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Carbon Content Effects on the Heat Affected Zone Harden Ability of Tungsten Inert Gas Mild Steelwelds

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Abstract:
The weldability, strength and microstructural configuration of mild steel welds is determined by the carbon content composition of the weldment. In this study ,the effects of carbon content on the hardness of the heat affected zone of mild steel welds has been investigated. A gas tungsten arc welding process was employed to weld the joints of the mild steel samples, thereafter data on carbon content and hardness was recorded. A data compatibility and suitability test criteria was done using the sequential sum of square and the analysis of variance (ANOVA). This rest indicated that welding has the most significant effect on the carbon content and hardness, combined interactive effects between the target response, current, voltage and gas flow rate.

Keywords: *Carbon content, hardenability, mild Steel, heat affected zone, Tungsten Inert Gas, Welding*

1. Introduction

The improvement of weld quality has been the main interest of most welding researchers today, a good weld must possess adequate strength greater than that of the parent materials and this can be achieved by optimizing the input parameters during the welding process. The contact between input and output process parameters determines the veracity of a weld. The HAZ, bead geometry, distortion, dilution and the thermal conductivity can be found out through this. If the carbon content can be reduced, it will improve the weldability and decrease the susceptibility. Boron additions commonly used to preserve hardenability [1]. If beyond the HAZ, material cracking happens it gives a good creep strength[2].

The heat affected zone (HAZ) estimation helps to find the accuracy level and the extent of occurrence without the need for many costly and time-consuming process [3]. It is very essential to have a knowledge about whole area and of subareas of the HAZ [4]. Prior austenite grain sizes on hardenability helps to predict the HAZ hardness. For 400 to 490MPa grade steels the prediction is easy [5]. HAZ represents a zone where some structural changes in the welded material occurred [6]. The IC GC HAZ in the steels van be received from a combination of Scanning Electron Microscopy (SEM) and Image Analysis of the resultant SEM micrographs [7].The result obtained from actual welds can be further confirmed through weld thermal cycle simulation[8].

The quality can be improved through the welding process optimization [9].The future estimation of the weld pool geometry has been evaluated through the artificial neural network[10]. Further, Response Surface Methodology (RSM), can be used for improving and optimizing processes. RSM also provides relationships among one or more measured responses and the vital input factors[11].The fractional factorial model can be used to forecast the bead geometry or to establish a grouping or a range of parameters to obtain the desired bead geometry dimensions inside the factors area [12]. It was found that the fractional factorial technique was suitable for the forecasting the main effects and the interaction effects of different combinations of welding parameters[13].

2. Research Methodology

2.1. Design of Experiment

For maximizing as well as minimizing the responses of the manufacturing process, design of experiment is very popular. This study considers many factors like welding current, gas flow rate, and voltage. The central composite design has been adopted here. Three principles of the experimental design, i.e. rules of repetition, randomization and local control have been followed here. The below mentioned table indicates the input factors.

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	110	150
Gas flow rate	Lit/min	F	25	28
Voltage	Volt	V	11	15

Table 1: Process Factors and Their Range

Std	Run	Current	Voltage	Gas flow	CC	Hardness
11	1	150.23	26.5	12.5	1.1	367
3	2	125	26.5	12.5	5.2	200
17	3	125	26.5	12.5	5.4	193
20	4	125	26.5	12.5	5.6	195
14	5	140	25	11	5	225
10	6	125	23.98	12.5	6	165
9	7	140	25	14	4.5	272
1	8	125	26.5	15.02	6.7	270
8	9	140	28	11	4.2	300
12	10	110	25	14	4.9	262
16	11	125	29.02	12.5	5.7	220
13	12	125	26.5	12.5	5.7	219
4	13	125	26.5	9.98	6.2	191
2	14	110	25	11	4.8	209
19	15	99.77	26.5	12.5	4.3	266
15	16	125	26.5	12.5	4.8	230
7	17	140	28	14	3.25	267
5	18	125	26.5	12.5	5	229
6	19	110	28	11	6.23	230
18	20	110	28	14	6.35	226

Table 2: Experimental Results

2.2. Experimental Procedure

Mild steel plates of 10mm thickness were cut into rectangular pieces measuring 60x40 mm using a hacksaw and coolant. Proper cleaning need to done to ensure a sound weld. Heat generated was minimized to avoid changes in the microstructure. TIG welding machine was appropriately calibrated to the desired amperage and voltage. A single bead can ensure uniform fusion of the plates. The weld was de-slagged, washed and welded again. After the final welding process a grinding machine has been employed to clean the weld. The specimen was allowed to cool before the carbon content and hardness was determined.

