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# Optimizing Mechanical Properties UT-Strength and Hardness Through Submerged Arc Welding of A24 SS316 Alloy

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***Abstract:-*** The study utilized the Taguchi technique to optimize the process parameters of submerged arc welding (SAW) with a focus on enhancing mechanical properties like Ultimate Tensile Strength (UTS) and hardness. Several weld quality factors were taken into account, and a thorough description of the process and outcomes using the Taguchi method was provided. This approach, known for its statistical analysis efficiency requiring minimal trials, was applied to Material A24 SS316 using an L9 orthogonal array across various current, voltage, and speed settings. By comparing expected and actual values with regression analysis-ANOVA, with and without interactions, the study successfully attained the desired outcomes. A validation experiment further confirmed the reliability of the Taguchi technique in predicting UTS and hardness performance. Consequently, the research offers valuable insights for optimizing SAW process parameters to enhance mechanical properties while showcasing the effectiveness of the Taguchi method in predicting and achieving optimal welding results.

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

## 1. Introduction

Submerged arc welding (SAW) is a widely utilized welding process in the manufacturing industry due to its high efficiency, deep penetration capabilities, and smooth bead formation. This process is commonly employed in the fabrication of pressure vessels, marine vessels, pipelines, and other industrial structures. One significant advantage of SAW is its ability to join thick sections of metals efficiently, making it a preferred choice for various applications in the manufacturing sector.

By incorporating the Taguchi method, the optimization of SAW process parameters can be achieved to enhance efficiency, reduce costs, and improve overall welding performance. The Taguchi method is a statistical approach that allows for the optimization of process parameters to achieve desired outcomes with minimal trials. This methodology ensures that the welding process is fine-tuned to operate at optimal levels, leading to improved productivity and cost-effectiveness in the manufacturing industry.

Optimizing SAW through the Taguchi method can help minimize energy consumption, reduce material waste, enhance weld quality, and ultimately lowering production costs. By adjusting parameters such as current, voltage, welding speed, and other factors using the Taguchi method, manufacturers can streamline their welding processes, increase process efficiency, and achieve significant cost savings. This optimization ensures that the welding operation is performed at its peak performance while driving cost efficiencies in the manufacturing sector.

## 2. Literature Review

The grey-based Taguchi technique was established in welding research by Y.S. Tarng et al. [1] to optimize many elements of performance, with a specific focus on the Submerged Arc Welding (SAW) process. They illustrated how to select the best welding parameters, assess weld quality, and enhance the process for hard-facing applications. Their work highlighted that employing the combined grey-based Taguchi technique can improve the deposition rate, dilution, and hardness of the SAW process. Furthermore, Y.S. Tarng et al. [2] also explored the use of the Taguchi technique with an L8 orthogonal array to optimize SAW process parameters, such as dilution and deposition rate, as a means of achieving improved signal-to-noise ratio, lower dilution, and higher deposition rate.

Saurav Datta et.al [3] explored the Grey-based Taguchi method for optimizing submerged arc welding processes. By utilizing specific electrode wire and flux, visual and macrostructural analyses were conducted to evaluate weld quality. Through Taguchi's L25 orthogonal array design, optimal parameter combinations for desired weld quality were determined. The study showcased an improvement in the overall Grey relational grade from 0.5876 to 0.8175 with the implementation of optimal process conditions. ANOVA highlighted traverse speed as a significant factor influencing Grey relational grade in submerged arc welding.

S. V. Sapakal et.al [4] extensively explore Taguchi optimization in MIG welding, emphasizing the impact on penetration and S/N ratios. ANOVA is employed to ascertain significant design parameters affecting quality characteristics. Overall, the results reveal a prominent increase in the S/N ratio and improved penetration of 5.25mm, affirming the effectiveness of Taguchi optimization.

Bharath et al. [5] Tig welded AISI 316 using the Taguchi method, ANOVA Technique identified parameters for tensile and bending strength. Minitab 17 was used to create linear regression models. Weld speed had a big influence on bend strength and current on tensile stress. In the microstructure study, inclusions were observed due to welding material changes.

The experimental results at 32V and 34V demonstrate significant improvements in the mechanical properties of the weld metal by MH Kakaei Lafdani et al. [6]. At 32V, the optimal combination of A1B2C1 produced better Vickers hardness, impact strength, and ultimate tensile strength. Meanwhile, at 34V, combination A1B1C2 showed enhanced results in these properties. ANOVA analysis highlighted MgO as a critical factor at both voltages, contributing significantly to the outcomes. The grey fuzzy Taguchi method proved superior for multi-response system optimization in this study. Overall, the hybrid approach effectively enhanced the mechanical properties, validating its usefulness in submerged arc welding.

