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OPTIMIZATION OF GMAW AND GTAW PARAMETERS TO IMPROVE TENSILE STRENGTH OF WELDED JOINTS OF A36 STEEL PLATE

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ABSTRACT: Achieving high-quality welds is essential for structural integrity in the manufacturing and construction industries. This study investigates the optimization of Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) parameters for A36 steel plates, using the Taguchi Method to assess the effects of different shielding gas compositions, including the unconventional use of Argon mixed with active gases in GTAW. Welding specifications provide safe parameter ranges, but these may not reflect optimal conditions for specific materials or processes. This highlights the need for optimization studies to identify the best parameter settings. Shielding gas composition, welding current, and root gap were evaluated as independent factors, with tensile strength as the response variable. An L9 orthogonal array was utilized to design the experiments, requiring 45 tensile test observations for robust statistical analysis. Specimens were welded using shielding gases of Ar with 10% CO_2, Ar with 5% O_2, 100% Ar, and 100% CO_2 and subjected to tensile strength tests. Signal-to-Noise (S/N) ratio analysis identified the optimal parameters as 100% CO_2, 140 A, and a 2.5 mm root gap for GMAW; and Ar with 10% CO_2, 120 A, and a 2.5 mm root gap for GTAW. Regression analysis confirmed that shielding gas and current significantly influence tensile strength, with ANOVA showing shielding gas as the most critical factor. The use of mixed shielding gases with active components in GTAW notably enhanced tensile strength, suggesting potential for both performance improvement and economic viability in industrial applications once it becomes more accessible.

Keywords: Gas Metal Arc Welding, Gas Tungsten Arc Welding, Taguchi Method, Regression Analysis

1. INTRODUCTION

Welding is a fundamental technique in the fabrication and construction industries, enabling the efficient joining of materials for various applications. In the Philippines, welding is extensively utilized across various sectors, particularly those involving metals. Among these materials, mild steel (A36 steel) is recognized for its versatility, affordability, and mechanical properties, making it the predominant material in structural engineering applications [1]. For joining mild steel, Gas Metal Arc Welding (GMAW), commonly known as MIG welding, is widely employed, particularly in structural steel fabrication, due to its cost-effectiveness and superior weld quality [2]. While Gas Tungsten Arc Welding (GTAW), commonly known as TIG welding, is preferred for various applications due to its ability to produce precise and high-quality welds, despite being a slower process compared to GMAW [3]. While welded connections play a vital role in structural engineering, offering several advantages, they also pose challenges [4]. Achieving optimal weld quality requires understanding the mechanical behavior of welded joints and recognizing the importance of welding parameters to maximize benefits while mitigating risks.

Previous studies have focused on optimizing various welding parameters for mild steel and similar materials using both GMAW and GTAW processes to improve weld quality and mechanical properties. One study optimized GTAW parameters—base metal thickness, welding current, and welding speed —on S235JR steel under EN 10025, comparable to ASTM A36 steel. The response S/N ratio and mean results revealed that base metal thickness had the most significant effect on tensile strength, followed by welding current, with welding speed having the least effect. Accordingly, the present study followed the recommendation to utilize a lower welding current to enhance the tensile strength of mild steel welds produced through GTAW [5].

Another study optimized GMAW welding parameters on mild steel using the Response Surface Methodology, examining factors such as current, voltage, and travel speed. 27 experimental trials were conducted, identifying welding current as the most significant parameter affecting tensile strength. Increasing the current up to an optimal level led to higher tensile strength; however, excessive current caused a decline in strength [6].

Another study focused on optimizing GMAW parameters for IS2062 mild steel, identifying welding current, voltage, and shielding gas as key variables.

The optimal welding parameters for achieving maximum tensile strength were a welding current of 120 Amps, a voltage of 24V, and a shielding gas composition of Ar+20% CO_2. ANOVA analysis confirmed that shielding gas and welding current had the most significant impact on tensile strength [7].

