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Comparative Analysis of the Combined Effect of Input Parameters on Heat Input and Heat Affected Zone in TIG Welding

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Abstract

The quality and integrity of welded joints is highly influenced by the optimal combination of the welding input parameters. Due to the rapidly changing scenario in the manufacturing industry, optimization of process parameters is essential for a manufacturing unit to respond effectively to the severe competitiveness and increasing demand for quality products in the market. An attempt is made to study the effect of heat input parameters properties of Tungsten Inert Gas (TIG) welding process. The application of the surface plot in the investigation of the combined effect of input parameters on heat input and heat affected zone was pursued in this study. The central composite design matrix was used to obtain data from sets of experiments. Mild steel coupons measuring 60mm x 40mm x 10mm were welded with tungsten inert gas welding process. This study developed a model using expert systems, such as Response Surface Methodology and Artificial Neural Network to optimize and predict weld heat input and heat affected zone from input parameter such as current, voltage and welding speed. With the data collected from twenty experimental runs in this study, the result from one Response Surface Methodology analysis shows that a current of 130.00Amps, voltage of 20.94V, speed of 0.48m/min will produce heat input of 0.64277Kj/mm and heat affected zone of 5.42078mm with a desirability of 0.962.

Keywords: TIG Welding, Surface plot, weld pool, .mild steel, Heat Input, Heat Affected Zone.

1.0 INTRODUCTION

In any welding process, the variation of input parameters plays an important role. The correct combination of parameters plays a vital role in getting properties suitable for specific applications. Among the various welding parameters, welding current and welding speed have significant effects on bead geometry and mechanical properties. The heat affected zone (HAZ) is one of an undesirable zone, but the inevitable region of a fusion welded joint.

Over the years, as the demand for welding new materials and larger thickness components arouse, mere gas flame welding, which was formerly used by welding engineers, has been seen to be inadequate. As a result, better suited welding methods such as Metal Inert Gas Welding, Tungsten Inert Gas Welding (TIG), Electron and Laser Beam Welding, and several others have evolved [1]. Welding plays an important role in the manufacturing of components like gas pipelines, pressure vessels, oil tankers, boilers and chemical reactors which are required in the above mentioned industries. Among all the available welding techniques, TIG welding which is also called Gas tungsten arc welding (GTAW) is found to be one of the suitable welding processes for joining high temperature materials as it produces high quality, clean welds. Tungsten inert gas (TIG) welding is a thermal process that mainly depends upon heat conducted through the weld joint materials [2]. The melting temperature needed to weld the materials in the TIG welding is achieved by inducing an arc between the work piece and a tungsten electrode. The weld pool temperatures can advance up to 2500ºC [3], [4]. In TIG welding, a non-consumable tungsten electrode with diameter varying from 0.5 to 6.5 mm is employed with an inert shielding gas to protect the weld pool from atmospheric effect. Both AC or DC can be used as power supply sources in this process. TIG welding generally uses a direct current (DC) arc, where the tungsten electrode has a negative polarity, consequently the tungsten electrode turns into the cathode and the work piece turns into the anode and the polarity is known as straight polarity or direct current electrode negative (DCEN) [5].

For achieving the best weld quality, nowadays design of experiments (DoE) are widely applied to formulate mathematical models between welding input parameters and output variables to determine the optimal

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welding input parameters [6], [7]. The experimental optimization of any welding process is usually a highly expensive and arduous task, due to many kinds of associated non-linear events [8]. Response Surface Methodology (RSM) serves as an alternative to this expensive experimental process. Response Surface Methodology (RSM) is a combination of mathematical and statistical models for analyzing processes in which a target response is influenced by several variables and the main objective is to optimize this response [9]. It also has an important application in the design, development and formulation of new products as well as in the improvement of existing product designs. The basic components of Response Surface Methodology include experimental design, regression analysis and optimization algorithms which are used to investigate the empirical relationship [10]. Response Surface Method (RSM) is used to develop empirical model, commonly called response surface, for the response of a process in terms of the relevant controllable factors. RSM determines the operating conditions that produce the optimum response. metal create harder heat affected zone (HAZ), cold crack susceptibility and residual stress in weldments [11]. The use of optimum welding input variables can have a significant influence on the weld quality in terms of reduction in desired mechanical properties for longevity of welded joints in service condition [12]. Therefore, the main aim of this work is to study the influence of welding parameters (current, arc voltage, speed) on the heat-affected zone (HAZ) and Heat Input so as to optimize the process parameters after accomplishment of the TIG welding process.