S. Vinodh et. Al [7] study was focused on the Submerged Arc Welding of carbon steel using a 4mm electrode. An L9 Orthogonal Array was used to analyze the impact of welding parameters, revealing the welding current's influence on penetration and welding speed's impact on bead width. ANOVA demonstrated that welding current had the highest influence on penetration, with the highest F-value at a 95% confidence level. Similarly, it showed that welding speed had the highest influence on bead width. This study highlights the successful application of statistical techniques for optimizing Submerged Arc Welding processes.

Sandeep Kumar et.al [8] studied submerged arc welding parameters for dissimilar materials, utilizing mild steel plates of specific dimensions. Experimental steps involved varying factors like welding current, voltage, and speed to analyze their impact on weld bead geometry. Findings highlighted welding current as the key influencer of bead width, emphasizing the need for optimization.

Tanawat Sirisatien et al. [9] investigated the impact of one side one pass submerged arc welding on ASTM A131 Grade A steel plates. Distortion and peak temperature variations are explored with different heat input levels, joint designs, and constraint conditions. Utilizing a ceramic backing to prevent burn-through during high-heat input welding, the research reveals different distortion levels based on these variables. The maximum distortion of 2.99 mm was observed in a specimen welded with 32 kJ/cm and a single 30 V groove without constraint. This research aims to address welding-induced distortion issues in shipbuilding, potentially replacing traditional two-sided welding methods with a more efficient approach to save time and costs.

Siddharth Choudharya et al. [10] examined the influence of flux composition on the impact strength and hardness of low-carbon steel plates welded under the submerged arc. Ankush Choudhary et al. [11] examined the application of SAW welding in the construction of pipelines, pressure vessels, and other structures and found that the welding rate was the most important variable influencing bead shape.

Mohammed Arif Iqbal Upletawala et al. [16] explore the optimization of submerged arc welding using the Taguchi method in combination with the Design of Experiments (DOE). Utilizing regression analysis with Analysis of Variance (ANOVA), the study assesses the impact of parameter interaction on welding performance. The ANOVA findings highlight the significant contributions of current, voltage, and welding speed to the ultimate tensile strength and hardness. Additionally, the study demonstrates that employing ANOVA with interaction enhances the accuracy and utility of the resulting regression model and equation. The research underscores the valuable agreement between the predicted Taguchi technique outcomes and the regression equation's results, with minimal percentage deviation between predicted and experimental values.

To summarize, studies have optimized welding settings and examined the effects of welding conditions on the quality of the weld by using a variety of statistical and optimization techniques, including regression analysis, grey relation analysis, and the Taguchi method. According to the findings, arc voltage, welding speed, root gap widths, current, and voltage all have a substantial impact on the quality of the weld. By maximizing these aspects, the welding process may be made better for a range of applications.

## 3. Objectives

Following are the objectives of the present study:

1) **Statistical Model Development:** Utilize the Taguchi method to construct a statistical model for the Submerged Arc Welding (SAW) process.
2) **Optimization of Welding Controls:** Determine the optimal settings for the welding controls by implementing the Taguchi method.
3) **Identification of Critical Inputs:** Identify the most critical inputs and assess the relative importance of each component within the SAW process.
4) **Analysis of Ultimate Tensile Strength and Hardness:** Calculate the Ultimate Tensile Strength and Hardness as individual functions of each input parameter, as well as their combined effects.
5) **Mathematical Modeling:** Develop mathematical models for the final tensile strength and hardness by adjusting the current, voltage, and welding speed parameters.
6) **Verification through Experiments:** Conduct experiments to validate the alignment of observed data with hypothesized outcomes in the SAW process.

## 4. Design Methodology

### 4.1 Taguchi Method

Genichi Taguchi is widely acknowledged as the originator of the Taguchi method, which has roots dating back to the 1960s. Taguchi and his associates 1 assert that the method's extensive adoption can be attributed to its proven capability to enhance the quality of industrial products significantly. Its distinctive characteristics, including requiring a reduced number of tests to ascertain the impact of varying process parameters on the final product's qualities, have contributed to its increasing prevalence.