These studies highlight the importance of optimizing welding parameters. However, there is limited research on the combined effects of welding parameters on mild steel, particularly in local contexts like the Philippines. While welding guidelines offer safe parameter ranges, these specifications may not reflect optimal settings for specific materials or joint configurations, highlighting the need for studies that optimize parameters to improve weld quality and performance. Additionally, GTAW conventionally employs inert gases to prevent contamination. As a result, making use of active gases in GTAW is an uncommon approach. This research aims to determine the optimal welding parameters for A36 steel using the Taguchi Method, focusing on welding current, root gap, and shielding gas composition. By investigating the feasibility of using active gases in GTAW and assessing the combined effects of these parameters on the tensile strength, this study addresses these gaps and provides practical insights to optimize welding processes suited locally.

The Taguchi Methodology, adapted from the general steps outlined in the literature [8] was employed to investigate the effects of varying welding parameters on the mechanical properties of ASTM A36 steel weldments. Known for its efficiency, the Taguchi approach enhances product and process robustness by minimizing variation-causing factors without completely eliminating them. A schematic diagram of the methodology is shown in Fig. 1. By utilizing orthogonal arrays, the method enables simultaneous evaluation of multiple factors with fewer trials, conserving both time and resources.

A study revealed that craftsmanship and durability are significant weaknesses in the welding fabrication industry, highlighting the need for welders to adopt new methods and techniques [9]. Since welding processes rely heavily on human judgment, optimizing parameters can lead to stronger and more efficient welds. This not only enhances product quality but also addresses gaps in current practices.

The paper is structured to first address the significance of optimizing welding processes, followed by an outline of the materials, instrumentation, and methodologies used in the study. It subsequently presents the results and statistical analysis, concluding with a discussion of the findings and their implications for welding optimization.

2. RESEARCH SIGNIFICANCE

This study contributes to welding optimization by examining the combined effects of welding current, root gap, and shielding gas composition on the tensile strength of A36 steel welds. In the Philippines, where GMAW and GTAW are widely used, welders often rely on pure Ar or CO_2 and depend on judgment within safe parameter ranges. The limited availability of mixed shielding gases and the prevalence of trial-and-error approaches underscore the need for optimization. This study systematically analyzes key parameters and provides locally relevant recommendations to improve weld strength, efficiency, and cost-effectiveness, supporting sustainable industrial growth in line with SDG 9.

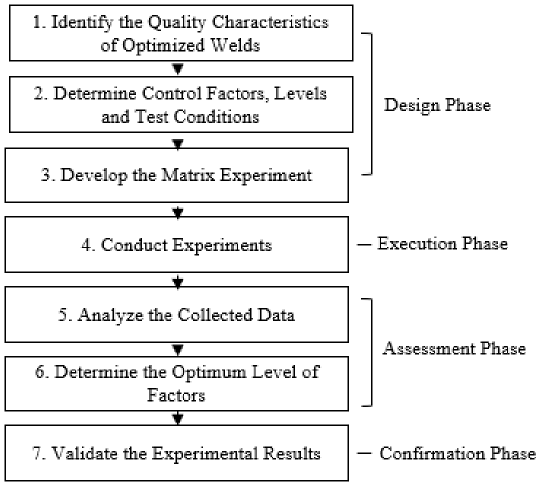


Fig. 1 Taguchi Methodology

3. MATERIALS AND METHODS

3.1 Materials

In this study, the analyzed plate is A36 steel, a material widely recognized for its excellent weldability and mechanical properties, making it a popular choice in structural applications. Commonly referred to as mild steel, it was introduced in the late 1800s and gained popularity in the early 1900s. It eventually replaced cast and wrought iron due to its superior reliability. With a carbon content ranging from 0.16% to 0.29%, ASTM A36 is both ductile and malleable, making it well-suited for processes such as grinding, punching, machining, and welding [10]. For this study, a 6 mm-thick A36 steel plate was used, and its chemical composition is provided in Table 1.

Table 1. Chemical Composition of A36 Steel Plate Used in the Study

Elements	C	Si	Mn	P	S
Weight %	0.18	0.15	0.38	0.019	0.020

The welding process was conducted using a YAMATEC MIG 200Y for GMAW and a GCE

ARControl 200 for GTAW. These machines were chosen due to their availability. GMAW utilized a 0.8 mm ER70s-6 wire, a standard size compatible with the machine, while GTAW required a 2.4 mm red-tipped tungsten electrode and a 2.4 mm ER70s-6 filler wire, both commonly available and suitable for the process.

