A Central Composite Design Approach to Minimize HAZ of TIG Weldments

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Abstract—Welding is a multi-input multi-output fabrication process, which requires a multi-response optimization technique. In this present work, the effect of heat affected zone and percentage dilution on the quality of Tungsten Inert Gas welded joints was investigated using mild steel plates. The Central Composite Design matrix was adopted to perform the welding experiment and collect the data, thereafter Response Surface Methodology (RSM) models was employed to minimize heat affected zone and percentage dilution with very significant statistical results. The result shows that the quadratic model was the most suitable for the HAZ data and the percentage dilution data with a P-value < 0.05 and R^2 value of 88% and 90% for the HAZ and percentage dilution respectively.

Index Terms—Heat Affected Zone, Percentage Dilution, Central Composite Design, Tungsten Inert Gas, Welding.

I. INTRODUCTION

A weld joint consist of a weld metal and heat affected zone (HAZ), the weld metal is the fusion zone where dilution of the deposited metal wire occurs by melting of the base metal. Hence the properties of the weld metal are dependent on several interacting factors such as filler material, degree of dilution, base metal and welding process. In contrast the heat affected zone composition is the same as that of the base metal, and is usually defined as the volume of base metal affected by the weld thermal cycle. Mechanical properties of a welded joint are dictated mainly by weld bead contour, HAZ area, precipitation process and heat input during welding [4]. Base metal in the vicinity of deposited weld metal undergoes a considerable change metallurgically and mechanically due to weld thermal cycle. Size of this heat affected zone (HAZ) depends on the heat input and is to be predicted for better analysis and understanding of the characteristics of HAZ affecting the microstructure and properties of the welded steel [3]. Reference [1] Classified weld metal into four main areas such as CGHAZ, fine grained supercritical HAZ (FGHAZ), intercritical HAZ (ICHAZ) and subcritical HAZ (SCHAZ). Among these, CGHAZ is the most affected area during welding process due to rapid cooling which caused hardening which in turn can be the main factor of cleavage cracking. Reference [5] has investigated the effects of coarse initial grain size on the microstructure, hardness and HAZ of low carbon steel. Reference [2] stated that weld quality is strongly influenced by various input process parameters which makes welding a multi-input multi-output process.

The improvement of weld quality has been the common interest of most welding researchers today, a weld is said to be good when the strength of the weldment is more than that of the parent materials, this can be achieved by optimizing the input parameters during the welding process. It is clear from the literature survey that a lot of work has been done in past years regarding the modelling of bead geometry with respect to TIG parameters. Various statistical and modelling techniques have used by different authors. HAZ, which is a critical zone in any weldment, has been only modelled by [3]. They correlated the HAZ area with the heat input and other welding parameters and comparison was done between HAZ produced in bead on plate welds and pipe joint welds. No studies in the past, however, been carried out to find the interactive effect of TIG welding parameters on the size of heat affected zone and percentage dilution of mild steel weld. The improper combination of this parameters affects the weld bead geometry, and can result in residual stresses and microstructural defects. Research shows that various statistical and prediction techniques have been developed to define the relationship between the input parameters and output variables. There are varieties of Artificial Intelligence (AI) methods available which includes time series models, regression models, adaptive neuro-fuzzy inference systems (ANFIS), artificial neural network (ANN) etc. have been implemented as major techniques for controlling and monitoring the welding processes. Presently the use of ANN has increased gradually in the field of engineering. As described by [6], it is one of the powerful modeling techniques based on statistical approach, presently practiced in the field of engineering for modeling complex relationships which are difficult to explain with physical models. Reference [7] and [8] interpreted that the Response surface methodology (RSM) is one of the most efficient statistical optimization technique for both single and multi-response optimizations. In the present work, an attempt is made to fill this gap by modelling the relationship between current voltage and gas flow rate and percentage dilution and heat affected zone by using Response Surface Methodology and Artificial Neural Network models. Reference [9] introduced ANN modelling as an alternative technique to those currently in the literature to predict the hardness of HAZ, and hence, trying to control it to minimize the risk of hydrogen assisted cold cracking in welding in-service pipelines by the hot tapping technique. The model developed included materials characteristics; chemical composition and hardness (as inputs), the peak temperature, holding time and cooling rate of the HAZ thermal cycle simulation were also used as key inputs in the model to predict the HAZ hardness. It was reported that the hardness of HAZ increases with increasing the following: carbon

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content, original hardness of pipe or fitting material and more rapid cooling. They compared the predictive capabilities of the models developed with other published works to the neural network model they developed. It was clear that the neural networks model produced a much lower error across a broader range of HAZ hardness values.

II. RESEARCH METHODOLOGY

A. 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 I: PROCESS FACTORS AND THEIR RANGE

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	180	240
Gas flow rate	Lit/min	F	16	22
Voltage	Volt	V	18	24
Welding speed	cm/min	S	3	4.5

TABLE II: EXPERIMENTAL RESULTS OF HAZ

Current	voltage	Gas flow	HAZ
170.00	16.64	17.00	1.3
150.00	22.00	15.00	1.3
170.00	20.00	17.00	2.1
170.00	20.00	17.00	2.18
170.00	20.00	20.36	2.3
203.64	20.00	17.00	1.4
136.36	20.00	17.00	1.9
150.00	18.00	15.00	2
190.00	22.00	19.00	1.5
170.00	23.36	17.00	1.2
170.00	20.00	17.00	2
170.00	20.00	13.64	2.2
190.00	22.00	15.00	1.39
190.00	18.00	15.00	1.6
170.00	20.00	17.00	2.2
170.00	20.00	17.00	2.4
150.00	22.00	19.00	2
150.00	18.00	19.00	2
190.00	18.00	19.00	1.4
170.00	20.00	17.00	1.7

B. Experimental Procedure

Power Hacksaw was used for cutting the mild steel plate to size measuring 60 x 40 x 10 mm. 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.