As an example, if an experiment involves three control factors, each with three levels, conventionally, 27 experiments would be necessary to gather the optimal solution and precise data. However, utilizing the L9 orthogonal array offered by the Taguchi method, only nine tests are required to fully incorporate all control parameters. These nine tests using the orthogonal array are statistically equivalent to the original 27 experiments in almost all situations. In some cases, a single confirmation experiment may be needed to authenticate the best combination of control parameters identified using the L9 orthogonal array method. As a result, the Taguchi method has significantly reduced the number of required trials from 27 to 10, resulting in substantial time and cost savings of 62.96 percent. This notable reduction underscores the efficiency and cost-effectiveness of the Taguchi method in industrial applications, highlighting its capacity to drive optimization and savings in manufacturing processes.

### 4.2 *S/N* Analysis

The Taguchi method leverages the Signal-to-Noise ratio (S/N ratio) to assess the extent of variance in the factors under evaluation. When looking at a specific situation, it's possible to identify the optimal signal-to-noise ratio by maximizing a value associated with a particular aspect of the problem. In this study, the researchers aim for the highest achievable ultimate tensile strength and hardness, which is why they are employing the larger-the-better (LB) criterion to evaluate characteristic values. It's important to note that the unit of measurement for the S/N ratio is the decibel. The LB criterion associated with the Taguchi method, where "yi" represents the measured characteristic value and "n" denotes the number of measurements, is expressed as follows:

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

## 5. Experimental Setup

### 5.1 Material

The material A24 SS316, commonly known as AISI 316 stainless steel, is a widely used austenitic stainless steel with notable properties such as good corrosion resistance, mechanical strength, and weldability. Moreover, when it comes to welding with submerged arc welding (SAW), AISI 316 stainless steel is well-suited for this process, as SAW allows for efficient and high-quality welding of stainless steel materials. The SAW process parameters can be optimized to achieve desirable mechanical properties such as ultimate tensile strength and hardness, with the potential to reduce costs and enhance welding performance.

**Table 1: A24 SS316 - Chemical Composition**

| (Cr) | (Ni) | (Mo) | (C) | (Mn) | (Si) | (P) | (S) |
|---|---|---|---|---|---|---|---|
| 16.50-18.50% | 10.00-13.00% | 2.00-2.50% | Up to 0.08% | Up to 2.00% | Up to 0.75% | Up to 0.045% | Up to 0.030% |

**Table 2: A24 SS316 - Mechanical Properties**

| Tensile Properties | | | | Hardness |
|---|---|---|---|---|
| **Tensile strength** | **Yield strength** | **Elongation (%)** | **Reduction in Area** | **Brinell Hardness (HBW)** |
| 580 MPa (83,992 psi) | 290 MPa (42,055 psi) at 0.2% offset | Min 50% | Approx. 79% | Max. 212 |

### 5.2 Experimental Setup Equipment

The Kaiyun automatic submerged arc welding machine, Model MZC-1200Z, Type 12000Z10, is a versatile industrial equipment designed for precision submerged arc welding applications. It offers advanced control features, high reliability, and efficiency, making it suitable for a wide range of welding tasks in industries such as manufacturing, construction, shipbuilding, and infrastructure development. This machine is known for its robust performance, consistent welding quality, and flexibility, making it a valuable asset for both standard welding operations and experimental research purposes.

**Figure 1: Submerged Arc Welding Machine for Experiments**


**Figure 2: Material- A24SS316-Welded Specimen**

**Table 3 Factors and levels for current study**

| Factors | Level -1 | Level-2 | Level-3 |
|---|---|---|---|
| Current (amp)_I | 300 | 325 | 350 |
| Voltage (volt)_V | 24 | 26 | 28 |
| Welding Speed (millimeter/ min) | 500 | 550 | 600 |

**Table 4: Orthogonal array-L9 & Combination of factors and levels for Experiments**

| 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 setup involved defining parameters and levels detailed in Table 3 to explore nine potential combinations of current, voltage, and welding speed. To facilitate this, the Taguchi-provided orthogonal array L9 was chosen, with the finalized matrix depicted in Table 4 for optimal experimental results. The experiments outlined in Table 4 were conducted to determine the most effective settings using the Taguchi method. Subsequently, nine samples were meticulously prepared, as shown in Figure 2, and subjected to welding utilizing the equipment displayed in Figure 1. Following welding, the samples underwent testing for ultimate tensile strength and hardness, adhering to ASME code standards, with response parameters for Minitab® 17.0's orthogonal array derived from these assessments. This led to the computation of the S/N ratio, a response table, and graphical representations

## 6. Results and Discussions

The analysis based on the Minitab-generated S/N ratio is showcased in Table 5. Laboratory data on ultimate tensile strength (UTS) and hardness (HBW) are fed into Minitab for determining the corresponding S/N ratios, demonstrated in Table 6 for UTS and Table 7 for HBW. Mean S/N values for related parameters can be located in the response tables. The delta value represents the disparity between the extreme values of a parameter, with higher delta values indicating greater importance. In the response table, parameters with the highest rankings signify increased significance in the analysis.

