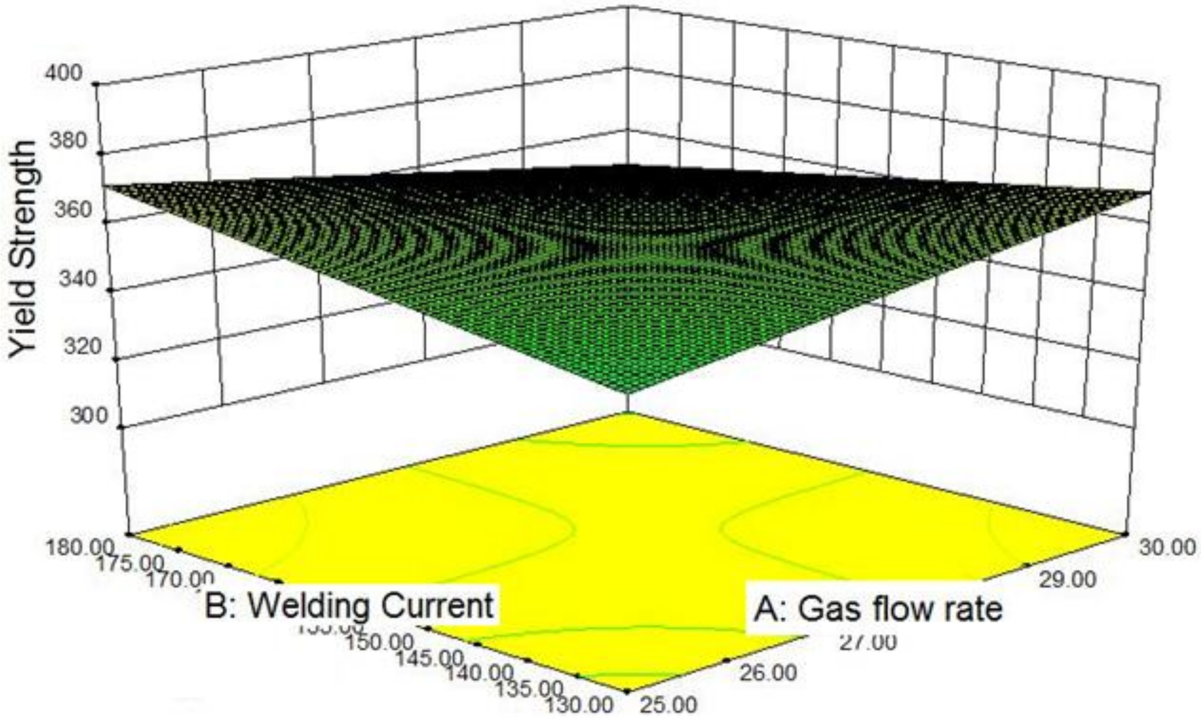

Figure 4.65: Variation of yield strength with welding current and gas flow rate

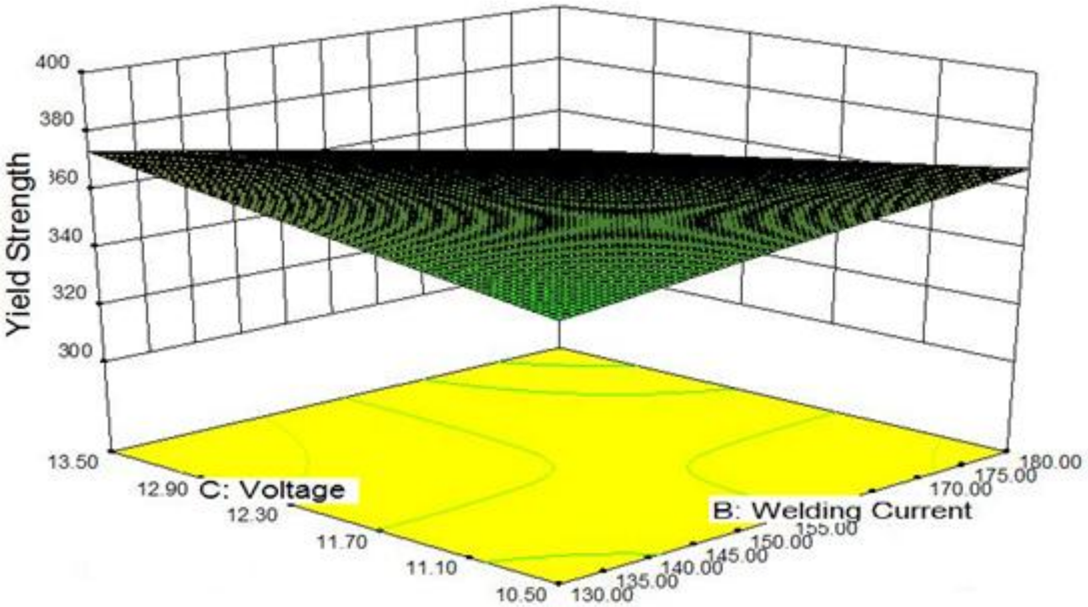