3.2 Process Parameters

Welding quality depends on the precise adjustment of parameters, a concept often emphasized in studies about GMAW and GTAW processes. These parameters were selected based on preliminary trial experiments to identify feasible and effective combinations suited to the machine specifications and were guided by a certified welding professional. Relevant literature was also reviewed to ensure that chosen levels fall within commonly used and technically appropriate ranges for A36 steel using GMAW and GTAW processes. The selection of shielding gas levels in this study was guided by both performance and cost considerations. In GMAW, while pure CO_2 is the most economical option, Argon blends are used for their potential to improve arc stability and weld quality, which may justify the additional cost in applications requiring high joint performance [11]. In GTAW, blending Argon with small amounts of active gases presents a more cost-effective alternative, provided that arc stability and oxidation are properly managed [12]. Tables 2 and 3 compile the key process parameters examined in the study, including their respective levels.

Table 2. Welding Parameters for GMAW

Welding Parameter	Unit	Level 1	Level 2	Level 3
Shielding Gas	-	Ar + 10% CO_2	100% CO_2	Ar + 5% O_2
Welding Current	Amps	140	150	160
Root Gap	mm	1.5	2	2.5

Table 3. Welding Parameters for GTAW

Welding Parameter	Unit	Level 1	Level 2	Level 3
Shielding Gas	-	Ar + 10% CO_2	100% Ar	Ar + 5% O_2
Welding Current	Amps	120	130	140
Root Gap	mm	1.5	2	2.5

3.3 Experimentation

3.3.1 Experimental Design

The Taguchi Methodology is utilized to optimize GMAW and GTAW welding parameters due to its ability to enhance quality by minimizing the impact of variations. Test coupons, shown in Fig. 2 (300 mm × 250 mm × 6 mm), were prepared from a commercial-sized plate, with one side beveled to form a single V-groove per AWS standards (Fig. 3).

Fig. 2 Actual Unwelded Test Coupon with V-groove Butt Joint

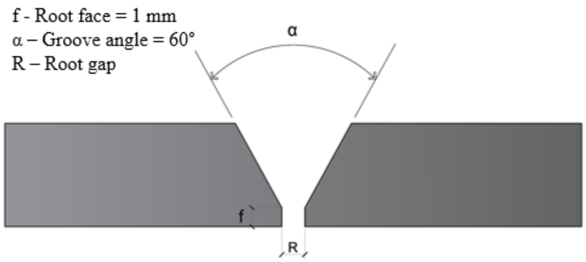


Fig. 3 Single V-groove Butt Weld Joint

Using Taguchi's orthogonal array, the formula used to determine the minimum number of experiments is:

$$NE = NP(NL - 1) + 1 \quad (1)$$

Where: NE is the number of experiments, NP is the number of parameters, and NL is the number of levels.

Given that there are three parameters, each with three levels, the calculation is as follows:

NE = 3(3-1) +1 = 7 ≈ 9

The least possible orthogonal array that can be used is L9, requiring nine experiments. To ensure the specimens remained in position during welding, spot welding was performed first. Tables 4 and 5 show the L9 orthogonal arrays for GMAW and GTAW, while Fig. 4 illustrates a sample welded specimen. Post-welding, visual inspection, and dye penetrant testing were performed based on AWS D1.1/D1.1M criteria.

Table 4. L9 Orthogonal Array for Input Parameters of GMAW

Run No.	Shielding Gas	Current	Root Gap
L1	Ar + 10% CO_2	140	2.5
L2	Ar + 10% CO_2	150	2
L3	Ar + 10% CO_2	160	1.5
L4	100% CO_2	140	1.5
L5	100% CO_2	150	2.5
L6	100% CO_2	160	2
L7	Ar + 5% O_2	140	2
L8	Ar + 5% O_2	150	1.5
L9	Ar + 5% O_2	160	2.5

Table 5. L9 Orthogonal Array for Input Parameters of GTAW

Run No.	Shielding Gas	Current	Root Gap
L1	Ar + 10% CO_2	120	2.5
L2	Ar + 10% CO_2	130	2
L3	Ar + 10% CO_2	140	1.5
L4	100% Ar	120	1.5
L5	100% Ar	130	2.5
L6	100% Ar	140	2
L7	Ar + 5% O_2	120	2
L8	Ar + 5% O_2	130	1.5
L9	Ar + 5% O_2	140	2.5

The workpieces were cut into a dog-bone shape with a single V-groove for tensile tests, and notches were prepared from the welded material to induce failure in the welded area [13]. Workpiece dimensions (in mm) are shown in Fig. 5.