The outcomes are displayed in Tables 6 and 7. The findings in Table 6 indicate that speed holds the highest precedence with Rank 1, followed by voltage at Rank 2, and current at Rank 3 for ultimate tensile strength (UTS) evaluation. Similarly, for hardness (HBW), the most crucial parameters are current with Rank 1, followed by welding speed, and voltage with Rank 2 & 3.

**Table 5: Experimental Test Results - For UTS and HBW and its S/N ratio (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 | 300 | 24 | 500 | 574 | 55.1782 | 185 | 45.3434 |
| 2 | 1 | 2 | 2 | 300 | 26 | 550 | 603 | 55.6063 | 188 | 45.4832 |
| 3 | 1 | 3 | 3 | 300 | 28 | 600 | 600 | 55.5630 | 190 | 45.5751 |
| 4 | 2 | 1 | 2 | 325 | 24 | 550 | 583 | 55.3134 | 197 | 45.8893 |
| 5 | 2 | 2 | 3 | 325 | 26 | 600 | 603 | 55.6063 | 188 | 45.4832 |
| 6 | 2 | 3 | 1 | 325 | 28 | 500 | 585 | 55.3431 | 192 | 45.6660 |
| 7 | 3 | 1 | 3 | 350 | 24 | 600 | 607 | 55.6638 | 202 | 46.1070 |
| 8 | 3 | 2 | 1 | 350 | 26 | 500 | 593 | 55.4611 | 192 | 45.6660 |
| 9 | 3 | 3 | 2 | 350 | 28 | 550 | 605 | 55.6351 | 207 | 46.3194 |

**Table 6: For UTS - Signal to Noise Ratios Response Table**

| Level | CURRENT | VOLTAGE | SPEED |
|---|---|---|---|
| 1 | 55.45 | 55.39 | 55.33 |
| 2 | 55.42 | 55.56* | 55.52 |
| 3 | 55.59* | 55.51 | 55.61* |
| Delta | 0.17 | 0.17 | 0.28 |
| Rank | 3 | 2 | 1 |

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**Table 7: For HBW - Signal to Noise Ratios Response Table**

| Level | CURRENT | VOLTAGE | SPEED |
|---|---|---|---|
| 1 | 45.47 | 45.78 | 45.56 |
| 2 | 45.68 | 45.54 | 45.9* |
| 3 | 46.03* | 45.85* | 45.72 |
| Delta | 0.56 | 0.31 | 0.34 |
| Rank | 1 | 3 | 2 |

Figures 3 and 4 depict the S/N ratio for Ultimate Tensile Stress (UTS) and Hardness, respectively (HBW). When considering the three options for each variable, the parameter with the highest Mean of S/N ratio is selected. Once combined, these choices yield the best possible tier. The main effects plots provide a graphical representation of the response table.

Figure 3 illustrates that for UTS, current is optimal at level 3 (350), voltage at level 2 (26), and speed at level 3 (600), resulting in the ideal UTS configuration A3B2C3.

Similarly, in Figure 4, the highest values for HBW are current at level 3 (350), voltage at level 3 (28), and speed at level 2 (550), leading to the optimal HBW combination A3B3C2.