2.3. Materials Used for the Experiment

Mild steel is very popular as it is easily available and cost-effective. Almost every product is being created from steel. Wielding can be easily done on the steel. It is very durable also. Steel generally contains less than 2% carbon. Due to its in expensive nature, it can be hugely used.

Figure 1: TIG Welding Machine

Figure 2: TIG Welding Torch

Figure 3: Shielding Gas Cylinder and Regulator

Figure 4: Welded Sample

3. Results and Discussion

In assessing the strength of the quadratic model towards minimize the carbon content one way analysis of variance (ANOVA) table was generated which is presented in Table 3

	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	Df	Square	Value	Prob> F	
Model	28.55	9	3.17	23.47	< 0.0001	Significant
A-current	8.40	1	8.40	62.16	< 0.0001	
B-voltage	7.756E-003	1	7.756E-003	0.057	0.8155	
C-gas flow rate	0.011	1	0.011	0.082	0.7804	
AB	3.04	1	3.04	22.48	0.0008	
AC	0.35	1	0.35	2.58	0.1394	
BC	0.023	1	0.023	0.17	0.6880	
A^2	12.47	1	12.47	92.22	< 0.0001	
B^2	0.49	1	0.49	3.60	0.0871	
C^2	2.26	1	2.26	16.70	0.0022	
Residual	1.35	10	0.14			
Lack of Fit	0.74	5	0.15	1.22	0.4156	not significant
Pure Error	0.61	5	0.12			
Cor Total	29.90	19				

Table 3: ANOVA Table for Carbon Content

To validate the adequacy of the quadratic model based on its ability to minimize carbon content the goodness of fit statistics is presented in table 3.2

Std. Dev.	**0.37**	**R-Squared**	**0.9548**
Mean	5.05	Adj R-Squared	0.9141
C.V. %	7.29	Pred R-Squared	0.7805
PRESS	6.56	Adeq Precision	19.810

Table 4: Goodness of Fit Statistics for Carbon Content

To obtain the optimal solution, we first consider the coefficient statistics and the corresponding standard errors. The computed standard error measures the difference between the experimental terms and the corresponding predicted terms. Coefficient statistics for carbon content response variable is presented in Table 5

	Coefficient		**Standard**	**95% CI**	**95% CI**	
Intercept	5.29	1	0.15	4.95	5.62	
A-current	-0.78	1	0.099	-1.01	-0.56	1.00
B-voltage	0.024	1	0.099	-0.20	0.25	1.00
C-gas flow rate	-0.028	1	0.099	-0.25	0.19	1.00
AB	-0.62	1	0.13	-0.91	-0.33	1.00
AC	-0.21	1	0.13	-0.50	0.081	1.00
BC	-0.054	1	0.13	-0.34	0.24	1.00
A^2	-0.93	1	0.097	-1.15	-0.71	1.02
B^2	0.18	1	0.097	-0.032	0.40	1.02
C^2	0.40	1	0.097	0.18	0.61	1.02

Table 5: Coefficient Estimates Statistics Generated for Carbon Content

The optimal equation which shows the individual effects and combine interactions of the selected input variables (current, voltage and gas flow rate) against the mesured carbon content is presented based on the actual values in Table 6

carbon content	=
-81.27340	
+1.82286	* current
-0.58817	* voltage
-2.62394	* gas flow rate
-0.027389	* current * voltage
-9.27778E-003	* current * gas flow rate
-0.023889	* voltage * gas flow rate
-4.13347E-003	* current^2
+0.081628	* voltage^2
+0.17591	* gas flow rate^2

Table 6: Optimal Equation in Terms of Actual Factors for Carbon Content

The diagnostics case statistics which shows the observed values of carbon content against their predicted values is presented in Table 7. The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal second order polynomial equation.