Fig. 4 Actual Welded Specimen

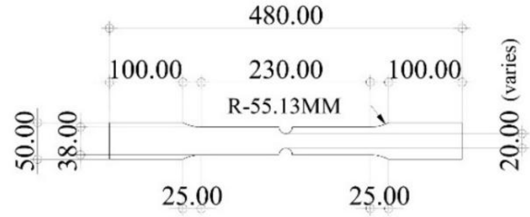
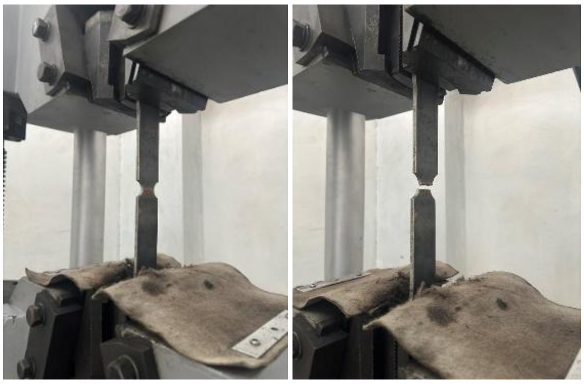


Fig. 5 Workpiece Dimension

3.3.2 Response Variable

For each combination of the L9 orthogonal array, five identical samples will be produced. In total, 45 test samples will be generated for each welding process. This resulted in an overall count of 90 test coupons to be welded and tested for tensile strength. The testing will be conducted using a universal testing machine (UTM). Figure 6 illustrates the tensile specimen before and after testing.



(a) (b)

Fig. 6 Condition of Tensile Specimen: (a) before testing and (b) after testing

3.3.3 Optimization, Evaluation, and Validation

To optimize results, the Taguchi process employs a statistical metric known as the S/N ratio. This ratio distinguishes desirable output characteristic values (signal) from undesirable ones (noise). The S/N ratio considers variations in data responses and the proximity of response averages to the predetermined target value. Typically, qualities such as ultimate tensile strength in welded specimens fall into the larger-the-better category. As a result, the most favorable setting for the process parameters corresponds to the value that yields the highest S/N ratio [8].

$$S/_N\, ratio = -10 \cdot log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

Where y represents the responses for a given combination of factor levels, and n represents the number of responses in that combination.

Regression analysis will be used to evaluate the results, as it is a widely recognized approach for assessing how multiple independent variables influence mechanical properties. One study examined the relationship between compressive strength, unit weight, and other factors on the modulus of elasticity of concrete with coal bottom ash, highlighting the effectiveness of regression modeling in material studies [14]. Similarly, this study applies regression analysis to investigate the effects of shielding gas, welding current, and root gap on the tensile strength of A36 steel welds.

ANOVA will be performed to validate the findings from the regression analysis. This statistical approach determines whether these factors influence tensile strength independently or through interaction, providing a more comprehensive evaluation of their overall impact.

4. RESULTS AND DISCUSSION

4.1 Experimental Results

Tables 6 and 7 summarize GMAW and GTAW tensile strength results, highlighting the effects of shielding gas compositions, current, and root gaps on weld strength.

GMAW produced a maximum tensile strength of 535.53 MPa using 100% CO_2, 140 A, and a 1.5 mm root gap. In contrast, GTAW achieved 575.45 MPa with Ar + 10% CO_2, 120 A, and a 2.5 mm root gap. While the use of Ar + 10% CO_2 in GTAW is unconventional, the results of this study suggest that the controlled addition of an active gas can lead to improved mechanical strength. Similar effects have been observed in a previous study, where small percentages of CO_2 mixed with Ar contributed to stronger welds in stainless steel [12]. These findings highlight the potential of active gas mixtures as viable alternatives to inert gases in GTAW applications.