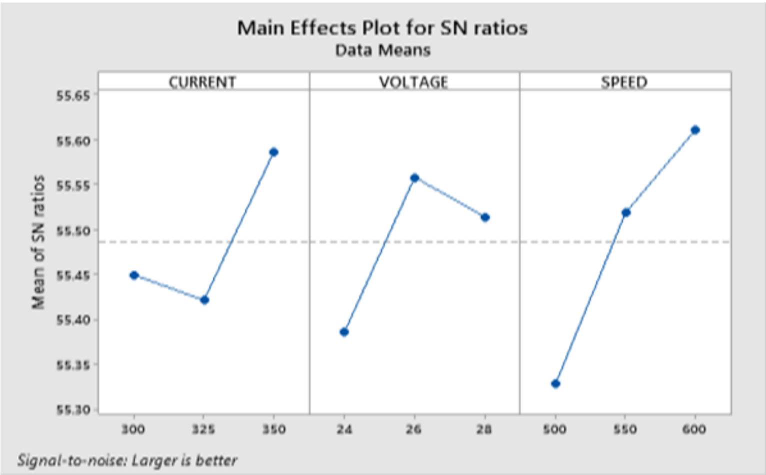


**Figure 3: For UTS - Response Graph: Main Effect Plot of *S/N* ratios**

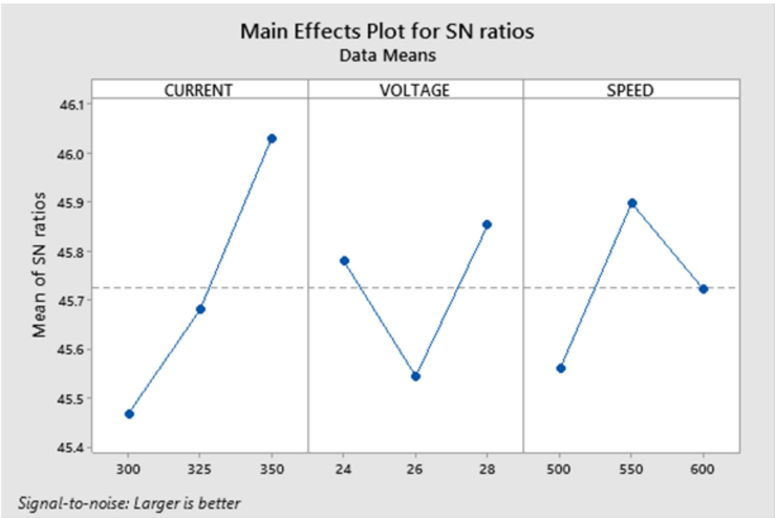


**Figure 4: For HBW - Response Graph: Main Effect Plot of *S/N* ratios**

## 7. Regression Analysis & ANOVA

A regression analysis serves to establish the mathematical connection between various performance metrics. Active involvement in the daily operation of the system is essential for its control. The primary objective of analyzing variance (ANOVA) is to identify the specific aspects of the welding process that have the greatest impact on the observed variations in performance. ANOVA enables the quantification of the individual contributions of diverse elements to the overall variability in the system's performance, encompassing the computation of the sum of squares, variance, and the relative influence of each factor.

**Table 8: For UTS: Analysis of Variance (case - without interaction)**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Regression | 3 | 804.0 | 74.06% | 804.0 | 268.00 | 4.76 | 0.063 |
| CURRENT | 1 | 130.7 | 12.04% | 130.7 | 130.67 | 2.32 | 0.188 |
| VOLTAGE | 1 | 112.7 | 10.38% | 112.7 | 112.67 | 2.00 | 0.216 |
| SPEED | 1 | 560.7 | 51.65% | 560.7 | 560.67 | 9.96 | 0.025 |
| Error | 5 | 281.6 | 25.94% | 281.6 | 56.31 | | |
| Total | 8 | 1085.6 | 100.00% | | | | |

**Regression Equation**

UTS = 371.4 + 0.187 CURRENT + 2.17 VOLTAGE + 0.1933 SPEED

**Table 9: For UTS: Analysis of Variance (case - with interaction)**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Regression | 6 | 818.29 | 75.38% | 818.286 | 136.381 | 1.02 | 0.572 |
| CURRENT | 1 | 130.67 | 12.04% | 0.829 | 0.829 | 0.01 | 0.944 |
| VOLTAGE | 1 | 112.67 | 10.38% | 0.670 | 0.670 | 0.01 | 0.950 |
| SPEED | 1 | 560.67 | 51.65% | 13.343 | 13.343 | 0.10 | 0.782 |
| CURRENT*VOLTAGE | 1 | 0.40 | 0.04% | 7.714 | 7.714 | 0.06 | 0.833 |
| CURRENT*SPEED | 1 | 0.17 | 0.02% | 4.667 | 4.667 | 0.03 | 0.869 |
| VOLTAGE*SPEED | 1 | 13.71 | 1.26% | 13.714 | 13.714 | 0.10 | 0.779 |
| Error | 2 | 267.27 | 24.62% | 267.270 | 133.635 | | |
| Total | 8 | 1085.56 | 100.00% | | | | |

