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Modelling and Optimization of Corrosion Rate in Mild Steel Weld Joints Using Response Surface Methodology

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ABSTRACT

Corrosion is a natural phenomenon that occurs in metal or material. The various form of corrosion includes Uniform, galvanic, crevice, pitting and intergranular corrosion. The effects of corrosion affect the quality of the welded joints, welded structure and it service life of the welded structures. The aim of this study is to develop a model that can reduce the effects of corrosion on mild steel weld joints using response surface methodology. Design of Experiment was conducted with current, voltage and gas flow rate as the input parameters and corrosion rate as the response. Twenty (20) experimental runs was generated by the design expert software adopting the central composite design (CCD). Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick using power hacksaw, before carrying out the welding. The response was measured after the experiment which is the rate of corrosion and the Experimental results was analyzed using response surface methodology to model and optimized this response. Results showed that the current has a very strong influence on the rate of corrosion. From our findings, it was observed that corrosion rate of 2.95048mpy was minimum at a voltage of 18V, current of 120A and gas flow rate of 13lit/min.

1. Introduction

Mild steel is one of the most widely used material in engineering but with low resistance to corrosion. It area of application are in pipelines, mining, marine, construction and metal-processing equipment, nuclear power and fossil fuel power plants, chemical processing, petroleum production and refining etc. Low carbon steel is widely used material in designing Engineering Structure because it is cheap and readily available, inexpensive and has good mechanical properties such as good ductility and weld ability, high tensile strength, high impact strength but with a high rate of corrosion and wear rate. Some researchers have done work to investigate the effect of welding process parameters on the corrosion rate of metals notable of them are: Rajakumar and Muralidhara [1] reported that all welding parameters have a significant effect on the corrosion rate of AA6061-T6 aluminium alloy. They observed that the corrosion rate was at its maximum at lower and higher levels tool rotational speed, and minimum at a welding speed of 80 mm/min.

Prachya and Anucha [2] studied the effect of shielding gas parameter on mechanical properties and microstructures of heat-affected zone and fusion zone on gas tungsten arc welding (GTAW) in aluminium alloy AA 5083. Using argon and helium as shielding gas and gas flow rate as the process parameter. The result showed that types of shielding gas and gas flow rate interaction hardness at heat affected zone and fusion zone with a P-value less than 0.05. Argon with a flow rate of 14 liters per minute was the most effective to the hardness at heat affected zone and fusion zone of 74.27HV and 68.97HV respectively. Experimental results showed that the argon condition provided smaller grain size, suitable size resulting in higher hardness both in weld metal and HAZ Ramachandran [3] studied the various effect of the TIG welding on the Austenitic stainless steel 316L on micro structural changes through destructive and nondestructive method and various parameters such as tensile strength, hardness on varying the current, voltage and gas flow ratio respectively. Prawoto [4] evaluated the corrosion rates and pitting morphology of the selected duplex stainless steel and found that decreasing pH increases the corrosion rate.

Oliver [5] investigated the relative exterior corrosion resistance of three alloys- two ferritic stainless steel (AISI Types 409 and 441) and an aluminized mild steel; concluded that the De-icing salts have a clearly detrimental effect on corrosion resistance and stated that primary external corrosion mechanism causing failure at the cold end of the exhaust system in the presence of de-icing salts is pitting. The result showed that chromium 441 alloy has a higher resistant than 409.

Corrosion is the deterioration of metals by chemical interaction and it environment. The most widely used metal is ferrous such as iron and steel. Corrosion is the destructive result of electrochemical reaction between a metal or alloy and its surrounding environment. The metals are generally in high energy state because some energy is added during production process from the ores. Low energy-state ores are more stable than the high energy-state metals. For this reason, the metals tend to release the energy and go back to their original form. Hence, the metals revert to their parent state or ore under a suitable corrosive environment.

Vargas-Arista et al [6] investigated the corrosion behavior of welded joints in API5L-X52 pipe steel aged at 250°C at different times under electrochemical technique like Tafel polarization, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies. Their results showed that there was an increase of the general corrosion rate in the weld bead, the heat affected zone and the base metal as the aging time of the welded joint elapsed.

Sabry and El-Kassas [7] carried out statistical analysis of corrosion rate and Mechanical Properties of Metal Inert gas welding using response surface methodology. They considered current, voltage and speed as the process parameters. Sitrorus[8] Investigated the effect of welding heat input on the corrosion rate of carbon steel manual metal arch Welding. He considered weight loss, duration and current as the process parameters. Jannifar et al [9] determined the effect of welding current on corrosion rate and hardness on welded joint, heat affected zone and base metal of steel grade st37.They considered current as the process parameter. This work aim at reducing corrosion rate in mild steel weldment using response surface methodology.