2.0 MATERIALS AND METHOD

2.1 Materials

As regard the design of experiment used for this study,100 pieces of mild steel coupons measuring 60mm x 40mm x 10mm were used for the experiments. The experiment was performed 20 times, using 5 specimens for each run. The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined.

Figure 1: Welding torch

Figure 2: TIG equipment

Figure 3: Digital thermometer

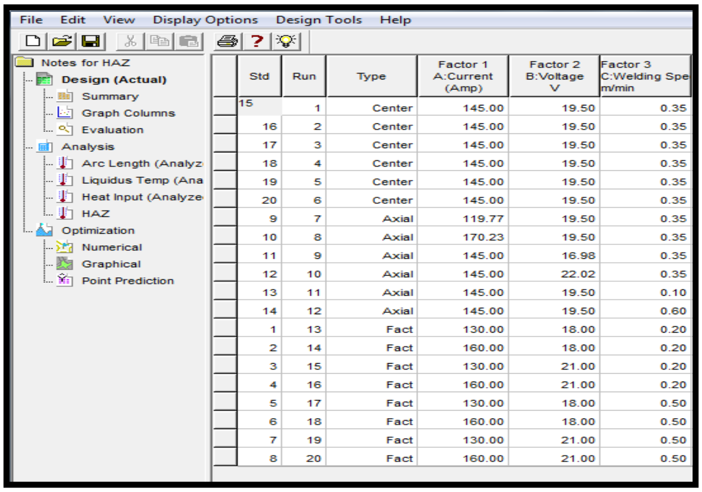
Figure 4: Weld sample

Table 1: Process parameters and their levels

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	100	180
welding speed,	M/min	F	0.10	0.6
Voltage	Volt	V	16	22

2.1 Method of Data Collection

The central composite design matrix was developed, using the design expert software, producing 20 experimental runs. The input parameters and the responses make up the experimental matrix. The responses (arc length and liquidous temperature) recorded from the weld samples were used as the data. The arc length was measured with the aid of a measuring tape while the liquidous temperature was measured with the aid of a digital thermometer alongside a thermocouple connection cable. Figure 1 below shows the central composite design matrix.



Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min
15	1	Center	145.00	19.50	0.35
16	2	Center	145.00	19.50	0.35
17	3	Center	145.00	19.50	0.35
18	4	Center	145.00	19.50	0.35
19	5	Center	145.00	19.50	0.35
20	6	Center	145.00	19.50	0.35
9	7	Axial	119.77	19.50	0.35
10	8	Axial	170.23	19.50	0.35
11	9	Axial	145.00	16.98	0.35
12	10	Axial	145.00	22.02	0.35
13	11	Axial	145.00	19.50	0.10
14	12	Axial	145.00	19.50	0.60
1	13	Fact	130.00	18.00	0.20
2	14	Fact	160.00	18.00	0.20
3	15	Fact	130.00	21.00	0.20
4	16	Fact	160.00	21.00	0.20
5	17	Fact	130.00	18.00	0.50
6	18	Fact	160.00	18.00	0.50
7	19	Fact	130.00	21.00	0.50
8	20	Fact	160.00	21.00	0.50

Figure 5: Central Composite Design Matrix (CCD)

3.0 RESULTS AND DISCUSSION

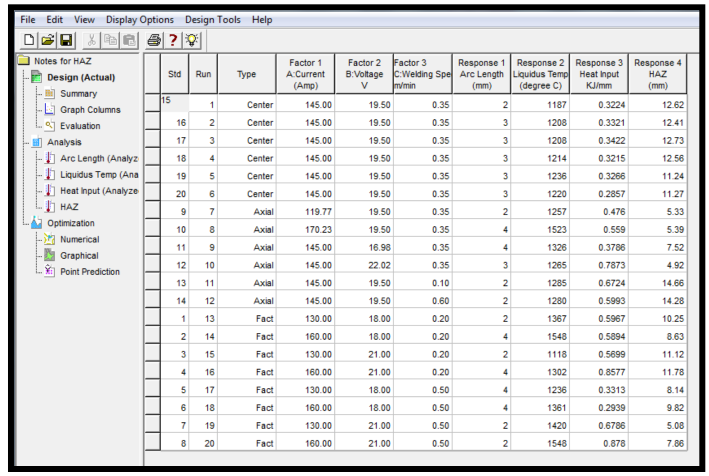
To generate the experimental data for the optimization process;

i. Statistical design of experiment (DoE) using the central composite design method (CCD) was done. The design and optimization was executed with the aid of statistical tool. For this particular problem, Design Expert 7.01 was employed.