4.2 Signal-to-Noise (S/N) Ratio in the Taguchi Method

The S/N ratio is a fundamental component of the Taguchi method, aimed at optimizing processes by minimizing the impact of uncontrollable factors. It identifies settings that maintain consistent performance despite variations in noise factors such as machine type, environmental conditions, or operator skill, ensuring the process remains robust and dependable without requiring complete control over each noise factor [8].

Table 6. Tensile Strength for GMAW Specimens

Exp. No	Shielding Gas	Shielding Gas Code	Current	Root Gap	Average Tensile Stress (MPa)	Standard Deviation	95% Confidence Intervals
L1	Ar + 10% CO_2	1	140	2.5	506.67	36.99	45.93
L2	Ar + 10% CO_2	1	150	2	488.54	29.67	36.84
L3	Ar + 10% CO_2	1	160	1.5	448.35	14.09	17.50
L4	100% CO_2	2	140	1.5	535.53	27.90	34.65
L5	100% CO_2	2	150	2.5	519.11	24.41	30.31
L6	100% CO_2	2	160	2	516.65	23.18	28.79
L7	Ar + 5% O_2	3	140	2	518.18	28.65	35.57
L8	Ar + 5% O_2	3	150	1.5	507.58	31.69	39.35
L9	Ar + 5% O_2	3	160	2.5	523.08	30.27	37.58

Table 7. Tensile Strength for GTAW Specimens

Exp. No	Shielding Gas	Shielding Gas Code	Current	Root Gap	Average Tensile Stress (MPa)	Standard Deviation	95% Confidence Intervals
L1	Ar + 10% CO_2	1	120	2.5	575.45	5.98	7.42
L2	Ar + 10% CO_2	1	130	2	560.04	19.88	24.68
L3	Ar + 10% CO_2	1	140	1.5	547.62	9.72	12.07
L4	100% Ar	2	120	1.5	580.99	11.35	14.09
L5	100% Ar	2	130	2.5	553.94	8.62	10.71
L6	100% Ar	2	140	2	538.33	22.52	27.96
L7	Ar + 5% O_2	3	120	2	513.18	33.97	42.18
L8	Ar + 5% O_2	3	130	1.5	512.97	30.47	48.49
L9	Ar + 5% O_2	3	140	2.5	522.22	10.35	12.85

The highest S/N ratio values are considered optimal for each parameter in the 'Larger-the-Better' category. Based on the ranking of factors, shielding gas has the most significant influence on tensile strength, followed by welding current and root gap. From the results of GMAW, the optimal parameters are pure carbon dioxide for the shielding gas, 140 amps for current, and a 2.5 mm root gap, with S/N ratios of 54.36, 54.28, and 54.22, respectively. Pure CO_2 is the typical shielding gas used in actual GMAW applications due to its cost-effectiveness and ability to enhance penetration and increase weld strength. Additionally, a reduced current setting is considered more effective, aligning with previous research that shows reducing welding current can significantly improve tensile strength and hardness [6].

For GTAW, similarly, shielding gas ranked first among the variables considered to have the most impact, followed by current and root gap. The optimal parameters are Ar with 10% CO_2 as the shielding gas, 120 amps for current, and a 2.5 mm root gap, with S/N ratios of 54.97, 54.88, and 54.81, respectively. While the presence of CO_2 in GTAW shielding gas is not typical, the results show that it produces a stronger weld. A lower current of 120 amps is preferred in GTAW to maintain precision and reduce excessive heat input. This is consistent with findings from a previous study, which reported that reduced current levels led to higher tensile strength and improved mechanical properties in mild steel [5].

Tables 8 and 9 present the S/N ratio and mean response tables for GMAW and GTAW, respectively. Figures 7 and 8 show the S/N ratio graphs and main effect plots, illustrating the influence of each factor level. Both plots follow a similar trend, confirming the consistency of the optimal parameters from Taguchi analysis.