Figure 4.66: Variation of yield strength with welding current and voltage

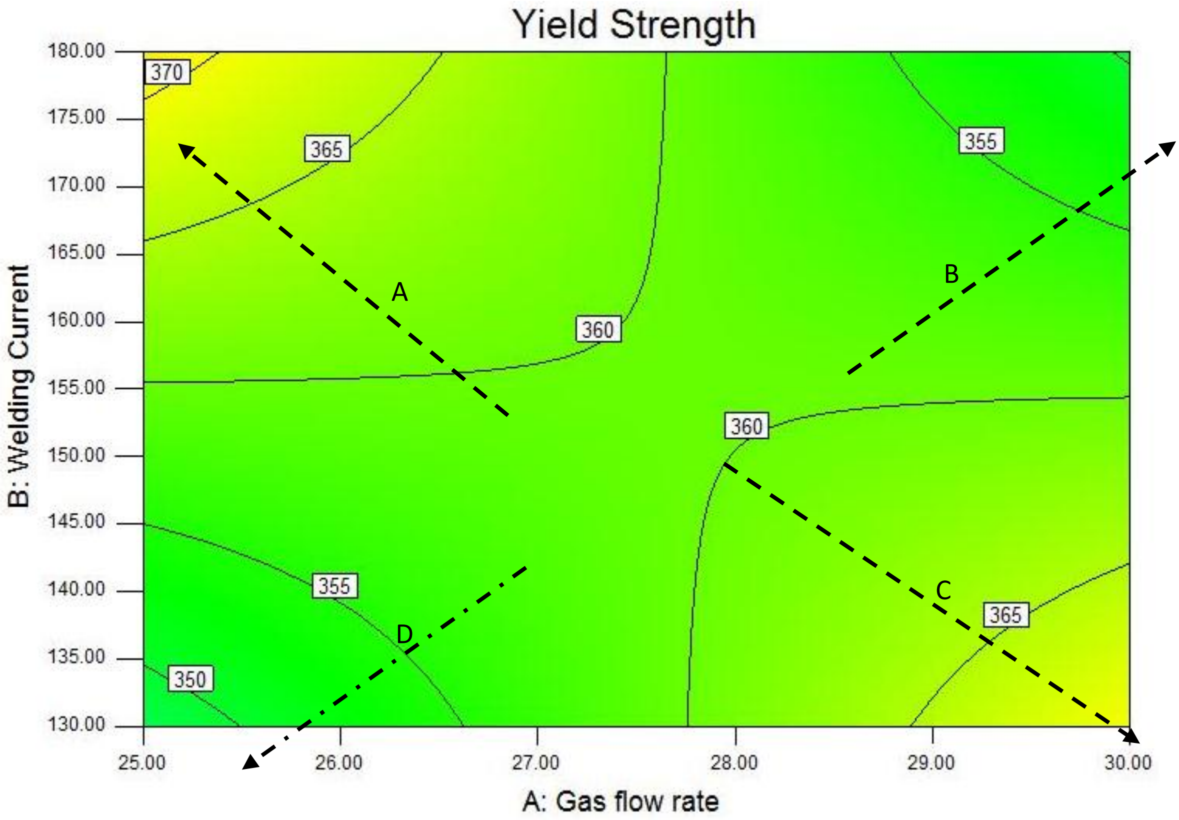

Figure 4.67: Contour plot of yield strength in terms of current and gas flow rate