					Internally	**Externally**	**Influence on**		
Standard	Actual	Predicted			Studentized	Studentized	Fitted Value	Cook's	Run
Order	Value	Value	Residual	Leverage	Residual	Residual	DFFITS	Distance	Order
1	4.80	4.85	-0.046	0.670	-0.216	-0.205	-0.292	0.009	14
2	5.00	4.93	0.073	0.670	0.346	0.330	0.470	0.024	5
3	6.23	6.23	-3.235E-003	0.670	-0.015	-0.015	-0.021	0.000	19
4	4.20	3.85	0.35	0.670	1.659	1.848	* 2.63	0.558	9
5	4.90	5.31	-0.41	0.670	-1.958	-2.365	* -3.37	0.777	10
6	4.50	4.56	-0.060	0.670	-0.283	-0.270	-0.385	0.016	7
7	6.35	6.49	-0.14	0.670	-0.645	-0.625	-0.890	0.084	20
8	3.25	3.27	-0.018	0.670	-0.083	-0.079	-0.112	0.001	17
9	4.30	3.97	0.33	0.607	1.413	1.498	1.863	0.309	15
10	1.10	1.34	-0.24	0.607	-1.025	-1.028	-1.279	0.163	1
11	6.00	5.77	0.23	0.607	1.019	1.021	1.270	0.161	6
12	5.70	5.85	-0.15	0.607	-0.631	-0.611	-0.760	0.062	11
13	6.20	6.45	-0.25	0.607	-1.099	-1.112	-1.383	0.187	13
14	6.70	6.36	0.34	0.607	1.487	1.598	1.988	0.342	8
15	5.20	5.29	-0.086	0.166	-0.256	-0.244	-0.109	0.001	2
16	5.00	5.29	-0.29	0.166	-0.852	-0.839	-0.375	0.014	18
17	5.60	5.29	0.31	0.166	0.936	0.929	0.415	0.017	4
18	5.70	5.29	0.41	0.166	1.234	1.271	0.568	0.030	12
19	4.80	5.29	-0.49	0.166	-1.447	-1.544	-0.690	0.042	16
20	5.40	5.29	0.11	0.166	0.340	0.324	0.145	0.002	3

Table 7: Diagnostics Case Statistics Report of Observed Versus Predicted Carbon Content

To study the effects of combine input variables on the carbon content, 3D surface plots presented in Figure 5 was generated as follows:

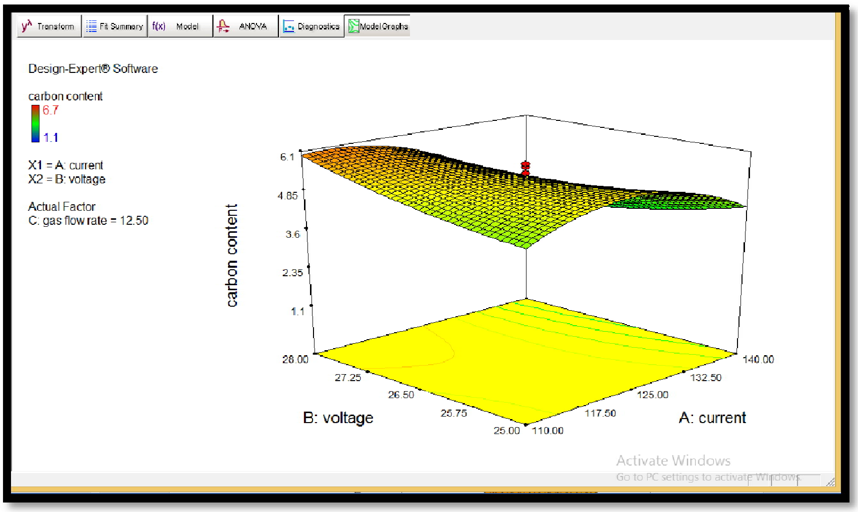

Figure 5: Effect Of Current and Voltage on Carbon Content

To study the effects of gas flow rate and current on the carbon content, 3D surface plots presented in Figure3.2 was generated as follows:

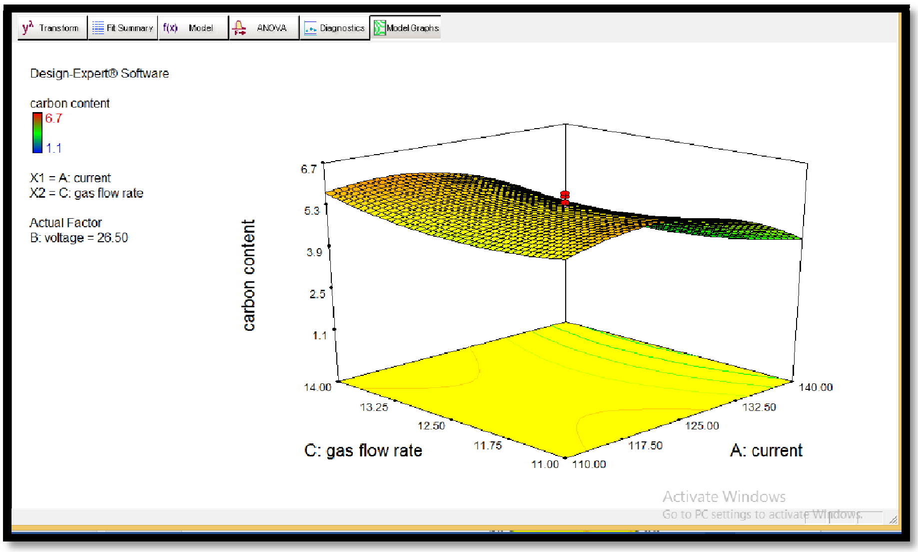

Figure 6: Effect of Current and Gas Flow Rate on Carbon Content

To study the effects of gas flow rate and voltage on the carbon content 3D surface plots presented in Figure 7 was generated as follows:

