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Submerged Arc Welding of SA 516 Gr70 Material: Parametric Optimization of Mechanical Properties UT-Strength and Hardness

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Abstract:- In this study, the Taguchi technique was employed to optimize the process parameters of submerged arc welding (SAW) in terms of mechanical properties such as Ultimate Tensile Strength (UTS) and hardness. The study considered a variety of weld quality factors and provided a detailed explanation of the procedure and results using the Taguchi method, which is a statistical analysis approach that requires fewer trials. The experiment was conducted on SA 516 GR70 material using a L9 orthogonal array and a range of current, voltage, and speed settings. The comparison of anticipated and experimental values with the mathematical model of regression analysis-ANOVA with and without interaction helped in achieving the desired results. Lastly, a verification experiment confirmed that the Taguchi technique is reliable in predicting UTS and hardness performance. Overall, this research provides valuable insights into optimizing the SAW process parameters for mechanical properties and demonstrates the effectiveness of the Taguchi technique in predicting and achieving optimal welding performance.

***Keywords**: Taguchi method, S/N ratio, ANOVA, Orthogonal array, Regression Analysis.*

1. Introduction

Today's manufacturing sectors rely heavily on submerged arc welding equipment. Its primary function [2] is the quick production of high-quality deposited weld metal. Power plant machinery, large-scale structural steelwork, shipbuilding, and other industrial uses account for the vast majority of SAW's current market. Another application of the approach in the manufacturing of pressure vessels is the high-speed welding of basic geometric seams in thin portions. These seams are typically found in the thinner sections.

There is a direct correlation between the welding input parameters used and the final quality of the welded joint. Most people rely on the welder's experience, charts, and manuals, which are all simple and inexpensive, to determine the correct welding conditions (which contain recommended values). Your carefully adjusted welding settings may or may not result in optimal performance from your welding equipment and surrounding environment. In response to this difficulty, a number of optimization procedures have surfaced that define the objective outcome variables through the development of mathematical models that characterise the connection between input parameters and the resulting variables.[3].

Taguchi's methods for quality engineering make use of the design of experiments to achieve optimal performance, quality, and cost in product development. For low-cost, high-efficiency system design, it is one of the most crucial statistical tools [17]. Taguchi emphasises process parameter optimization to keep quality good at low cost. The Taguchi approach increases performance characteristics because it creates optimal process parameters that are robust to changes in environmental circumstances and other noise factors. In other words, Taguchi employs the loss function to quantify irregular performance features [1]. Based on the results of the loss function, a signal-to-noise (S/N) ratio can be determined. There are three distinct performance factors to keep in mind while evaluating the S/N ratio: lower is better, greater is better, and nominal is ideal.

2. Literature Review

In the field of welding, Y.S. Tarng et al. [1] introduced the grey-based Taguchi method as a means of optimizing a variety of performance characteristics. Specifically, the authors applied this method to the Submerged Arc Welding (SAW) process, demonstrating how to choose optimal welding parameters, evaluate the quality of the resulting weld, and optimize the process for hard-facing applications. Through their study, Tarng et al. showed that the SAW process's deposition rate, dilution, and hardness can be enhanced when using the combined grey-based Taguchi technique. Additionally, Tarng et al. [2] explored the optimization of SAW process parameters, such as deposition rate and dilution, using the Taguchi method with a L8 orthogonal array. The authors found that the optimized settings resulted in a higher deposition rate, lower dilution, and improved signal-to-noise ratio.

Similarly, Dr. J. Edwin Raja Dhas et al. [3] utilized the Taguchi method to optimize SAW welding parameters for mild steel. The authors employed a L8 orthogonal array to collect data on four variables: current, voltage, speed, and electrode stick-out, and used both the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to identify optimal welding parameters. Mohd Hassan et al. [4] also used a L8 orthogonal array in conjunction with the Taguchi method and regression analysis in SPSS to optimize welding settings and achieve the optimum bead width.

Moreover, welding parameters have been optimized using grey relation analysis and the Taguchi method by Edwin Raja Dhas et al. [5]. The authors conducted experiments using Taguchi's L9 orthogonal array, and found that both current and voltage significantly impacted the quality of the weld. Bharath et al. [6] conducted a Taguchi analysis on AISI 316 material using L27 Orthogonal Array and found that the current and root gap sizes had a greater impact on tensile stress than the welding speed did on bending strength. Zuhair Issa Ahmed et al. [7] studied the mechanical properties of ASTM A516 Grade 70 steel and found that all three input parameters for the SAW process, including current, voltage, and welding speed, were statistically significant in affecting the quality of the weld.

