Optimization of Pulsed TIG Welding Process Parameters on 2. 25Cr - 1Mo Steel Pipe Using Multivariate Linear Regression

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Abstract: *When compared to constant current gas tungsten arc welding (TIG welding), the pulsed TIG welding process has huge advantages in welding of thin materials with low heat input and thus a decrease in distortion and war page. Also, it allows for greater control of the weld pool, greater weld penetration, and weld quality. In structural applications of nuclear power plants and boilers, 2.25 Cr-1 Mo steel pipes are employed in operating temperatures greater than 550^{0}CUsing multivariate linear regression, the parameters of the pulsed TIG welding process on pipe joints were optimized in this work. The goal of the research is to find the best set of welding process parameters for a 2.25 Cr- 1 Mo steel weld using a pulsed TIG welding technique, as well as a relationship between the four welding process parameters and ultimate tensile strength, impact strength, and microhardness. As a result, experimental research using the L9 orthogonal array was conducted. At 220 A, 120 A, 4Hz, and 40% pulse on time, the experimental and predicted results show that pulse current and background current have an effect on ultimate tensile strength. It was also found that as the pulse current & impact strength increase, the ultimate tensile strength increases, whereas microhardness values decrease.*

Key words: Linear regression, Orthogonal array, Pulse current, Pulse frequency, Pulse on

1. INTRODUCTION

2.25 Cr -1 Mo steels are extensively used it for boilers, pipelines, and chemical reaction vessels in high-temperature structures such as fossil-fired power plants and the petrochemical industry. Steel structural components in power plants and oil refineries are frequently subjected to long-term loading at high temperatures. When subjected to high temperatures and pressure, mechanical characteristics such as tensile, impact, and microhardness deteriorate. Microstructural deterioration causes a loss of strength and toughness. Pulsed TIG welding process is employed to weld 2.25 Cr 1- Mo steel pipes. In this procedure reduced heat input is supplied to the pipes by varying different process parameters like pulse current, background current, pulse frequency and pulse on. The A-TIG welding procedure was used to join 12 mm thick double side square butt joints that were manufactured on 2.25Cr-1Mo steel plates using in-house developed active fluxes. Because the 2.25Cr-1Mo steel A-TIG weld joint has a high hardness and good impact toughness, no post-weld heat treatment is needed [1]. Researchers tested thermal ageing for various times and temperatures to investigate microstructural changes associated to carbide precipitation and coarsening in 2.25 Cr1 Mo steel. When subjected to service temperatures, the coarsening of alloy carbide precipitates, as well as changes in their forms and morphologies, are the two main causes impacting hardness deterioration in this type of steel [2]. The impact of several microstructural regions on the hot corrosion of tungsten inert gas weldment in 2.25Cr-1Mo boiler tube steel has been investigated. According to the findings, several parts of the weldment were oxidized at 900^0 C in a brine Na_2SO_4-60 percent V_2O_5 atmosphere. The study looks at how inner scales form over the HAZ in the presence of free Cr [3]. Multipass welding procedures have been devised based on the temper-bead and traditional weaving techniques to remove post-weld heat treatment (PWHT) of creep resistant 2.25Cr -1Mo steel. The goal of both treatments is to smooth and cool the heat-affected zone (HAZ). The PWHT resulted in the greatest decrease in hardness and decreased hardness variation throughout the HAZ, according to the results[4]. The Taguchi approach was used to study parametric optimization of the pulsed TIG welding process. To improve ultimate tensile strength and hardness in bead shape, welding parameters such as welding current, wire feed rate and gas flow rate, were used. Welding operations were carried out with 1.2 mm filler rods and shielding gases of Argon (85%) and Co2 (15%). MINITAB -16 was used to create the L27 orthogonal array. According to the results of the experiments, welding current is the most important element for ultimate tensile strength, followed by gas flow rate. For hardness, the ANOVA approach findings show wire feed rate followed by gas flow rates [5]. Long pulsing duration created a coarser microstructure than pulse width duration, according to the findings. The structure coarsened as the peak current increased [6]. The Taguchi technique was used to bead on welding trials in order to optimize the Pulsed TIG welding process parameters of alloy C-276. The researchers used a Taguchi L_9 orthogonal array with nine trials for four parameters with three levels. According to the findings, the pulse current had the greatest influence on penetration depth, followed by the pulse on time. A confirmation test was performed to check the Taguchi analysis results, and the results reveal a good match between expected and predicted results [7]. Using a pulsed TIG welding method, the result of pulse frequency an aluminum lithium alloy is investigated. Pulse frequency has an impact on tensile characteristics, hardness, and bead microstructure. The insertion of pulse current results in the formation of an equiaxed grain structure. After Solution treatment and ageing, tensile strength is boosted using a 6Hz pulse frequency. Maximum in hardness, ultimate tensile strength, and % elongation was all good [8]. The study's practical advantage is that using the determined optimum condition increases mechanical quality, and the regression models created are useful for process automation [9]. The effect of microstructure on the impact toughness of titanium alloys welded with pulsed current TIG was examined. The findings show that impact toughness and grain size have an inverse relationship. Pulsing current, according to other studies, increases impact toughness up to a specific frequency (6Hz) [10].