2.0 Materials and Method

2.1 Materials

Materials used in this work is mild steel pipe. Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick before carrying out welding. Two pieces of the mild steel pipes were welded using Tungsten Inert Gas welding machine. The process parameters considered in the Experiment are current, voltage and gas flow rate. The process parameters and their levels are shown in Table 1:

Table 1. Process Parameters and their Levels

Parameters	Units	Symbol	Coded value	Coded value
			Low (-1)	High(+1)
Current	Ampere	A	120	170
Voltage	Volt	V	18	24
Gas Flow Rate	Lit/min	F	13	16

2.2 Method of Data Collection

The central composite design matrix was developed using the design expert software producing twenty (20) experimental runs. Twenty experimental runs of eight (8) factorial points, six (6) center points and six (6) axial points were carried out to dig out minimum rate of corrosion on tungsten inert gas weld joints of mild steel pipe. Each runs consists of the welding process parameters such as current, voltage and gas flow rate.

The following information were needed in computing the corrosion rate:

- Weight loss with respect to time period.
- Density of the metal
- Total initial surface area of the metal piece.
- Time
- ➢ Conversion of corrosion rate
- 1mpy = 0.0254 mm/y = 25.4 microm/y
  1mpy – 1 mil per year
- ➢ Calculate the corrosion rate from metal loss:

$$\frac{mm}{y} = 87.6X(\frac{W}{DAT})$$

M/y = 0.0254mm/y

2.3 Method of Data Analysis

Response surface methodology was used to analyze the Experimental results obtained. The analysis was carried out based on response surface regression system that use the second-order polynomial equation. The level of significance of the coefficients was less than 0.05. Statistical software package design expert version 8.06 was used to determine the regression coefficient which help to optimize and predict the response (corrosion rate) and the process parameters as well as their interaction that provide a better understanding of the behavior of the system.

3. Results and Discussion

Results obtained are presented in Table 2. The Analysis involving the interaction of the process parameters and their combined effect on response was carried out. Data obtained and regression analysis are presented. The optimal values of the process parameters were gotten by solving the regression equation. The response surface plots and contour plot were analyzed. The Design matrix for the real and the experimental values are presented in Table 2

Table 2. Experimented Results

Std	Block	Run	Space type	Factor 1 A: current I	Factor 2 B: Voltage v	Factor 3 C: Gas flow rate Lit/min	Response corrosion rate mpy
17	Block 1	1	center	145	21	14.5	3.24829
2	Block 1	2	Center	145	21	14.5	3.24829
1	Block 1	3	Center	145	21	14.5	3.24966
14	Block 1	4	Center	145	21	14.5	3.24829
20	Block 1	5	Center	145	21	14.5	3.24966
16	Block 1	6	center	145	21	14.5	3.24829
11	Block 1	7	Axial	145	15.95	14.5	3.07885
3	Block 1	8	Axial	145	26.05	14.5	4.5337

7	Block 1	9	Axial	102.96	21	14.5	3.06139
8	Block 1	10	Axial	187.04	21	14.5	3.57162
5	Block 1	11	Axial	145	21	11.96	3.82674
12	Block 1	12	Axial	145	21	17.02	4.33697
18	Block 1	13	Factorial	120	18	13	2.95048
9	Block 1	14	Factorial	120	24	13	4.17462
6	Block 1	15	Factorial	170	18	13	2.92224
13	Block 1	16	Factorial	170	24	13	4.7558
15	Block 1	17	Factorial	120	18	16	3.3397
19	Block 1	18	Factorial	120	24	16	3.3397
10	Block 1	19	Factorial	170	18	16	3.54843
4	Block 1	20	Factorial	170	24	16	4.80218

The model summary showing current, voltage, gas flow rate, corrosion rate and standard deviation and their values are shown in Table 3

Table 3. Model summary showing highest and lowest values of factors

Name	**Units**	**Type**	**Changes**	**Std. Dev.**	**Low**	**High**
Current	I	Factor	Easy	0	120	170
Voltage	V	Factor	Easy	0	18	24
Gas flow rate	Lit/min	Factor	Easy	0	13	16
Corrosion rate	mpy	response		0.141258	2.92224	4.80218