In addition to optimizing welding parameters, researchers have also investigated the impact of welding conditions on bending distortion. Mohammed T. Hayajneh et al. [8] studied the bending distortion of I-beams fabricated through SAW welding and identified arc voltage as the most significant factor in reducing bending distortion during production. Furthermore, Ajitanshu Vedrtnam et al. [9] studied the impact of current and voltage on the hardness and bead height of SAW welding on 316 stainless steel. Similarly, Siddharth Choudharya et al. [10] investigated the impact of flux composition on the hardness and impact strength of submerged arc welded low carbon steel plates. Finally, Ankush choudhary et al. [11] studied the use of SAW welding in the fabrication of pressure vessels, pipelines, and other structures and identified the welding rate as the most critical factor affecting bead geometry.

In summary, researchers have applied various statistical and optimization methods, such as the Taguchi method, grey relation analysis, and regression analysis, to optimize welding parameters and study the impact of welding conditions on the quality of the weld. The results suggest that factors such as current, voltage, welding speed, root gap sizes, and arc voltage significantly impact the quality of the weld, and that optimizing these factors can improve the welding process for a variety of applications.

3. Objectives

The ultimate tensile strength and hardness of the SAW process are examined in this study utilising the Taguchi method. Experiments are conducted using the stated Taguchi method, which involves three variables (Current, Voltage and Welding Speed). This paper serves the following specific goals.

1) To apply the Taguchi method to the development of a statistical model.
2) To zero in on the optimal settings for all of your welding controls.
3) To identify the most critical inputs and the relative importance of each component.
4) The goal is to calculate the Ultimate Tensile Strength and Hardness as a function of each input parameter separately and in combination.
5) The final tensile strength and hardness can be modelled mathematically by adjusting the current, voltage, and welding speed.
6) Experiments to verify that observed data are consistent with hypothesised outcomes

4. Design Methodology

4.1 Taguchi Method

Genichi Taguchi is credited as being the first person to suggest using this tactic, which dates back to the 1960s. Taguchi and colleagues [16] contend that the reason this pattern is utilised to such a great extent is because it has been demonstrated to enhance the quality of industrial products. Its unique qualities, such as the reduced number of tests required to establish the influence of varying the process parameters on the qualities of the final product, have contributed to the rise in popularity that has accompanied this trend. Consequently, its use has become increasingly widespread.

If an experiment, for example, had three control factors, each of which had three levels, then it would take 27 experiments to collect the best solution and the most precise data possible. However, in order to take into consideration all of the control parameters, you only need to carry out nine tests utilising the L9 orthogonal array that the Taguchi technique provides. In 99.96 percent of all circumstances, these nine tests can be considered an equivalent to the original 27. One single confirmation experiment can be necessary in certain circumstances in order to validate the optimal combination of control parameters that was discovered by employing the L9 orthogonal array. Because of this, the required number of trials was cut in half using the Taguchi method, going from 27 to 10, which resulted in a time and cost savings of 62.96 percent.

4.2 *S/N* Analysis

The Taguchi method makes use of the Signal-to-Noise ratio (S/N ratio) to quantify the range of variance in the evaluated factors. For any given situation, we may determine the optimal signal-to-noise ratio by maximising some value associated with some aspect of the problem. The researchers in this study are interested in the highest possible ultimate tensile strength and hardness, hence they are using the larger-the-better (LB) criterion for evaluating characteristic values. Decibel is the unit of S/N ratio. Here is a formal expression of the LB criterion in numbers:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{\,2}}\right) \tag{1}$$

Where, y_i is the measured characteristic value & n is the number of measurements.

5. Experimental Setup

5.1 Material

Steel of the SA 516 GR 70 kind is quite prevalent. B. These components find use in a diverse selection of systems and applications, such as thermal power plants, the liquid oil industry, the chemical industry, gas and steam turbines, separators, slide conveyors, steam exchangers, boiler exchangers, heat exchangers, steam generation, and a great deal more. Table 1 and Table 2 contains the chemical composition and mechanical properties of the material SA 516 GR 70. The plate is superior to its competitors in terms of strength and abrasion resistance, despite the fact that it is thinner than standard steel sheets. These panels are incredibly versatile because they may be cut down to any size that is required of them by the user. The welding of pressure vessels is its primary application, which is why qualities such as notch toughness are so important for the material. Because of how easily it can be welded, it is highly recommended for use in manufacturing environments like these. Finding the conditions under which SAW welding may be performed most effectively is an essential stage in the process of optimising it.