2. Experimental Methods

The pipes of 2.25 Cr -1 Mo steel pipe of 5 mm thickness and 45 mm outer diameter are shown in Figure 1. chosen for the present work. Pulse current, background current, pulse frequency, and pulse on are the input parameters. With argon as a shielding gas, the root welding is done with 1.6 mm diameter filler wire and the finish welding is done with 2.5 mm diameter EB90S3 filler wire.

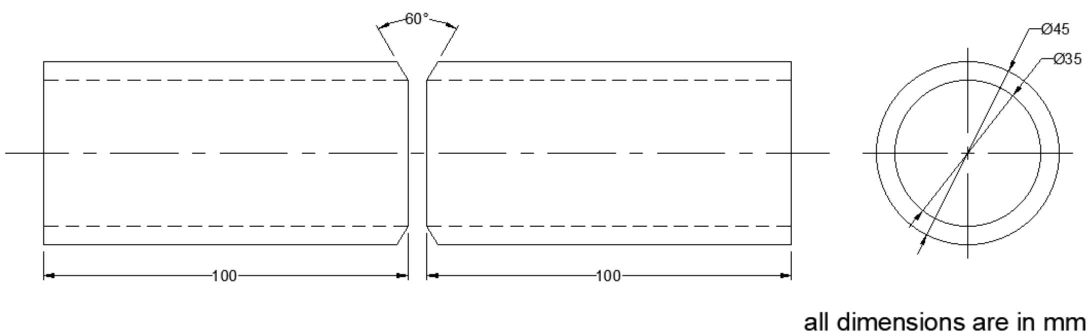

Figure 1. 2.25 Cr-1 Mo steel pipe two-dimensional view

The chemical composition and mechanical properties of 2.25 Cr- 1 Mo steel are presented in Table 1 and 2.

Table 1. 2.25 Cr -1 Mo steel chemical composition

Element	C	Mn	S	P	Si	Cr	Ni	Mo	Cu
Weight (%)	0.15	0.66	0.02	0.02	0.26	2.36	0.019	0.93	0.05

Table 2. Mechanical Properties of 2.25 Cr 1 Mo steel Properties

Mechanical Property	Density, kg/m^3	Young's, modulus kN/mm²	Tensile strength, MPa	Thermal conductivity, W/m K	Hardness, Hv	Yield strength, MPa	% Elongation,
T22 Steel	7800	210	415	40	182	205	30

The PCGTAW experiments are conducted manually using the Indus Arc welding equipment is shown in Figure 2. Taguchi design parameters and its levels are displayed in Table 3. The pipes are cleaned thoroughly before conduction of experiments. Shielding gas of Argon with a flow rate of 14 lit /min. used protect the weld pool with a constant speed of 2.09 mm/sec. to obtain maximum ultimate tensile strength.