Result of Table 3 showed that the model is quadratic type with a second order polynomial as depicted by a typical response surface design. The minimum value of corrosion rate was observed to be 2.92224mpy while the maximum value was 4.80218mpy and a standard deviation of 0.141258. Analysis of variance was carried out to check for significance of model developed is presented in Table 4

Table 4. Analysis of variance(ANOVA) Result for the process parameters

Source	**Sum of squares**	**Df**	**Mean square**	**F-value**	**P-value**	
Model	6.70	9	0.7441	37.29	< 0.0001	Significant
A-Current	0.6957	1	0.6957	34.86	0.0002	
B-Voltage	3.34	1	3.34	167.59	< 0.0001	
C-Gas flow rate	0.0898	1	0.0898	4.50	0.0599	
AB	0.4339	1	0.4339	21.75	0.0009	
AC	0.1563	1	0.1563	7.83	0.0188	
BC	0.4068	1	0.4068	20.39	0.0011	
A^2	0.0041	1	0.0041	0.2055	0.6600	
B^2	0.5200	1	0.5200	26.06	0.0005	
C^2	1.19	1	1.19	59.48	< 0.0001	
Residual	0.1995	10	0.0200			
Lack of fit	0.1995	5	0.0399	79733.41	< 0.0001	Significant
Pure Error	2.50E-06	5	5.005E-07			
Cor Total	6.90	19				

The Model F-value of 37.29 and a P- vaue of 0.0001shows the model is significant. In this case A, B, AB, AC, BC, B^2, C^2 are significant model terms. A Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms model reduction becomes necessary in improving the model developed. The Lack of Fit F-value of 79733.41 implies the Lack of Fit is significant.

Table 5. Fit statistics

Std. Dev.	0.1413	**R^2**	0.9711
Mean	3.59	**Adjusted R^2**	0.9450
CV. %	3.94	**Predicted R^2**	0.7686

Adeq Precision	19.0828

The Predicted R^2 of 0.7686 is in reasonable agreement with the Adjusted R^2 of 0.9450, with a difference of 0.1764 less than 0.2 which implies that the model is adequate. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 19.083 obtained indicates an adequate signal. The coefficient of determination R^2 for the TIG weld joints was obtained to be 0.9711. The result point to the model been effective in describing 97.11% of variation in the original data. The value of 0.9450 was gotten for the adjusted R^2, Predicted R^2 value obtained through cross-validation shows that the model is capable of explaining about 97.11% variation in predicting novel observation. Figure 1 (a-c) shows the contour plots of the empirical model developed for the input variables. In order to understand the relationship between this variables, the response surface curve was plotted. This plots helps to evaluate the optimum level of the input parameters for maximum response. And the optimal equations which represent the model developed are presented in Equation (1) and (2)

Optimal equation in terms of coded and actual factor

The optimal equations which represent the combined effect and combined interactions of the process parameters and measured response are shown in equation (1) and (2) respectively

$$\mathbf{Y = 3.5 + 0.2257A + 0.04946B + 0.0810C + 0.2329AB + 0.1398AC - 0.2255BC + 0.0169A^2 + 0.1897B^2 + 0.2857C^2} \quad (1)$$

$$\mathbf{Y = 36.28818 - 0.118063A - 0.44048B - 3.11632C + 0.003105AC - 0.050110BC + 0.000027A^2 + 0.021077B^2 + 0.126970C^2} \quad \mathbf{(2)}$$

Where, A, B, C and D represents current, Voltage, Gas Flow Rate and Corrosion Rate respectively