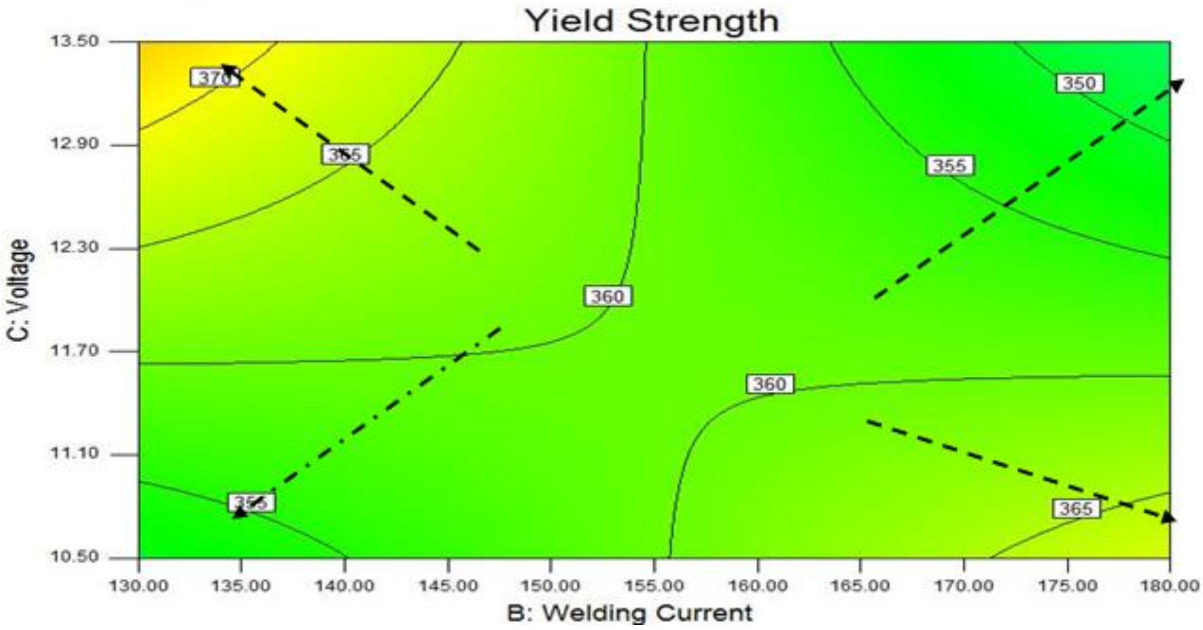

Figure 4.68: Contour plot of yield strength in terms of current and current

Contour plots show distinctive saddle shape indicative of possible dependence of factors with response. A contour plot is produced to visually display the region of optimal factor settings. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point by identifying whether the stationary point found is a maximum response or minimum response or a saddle point. To classify this, the most straightforward way is to examine through a contour plot. Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. For a saddle one can locate optimum response can either decrease or increase the response by selecting factor levels along 45° and 135°line respectively, from the centre of the region. Response surfaces have been developed for both the models, taking two parameters in the middle level and two parameters in the X and Y axis and response in Z axis. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of process parameters that produce a maximum or minimum value of the response (Shetty et al., 2006).

In the present investigation the process parameters corresponding to the maximum tensile strength are considered as optimum. Figures 4.2 and 4.3 presents three dimensional response surface plots for the response tensile strength obtained from the regression model. The optimum tensile strength is exhibited by the apex of the response surface. The saddle line variation of the surface plot indicates a marked influence of the chosen interactions (BC and AB) on the tensile strength of the TIG weld. Figures 4.6 and 4.7 presents three dimensional response surface plots for the response tensile strength obtained from the regression model. The optimum tensile strength is exhibited by the apex of the response surface. The linear variation of the surface plot indicates a marked influence of the chosen interactions (BC and AB) on the yield strength of the TIG weld.

Figure 4.4 shows a saddle shaped contour plot for tensile strength considering two factor interaction of current and voltage. Dotted lines are drawn at 45° and 135° to the horizontal to show regions of maximum tensile strength. At lower voltage tensile strength will be maximum as we go down the “C” arrow. At higher voltage line “A” describes the maximum tensile strength. Figure 4.5 shows a saddle shaped contour plot for tensile strength considering two factor interaction of current and gas flow rate. Dotted lines are drawn at 45° and 135°to the horizontal to show regions of maximum tensile strength. At lower gas flow rate tensile strength will be maximum as we go down the “C” arrow. At higher voltage line “A” describes the maximum tensile strength.