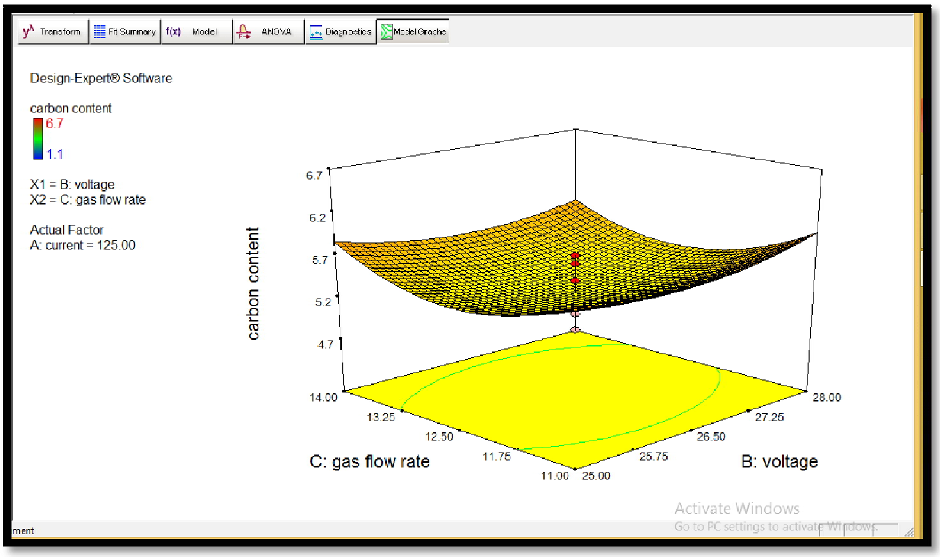

Figure 7: Effect of Voltage and Gas Flow Rate on Carbon Content

The numerical optimization produces about fifteen (15) optimal solutions which are presented in table 3.6

Number	Current	Voltage	Gas Flow Rate	Carbon Content	Hardness
1	140.00	28.00	11.00	3.84955	298.611
2	140.00	27.99	11.00	3.8508	298.444
3	140.00	28.00	11.02	3.83651	298.38
4	139.83	28.00	11.00	3.88348	297.339
5	140.00	27.96	11.00	3.85412	298.008
6	139.69	28.00	11.00	3.91195	296.272
7	139.38	28.00	11.00	3.97431	293.937
8	140.00	27.87	11.00	3.86612	296.522
9	140.00	28.00	11.22	3.70094	295.945
10	138.49	28.00	11.00	4.14768	287.453
11	140.00	27.50	11.00	3.92656	290.225
12	140.00	25.23	14.00	4.40682	276.568
13	140.00	25.24	14.00	4.39975	276.7
14	140.00	25.35	14.00	4.33181	277.952
15	139.95	25.21	14.00	4.42895	276.017
16	139.96	25.12	14.00	4.48805	274.94
17	140.00	25.46	14.00	4.26847	279.087
18	139.90	25.40	14.00	4.32078	277.891
19	140.00	28.00	11.66	3.45018	291.399
20	140.00	25.46	13.93	4.24075	277.724
21	139.90	26.28	14.00	3.84668	285.229
22	140.00	26.48	14.00	3.74006	286.824
23	139.43	27.30	14.00	3.55575	285.002
24	140.00	25.79	12.79	3.86702	262.843
25	110.00	25.00	14.00	5.31355	263.391

Table 8

From the results of table 3.6, it was observed that a current of 140-amp, voltage of 28volt, and gas flow rate of 11.00 L/min will result in a welding process with Carbon content of 3.84%and hardness 298.

4. Conclusion

The effects of carbon content on the hardness of the heat affected zone of mild steel welds has been investigated in this paper. The result obtained shows that a second order quadratic polynomial can best explain the effect of the carbon content on the hardenability. A suitability test criterion was done by the analysis of variance, he ANOVA result shows that the current parameter has significant effect on the carbon content and hardness. The higher the current the lower the carbon content and the better the hardness value, the surface plots showed the combined interactive effects between the target response, current, voltage and gas flow rate. A final optimal solution of current of 140-amp, voltage of 28volt, and gas flow rate of 11.00 L/min will result in a welding process with Carbon content of 3.84%and hardness 298 was achieved.

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