Modelling the Environmental Effects of Corrosion in a Tungsten Inert Gas Weld Joints Using Response Surface Methodology

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ABSTRACT

Corrosion of metal is an ubiquitous phenomenon that occurs in various forms. Atmospheric or uniform, galvanic, crevice, pitting, and microbial corrosion are most familiar forms of corrosion. The service life of engineering structures is affected by the quality and strength of the welded joints. The effects of corrosion affect the quality of the welded joints and the general structure. The offshore structures are exposed to the various environments, and it is well known that the corrosion rate and the corrosion mechanism under each environment affect the general structure. The aim of this study is to model the environmental effects of corrosion on tungsten inert gas weld joints of a mild steel pipe using response surface methodology.Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick with a power hacksaw, grinded and cleaned before the welding process. The experimental matrix was made of twenty (20) runs, generated by the design expert 11.1.0.1 software adopting the central composite design. The response was measured, which is the rate of corrosion and then modelled using the response surface methodology.The result obtained in this study shows that the current has a very strong influence on the rate of corrosion. The minimum value of the rate of corrosion was observed to be 2.922mpy with a maximum value of 4.802mpy and standard deviation of 0.141.Based on the findings, it is summarized that the corrosion rate is minimum when a welding voltage of V = 18V, current = 120A and gas flow rate = 13lit/min.

Keywords: *Mild steel pipe; Response Surface Methodology; Rate of corrosion; Contour plot; Surface plot.*

I. INTRODUCTION

Carbon steel is the most widely used engineering material despite its relatively limited corrosion resistance. It is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction and metal-processing equipment. Carbon steel has been the popular choice of structural material as it is abundantly available, inexpensive and has adequate mechanical properties, but it has a high general corrosion rate.

Several studies have been done to investigate the effect of welding parameters on the corrosion behaviour of various metals. Rajakumaret al.[1] reported that all welding parameters have a significant effect on the corrosion rate of AA6061-T6 aluminum alloy. He mentioned that the corrosion rate was at its maximum when the tool rotational speed was at lower and higher levels, whereas the corrosion rate was found to be the minimum when the welding speed was at 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. Factorial experiment was designed for this research. 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 < .05. The factor which was the most effective to the hardness at heat affected zone and fusion zone was argon with a flow rate of 14 liters per minute at heat-affected zone with 74.27HV and fusion zone with 68.97HV. Experimental results showed that the argon condition provided smaller grain size, suitable size resulting in higher hardness both in weld metal and HAZ. They also indicated that the grain size and precipitation Mg affect the hardness of sample.Ramchandran[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. Similarly, increasing temperature increases corrosion rates this can be achieved well using different solutions with different temperature and periods of immersion. 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-icingsalts 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 higher chromium type 441 alloy was far more resistant than type 409.

Corrosion is the deterioration of materials by chemical interaction with their environment. The term corrosion is sometimes also applied to the degradation of plastics, concrete and wood, but generally refers to metals. The most widely used metal is iron (usually as steel) and the following discussion is mainly related to its corrosion. 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 their manufacturing 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. This conversion phenomenon is nothing but the corrosion. The electrochemical process involved in corrosion is by nature opposite to the extractive metallurgy involved in manufacturing of the metals. Therefore, corrosion is sometimes considered as the reverse process of extractive metallurgy.Rajakumaret al. [1] reported that all welding parameters have a significant effect on the corrosion rate of AA6061-T6 aluminium alloy. He mentioned that the corrosion rate was at its maximum when the tool rotational speed was at lower and higher levels, whereas the corrosion rate was found to be the minimum when the welding speed was at 80 mm/min.Sanga et al. [6] investigated the effects of welding energy on the mechanical, thermal and microstructural characteristics of the weld joint. The ultrasonic welding was performed on 0.36 mm thick phosphor bronze (UNS C51100) sheets. It was observed that the values of peak interface temperature and tensile-shear strength increase with the welding energy. The microstructural analysis carried out using scanning electron microscope (SEM) revealed that the joining line appears almost straight at low energy level but fades away at higher energy level. Other similar works includes that of [7-10].This study is therefore aimed at modeling the environmental effects of corrosion in a tungsten inert gas weld joints using Response Surface Methodology.