**Regression Equation**

UTS = 51 - 0.34 CURRENT + 3.8 VOLTAGE + 1.63 SPEED + 0.051 CURRENT*VOLTAGE - 0.00160 CURRENT*SPEED - 0.034 VOLTAGE*SPEED

As presented in Table 8, the ANOVA outcomes concerning UTS in the absence of interaction highlight the predominant contribution of speed (51.65%), succeeded by current (12.04%) and voltage (10.38%). Conversely, Table 9 exhibits the ANOVA findings for UTS considering interaction effects, indicating similar percentage contributions for current, voltage, and speed as Table 8. However, Table 9 also incorporates the interaction among parameters, which notably impacts the quality parameters and makes a substantial percentage contribution. Consequently, the error rate in ANOVA without interaction stands at 25.94 percent, whereas the error rate in ANOVA with interaction decreases to 24.62 percent. Employing ANOVA with interaction enhances the precision and applicability of the resulting model and equation.

**Table 10 For HBW: Analysis of Variance (case - without interaction)**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Regression | 3 | 265.000 | 63.67% | 265.000 | 88.333 | 2.92 | 0.139 |
| CURRENT | 1 | 240.667 | 57.82% | 240.667 | 240.667 | 7.96 | 0.037 |
| VOLTAGE | 1 | 4.167 | 1.00% | 4.167 | 4.167 | 0.14 | 0.726 |
| SPEED | 1 | 20.167 | 4.85% | 20.167 | 20.167 | 0.67 | 0.451 |
| Error | 5 | 151.222 | 36.33% | 151.222 | 30.244 | | |
| Total | 8 | 416.222 | 100.00% | | | | |

**Regression Equation**

HBW = 80.1 + 0.2533 CURRENT + 0.42 VOLTAGE + 0.0367 SPEED

**Table 11 For HBW: Analysis of Variance (case - with interaction)**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Regression | 6 | 292.000 | 70.15% | 292.000 | 48.6667 | 0.78 | 0.655 |
| CURRENT | 1 | 240.667 | 57.82% | 13.981 | 13.9812 | 0.23 | 0.682 |
| VOLTAGE | 1 | 4.167 | 1.00% | 2.832 | 2.8321 | 0.05 | 0.851 |
| SPEED | 1 | 20.167 | 4.85% | 6.189 | 6.1894 | 0.10 | 0.782 |
| CURRENT*VOLTAGE | 1 | 12.100 | 2.91% | 0.214 | 0.2143 | 0.00 | 0.959 |
| CURRENT*SPEED | 1 | 13.376 | 3.21% | 12.595 | 12.5952 | 0.20 | 0.697 |
| VOLTAGE*SPEED | 1 | 1.524 | 0.37% | 1.524 | 1.5238 | 0.02 | 0.890 |
| Error | 2 | 124.222 | 29.85% | 124.222 | 62.1111 | | |
| Total | 8 | 416.222 | 100.00% | | | | |

**Regression Equation**

HBW = 755 - 1.39 CURRENT - 7.8 VOLTAGE - 1.11 SPEED + 0.009 CURRENT*VOLTAGE + 0.00263 CURRENT*SPEED + 0.0114 VOLTAGE*SPEED

In Table 10, the ANOVA analysis without interaction for HBW reveals that current makes the most significant contribution, accounting for 57.82%, followed by speed at 4.85% and voltage at 1%. Table 11 presents the ANOVA results with interaction where the percentage contributions for the parameters remain consistent. Furthermore, Table 11 illustrates the percentage contribution of the interacted parameters. Notably, the error percentage is lower when ANOVA is conducted with interaction (29.85%) compared to without interaction (36.33%).

**Table 12 For UTS: Comparison Experimental and Predicted values**

| 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 | 300 | 24 | 500 | 574 | 576.111 | 574.683 | 573.9975 | 55.1782 |
| 2 | 300 | 26 | 550 | 603 | 590.111 | 591.825 | 602.9968 | 55.6063 |
| 3 | 300 | 28 | 600 | 600 | 604.111 | 602.111 | 599.9983 | 55.5630 |

| 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 | |
| 4 | 325 | 24 | 550 | 583 | 590.444 | 591.444 | 583.0019 | 55.3134 |
| 5 | 325 | 26 | 600 | 603 | 604.444 | 605.730 | 602.9968 | 55.6063 |
| 6 | 325 | 28 | 500 | 585 | 589.444 | 590.587 | 584.9988 | 55.3431 |
| 7 | 350 | 24 | 600 | 607 | 604.778 | 604.206 | 607.0018 | 55.6638 |
| 8 | 350 | 26 | 500 | 593 | 589.778 | 588.778 | 593.0004 | 55.4611 |
| 9 | 350 | 28 | 550 | 605 | 603.778 | 603.254 | 603.635 | 55.6351 |