Table 1: Chemical Composition: SA_516_GR_70

C	Cr	Si	Mo	Ni	Mn	Ti	P	S	Al	Cu	Nb	V
0.181	0.3	0.401	0.08	0.3	0.95/ 1.50	0.03	0.016	0.008	0.02 (Min)	0.3	0.01	0.02

Table 2 Mechanical Properties: SA_516_GR_70

Tensile strength	Yield strength	Elongation in 200 mm (%)	Elongation in 50mm (min) (%)
484-620	260	16-17	20-21

5.2 Experimental

As can be seen in Fig.1, we employ a Kaiyun automatic submerged arc welding machine (Model MZC-1200Z, Type 12000Z10) for our experiments. The pressure vessel, shipbuilding, and infrastructure sectors all benefit from using automatic SAW machines. In Fig.2, we see SA516GR70 material being welded into various shapes.

Figure 1: Experimental Lab Setup of SAW (Submerged Arc Welding Machine)

Figure 2: Welded Specimen of SA516GR70 Material

Table 3 Specified factors and their levels for present study

Variables	Level -1	Level-2	Level-3
Current (in amp)_I	400	425	450
Voltage (in volt)_V	28	29	30
Welding Speed (millimeter/ min)	400	450	500

Table 4: L-9 Orthogonal array including control factors and the levels of them

Sr. No.	CURRENT(I)	VOLTAGE(V)	SPEED
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The experimental parameters and levels are listed in Table 3. There are nine possible combinations of the three variables (current, voltage, and welding speed). As a result, the Taguchi-provided orthogonal array L9 was selected. The final L9 orthogonal array matrix is displayed in Table 4. In order to get the best answer using the Taguchi technique, the experiments needed to get there are laid out in Table 4. The nine samples used for testing were prepared as illustrated in Figure 2 and welded using the apparatus in Figure 1. The samples were then transported to a facility where they were tested for ultimate tensile strength and hardness in accordance with the ASME code. Response parameters for Minitab® 17.0's orthogonal array were provided based on these findings. After that, we got our hands on the S/N ratio, a response table, and some response graphs. The succeeding sections elaborate on this procedure.

6. Results and Discussions

The Minitab-determined S/N ratio is presented in Table 5. The ultimate tensile strength and hardness values obtained in the laboratory are entered as response parameters or input into Minitab software to calculate the associated S/N ratio. The S/N ratio for UTS and HBW is displayed in Table 6 and Table 7, respectively. Mean S/N values for similar parameters or factors can be found in response tables. The delta value of a parameter is the difference between its extremes. The highest Delta values are ranked highest. In the table of responses, the highest ranking indicates greater significance.

Tables 6 and 7 show the results. Voltage comes in first, followed by welding speed, and then current in terms of UTS importance. Welding speed and current are secondary considerations to voltage while using UTS. Similarly, for HBW, the most critical parameters for determining hardness are the welding current, the welding voltage, and the welding speed in that order.

Table 5: Experimental outcomes - UTS and HBW and its S/N ratio calculated with Minitab_V17.0

Experiment No.	CURRENT (A)	VOLTAGE (B)	SPEED (C)	CURRENT (A)	VOLTAGE (B)	SPEED (C)	For UTS		For HBW	
							UTS	S/N Ratio	HBW	S/N Ratio
1	1	1	1	400	28	400	512	54.1927	169	44.5577
2	1	2	2	400	29	450	541	54.7011	172	44.7106
3	1	3	3	400	30	500	538	54.5712	176	44.9103
4	2	1	2	425	28	450	529	54.4246	180	45.1055
5	2	2	3	425	29	500	544	54.7193	169	44.5577
6	2	3	1	425	30	400	523	54.4072	176	44.9103
7	3	1	3	450	28	500	531	54.5390	185	45.3434
8	3	2	1	450	29	400	543	54.6515	176	44.9103
9	3	3	2	450	30	450	545	54.7353	190	45.5751

Table 6: Signal to Noise Ratios Response for UTS

Level	CURRENT	VOLTAGE	SPEED
1	54.49	54.39	54.42
2	54.52	54.69	54.62
3	54.64	54.57	54.61
Delta	0.15	0.31	0.20
Rank	3	1	2