Figure 2. 2.25 Cr 1 Mo steel pipe joints

The multiple linear regression method was employed as the primary method in this investigation. MINITAB is used to create the regression equations. Equation 1 shows the general form of multiple linear regression models.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \beta_n X_n \quad (1)$$

y = dependent variable

X_1, X_2, X_3 are independent variables

3. Results and Discussions

3.1 Results

Table 3. lists the process variables and their ranges which were used in this study. Where X1, X2, X3, and X4 denote the pulse current, background current, pulse frequency, and pulse on, as well as their minimum and maximum values. The 2.25 Cr-1 Mo steel pipes are joined using these range values.

Table 3. Factors and levels

Level	PC (A)	BC (A)	PF (Hz)	PO (%)
Notations	X_1	X_2	X_3	X_4
Range	180-220	100-120	4-8	40-60
Level 1	180	100	4	40
Level 2	200	110	6	50
Level 3	220	120	8	60

Table 4 illustrates the results for ultimate tensile strength, impact strength, and microhardness derived from the experimental test conducted out on 9 specimens utilizing the L9 orthogonal array while adjusting different process parameters. Process parameters are independent variables, while the produced values are dependent variables. The data in Tables 3 and 4 are modelled using the MINITAB software's linear regression.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \quad (2)$$

Figure 3. Tensile test specimens

Table 4. Values of ultimate tensile strength, impact strength and microhardness

S. No	Control Factors				Ultimate tensile strength	Impact strength	Micro hardness
	PC	BC	PF	PO			
Units	A	A	Hz	%	MPa	J	Hv
1	180	100	4	40	411.891	100	308
2	180	110	6	50	426.971	97	299
3	180	120	8	60	475.395	114	300
4	200	100	6	60	477.895	119	303
5	200	110	8	40	491.105	100	291
6	200	120	4	50	473.275	103	309
7	220	100	8	50	478.175	111	293
8	220	110	6	60	485.025	118	305
9	220	120	4	40	496.495	102	296

The independent variables pulse current, pulse frequency, background current, and pulse on are represent X_1, X_2, X_3, and X_4 respectively. The recorded results become the dependent variables. The following fitted model was obtained is shown in equation 3 by using MINITAB.

Where X_1, X_2, X_3 and X_4 represent the pulse current (PC), background current (BC), pulse frequency (PF) and pulse on (PO) respectively, while 'y' represents the ultimate tensile strength.

$$y=356.5 + 24.24 X_1 + 12.87 X_2 + 12.41 X_3 + 6.47 X_4 \quad (3)$$

The predicted ultimate tensile strength values are shown in Table 5 with different welding process parameters.

Table 5. Experimental and predicted results of ultimate tensile strength

S. No	Control Factors				Ultimate tensile strength	Predicted ultimate tensile strength
	PC	BC	PF	PO		
Units	A	A	Hz	%	MPa	MPa
1	180	100	4	40	411.89	412.49
2	180	110	6	50	426.97	444.24
3	180	120	8	60	475.39	475.99
4	200	100	6	60	477.89	462.08
5	200	110	8	40	491.10	474.42
6	200	120	4	50	473.27	468.94
7	220	100	8	50	478.17	492.26
8	220	110	6	60	485.02	486.78
9	220	120	4	40	496.49	499.12

