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A Central Composite Design Approach to Minimize Percentage Dilution of TIG Weldments

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Abstract: The integrity of welded joints is dependent on the strength and load bearing capacity of the welded joint, of which this can be achieved by maximizing the process parameters that has a positive effect on the strength and minimizing those having negative effects on the weld joints. This study is carried out with a purpose of minimizing the percentage dilution considering current, voltage and gas flow rate as the input parameters on TIG mild steel weld using expert systems. The welding experiment was performed using the Central Composite Design matrix, thereafter percentage dilution responses was measured, recorded and modelled using the Response Surface Methodology (RSM). The result obtained shows that the quadratic model has adequate strength to explain the relationship between the process factors and the percentage dilution, with with a P-value < 0.05 and coefficient of determination (R^2) value of 90% and a noise to signal ratio of 10.14 indicating the accuracy and reliability of the optimal solutions.

Keywords: Percentage Dilution, Central Composite Design, Tungsten Inert Gas, Welding

1. Introduction

An extensive research work on optimization of welding process was done [1]. The authors studied the optimization of different welding processes using statistical and numerical approach. The optimization methods covered in their study were appropriate for modelling, control and optimizing the different welding process. The survey reveals the high level of interest in the adaptation of RSM and ANNs to predict response(s) and optimize the welding process. Generally, there is a lack of comparative study regarding the performance of the optimization methods, in other words for a given optimization problem which method would suit better. Combining two optimization techniques, such as GA and RSM, would reveal good results for finding out the optimal welding conditions. Future work should focus on the application of these modelling and optimization techniques to find out the optimal welding combinations for a certain welding process at which the process could be considered safe, environment friendly and economical. Mathematical models have been built using the fractional factorial technique to predict the weld bead geometry and shape relations (penetration, width, and reinforcement height, width to penetration ratio and percentage dilution [2]. mathematical models have also been using response surface methodology (RSM) to study the direct and interaction effects of SAW parameters (open circuit voltage, wire feed rate, welding speed and nozzle-to-work piece distance) on the cladding geometry (depth of penetration, height of reinforcement, weld width and dilution%) [3]. The process parameters obtained from the developed models were employed to clad IS2062 structural steel plate of 20-mm thickness using 316L stainless steel wire of 3.15 mm diameter. They concluded that a low dilution of 22.57% can be produced by both high voltage and high welding speed or by low voltage and low welding speed. It was reported that the hardness of the existing martensitic structures at the intermediate mixed zones in overlays was below 400 VHN, due to low carbon content in the cladding. The use of RSM to develop mathematical models and plot contour graphs relating important input parameters have been highlighted [4]. The parameters are the open-circuit voltage, wire feed rate, welding speed and nozzle-to-plate distance and the responses includes the depth of penetration, reinforcement, bead width and percentage dilution of the weld bead in SAW of pipes. They demonstrated that all responses decrease with increasing welding speed. Also, when the nozzle-to-plate distance increases all responses decrease, but reinforcement increases. Moreover, an increase in the wire feed rate results in an increase in all responses but the width remains unchanged. studied the effect of flux cored arc welding process parameters (welding current, welding speed, nozzle-to-plate distance and welding torch angle with reference to vertical) on the duplex stainless steel clad quality in terms of penetration, width, reinforcement and percentage dilution has been studied [5]. It was demonstrated that the process parameters have a significant effect on the bead geometry of the clad. The effect of the input process parameters on the clad quality parameters have been presented in graphical form, which assist in finding the welding parameters combination that would lead to the desired clad quality quickly. The base metal chemistry of the welding metal depends on the compositions of the parent metal and filler metals, the main factors that affect the characteristics and properties of the welding metal are dilution, volatilization, chemical reactions, gases absorption and solidification structures [6]. Most joint welding applications involving structural steels or mechanical construction steels with low carbon content do not present any type of problem dependent on the dilution value, since the consumable used, being sticks, wires or electrodes, has properties similar to the base metal involved [7]. However, when the welding is dissimilar, in other words, when one of the base materials or the consumable used presents dissimilar composition relatively to the others, problems of high dilution can occur [8, 9]. There are also cases in which the welding is not considered dissimilar (as low alloy steels are used) but the dilution still a factor that needs to be considered [10, 11]. Moreover, in mechanical industry, there are numerous examples of welding, involving materials such as high-strength low-alloy (HSLA) or high strength as AISI 4140 or AISI 5160 steels (with higher amount of carbon), in which the dilution of certain base metal alloying or carbon elements on the welding metal can promote disastrous effects. A study on the evaluation of percentage of dilution in Gas Metal Arc Welding was done, he observed that the properties and characteristics of welds depends on factors such as gap between plates, types of materials, filler rod, voltage, current, wire feed rate, and the skill of the operator. He mentioned that these parameters should be greatly investigated and should be controlled. This observation and investigation on this welded joint gives the percentage of dilution of base metal fused with the electrode. The results showed that whenever the current, wire feed rate increases the percentage of dilution also increases which results an increase in strength of the weld [12, 13]. A comparative Study between the hot-wire TIG process and the conventional TIG process with cold-wire and achieved large deposition rates and low dilution percentages, There are many options of electrical circuit configurations to heat the addition wire in the TIG Hot-Wire process, highlighting the utilization of the continuous pulsed current and the alternating current. A first analysis done on the welding arc, which demonstrates that to heat the wire with continuous constant current generates a permanent magnetic blow over the arc. According to trials made, the direction and intensity of the magnetic blow will depend on the polarity and on the current value to heat the wire. A macro graphic analysis of the weld beads demonstrated that the best results were for the tests made with hot-wire, achieving dilutions up to 2% for a wire velocity of 7.5 m/min, 1 kW of power for to heat the wire and using a welding velocity of 30 cm/min [14].