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II. MATERIALS AND METHOD

A. Materials

The material used in this study is mild steel pipe. Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick with a power hacksaw, grinded and cleaned before the welding process. Two pieces of the mild steel pipes were welded together using the input process parameters contained in Tungsten Inert Gas welding machine. The input process parameters are current, voltage and gas flow rate.

B. Methods

Twenty (20) experimental runs comprises of eight (8) factorial points, six (6) center points and six (6) axial (star) points were carried out to dig out minimum rate of corrosion on tungsten inert gas weld joints of a mild steel pipe . Each experimental run comprises of the welding input parameters which are the welding current, voltage and gas flow rate.The rate of corrosion is the speed at which any given metal deteriorates in a specific environment. The rate or speed is dependent upon environmental conditions as well as the type and condition of the metal.In order to calculate the rate of corrosion, the following information were collected:

- Weight loss (the decrease of metal weight during the reference time period).
- Density (the density of the metal).
- Area (total initial surface area of the metal piece).
- Time (the length of the reference time period).
- Converting corrosion rate
- 1mpy = 0.0254 mm/y = 25.4 microm/y
    - 1mpy – 1 mils per year
- Calculate the corrosion rate from metal loss:

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

W = weight loss in milligrams
D = metal density in g/cm3
A = area of sample in cm^2
T = time of exposure of the metal sample in hours.

- m/y = 0.0254mm/y

1) *Experimental Design and Data Analysis*

A Three-factor layout of Central Composite Design (CCD) in surface response methodology (RSM) was employed with replicates at the Centre point and star points. Input parameters such as welding current, voltage and gas flow rate are the variables used in this study with each at low (-1) and high (+1) coded levels.Table 1 show the CCD experimental conditions for the process parameters.

Table 1: The CCD Experimental Conditions for process parameters and their range

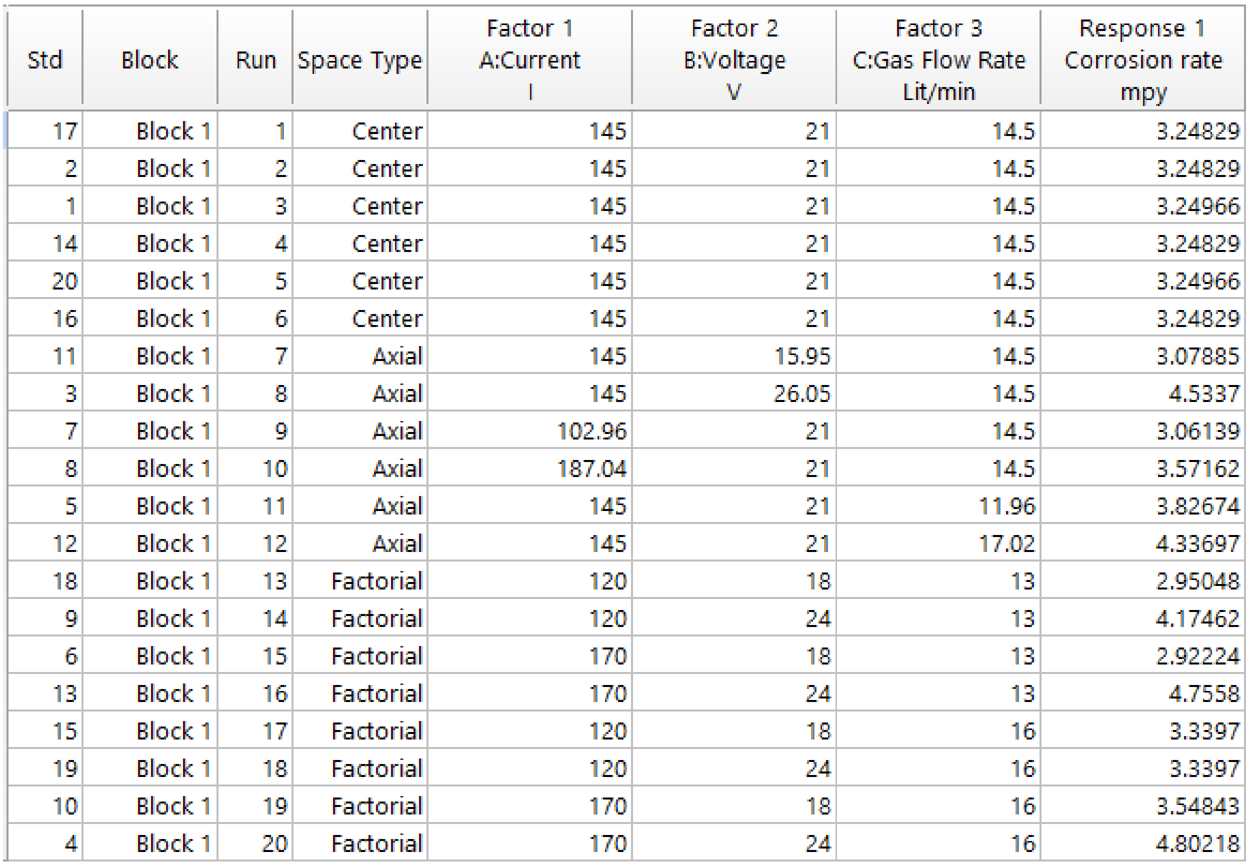
Factor	Units	Low Level (-1)	High Level (+1)
A – Current	Ampere	120	170
B – Voltage	Voltage	18	24
Gas Flow Rate	Lit/min	13	16