Figure 4.8 shows a saddle shaped contour plot for yield strength considering two factor interaction of current and voltage. Dotted lines are drawn at 45° and 135°to the horizontal to show regions of maximum tensile strength. At lower voltage yield strength will be maximum as we go down the “C” arrow. At higher voltage line “A” describes the maximum yield strength. Figure 4.9 shows the a saddle shaped contour plot for yield strength considering two factor interaction of current and gas flow rate. Dotted lines are drawn at 45° and 135°to the horizontal to show regions of maximum yield strength. At lower gas flow rate, yield strength will be maximum as we go down the “C” arrow. At higher voltage line “A” describes the maximum tensile strength.

V. CONCLUSION

The results of optimization of tensile and yield strength using the response surface methodology shows that maximizing tensile and yield strength with all input parameters within the range of test, tensile strength of up to 542MPa can be achieved and yield strength of up to 457 MPa can be achieved at certain combination of parameters. Moreover, miximising current and voltage to a bearest minimum tensile and yield strength of 535MPa and 409MPa can be achieved at certain combination of parameters.

The findings of Lakshimna rayanam and bala Subramanian (2009) confirms the appropriateness of these predicted values. The predicted values are also in the range the literature discussed earlier.

A response surface exist where tensile strength values within the range of 535.85 to 377.66 MPa and yield strength values between 409.05 to 346.26 MPa can be achieved at minimized current and voltage. Artificial neural network model capable of predicting tensile and yield strength to a mean square error of 34.2 has been formulated. A model based on the adaptive-Neuro inference system capable of predicting tensile and yield strength values to an absolute error of 3.89% has also been formulated. Finally a response surface where desired tensile and yield strength at desired process parameters can be deduced at reduced welding cost has also been formulated.

REFERENCES

[1] Box, G. E. P. and Wilson, K.B. (1951) *On the Experimental Attainment of Optimum Conditions (with discussion)*. Journal of the Royal Statistical Society Series B13(1):1–45.

[2] Elangovan, S. Venkateshwaran, S., Prakasan, K.,2012, *experimental investigations on optimization of ultrasonic welding parameters for copper to brass joints using response surface method and genetic algorithm* International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974 IJAERS/Vol. I/ Issue III/April-June, 2012/55-64

[3] Gunaraj, V., Murugan, N., (1999) *Application of response surface methodology for predicting weld bead quality in submerged arc welding of pipes*. Journal: Journal of Materials Processing

Technology - J MATER PROCESS TECHNOL , vol. 88, no. 1, pp. 266-275.

[4] Jayachandran Murugan, (2011), *Investigations on the Influence of Surfacing Process Parameters Over Bead Properties During Stainless Steel Cladding*, European Journal of Pain Supplements , vol. 5, no. 1, pp. 76-77.

[5] Krishankant, Mohit B., Rajesh K., Jatin T., (2012) *Application of response surface modeling for determination of flux consumption in submerged arc welding by the effect of various welding parameters*. Journal of Mechanical and Production Engineering, ISSN 2278-3512 Vol.2, Issue 2. Pp 118-126

[6] Kundan K, Somnath C, Avadhesh Y, 2012, *Surface response methodology for predicting the output responses of tig welding process.*, Asian Journal of Engineering Research ISSN--2319–2100, Asian J Eng Res/Vol. I/Issue I/

[7] Lakshminarayanan, A.K, Balasubramanian V, (2008), *Comparison of RSM with ANN in predicting tensile strength of friction stir welded AA7039 aluminium alloy joints Centre for materials Joining & Research (CEMAJOR),* Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar-608 002, Tamil Nadu, India

[8] Palani.P.K, Saju.M, 2013, *Modelling And Optimization Of Process Parameters For Tig Welding Of Aluminium-65032 Using Response Surface Methodology* International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 2. pp.230-236 230

[9] Sudhakaran, R,Vel-Muruganb, V, and Sivasakthivelc, P. S. 2012, *Effect of Process Parameters on Depth of Penetration in Gas Tungsten Arc Welded (GTAW) 202 Grade Stainless Steel Plates Using Response Surface Methodology. TJER 2012, Vol. 9, No. 1, 64-79*

[10] Sudhakaran, R., Vel Murugan, V, Sivasakthivel, P. S, 2012. *optimization of process parameters to minimize angular distortion in gas tungsten arc welded stainless steel 202 grade plates using particle swarm optimization,* Journal of Engineering Science and Technology Vol. 7, No. 2 (2012) 195 – 208.