ii. The randomized design matrix consisting of the input variables and responses namely (heat input and heat affected zone) in real values is shown in Figure 6

To study the effects of combine input variables on the response variable (heat input), the 3D surface plot presented in Figure 7 was developed.

The contour plots showing each response variable (heat input) against the optimized value of the input variable is presented in figure 8.



Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min	Response 1 Arc Length (mm)	Response 2 Liquidus Temp (degree C)	Response 3 Heat Input KJ/mm	Response 4 HAZ (mm)
15	1	Center	145.00	19.50	0.35	2	1187	0.3224	12.62
16	2	Center	145.00	19.50	0.35	3	1208	0.3321	12.41
17	3	Center	145.00	19.50	0.35	3	1208	0.3422	12.73
18	4	Center	145.00	19.50	0.35	3	1214	0.3215	12.56
19	5	Center	145.00	19.50	0.35	3	1236	0.3266	11.24
20	6	Center	145.00	19.50	0.35	3	1220	0.2857	11.27
9	7	Axial	119.77	19.50	0.35	2	1257	0.476	5.33
10	8	Axial	170.23	19.50	0.35	4	1523	0.559	5.39
11	9	Axial	145.00	16.98	0.35	4	1326	0.3786	7.52
12	10	Axial	145.00	22.02	0.35	3	1265	0.7873	4.92
13	11	Axial	145.00	19.50	0.10	2	1285	0.6724	14.66
14	12	Axial	145.00	19.50	0.60	2	1280	0.5993	14.28
1	13	Fact	130.00	18.00	0.20	2	1367	0.5967	10.25
2	14	Fact	160.00	18.00	0.20	4	1548	0.5894	8.63
3	15	Fact	130.00	21.00	0.20	2	1118	0.5699	11.12
4	16	Fact	160.00	21.00	0.20	4	1302	0.8577	11.78
5	17	Fact	130.00	18.00	0.50	4	1236	0.3313	8.14
6	18	Fact	160.00	18.00	0.50	4	1361	0.2939	9.82
7	19	Fact	130.00	21.00	0.50	2	1420	0.6786	5.08
8	20	Fact	160.00	21.00	0.50	2	1548	0.878	7.86