Table 7: Signal to Noise Ratios Response for HBW

Level	CURRENT	VOLTAGE	SPEED
1	44.73	45.00	44.79
2	44.86	44.73	45.13
3	45.28	45.13	44.94
Delta	0.55	0.41	0.34
Rank	1	2	3

The S/N ratio of Ultimate Tensile Stress (UTS) and Hardness main effects plots are shown in Figures 3 and 4, respectively (HBW). From the three options provided for each variable, the parameter with the highest Mean of S/N ratio is chosen. When these tiers are joined with their respective parameters, the result is the best possible tier. The main effects plots graphically display the response table. Figure 3 shows that the UTS's current is greatest at level 3, or 450, its voltage is greatest at level 2, or 29, and its speed is greatest at level 2, or 450. Therefore, the best possible UTS configuration is A3B2C2. Similarly, the greatest values for current (level 3), voltage (30), and speed (level 2) are all found in Fig. 4 for HBW. As a result, the best possible HBW combination is A3B3C2.

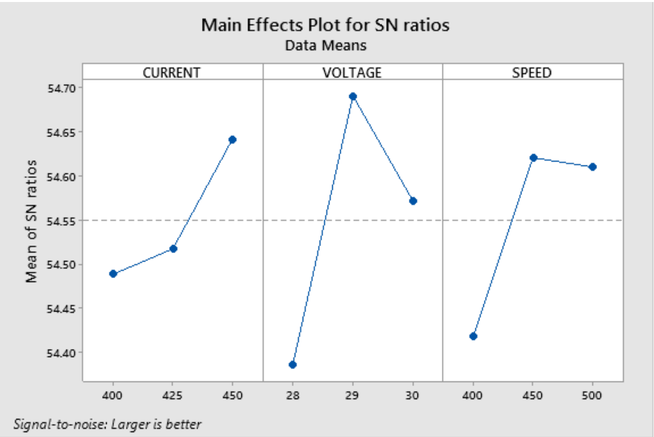

Figure 3: Response Graph for mean of *S/N* ratios for UTS (Main Effect Plot)

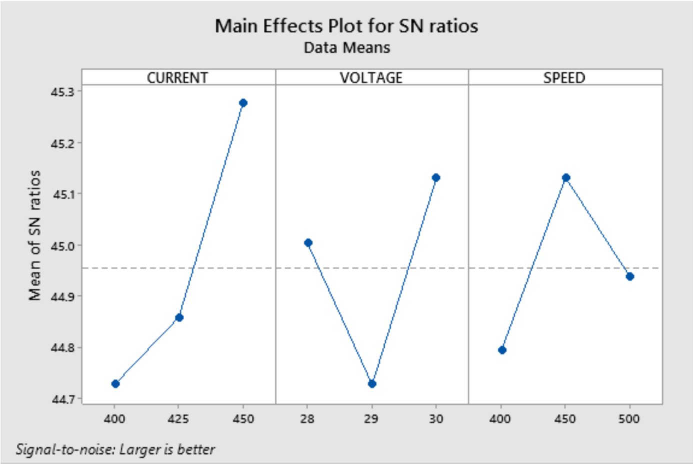

Figure 4: Response Graph for mean of *S/N* ratios for HBW (Main Effect Plot)

7. Regression Analysis & ANOVA

A regression analysis is used to determine the mathematical relationship between multiple performance metrics. Control of the system requires participation in its daily functioning. The purpose of the analysis of variance is to pinpoint which aspects of the welding procedure are most responsible for the observed performance difference. Analysis of variance (ANOVA) can be used to determine how significantly different elements contribute to the overall variance in the system's performance. The sum of squares, variance, and relative contributions of each factor are calculated during ANOVA analysis.