Table 8. Response Table for Signal-to-Noise Ratios (Large is better) and for Mean of GMAW

Parameter	Level 1	Level 2	Level 3	Delta	Rank
Shielding Gas	S/N: 53.60 Mean: 481.2	S/N: 54.36 Mean: 523.8	S/N: 54.22 Mean: 516.3	S/N: 0.76 Mean: 42.6	1
Current	S/N: 54.28 Mean: 520.1	S/N: 54.03 Mean: 505.1	S/N: 53.87 Mean: 496.0	S/N: 0.41 Mean: 24.1	2
Root Gap	S/N: 53.88 Mean: 497.2	S/N: 54.08 Mean: 507.8	S/N: 54.22 Mean: 516.3	S/N: 0.34 Mean: 19.1	3

Table 9. Response Table for Signal-to-Noise Ratios (Large is better) and for Mean of GTAW

Parameter	Level 1	Level 2	Level 3	Delta	Rank
Shielding Gas	S/N: 54.97 Mean: 561.0	S/N: 54.92 Mean: 557.8	S/N: 54.23 Mean: 516.1	S/N: 0.75 Mean: 44.9	1
Current	S/N: 54.88 Mean: 556.5	S/N: 54.66 Mean: 542.3	S/N: 54.57 Mean: 536.1	S/N: 0.31 Mean: 20.5	2
Root Gap	S/N: 54.74 Mean: 547.2	S/N: 54.57 Mean: 537.2	S/N: 54.81 Mean: 550.5	S/N: 0.23 Mean: 13.4	3

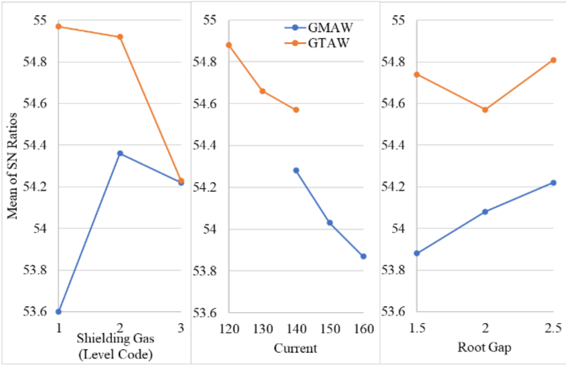


Fig. 7 Main Effect Plot for S/N Ratios of GMAW and GTAW Specimens

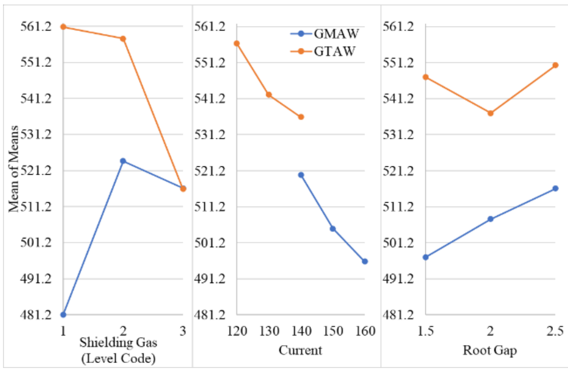


Fig. 8 Main Effect Plot for Means of GMAW and GTAW Specimens

4.3 Regression Analysis

4.3.1 Individual Effects of Three Independent Variables on Tensile Strength

Regression analysis was conducted to assess the impact of individual variables—shielding gas, current, and root gap—on tensile strength. The results are shown in Table 10. Shielding gas significantly influences tensile strength, while current and root gap are not statistically significant (p-values > 0.05) in both welding techniques, suggesting their influence on tensile strength is insufficient to support definitive conclusions. The R^2 values of 28.45% for GMAW and 47.50% for GTAW reflect the influence of shielding gas on tensile strength, with a significantly higher impact observed in the GTAW process. This observed difference aligns with findings from an existing study, where GTAW generally yielded higher tensile strengths compared to GMAW under similar shielding gas conditions [12]. While moderate, these R^2 values are consistent with trends observed across various materials.

4.3.2 Combined Effect of Three Independent Variables on Tensile Strength

An initial regression analysis was conducted for both GMAW and GTAW using shielding gas, current, and root gap as predictors. Results showed that the root gap was not statistically significant (p-value = 0.071 for GMAW and p-value = 0.674 for GTAW), exceeding the 0.05 threshold, and was therefore excluded from the final model. In contrast, shielding gas and current were significant (p-value = 0.00 for shielding gas in both processes; p-value = 0.03 and 0.01 for current in GMAW and GTAW, respectively). A second regression analysis was then performed, focusing only on these variables. Table 11 presents the results, while Eqs. (3)– (8) provide the regression models for tensile strength. In this analysis, shielding gas was treated as a categorical variable and current as continuous, resulting in separate equations for each gas type to account for their specific effects on tensile strength.