**Table 13 For HBW: Comparison Experimental and Predicted values**

| 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 | 300 | 24 | 500 | 185 | 184.444 | 186.873 | 185.223 | 45.3539 |
| 2 | 300 | 26 | 550 | 188 | 187.111 | 186.540 | 187.4325 | 45.4569 |
| 3 | 300 | 28 | 600 | 190 | 189.778 | 188.492 | 190.3444 | 45.5908 |
| 4 | 325 | 24 | 550 | 197 | 192.611 | 190.968 | 197.3558 | 45.9050 |
| 5 | 325 | 26 | 600 | 188 | 195.278 | 195.492 | 188.2283 | 45.4937 |
| 6 | 325 | 28 | 500 | 192 | 192.444 | 192.730 | 191.4212 | 45.6398 |
| 7 | 350 | 24 | 600 | 202 | 200.778 | 201.635 | 201.391 | 46.0808 |
| 8 | 350 | 26 | 500 | 192 | 197.944 | 195.016 | 192.3468 | 45.6817 |
| 9 | 350 | 28 | 550 | 207 | 200.611 | 203.254 | 207.2502 | 46.3299 |

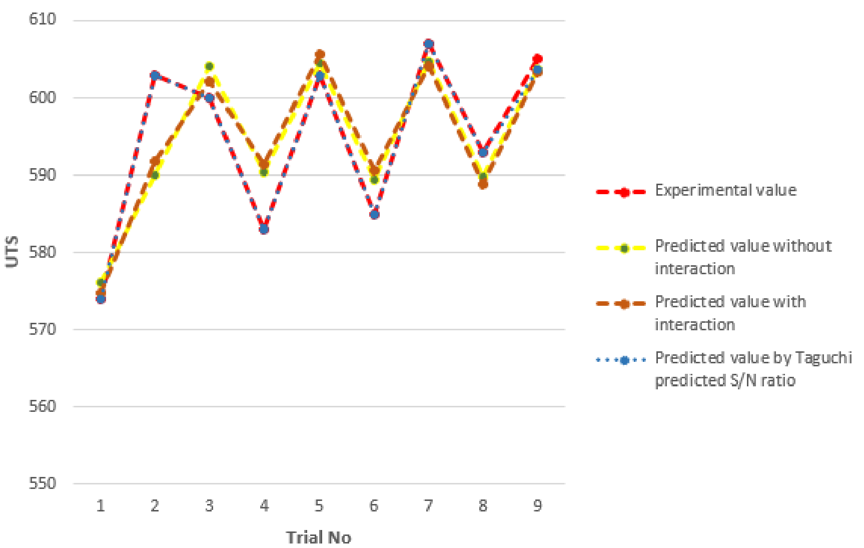


**Figure 5: Comparison Chart for Ultimate Tensile Strength (UTS): Experiment & Predicted Values**

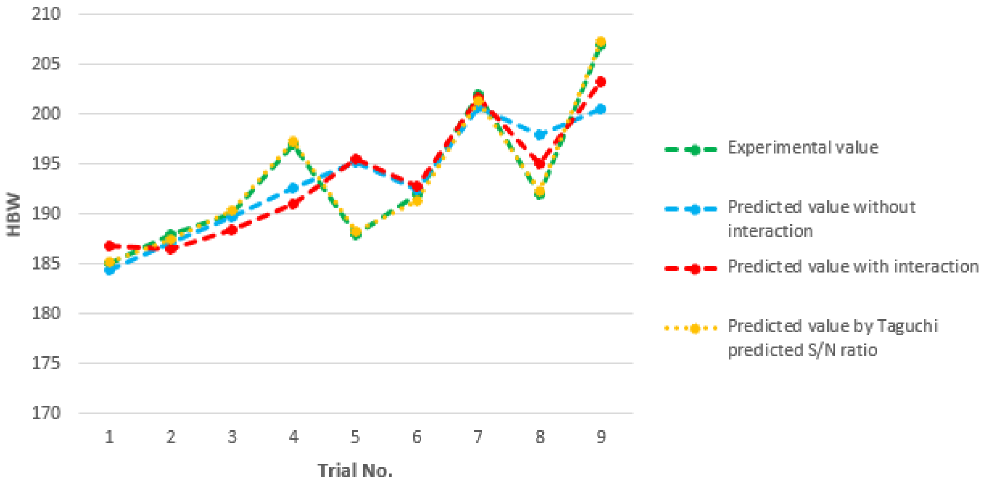


**Figure 6: Comparison Chart for Hardness (HBW): Experiment & Predicted Values**

In Tables 12 and 13, along with Figures 5 and 6, a close resemblance is evident between the experimental outcomes and the values predicted by the Taguchi – S/N ratio method. This highlights the impressive predictive ability of Minitab and the Taguchi method. Furthermore, the results of the regression analysis, especially when considering interaction effects, show a significant alignment with the experimental data. This underscores the importance and reliability of the regression equation established during the current study. The strong correlation observed between the anticipated outcomes through the Taguchi technique and the actual results further confirms the accuracy and validity of the regression equation's forecasts.

## 8. Confirmation Experiment

Analyzing the correlation between Ultimate Tensile Stress (UTS) and Hardness (HBW) can be achieved through Main Effect plots or a Response graph to identify the most effective combination. However, the L9 array does not explicitly consider this specific pairing. Therefore, it is essential to anticipate the performance of UTS and HBW for this optimal combination and validate the results using experimental data. In line with this approach, the methodology expressed earlier is utilized to carry out this experiment and confirm its findings. The results of this experiment, outlined in Tables 14 and 15, serve to validate our conclusions.

**Table 14 For UTS: Confirmation Experiment**

| | Initial Parameter | Optimum Parameter | |
|---|---|---|---|
| | | Prediction | Experiment |
| Combination | A2B2C2 | A3B2C3 | A3B2C3 |
| UTS | 597.441 | 615.4886 | 612 |
| S/N Ratio | 55.5259 | 55.7844 | 55.7350 |
| Improvement in S/N Ratio | 0.2091 | | |

**Table 15 For HBW: Confirmation Experiment**

| | Initial Parameter | Optimum Parameter | |
|---|---|---|---|
| | | Prediction | Experiment |
| Combination | A2B2C2 | A3B3C2 | A3B3C2 |