Table 8: Analysis of Variance results for UTS (case - without interaction)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	527.5	52.44%	527.5	175.83	1.84	0.258
CURRENT	1	130.7	12.99%	130.7	130.67	1.37	0.295
VOLTAGE	1	192.7	19.15%	192.7	192.67	2.01	0.215
SPEED	1	204.2	20.29%	204.2	204.17	2.13	0.204
Error	5	478.5	47.56%	478.5	95.70		
Total	8	1006.0	100.00%				

Regression Equation

UTS = 238 + 0.187 CURRENT + 5.67 VOLTAGE + 0.1167 SPEED

Table 9: Analysis of Variance results for UTS (case - with interaction)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	6	846.29	84.12%	846.29	141.05	1.77	0.405
CURRENT	1	130.67	12.99%	63.43	63.43	0.79	0.467
VOLTAGE	1	192.67	19.15%	114.61	114.61	1.44	0.354
SPEED	1	204.17	20.29%	138.24	138.24	1.73	0.319
CURRENT*VOLTAGE	1	12.10	1.20%	141.17	141.17	1.77	0.315
CURRENT*SPEED	1	256.30	25.48%	277.71	277.71	3.48	0.203
VOLTAGE*SPEED	1	50.38	5.01%	50.38	50.38	0.63	0.510
Error	2	159.71	15.88%	159.71	79.86		
Total	8	1006.00	100.00%				

Regression Equation

UTS = 1815 - 7.15 CURRENT - 130 VOLTAGE + 9.28 SPEED + 0.440 CURRENT*VOLTAGE - 0.01234 CURRENT*SPEED - 0.131 VOLTAGE*SPEED

According to Table 8, the ANOVA findings for UTS without interaction reveal that speed contributes the most (20.29%), followed by voltage (19.15%) and current (12.99%). Table 9 displays the ANOVA results for UTS with interaction, which show the same percentage contribution for the current, voltage, and speed parameters as Table 8, but also takes into account the interaction of parameters with each other, which affects the quality parameters and has a significant percentage contribution. For this reason, the error rate in an ANOVA without interaction is 47.56 percent, while the error rate in an ANOVA with interaction is just 15.88 percent. Using ANOVA with Interaction helps to improve the accuracy and usefulness of the resulting model and equation.

Table 10 Analysis of Variance results for HBW (case - without interaction)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Regression	3	216.83	72.28	1.99	0.233	54.47 %
CURRENT	1	192.67	192.67	5.32	0.069	48.4 %
VOLTAGE	1	10.67	10.67	0.29	0.611	2.68 %
SPEED	1	13.50	13.50	0.37	0.568	3.39 %
Error	5	181.17	36.23			
Total	8	398.00				

Regression Equation

HBW = 28.5 + 0.2267CURRENT + 1.33 VOLTAGE + 0.0300 SPEED

Table 11 Analysis of Variance results for HBW (case - with interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Regression	6	240.762	240.762	40.1270	0.51	0.779	60.49%
CURRENT	1	192.667	0.994	0.9942	0.01	0.921	48.41%
VOLTAGE	1	10.667	0.592	0.5916	0.01	0.939	2.68%
SPEED	1	13.500	15.442	15.4422	0.20	0.701	3.39%
CURRENT*VOLTAGE	1	2.500	4.024	4.0238	0.05	0.842	0.63%
CURRENT*SPEED	1	11.905	21.429	21.4286	0.27	0.654	2.99%
VOLTAGE*SPEED	1	9.524	9.524	9.5238	0.12	0.761	2.39%
Error	2	157.238	157.238	78.6190			39.51%
Total	8	398.000					100.00%

Regression Equation

HBW = 436 + 0.90 CURRENT + 9 VOLTAGE – 3.10 SPEED - 0.074 CURRENT*VOLTAGE+ 0.00343 CURRENT*SPEED + 0.057 VOLTAGE*SPEED

Table 10 shows the ANOVA without interaction for HBW in which current has highest percentage contribution i.e. 48.47 % followed by speed (3.39%) & voltage (2.68 %). **Table 11** shows ANOVA with interaction percentage contribution is same for the parameters. In addition to that it also shows the percentage contribution of interacted parameters. It is also worth noting that error percentage is less, when ANOVA is performed with interaction compared to without interaction.

Table 12 Experimental and predicted values of *UTS*

Trial No.	CURRENT	VOLTAGE	SPEED	UTS				S/N Ratio (Predicted value) by Taguchi method
				Experimental value	Predicted value without interaction	Predicted value with interaction	Predicted value by Taguchi predicted S/N ratio	
1	400	28	400	512	517.833	512.333	512.4305	54.1927
2	400	29	450	541	529.333	532.619	543.3191	54.7011
3	400	30	500	538	540.833	539.762	535.2541	54.5712
4	425	28	450	529	528.333	536.048	526.2959	54.4246
5	425	29	500	544	539.833	545.333	544.4588	54.7193
6	425	30	400	523	533.833	527.190	525.2427	54.4072
7	450	28	500	531	538.833	528.905	533.2735	54.5390
8	450	29	400	543	532.833	539.476	540.2254	54.6515
9	450	30	450	545	544.333	544.333	545.4626	54.7353