2. Research Methodology

2.1. Design of Experiment

The experimental design considers the following factors such as welding current, gas flow rate, welding speed and voltage as input. The experimental matrix was generated with the design expert software, the central composite design was the most suitable for this experiment. This process followed the rules of repetition, randomization and local control so as to achieve an optimal experimental design. The input factors considered and their levels is shown in the table below.

Table 1. *Process factors and their range.*

Parameters	Unit	Symbol	Coded value	
			Low (-1)	High (+1)
Current	Amp	A	180	240
Gas flow rate	Lit/min	F	16	22
Voltage	Volt	V	18	24

Table 2. *Experimental results of percentage Dilution.*

Current	Voltage	Gas flow rate	% Dilution
170.00	16.64	17.00	54
150.00	22.00	15.00	54
170.00	20.00	17.00	56.7
170.00	20.00	17.00	56.4
170.00	20.00	20.36	56.22
203.64	20.00	17.00	56.17
136.36	20.00	17.00	56.55
150.00	18.00	15.00	56.21
190.00	22.00	19.00	56
170.00	23.36	17.00	54
170.00	20.00	17.00	57
170.00	20.00	13.64	56
190.00	22.00	15.00	56
190.00	18.00	15.00	55
170.00	20.00	17.00	57
170.00	20.00	17.00	57
150.00	22.00	19.00	56
150.00	18.00	19.00	56
190.00	18.00	19.00	54
170.00	20.00	17.00	57

2.2. Experimental Procedure

Power Hacksaw was used for cutting the mild steel plate to size measuring 60 x 40 x 10mm. The grinding machine was used for preparing the groove on the double transverse side of the plates of Mild Steel Subsequently single ‘V’ groove angles (30 degree) were cut in the plates with 2 mm root faces for a total of 60 degree inclined angle between After the V-groove preparation, the Mild Steel were ready for the welding. The mild steel plates were tightly clamped during welding. The root gap of 2 mm is provided between the two plates while performed for the welding. The V-groove butt welding is performed during TIG welding process. The tungsten non consumable electrode having diameter 3 mm was used in experiment. The argon gas is used as a shielding gas. The pressure regulator was used to adjust the gas flow rate during operation. The filler metal ER309L having 2 mm diameter was used for the welding. The direct current Electrode positive (reverse polarity) was used for the welding

Figure 1. *Welded sample.*

Figure 2. *TIG welding torch.*

2.3. Materials Used for the Experiment

Mild Steel is one of the most common of all metals and one of the least expensive steels used. It is found in almost every product created from metal. It is easy to weld, very durable. Having less than 2% carbon, it will magnetize well and being relatively inexpensive can be used in most projects requiring a lot of steel.

Figure 3. *TIG welding machine.*

3. Results and Discussion

Vikram (2013) explained that the purpose of analysis of variance (ANOVA) is to investigate which design parameter significantly affect the weld quality characteristic. The ANOVA results in this study shows that the factorial state of current and voltage has more significant effect on the percentage dilution than its independent state, the strength of the model can also be assessed by the ANOVA towards minimizing the percentage dilution one way ANOVA table was generated which is presented in table 3.