Although the root gap was not statistically significant, the consistent identification of a 2.5 mm root gap in optimal settings through Taguchi S/N ratio analysis suggests its practical importance in achieving desirable weld quality. This aligns with an existing study, which shows that increasing root gap in TIG welding leads to deeper penetration and higher tensile strength, highlighting the significant influence of root gaps on weld quality [15].

Both regression models showed that shielding gas and current are significant factors at a 95% confidence level. However, the low R^2 of 36.45% for GMAW indicates that other variables not included in this model likely have a significant impact on weld strength. In contrast, GTAW showed a higher R^2 of 55.91%, indicating that the selected parameters explain over half of the variability in tensile strength. The models were developed using a broadly aligned methodological framework to ensure comparability, and the observed difference in performance is likely influenced by inherent physical differences between the GTAW and GMAW processes. Expanding the design could enhance predictive capability, especially for the GMAW process. The models provide a preliminary framework for comparing process behavior and guiding future improvements.

To explore potential parameter synergies, post hoc regression models were developed, each including one interaction term alongside the main effects. All interactions (shielding gas × root gap, shielding gas × current, root gap × current) were statistically insignificant (p > 0.05), showing that tensile strength is predominantly affected by main effects.

Regression Equation for GMAW
Shielding Gas:

$$1 \quad Tensile\ Stress\ (MPa) = 661.9 - 1.205\ Current \quad (3)$$

$$2 \quad Tensile\ Stress\ (MPa) = 704.5 - 1.205\ Current \quad (4)$$

$$3 \quad Tensile\ Stress\ (MPa) = 697.0 - 1.205\ Current \quad (5)$$

Regression Equation for GTAW
Shielding Gas:

$$1 \quad Tensile\ Stress\ (MPa) = 694.2 - 1.024\ Current \quad (6)$$

$$2 \quad Tensile\ Stress\ (MPa) = 690.9 - 1.024\ Current \quad (7)$$

$$3 \quad Tensile\ Stress\ (MPa) = 649.5 - 1.024\ Current \quad (8)$$

Table 10. Regression Analysis: Effect of Individual Variables on Tensile Strength

Welding Technique	Variables	R-squared (%)	Adjusted R-squared (%)	F-value	P-value
GMAW	Shielding Gas	28.45	25.04	8.35	0.00
	Current	7.99	5.85	3.74	0.06
	Root Gap	5.04	2.83	2.28	0.14
GTAW	Shielding Gas	47.50	44.94	18.55	0.00
	Current	8.41	6.23	3.86	0.06
	Root Gap	0.03	0.00	0.01	0.91

Table 11. Regression Analysis: Combined Effect of Variables on Tensile Strength

GMAW		GTAW	
Factor	Result	Factor	Result
Significant Factors	Shielding Gas (p-value = 0.001) Current (p-value = 0.028)	Significant Factors	Shielding Gas (p-value = 0.000) Current (p-value = 0.009)
Model Fit	R^2 = 36.45% Adjusted R^2 = 31.79% Predicted R^2 = 23.23%	Model Fit	R^2 = 55.91% Adjusted R^2 = 52.60% Predicted R^2 = 46.33%
ANOVA	Overall model: F-value = 7.84, p-value = 0.000 Contribution of predictors: Shielding Gas: F-value = 9.18, p-value = 0.001 Current: F-value = 5.16, p-value = 0.028	ANOVA	Overall model: F-value = 16.91, p-value = 0.000 Contribution of predictors: Shielding Gas: F-value = 21.55, p-value = 0.000 Current: F-value = 7.63, p-value = 0.009

Table 12. Two-Way ANOVA and Tukey's Comparison for GMAW and GTAW Tensile Strength