Table 13 Experimental and predicted values of HBW

Trial No.	CURRENT	VOLTAGE	SPEED	HBW				S/N Ratio (Predicted value) by Taguchi method
				Experimental value	Predicted value without interaction	Predicted value with interaction	Predicted value by Taguchi predicted S/N ratio	
1	400	28	400	169	168.500	171.143	168.9993	44.5577
2	400	29	450	172	171.333	169.905	172.0006	44.7106
3	400	30	500	176	174.167	174.381	176.0009	44.9103
4	425	28	450	180	175.667	173.524	180.001	45.1055
5	425	29	500	169	178.500	177.571	168.9993	44.5577
6	425	30	400	176	176.833	177.048	176.0009	44.9103
7	450	28	500	185	182.833	184.476	184.9993	45.3434
8	450	29	400	176	181.167	179.238	176.0009	44.9103
9	450	30	450	190	184.000	185.714	190.0006	45.5751

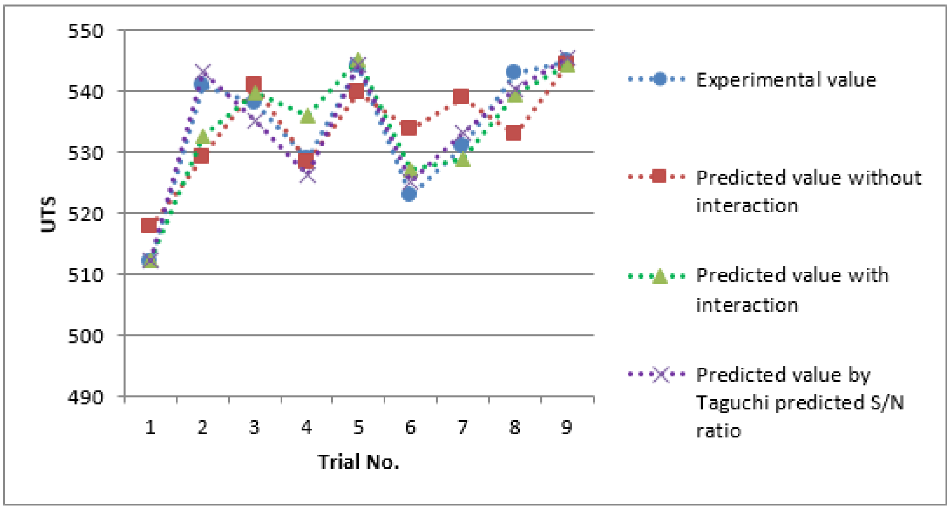

Figure 5: Predicted & Experimental values of *Ultimate Tensile Strength (UTS)*

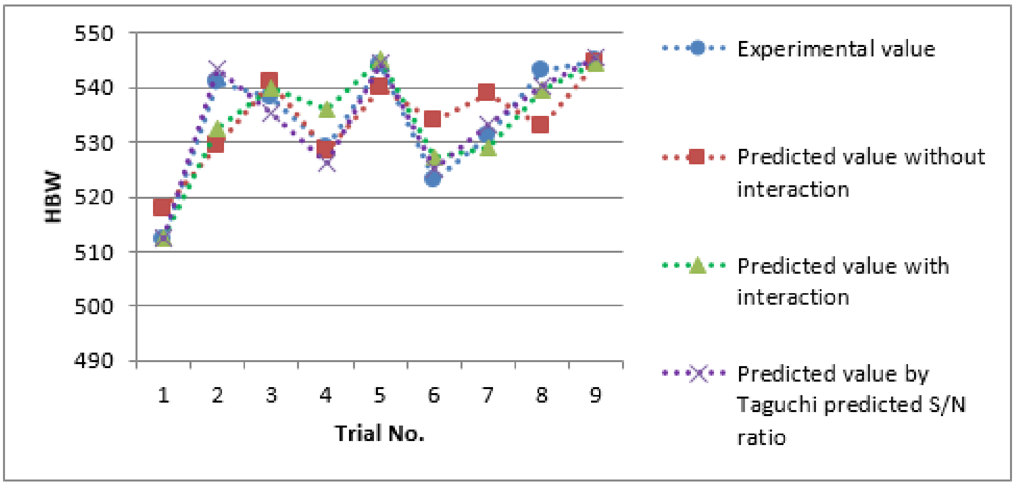

Figure 6: Predicted & Experimental values of *Hardness (HBW)*

As can be seen in Tables 12 and 13, as well as Figs. 5 and 6, the results of regression analysis with interaction demonstrate higher agreement with experimental data. This exemplifies the value of the regression equation that was found in the present investigation. The high agreement between the projected Taguchi technique outcomes and the observed results provides further evidence for the validity of the regression equation's predictions.