Table 3. *ANOVA table for minimizing the percentage dilution.*

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	5.04	9	0.56	10.44	0.0005	significant
A-CURRENT	4.543E-003	1	4.543E-003	0.085	0.7770	
B-VOLTAGE	0.29	1	0.29	5.39	0.0427	
C-GAS FLOW RATE	0.042	1	0.042	0.79	0.3955	
AB	0.082	1	0.082	1.53	0.2446	
AC	0.019	1	0.019	0.35	0.5649	
BC	0.082	1	0.082	1.53	0.2446	
A^2	0.37	1	0.37	6.81	0.0261	
B^2	3.84	1	3.84	71.60	< 0.0001	
C^2	0.88	1	0.88	16.47	0.0023	
Residual	0.54	10	0.054			
Lack of Fit	0.22	5	0.044	0.70	0.6456	not significant
Pure Error	0.31	5	0.063			
Cor Total	5.58	19				

In the Response surface modelling, to check for the strength and accuracy of the selected quadratic model, the goodness of fit statistics is determined. The R^2 component measures the models coefficient of determination, that is the model has 90.3% capacity to predict the percentage dilution based on the relationship between the input parameters. To further validate the adequacy of the quadratic model a noise to signal ratio or adequacy precision greater than 4 is desired.

The goodness of fit statistics table for percentage dilution is presented in table 4.

Table 4. *Goodness of fit statistics for percentage dilution.*

Std. Dev.	0.23	R-Squared	0.9038
Mean	56.22	Adj R-Squared	0.8172
C.V.%	0.41	Pred R-Squared	0.5940
PRESS	2.26	Adeq Precision	10.410

In selecting the quadratic model a normal probability plot of studentized residuals done, a plot of the residuals is supposed to cluster along a straight at an angle of 45 degrees. If a scatter is observed that means there exist an outlier in the data indicating that the data is not suitable for the quadratic model. The normal probability plot of residual for minimizing percentage dilution zone is produced and presented in Figure 4.

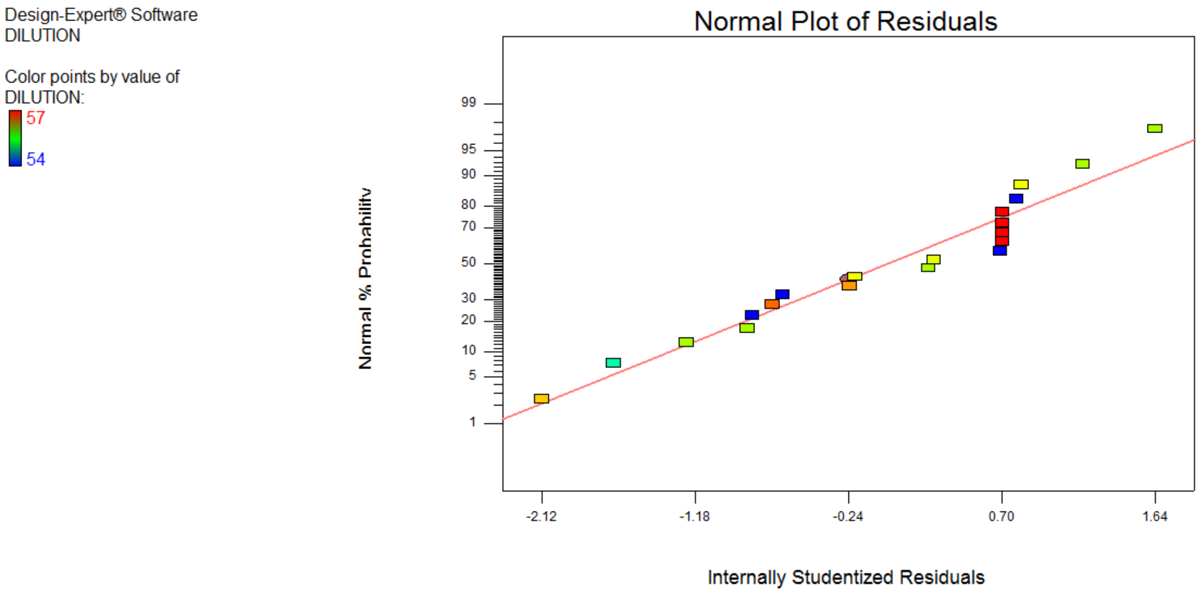

Figure 4. *Normal probability plot of studentized residuals for minimizing percentage dilution.*

Most industrial processes are multiresponsive in nature, the various parameters interact with each other differently that is the combined interaction between current, voltage and dilution is different from the interaction between voltage gas flow rate and dilution. The contour plot produces a 3 D infographic showing us the combined effect of two input parameters on a response showing us the region with the maximum or minimum response, the contour plot has transition colours of which the red indicates a region with maximum percentage dilution and the green, blue region indicates the minimum percentage dilution. a surface plot is produced reflecting the combined interaction between the percentage dilution, current and voltage as shown in figure 5.