C. 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 easily weldable, 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.

Fig. 1. Welded Sample

Fig. 2. TIG Welding Torch

Fig. 3. TIG Welding Machine

III. RESULTS AND DISCUSSION

The results for HAZ was analyzed by using ANOVA in order to identify the significant factors affecting the performance measures. It is clear from results so obtained in Table III that current is the most important parameter having the most significant effect on the HAZ and then voltage and gas flow rate have almost negligible effect on the same. In assessing the strength of the quadratic model towards minimizing the heat affected zone one-way analysis of variance (ANOVA) table was generated which is presented in Table III.

TABLE III: ANOVA TABLE FOR HAZ

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	2.49	9	0.28	8.44	0.0013	Significant
A-CURRENT	0.37	1	0.37	11.30	0.0072	
B-VOLTAGE	0.070	1	0.070	2.13	0.1748	
C-GAS FLOW RATE	0.044	1	0.044	1.35	0.2722	
AB	0.044	1	0.044	1.32	0.2765	

AC	0.078	1	0.078	2.38	0.1543	
BC	0.13	1	0.13	3.88	0.0771	
A^2	0.40	1	0.40	12.29	0.0057	
B^2	1.37	1	1.37	41.85	< 0.0001	
C^2	0.029	1	0.029	0.88	0.3707	
Residual	0.33	10	0.033			
Lack of Fit	0.052	5	0.010	0.19	0.9545	not significant

To validate the adequacy of the quadratic model based on its ability to minimize the heat affected zone the goodness of fit statistics presented in Table IV.

TABLE IV: GOODNESS OF FIT STATISTICS FOR HAZ

Std. Dev.	0.18	R-Squared	0.8836
Mean	1.80	Adj R-Squared	0.7789
C.V. %	10.05	Pred R-Squared	0.7084
PRESS	0.82	Adeq Precision	9.492

To diagnose the statistical properties of the response surface model, the normal probability plot of residual for minimizing heat affected zone is produced and presented in Fig. 4.

Fig. 4. Normal probability plot of studentized residuals for minimizing heat affected zone

To study the combined interaction between the heat affected zone, current and voltage a surface plot is produced as shown in Fig. 5

Fig. 5. A surface plot of heat affected zone

TABLE V: THE NUMERICAL OPTIMAL SOLUTION

Number	CURRENT	VOLTAGE	GAS FLOW RATE	HAZ	Desirability	Select ed
1	150.00	22.00	15.00	1.40413	0.911	
2	150.01	22.00	15.03	1.40687	0.907	
3	150.00	21.98	15.00	1.4138	0.906	
4	150.00	22.00	15.07	1.4111	0.900	
5	151.39	22.00	15.00	1.42723	0.896	
6	151.75	22.00	15.00	1.43286	0.893	
7	150.00	22.00	15.13	1.41705	0.892	
8	150.00	22.00	15.15	1.4186	0.890	
9	152.26	22.00	15.00	1.44075	0.888	
10	150.00	22.00	15.18	1.42169	0.885	
11	150.00	22.00	15.19	1.42318	0.883	
12	150.91	21.88	15.00	1.47279	0.876	
13	150.00	22.00	15.26	1.42986	0.874	
14	153.94	22.00	15.00	1.46505	0.871	
15	150.00	21.78	15.00	1.49617	0.866	
16	150.00	22.00	15.35	1.43966	0.860	
17	150.00	21.73	15.02	1.51886	0.852	
18	150.00	22.00	15.44	1.44874	0.848	
19	157.85	22.00	15.00	1.51272	0.834	
20	158.04	22.00	15.00	1.51475	0.832	
21	150.00	22.00	15.59	1.46434	0.827	
22	159.52	22.00	15.00	1.52918	0.819	
23	150.00	21.48	15.00	1.61405	0.805	
24	150.00	22.00	15.80	1.48828	0.797	
25	162.92	22.00	15.00	1.55551	0.789	

IV. CONCLUSION

1. The optimization of HAZ in tungsten inert gas welding of mild steel was done using ANOVA. The minimum value of HAZ is 1.331mm at current value 190A.
2. The current is the most important parameter having the most significant effect on the HAZ.
3. On increasing the current, the value of HAZ which is not desirable.

In this paper the influence of TIG welding parameters on heat affected zone has been examined on the quality of weldments, this study has systematically applied the response surface methodology (RSM) to prioritize the HAZ 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 heat affected zone of TIG mild steel weld. It was observed that the HAZ of TIG mild steel weld are strongly influenced by input variables such as current. The surface plot shows that current and voltage were observed to have the highest significant effect on the HAZ of TIG mild steel weld. The result shows that a current of 190 amps, voltage of 18 volts, and gas flow rate of 19.00 L/min will result in a welding process with Heat affected zone 1.331mm. This solution was selected by design expert as the optimal solution with a desirability value of 94.3%.

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