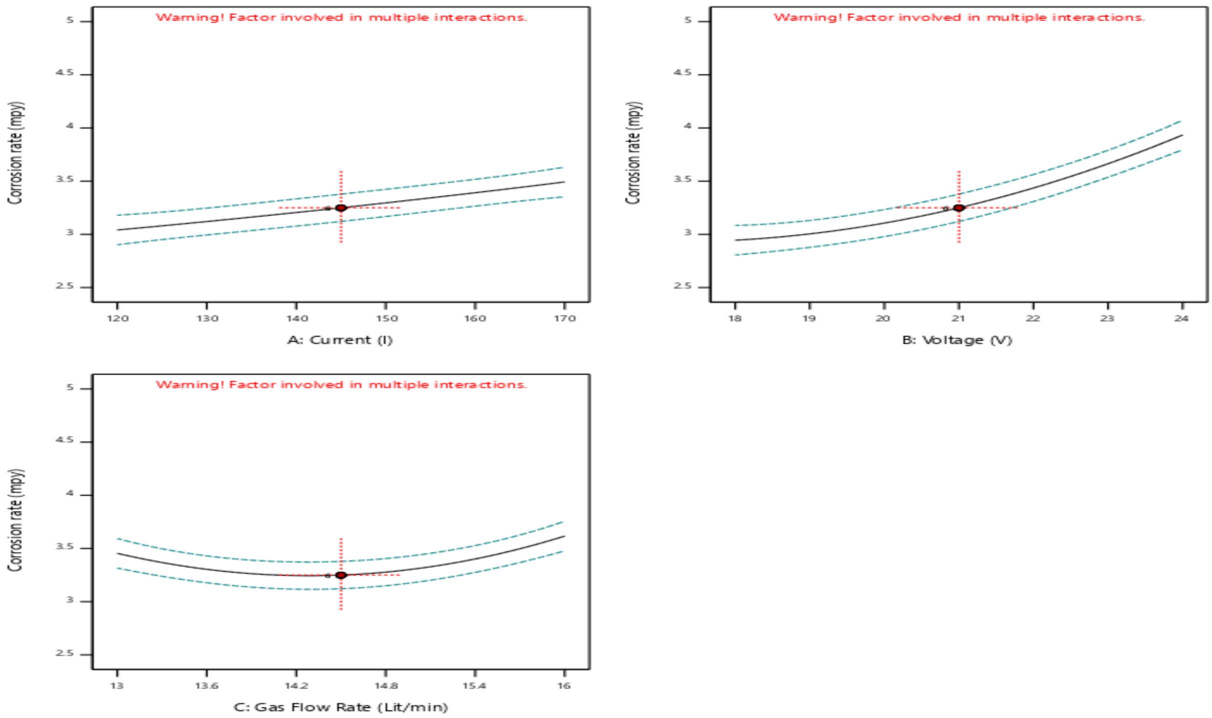

Figure 1(a-c). contour plot

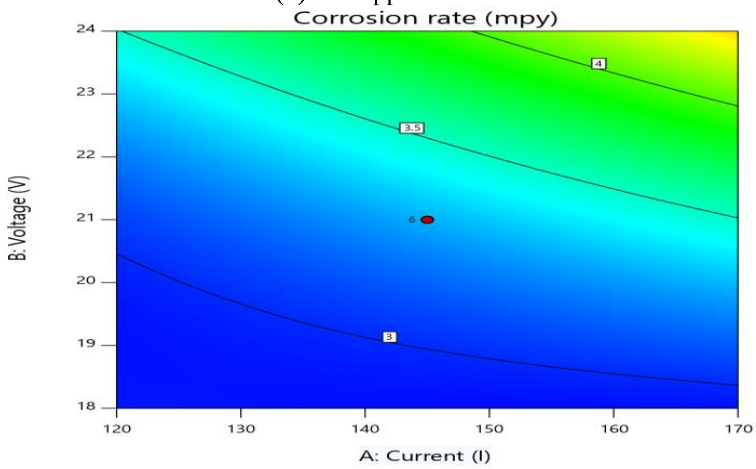

Figure 2. Contour Plot

Figure 2 is a contour plot. The contour plot is a 2 Dimensional plot showing the relationship between princess parameters (current, voltage and gas flow rate) and the response variable (Corrosion rate). The response plotted against combinations of factors or the independent variable components. It shows the relationship that exist between the dependent variable component and the independent variable. In this case you see a plot of corrosion rate as a function of current and voltage at a mid-level slice is gas flow rate. This slice includes six center points as indicated by the dot at the middle of the contour plot. By replicating center points, it gives a very good power of prediction at the middle of your experimental region.