The above experimental analysis was carried out based on the response surface regression system to accommodate the second-order polynomial equation. The level of significance of the coefficients was less than 0.05. Statistical software package design-expert® (version 8.0.6; stat-ease, Inc., Minneapolis, USA) was used to determine the regression coefficient which help to predict the process response (rate of corrosion) as a function of the independent variables as well as their interaction that help the understanding of the system behavior.

III.RESULTS AND DISCUSSION

The rate of corrosion was determined and the results are presented in Table 2. The in-depth analysis involving the interaction of the process parameters (welding current, voltage and gas flow rate) was carried out. The Design-Expert (Stat-Ease, Inc., Minneapolis USA) software was employed for regression analysis and graphical analysis of the data obtained. The optimum values of the process parameters were gotten by solving the regression equation. This was also reached by analyzing the response surface and the contour plots. Table 2 show the design matrix for the real and the experimented values.

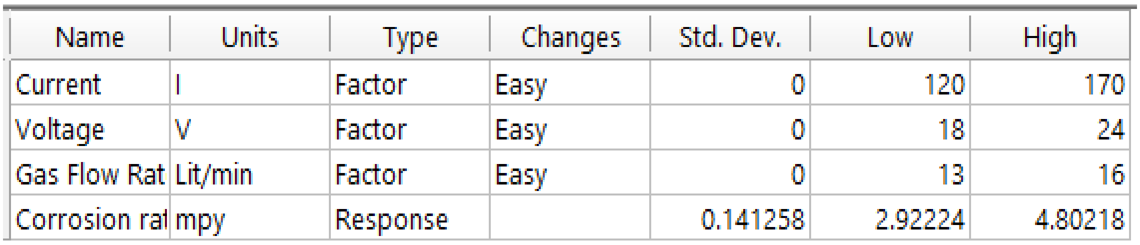
Table 2: Design matrix for Actual values and Experimental responses for CCD experimental combination of welding current, voltage and gas flow rate



Std	Block	Run	Space Type	Factor 1 A:Current I	Factor 2 B:Voltage V	Factor 3 C:Gas Flow Rate Lit/min	Response 1 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 which shows the factors and their lowest and highest values including the standard deviation is presented in Table 3:

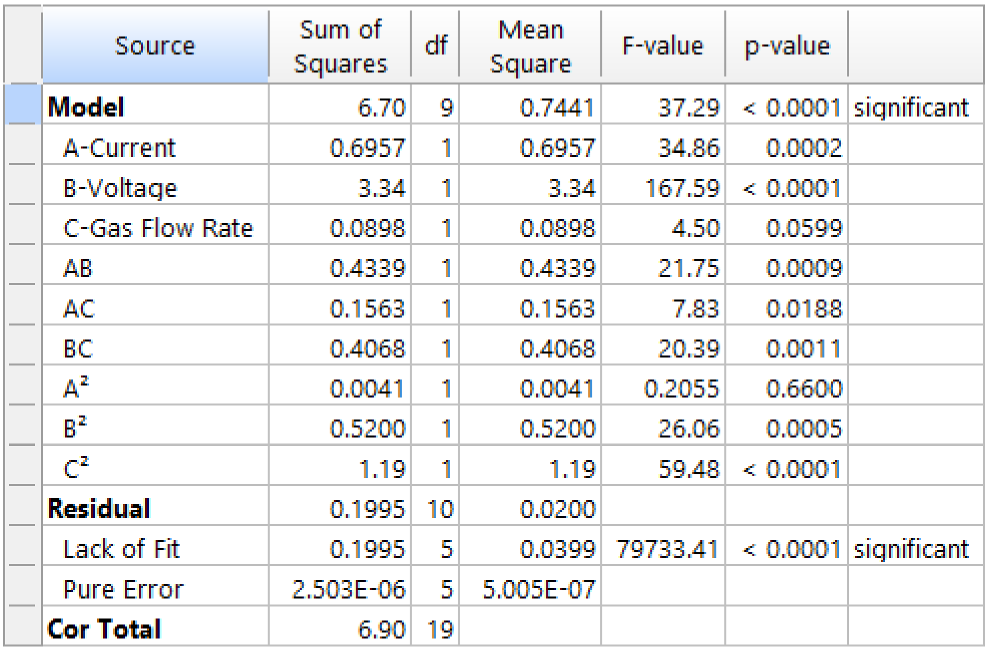
Table 3: Model summary showing highest and lowest values of factors



Name	Units	Type	Changes	Std. Dev.	Low	High
Current	I	Factor	Easy	0	120	170
Voltage	V	Factor	Easy	0	18	24
Gas Flow Rat	Lit/min	Factor	Easy	0	13	16
Corrosion rat	mpy	Response		0.141258	2.92224	4.80218

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 the rate of corrosion was observed to be 2.92224mpy with a maximum value of 4.80218mpy and standard deviation of 0.141258. Table 4 depict the analysis of variance result table for the process parameters.

Table 4: Analysis of Variance Result for the process parameters

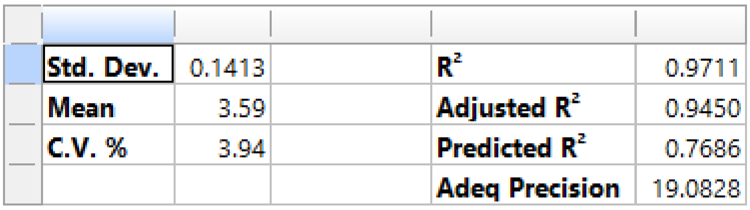


Response 1: Corrosion rate

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	2.503E-06	5	5.005E-07			
Cor Total	6.90	19				

The F-value of 37.29 obtained in Table 4 implies the model is significant which indicate that there is only a 0.01% chance that an F-value this large could occur due to noise. The P-values that is less than 0.0500 indicate model terms are significant. In this case A, B, AB, AC, BC, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The Lack of Fit F-value of 79733.41 suggests the Lack of Fit is significant. There is only a 0.01% chance that a Lack of Fit F-value this large could occur due to noise. Table 5 depict Fit statistics for the process

Table 5: Fit statistics



Std. Dev.	0.1413		**R^2**	0.9711
Mean	3.59		**Adjusted R^2**	0.9450
C.V. %	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; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 19.083 indicates an adequate signal. This model can be used to navigate the design space.The coefficient of determination R^2 for the tungsten inert gas 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 obtained for the respective adjusted R^2. The R^2_{pre} value gotten through cross-validation advocated that the model is capable of explaining about 77% variation in predicting novel observations. Fig. 1 (a-c) shows residuals based on the empirical model developed for the input variables (current, voltage and gas flow rate). To fully understand the relationship between the variables studied, the response surface curves was plotted as it also helped us to evaluate the optimum level of the input variables for maximum response.