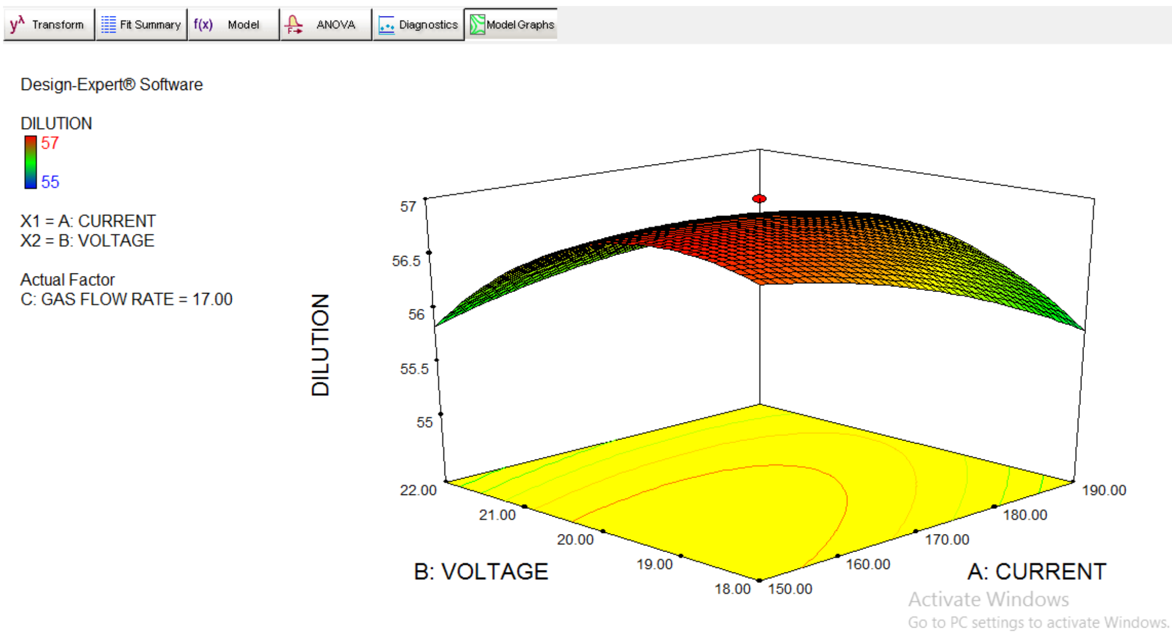

Figure 5. *A surface plot of percentage dilution.*

Table 5. *The numerical optimal solution.*

Number	Current	Voltage	Gas flow rate	Dilution	Desirability	
1	150.00	22.00	15.00	55.4906	0.911	Selected
2	150.01	22.00	15.03	55.4999	0.907	
3	150.00	21.98	15.00	55.5056	0.906	
4	150.00	22.00	15.07	55.5154	0.900	
5	151.39	22.00	15.00	55.5212	0.896	
6	151.75	22.00	15.00	55.5288	0.893	
7	150.00	22.00	15.13	55.5358	0.892	
8	150.00	22.00	15.15	55.541	0.890	
9	152.26	22.00	15.00	55.5395	0.888	
10	150.00	22.00	15.18	55.5512	0.885	
11	150.00	22.00	15.19	55.5561	0.883	
12	150.91	21.88	15.00	55.5936	0.876	
13	150.00	22.00	15.26	55.5773	0.874	
14	153.94	22.00	15.00	55.573	0.871	
15	150.00	21.78	15.00	55.633	0.866	
16	150.00	22.00	15.35	55.607	0.860	
17	150.00	21.73	15.02	55.673	0.852	
18	150.00	22.00	15.44	55.633	0.848	
19	157.85	22.00	15.00	55.6427	0.834	
20	158.04	22.00	15.00	55.6458	0.832	
21	150.00	22.00	15.59	55.6745	0.827	
22	159.52	22.00	15.00	55.6688	0.819	
23	150.00	21.48	15.00	55.814	0.805	
24	150.00	22.00	15.80	55.7313	0.797	
25	162.92	22.00	15.00	55.715	0.789	

4. Conclusion

In this paper the influence of TIG welding parameters on percentage dilution has been examined on the quality of weldments, this study has systematically applied the response surface methodology (RSM) to prioritize percentage dilution of Tungsten inert gas mild steel weld. Result of the study have shown that the RSM are highly effective tools for modelling the interaction between the current, voltage, gas flow rate and the percentage dilution of TIG mild steel weld. It was observed that the percentage dilution of TIG mild steel weld are strongly influenced by input variables such as current, voltage and gas flow rate. The surface plot shows that current and voltage were observed to have the highest significant effect on the percentage dilution of TIG mild steel weld. The result shows that a current of 190 amp, voltage of 18volt, and gas flow rate of 19.00 L/min will result in a welding process with Percentage dilution of 53.89%. This solution was selected by design expert as the optimal solution with a desirability value of 94.3% compared to the findings of Erik (2017) with the lowest percentage dilution achieved using hot-wire TIG process of 2%, for a wire speed of 7.5 m/min. For a speed of 5.5 m/min, the dilution obtained was 7%.

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