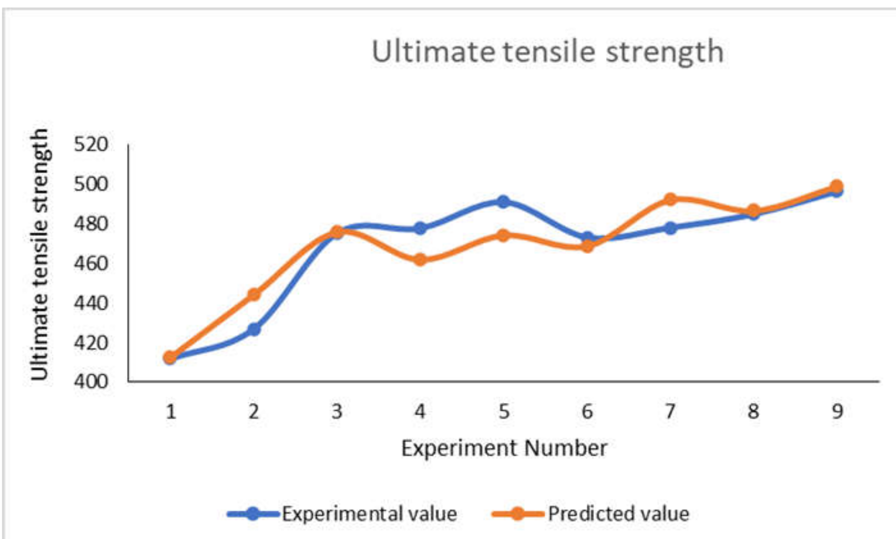

Fig. Predicted vs Experimental ultimate tensile strength

The welding process was carried out using the process parameters. The impact strength values for the run were determined and recorded. Process parameters are independent variables, whereas recorded results are dependent variables. Using MINITAB, the following fitted model was generated, as shown in equation 4.

The fitted model is $y = 85.67 + 3.33 X_1 - 3.00 X_2 + 1.83 X_3 + 8.17 X_4$ (4)

Where X_1, X_2, X_3 and X_4 represent the pulse current (PC), background current (BC), pulse frequency (PF) and pulse on (PO) respectively, while 'y' represents the impact strength. The predicted impact strength values are shown in Table 6 with different welding process parameters.

Table 6. Experimental and predicted results of impact strength

S. No	**Control Factors**				Impact strength values	Impact strength predicted values
	PC	BC	PF	PO		
Units	A	A	Hz	%	J	J
1	180	100	4	40	100	96
2	180	110	6	50	97	103
3	180	120	8	60	114	110
4	200	100	6	60	119	117
5	200	110	8	40	100	99
6	200	120	4	50	103	101
7	220	100	8	50	111	114
8	220	110	6	60	118	116
9	220	120	4	40	102	98

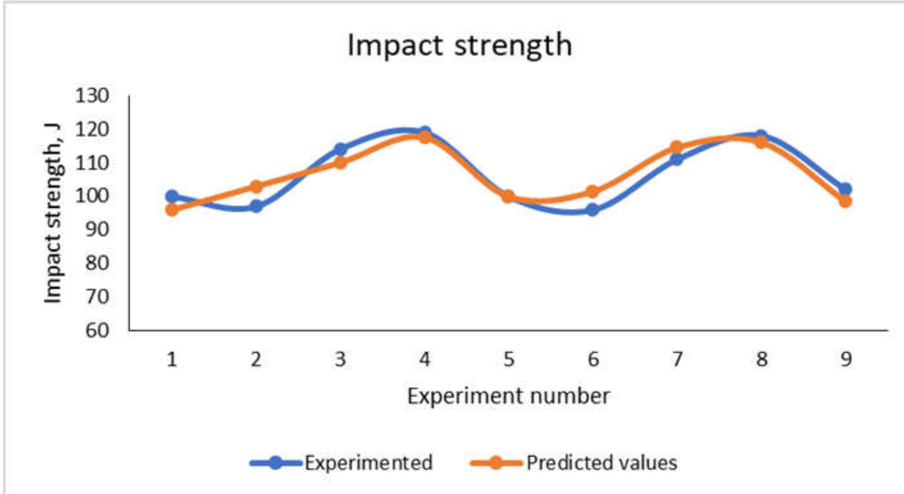

Fig. 5. Predicted impact strength vs Experimental impact strength

The experimental impact strength values and predicted impact strength values obtained from regression equations are shown in Fig 5.

The fitted model is $y = 312.78 - 2.17\,X_1 + 0.17\,X_2 - 6.33\,X_3 + 2.17\,X_4$ (5)

The predicted microhardness values are shown in Table 7 with different welding process parameters.