| HBW | 192.0702 | 207.2502 | 207 |
| S/N Ratio | 45.6692 | 46.3299 | 46.3194 |
| Improvement in S/N Ratio | 0.6502 | | |

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The Absolute Percentage deviation for UTS is calculated as follows;

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

%UTS = | (612-615.4886)/612 |

%UTS = 0.57 %

The Absolute Percentage deviation for HBW is calculated as follows;

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

%HBW = | (207-207.2502)/207 |

%HBW = 0.12 %

According to Table 14, the predicted S/N ratio for UTS is 0.0494 dB higher than the data obtained through experimentation. The difference between theoretical and empirical findings is 0.57%. The S/N ratio increases by 0.2091 dB when comparing the experimental parameter to the default setting. Table 14 shows that the predicted and experimental S/N ratios are identical. The S/N ratio for HBW in Table 15 was enhanced by 0.6502 dB, and the difference between the experimental and projected results was only 0.12%.

The comparison of Tables 14 and 15 reveals that the projected signal-to-noise (S/N) ratio closely aligns with the experimental S/N ratio, demonstrating the accuracy of the prediction. The results showcase the high level of precision in predicting the performance of UTS and HBW using the Taguchi method of statistical evaluation

## 9. Conclusions

This paper presents an experimental inquiry that was carried out to determine the ideal combination of process parameters for ultimate tensile strength and hardness using regression analysis and the Taguchi Method. The following conclusions can be made based on the aforementioned experiments.

1) The successful utilization of both the Taguchi Method and Regression Analysis with ANOVA has resulted in achieving the desired outcomes.
2) In UTS, speed takes precedence over voltage and current, while for hardness, current is the primary factor, followed by welding speed and voltage in comparison.
3) The best combination for Ultimate Tensile Strength (UTS) is A3B2C3, while the best combination for Hardness Brinell (HBW) is A3B3C2.
4) Compared to regression analysis without interaction, regression analysis with interaction shows better agreement with experimental data.
5) There is a strong correlation between the regression equations and the predicted Taguchi technique outputs.
6) There is a minimal percentage deviation between predicted and experimental values for UTS and hardness.

## 10. Declarations

**Ethics approval and consent to participate:** Not Applicable

**Consent for publication:** Not Applicable

**Availability of data and materials:** This article contains all of the data created or analyzed during this investigation.

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**Competing interests:** "The authors declare that they have no competing interests"

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