8. Confirmation Experiment

The relationship between Ultimate Tensile Stress (UTS) and Hardness (HBW) can be analysed using Main Effect plots or a Response graph to determine the optimal combination. However, L9 array does not take into account this pairing. As a result, it is crucial to foresee UTS and HBW performance for this optimal combination and to validate the output using experimental result. As was previously said, the expression is used to conduct this experiment to confirm its results. Tables 14 and 15 show the outcomes of this experiment to validate our findings.

Table 14 Confirmation Experiment for UTS

	Initial Parameter	Optimum Parameter	
		Prediction	Experiment
Combination	A2B2C2	A3B3C2	A3B3C2
UTS	545.1173	553.0126	556
S/N Ratio	54.7298	54.8547	54.9014
Improvement in S/N Ratio	0.1716		

Table 15 Confirmation Experiment for HBW

	Initial Parameter	Optimum Parameter	
		Prediction	Experiment
Combination	A2B2C2	A3B3C2	A3B3C2
HBW	173.9302	190.0006	190
S/N Ratio	44.8075	45.5751	45.5751
Improvement in S/N Ratio	0.7676		

The Absolute Percentage deviation for UTS is calculated as follows;

$$\%UTS = \left| \frac{(UTS)_{exp} - (UTS)_{pred}}{(UTS)_{exp}} \right| \quad (2)$$

$$\%UTS = \left| \frac{556 - 553.0126}{556} \right|$$

%UTS = 0.5373 %

The Absolute Percentage deviation for HBW is calculated as follows;

$$\%HBW = \left| \frac{(HBW)_{exp} - (HBW)_{pred}}{(HBW)_{exp}} \right| \qquad (3)$$

$$\%HBW = \left| \frac{190 - 190.0006}{190} \right|$$

%HBW = 0.0003 %

Table 14 shows that the expected S/N ratio for UTS is 0.0467 dB lower than the experimental measurement. There is a 5%3.73% discrepancy between theoretical and empirical findings. From the default setting to the experimental parameter, the S/N ratio improves by 0.1716 dB. Predicted and experimental S/N ratios are identical, as seen in Table 15. The S/N ratio was improved by 0.7676 dB, while the discrepancy between predicted and experimental findings was only 0.0003%.

Tables 14 and 15 show that the projected S/N ratio is extremely similar to the experimental S/N ratio, indicating that the prediction was accurate. It also shows that the Taguchi method of statistical evaluation may be used to predict UTS and HBW performance with high precision.