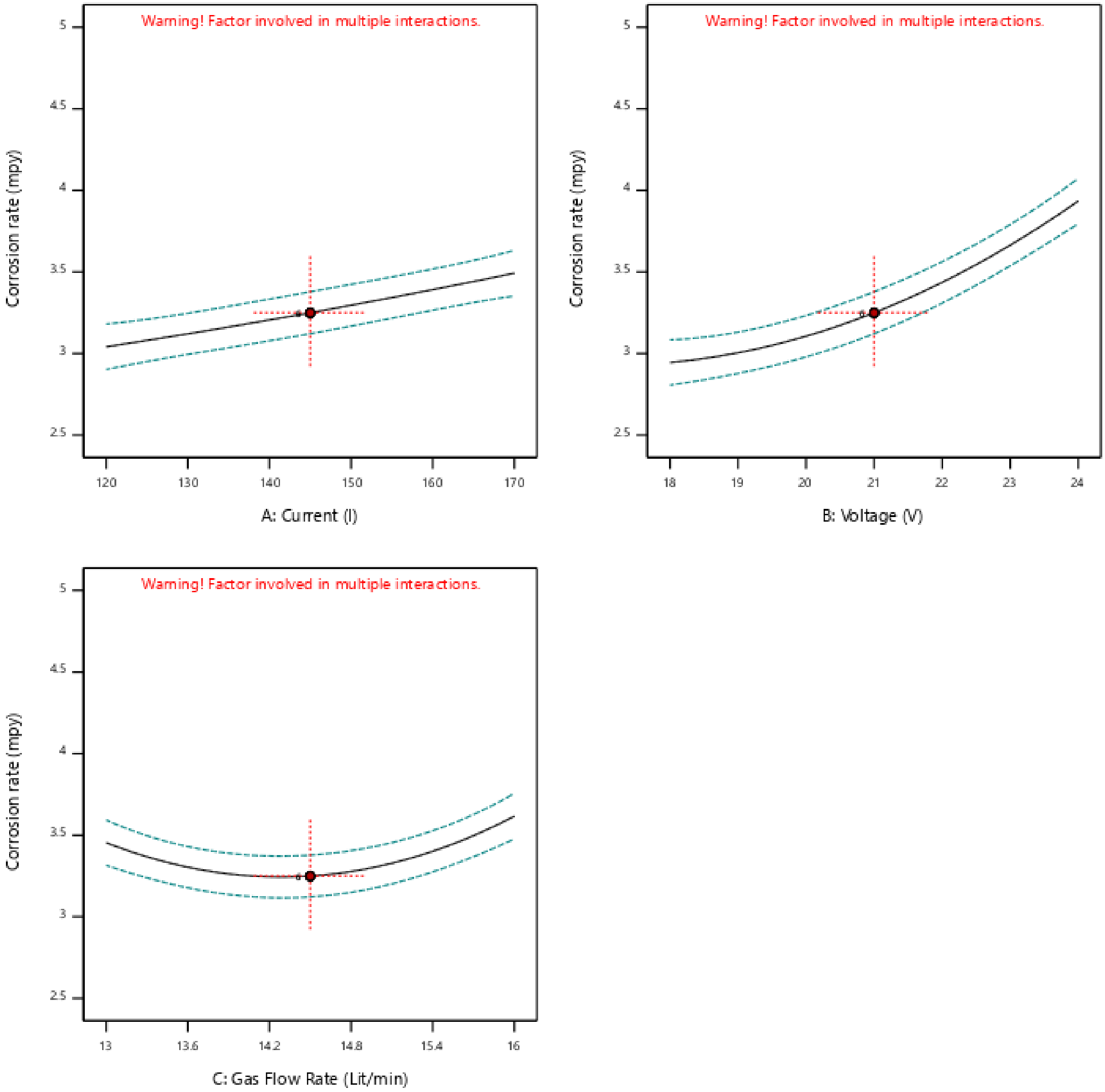


Fig. 1(a-c): ResidualPlots

Fig. 2 is a two-dimensional (2D) representation of the response plotted against combinations of numeric factors and/or mixture components. It shows the relationship between the responses, mixture components and/or numeric factors. In this case you see a plot of corrosion rate as a function of current and voltage at a mid-level slice of 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, you get a very good power of prediction at the middle of your experimental region.