Figure 6: Design matrix showing the real values and the experimental value

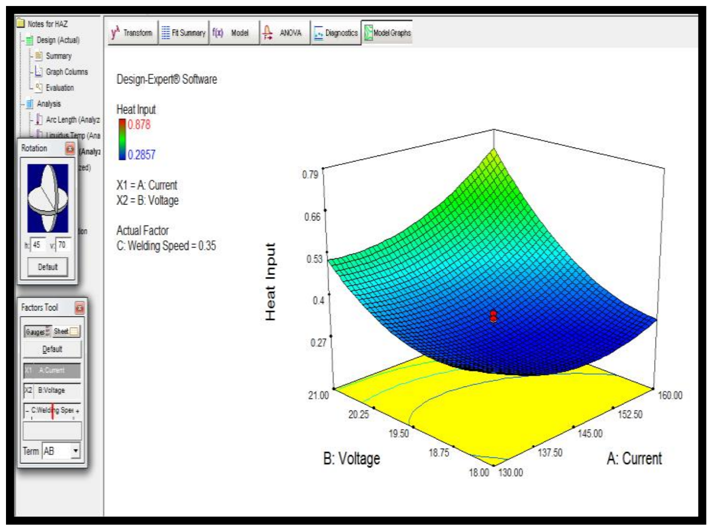


Figure 7: Effect of current and voltage on the heat input

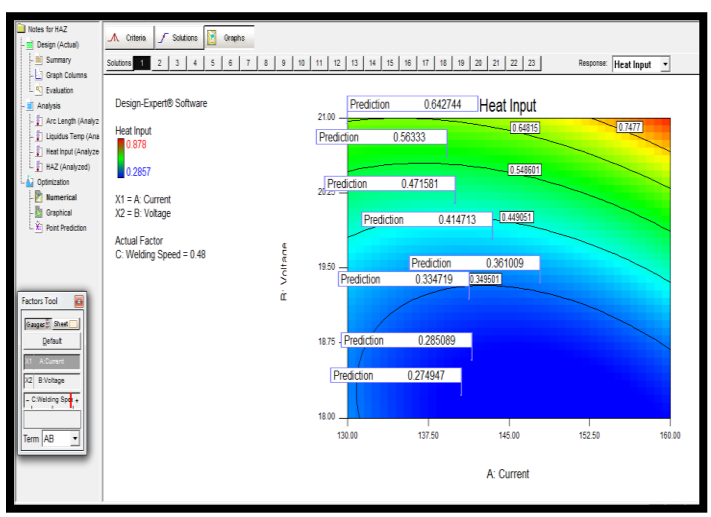


Figure 8: Predicting heat input using contour plot

To study the effects of combine input variables on the response variable (heat affected zone), the 3D surface plot presented in Figure 9 was developed.

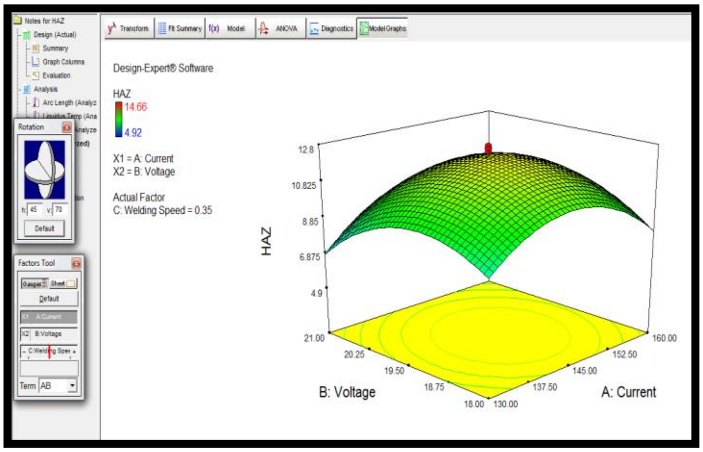


Figure 9: Effect of current and voltage on the heat affected zone (HAZ)

The 3D surface plot as observed in Figures 7 and 9 shows the relationship between the input variables (current, voltage and welding speed) and the response variables (heat input and heat affected zone). 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 picture of the surface. As the colour of the curved surface gets darker, heat input and heat affected zone decreases proportionately while the liquidus temperature increases. 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.

The contour plots showing each response variable (heat affected zone) against the optimized value of the input variable is presented in figure 10.

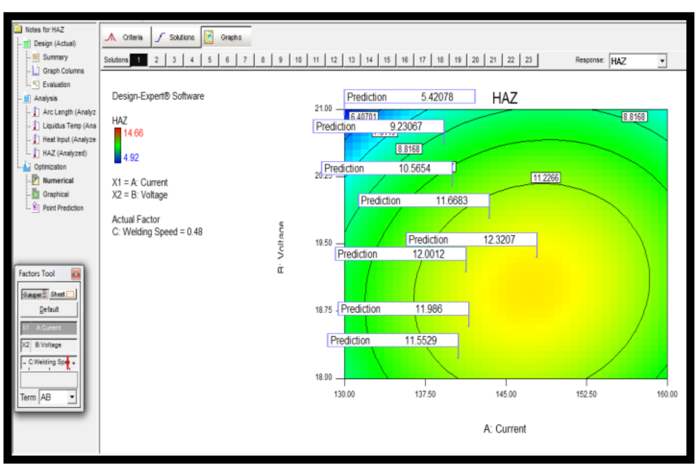


Figure 10: Predicting heat affected zone (HAZ) using contour plot

4.0 CONCLUSION

Based on the data collected from the experimental runs in this study, the result from analysis shows that a current of 130.00Amps, voltage of 20.94V, speed of 0.48m/min will produce heat input of 0.4277Kj/mm and heat affected zone of 5.42078mm with a desirability of 0.962. The analysis also produced appreciable predictions with 99.8% for heat input and 99.3% for heat affected zone. A new approach using expert systems in the form of Response Surface Methodology to optimize and predict Tungsten inert gas weld heat input and heat affected zone has been carried out successfully.

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