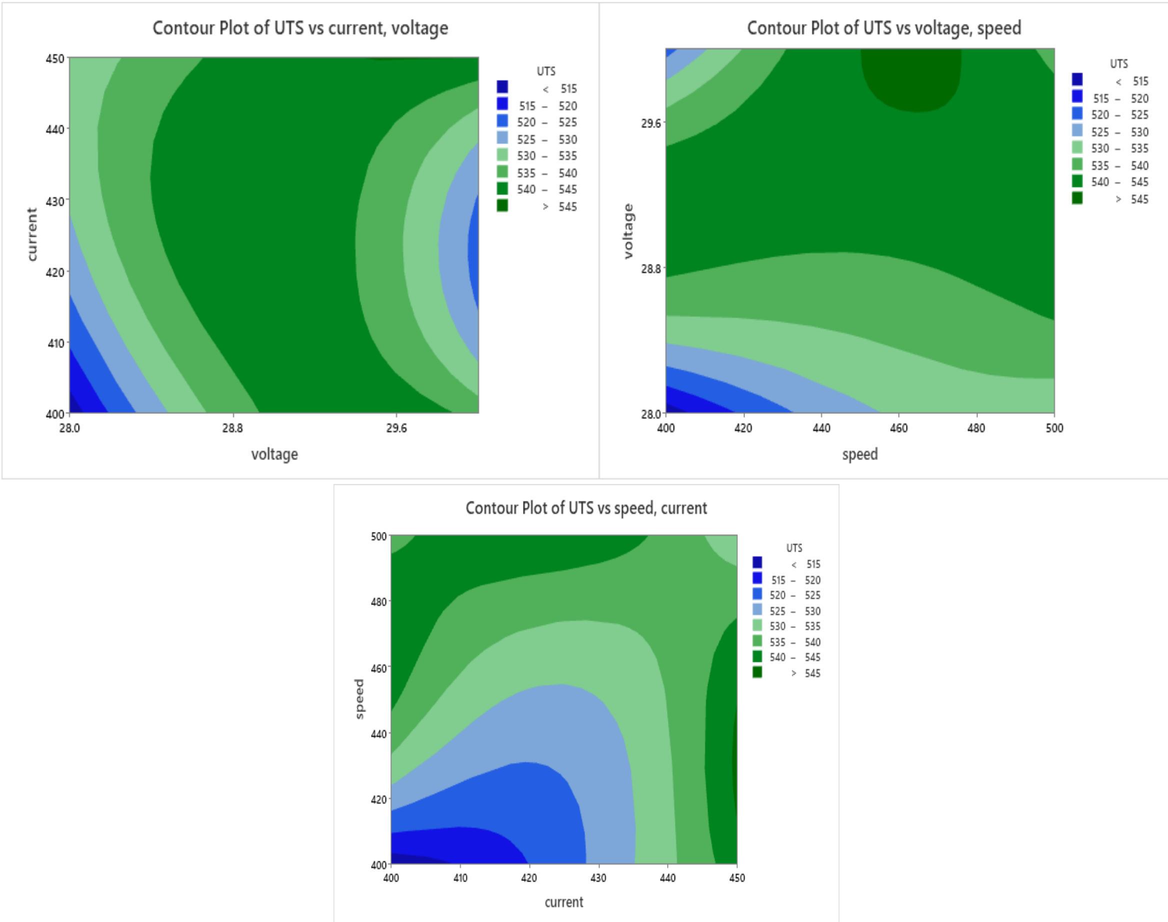

Fig 7, 8 & 9 Contour Plots for UTS

9. Contour plots

Contour plots are suitable for examining desired response values and operating conditions. In other words, It is used when you have saved a model and want to graph the relationship between a fitted response and two continuous variables. A contour plot represents a two-dimensional view in which points with the same response value are connected to create contour lines.

The darker green region indicates the highest UTS value and the blue region indicates the lowest. In **Figure 7** the UTS value will be higher when the voltage varies from 28.6 to 29.6 and the current ranges from 400 to 450. This means that regardless of the current value, the voltage range is important to obtain a high UTS value. In **Figure 8**, the UTS value is maximum when the speed varies from 450 to 480 and the voltage is above than 29.6. In **Figure 9**, the UTS value is maximum for the current from 400 to 435 and the speed value from 450 to 490. Also on the right side where the current is 445 and above the value and speed varies from 400 to 460, UTS is maximum.

As welding speed is increased, voltage value needs to be high, and current should be kept at medium to low level to get a high UTS value. When welding speed is in a range from low to medium, voltage and current should be kept at medium level to get a high UTS value.

That means A3B3C2 optimum combination with Current 450 voltage 30 and speed 450 justifies the maximum UTS value.

10. Conclusions

In this Paper, Experimental investigation was conducted to get the Optimum combination of process parameters using Taguchi Method along with Regression Analysis for Ultimate Tensile Strength and Hardness. The conclusion drawn from the above experiments are as follows.

1) Taguchi Method and Mathematical model of Regression Analysis with ANOVA have been successfully used together to get the desired outcome.
2) For UTS the most important factor is voltage followed by welding speed and current. Similarly, For Hardness the most important parameter is current followed by voltage and welding speed.
3) Optimum Combination for UTS is A3B2C2 & Optimum Combination for HBW is A3B3C2.
4) The regression analysis of with interaction demonstrate superior agreement with experimental data compare to regression Analysis of without interaction.
5) The Predicted Taguchi technique outcomes and the regression equation's shows good agreement with each other.
6) The Percentage Deviation for UTS and Hardness between the Predicted and Experimented value is very less.

11. Declarations

Ethics approval and consent to participate: Not Applicable

Consent for publication: Not Applicable

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