Two-Way ANOVA Results for GMAW			Two-Way ANOVA Results for GTAW		
Variable	F-value	P-value	Variable	F-value	P-value
Shielding Gas	9.83	0.000	Shielding Gas	24.42	0.000
Current	2.82	0.073	Current	4.52	0.018
Shielding Gas*Current	1.95	0.124	Shielding Gas*Current	2.45	0.064
R- squared	47.88%		R- squared	65.86%	
Adjusted R-squared	36.30%		Adjusted R-squared	58.06%	
Tukey Pairwise Comparisons for Shielding Gas			Tukey Pairwise Comparisons for Shielding Gas		
Shielding Gas	Mean	Group	Shielding Gas	Mean	Group
1 (Ar + 10% CO_2)	481.185	B	1 (Ar + 10% CO_2)	561.036	A
2 (100% CO_2)	523.766	A	2 (100% Ar)	557.756	A
3 (Ar + 5% O_2)	516.278	A	3 (Ar + 5% CO_2)	516.122	B
Current	Mean	Group	Current	Mean	Group
140	520.127	A	120	556.539	A
150	505.076	A	130	542.317	AB
160	496.027	A	140	536.058	B

4.4 Validation of Results Using Two-Way ANOVA

To confirm the results from the regression analysis, a two-way ANOVA was employed to analyze the individual and interaction effects of shielding gas and current, following a statistical approach used in the existing literature. The study demonstrated how two-way ANOVA effectively identified significant input variables influencing key mechanical properties, which guided the statistical methodology used in this investigation [16]. Results, as summarized in Table 12, show that for GMAW, shielding gas significantly affects tensile strength (p-value = 0.00), while the current alone and the interaction between shielding gas and current are not significant (p-value = 0.073 and p-value = 0.124, respectively). Tukey's comparisons show that 100% CO_2 and Ar + 5% O_2 produce similar tensile strengths, significantly higher than Ar + 10% CO_2. Current levels (140A, 150A, and 160A) show no significant differences.

For GTAW, shielding gas and current significantly affect tensile strength (p-value = 0.00 and p-value = 0.018), while their interaction is insignificant with a p-value equal to 0.064. Tukey's comparisons in Table 12 indicate that Ar + 10% CO_2 and 100% Ar produce similar, significantly stronger results than Ar + 5% CO_2. Tensile strength is highest at 120A, with 130A showing similar results, while 140A produces the lowest tensile strength, significantly different from both.

5. CONCLUSION

This study investigated the effects of shielding gas, current, and root gap on the tensile strength of A36 steel plates welded using GMAW and GTAW with a single V-groove configuration. Based on the findings, the following conclusions were made:

- For GMAW, the optimal parameters are 100%

CO_2, 140A, and a 2.5 mm root gap, with corresponding S/N ratios of 54.36, 54.28, and 54.22. For GTAW, Ar + 10% CO_2, 120A, and a 2.5 mm root gap yield the best results, with S/N ratios of 54.92, 54.88, and 54.81. GTAW consistently achieved higher tensile strength than GMAW.

- The most influential factor for tensile strength is shielding gas, followed by the current, as determined through Taguchi analysis and confirmed through regression analysis (p-values < 0.05). While the root gap is not statistically significant (p-value = 0.071 for GMAW and p-value = 0.674 for GTAW), its practical influence on weld quality should not be disregarded. Lower currents (140A for GMAW, 120A for GTAW) produced higher tensile strength, indicating that excessive heat at higher currents may reduce weld integrity.
- The study demonstrated that the use of an active gas (Ar + 10% CO_2) in GTAW is feasible and results in optimal weld performance (561 MPa), suggesting that the controlled introduction of active gas can improve mechanical properties without significantly compromising weld quality.
- The R-squared values (36.45% for GMAW and 55.91% for GTAW) indicate that there are other variables not accounted for in this study that could also be influencing the results. Future research may explore a broader range of shielding gas mixtures and other variables, such as travel speed, essential for calculating heat input. Moreover, while tensile strength is a fundamental metric for weld quality, further tests, such as impact and hardness tests, are recommended for a more comprehensive investigation of weld performance.

The application of active gas in GTAW challenges conventional norms and encourages further investigation into shielding gas compositions. The study highlights the practical benefits of adjusting process parameters to reduce trial and error, meet strength requirements, and achieve sound welds more reliably. Furthermore, identifying the key factors that influence weld strength helps practitioners improve parameter control, ultimately enhancing their technical skills.

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