Table 7. Experimental and predicted microhardness results

S. No	**Control Factors**				Microhardness	Predicted values
	PC	BC	PF	PO		
Units	A	A	Hz	%	Hv	Hv
1	180	100	4	40	308	307.0
2	180	110	6	50	299	303.0
3	180	120	8	60	300	299.0
4	200	100	6	60	303	302.0
5	200	110	8	40	291	292.0
6	200	120	4	50	309	307.0
7	220	100	8	50	293	292.0
8	220	110	6	60	305	307.0
9	220	120	4	40	296	296.0

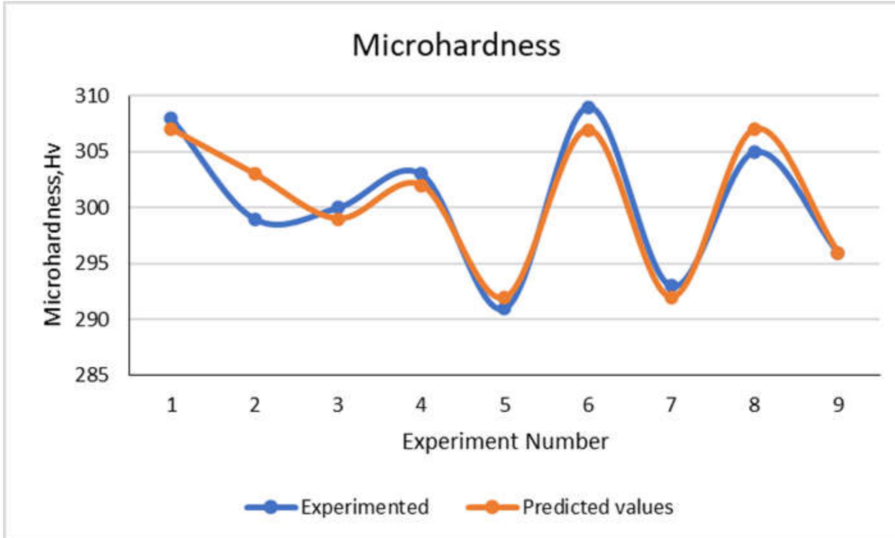

Fig. 6. Predicted microhardness vs Experimental microhardness

Figure 6 depicts the experimental impact strength values and the projected impact strength values obtained using regression equations. Table 7 displays the regression model coefficients generated from equations 3,4,5 by inserting process parameters from table 5,6,7.

Table 7. Regression model coefficients

Regression coefficients	Ultimate tensile strength (MPa)	Impact Strength (J)	Microhardness (Hv)
β_0	356.5	85.67	312.78
β_1	24.24	3.33	- 2.17
β_2	12.87	3.00	0.17
β_3	12.41	1.83	- 6.33
β_4	6.47	8.17	2.17

The regression equations for ultimate tensile strength, micro hardness and impact strength are

Ultimate tensile strength $=356.5 + 24.24\ X_1 + 12.87\ X_2 + 12.41\ X_3 + 6.47\ X_4$

Impact strength $= 85.67 + 3.33\ X_1 - 3.00\ X_2 + 1.83\ X_3 + 8.17\ X_4$

Microhardness $= 312.78 - 2.17\ X_1 + 0.17\ X_2 - 6.33\ X_3 + 2.17\ X_4$

3.2 Discussions

Table 4 shows the experimental results of ultimate tensile strength, impact strength, and microhardness when various process parameters were taken into account. The greatest tensile strength is reached at 220 A, 120 A, 4 Hz, 40 process parameters, impact and microhardness values are smaller, according to the table. Increases in pulse current and background current were also found to boost ultimate tensile strength while decreasing impact strength and microhardness. The relationship between ultimate tensile strength and predicted ultimate tensile strength is seen in Figure 3. Here is some relationship between the predicted and experimental values, as shown in the graph, although there is some evident variation. From figure 4 and 5 the correlation is fine for the impact and microhardness values.

4. Conclusions

The linear regression method was used to study the optimization of 2.25 Cr 1 Mo steel pipe joints fabricated by pulsed TIG welding. The research comprises determining the best process parameters for a 2.25 Cr 1- Mo weld, as well as establishing a link between process factors and ultimate tensile strength, impact strength, and microhardness. As a result, experimental research using the L9 orthogonal array was conducted and also used linear regression analysis to model and analyze ultimate tensile strength, impact strength, and microhardness in pulsed TIG welding. At 220 A, 120 A, 4 Hz, and 40%, the experimental and predicted results reveal that pulse current and background current affect ultimate tensile strength.

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