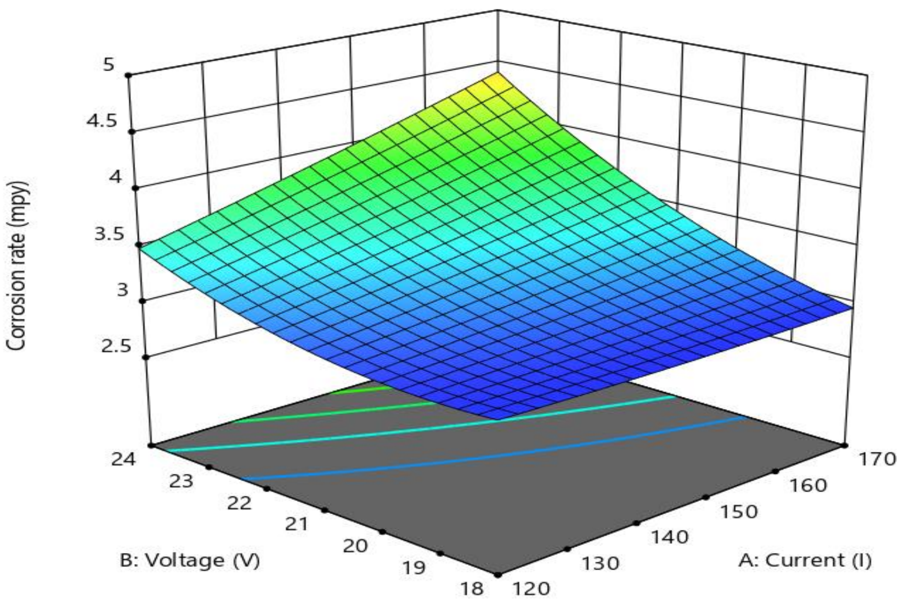

Figure 3. Surface plot

Figure 3 is a 3D surface plot which shows the relationship between the input variables (current, voltage and gas flow rate) and the response variables (corrosion rate). The 3-dimensional surface plot shows the combined effect of process parameters on response. Although not as useful as the contour plot for predicting responses and coordinates, but it provides a clearer view of the surface. The presence of a coloured hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface.

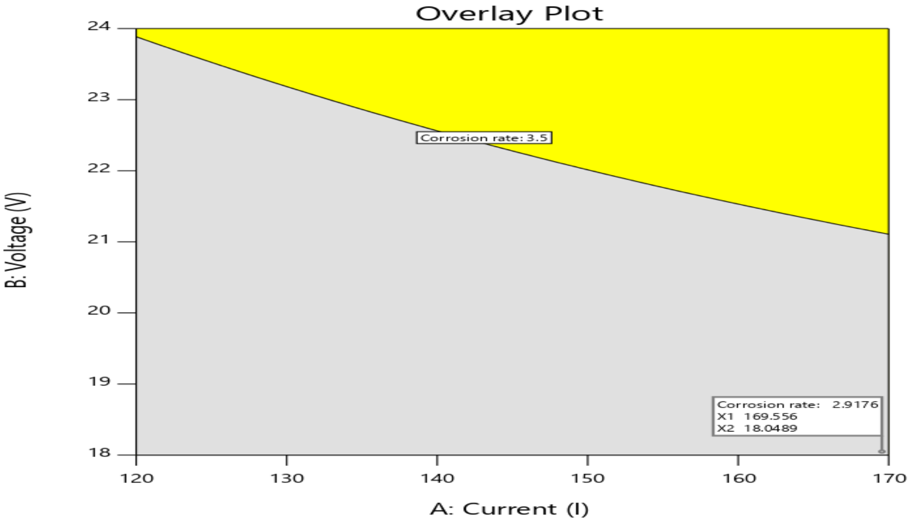

Figure 4. overlay plot

Figure 4 shows an overlay plot generated from the model. The coloured area represents the region of rate of corrosion above 3.5mpy. Hence, the optimal rate of corrosion falls within the unshaded region. As part of validation, this work was in agreement with the work of Sabry and El-Kassas [7]. When compared with Sabry and El-Kassas work, they obtained minimum corrosion rate of 2.9000mpy whereas the present study obtained a minimum corrosion rate of 2.95048mpy at a current of 120A, voltage of 18V and gas flow rate of 13lit/min.

4. Conclusion

In this work, an effort was made in investigating the effects of combined welding input parameters such as gas flow rate, voltage and current on response (corrosion rate). Response surface methodology was adopted to optimize and predict the rate of corrosion. The butt joint specimens were performed based on varying the welding input parameters. The result obtained in this study shows that the welding current has a strong influence on the rate of corrosion. From the investigation, it is summarized that the corrosion rate is minimum at 2.95048mpy with a welding voltage of V = 18V, current = 120A and gas flow rate = 13lit/min

Nomenclature

A, B,C	Regression parameters
W	Weight loss in mg
D	Metal density in g/cm^3
A	Area of sample in cm^2
T	Time of exposure of the metal sample in hours
I	Current in Ampere
V	Voltage in Volt
F	Gas flow rate in Lit/min
Y	Dependent variable (Regression)
R	Co-efficient of correlation
R^2	Co-efficient of determination
SNR	Signal to noise ratio
TIG	Tungsten Inert Gas

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