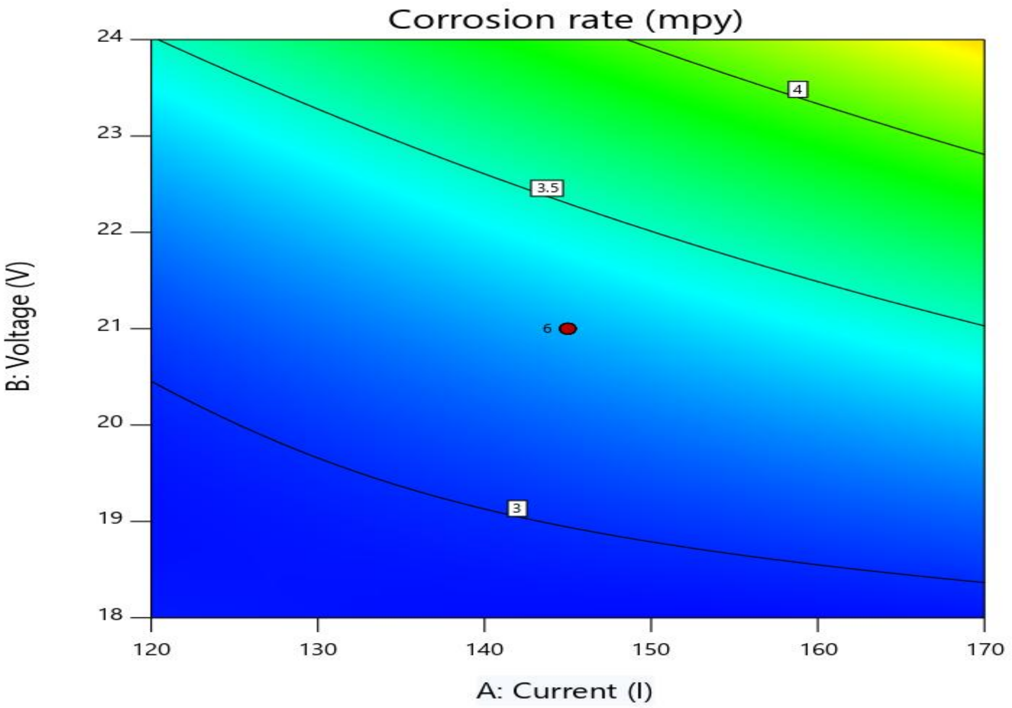


Fig. 2: Contour Plot

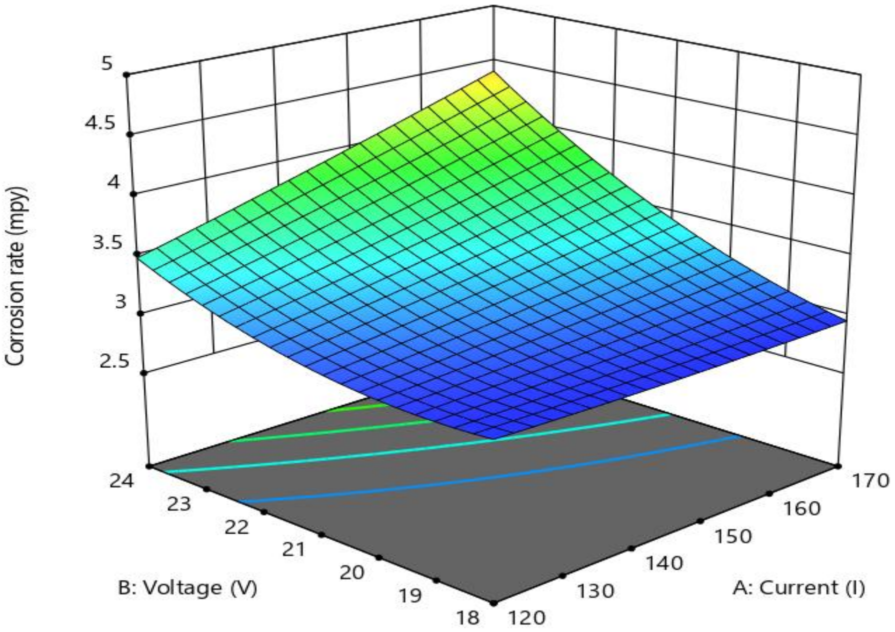


Fig. 3: Response Surface Plot

The response surface plot shown in Fig.3 is a 3D surface plot. It shows the relationship between the input variables (current, voltage and gas flow rate) and the response variables (rate of corrosion). It is a 3-dimensional surface plot which was employed to give a clearer concept of the response surface. Although not as useful as the contour plot for establishing responses values and coordinates, this view may provide 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.

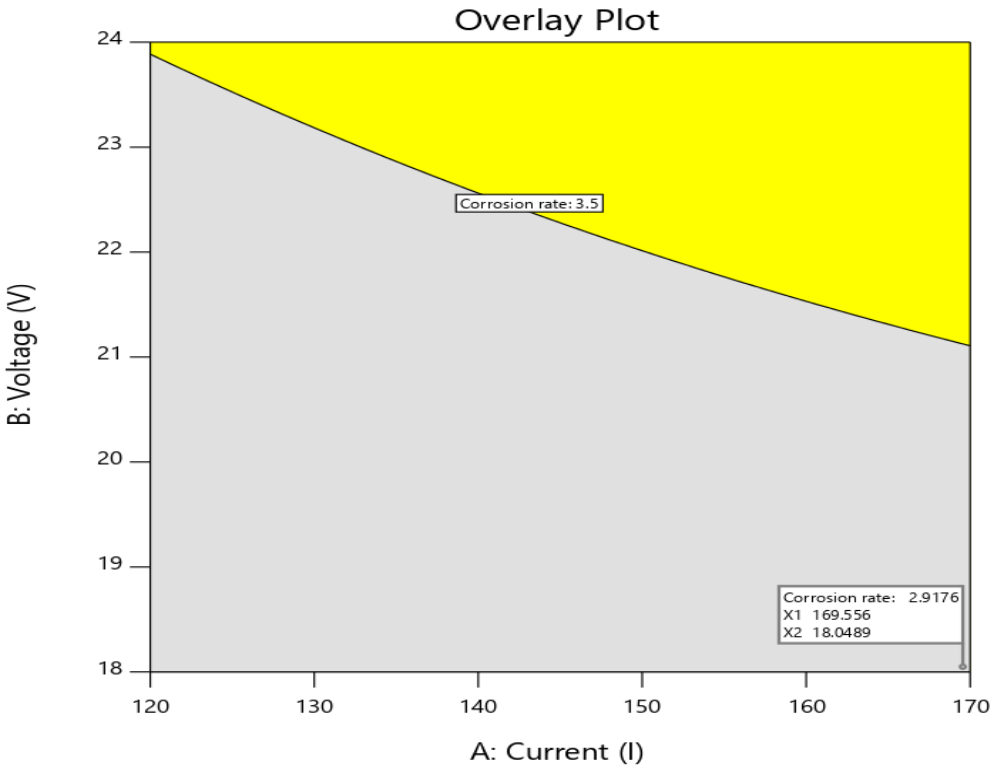


Fig. 4: Overlay Plot

Fig.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.

IV. CONCLUSION

This study has been able to determine the effects of combined welding input parameters such as gas flow rate, voltage and current using response surface methodology. In this study, the application of response surface methodology to optimize and predict the rate of corrosion of a mild steel pipe welded joint has been successfully established. The reliability of central composite design in response surface methodology was also established in determining the process parameters such as gas flow rate, voltage and current leading to optimum rate of corrosion mild steel pipe welded joint. The butt joint specimens were performed varying the welding input parameters. The result obtained shows that current has a very strong influence on the rate of corrosion. Based on the findings, it is summarized that the corrosion rate is minimum when a welding voltage $(V) = 18V$, Current = 120A and gas flow rate =13lit/m.

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