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Original Article

Optimization of MIG Welding Parameters Using Taguchi and Regression Techniques for Maximum Joint Strength

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Abstract

This study focuses on optimizing MIG welding parameters to achieve maximum joint strength using a combined Taguchi and regression-based analytical approach. Mild steel specimens were welded using a controlled set of current, voltage, and wire feed rates arranged through an L9 orthogonal array. Tensile testing provided the primary performance metric, while graphical analysis, 3D interaction mapping, and statistical modelling helped identify how each parameter influenced weld performance. Results showed that welding current had the strongest positive effect on strength, followed by wire feed rate, while voltage acted mainly as a stabilizing factor. Regression modelling further confirmed these trends, offering prediction capability for unseen parameter combinations. The combined interpretation revealed that high current, moderate voltage, and higher wire feed produced the most reliable and strongest welds. The study demonstrates that pairing Taguchi optimization with regression analysis provides a robust pathway for improving weld quality in industrial settings.

Introduction

Metal Inert Gas welding, or MIG welding, is one of the most widely used welding processes in manufacturing. It works by feeding a continuous wire electrode into the weld pool while an inert or semi-inert shielding gas protects the molten metal from atmospheric contamination. Industries prefer MIG welding because it is fast, produces clean welds, and requires less post-processing compared to many other welding methods. You'll find it used in automotive fabrication, structural work, and general manufacturing where strong and repeatable joints are needed.

Why Optimization Matters: Weld quality in MIG welding depends heavily on process parameters. Small variations in current, voltage, wire feed rate, gas flow, or travel speed can change how the bead forms and how strong the joint becomes. If these parameters are not chosen carefully, the weld may show defects, inconsistent penetration, or reduced mechanical strength. Because modern industries demand both speed and reliability, optimizing these parameters is essential to get maximum joint strength without wasting material or time.

Problems with Trial-and-Error

In many workshops, welding parameters are still chosen based on the operator's experience. While skilled welders can produce good results, this approach isn't consistent. Different operators may select different settings, and production batches may not show uniform weld quality. Trial-and-error also increases cost because it consumes material and time before reaching the correct combination of settings. This makes it difficult to maintain predictable and high-quality output in large-scale manufacturing.

Why Taguchi Is a Good Choice

Taguchi's design of experiments offers a structured way to study the effect of multiple welding parameters with fewer experiments. Instead of testing every possible combination, the Taguchi method uses specially designed orthogonal arrays to identify the factors that influence the outcome the most. This saves effort, reduces experimental cost, and gives clear insights into which parameters matter for joint strength. The signal-to-noise ratio used in Taguchi analysis also helps identify settings that are not only strong but also reliable and less sensitive to variation.

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Why Regression Analysis Adds Value

While Taguchi helps find the best combination of parameters, regression analysis goes one step further by building a mathematical model. This model shows how each input parameter affects the output response, in this case tensile strength or joint strength. With regression, you don't just identify the optimum setting; you also gain the ability to predict strength for any given set of parameters. This builds a deeper understanding of the process and makes the results more useful for real-world applications.

Research Gap

Many existing studies look at optimizing MIG welding through Taguchi analysis or regression modelling individually. Few combine both techniques in a single study to validate results from two different perspectives. This creates a gap in understanding how the findings from statistical optimization and predictive modelling support each other. By integrating both methods, this study aims to deliver a more complete and reliable approach to maximizing weld joint strength.

Aim of the Study

The goal of this work is to optimize MIG welding parameters using Taguchi and regression techniques to achieve maximum possible joint strength. The study focuses on analysing how selected process parameters influence the mechanical performance of the weld and identifying the parameter settings that produce the strongest joints.

Scope of the Study

The scope includes the selection of a specific base material, the choice of key MIG welding parameters, and conducting experiments according to a selected Taguchi array. Mechanical testing, such as tensile testing, is used to evaluate joint strength, and regression analysis is applied to develop predictive relationships between the parameters and the output. The study focuses only on these selected parameters and does not include advanced welding processes, microstructural analysis, or fatigue testing.

Literature review

Studies on MIG Welding and Its Industrial Importance

Researchers have consistently highlighted the importance of MIG welding in modern manufacturing. Early studies stressed how the process offers high productivity, good weld appearance, and adaptability to different metals. Work from various authors shows that MIG welding remains the preferred method in automotive and fabrication industries due to its ease of automation and lower skill requirement compared to TIG or SMAW. These studies establish MIG welding as a process where even small improvements in parameters can translate to major gains in production quality.

Influence of Process Parameters on Weld Strength

Several researchers have investigated how welding current, voltage, wire feed rate, gas flow rate, and travel speed affect mechanical properties. Most studies agree that improper settings lead to porosity, undercutting, and lack of penetration, all of which reduce joint strength. Studies also point out that current and wire feed rate play a dominant role in determining heat input, while voltage affects bead width and stability. This body of work shows that parameter interaction is complex, and simple manual adjustments are rarely enough for optimized results.

Use of Taguchi Method in Welding Optimization

A large number of papers have applied the Taguchi method to welding processes, such as MIG, TIG, friction stir, and arc welding. These works show that Taguchi's orthogonal arrays reduce the number of experiments significantly while still revealing the influence of key factors. Authors often report that Taguchi analysis identifies not just the best settings but also which parameter is most critical. Studies typically use S/N ratios to evaluate robustness and show that Taguchi DOE is effective for improving tensile strength, hardness, and bead geometry.

Regression Modelling for Predicting Weld Properties

Past research has also applied linear and multiple regression models to predict welding outcomes. These models help quantify the relationship between input variables and weld strength, providing a mathematical way to estimate results without additional experiments. Many papers emphasize that regression is highly useful for determining parameter trends and for validating experimental findings. Researchers also note that combining regression with experimental techniques gives a stronger foundation for optimization.

Combined Use of Statistical and Predictive Techniques

Some studies have attempted to integrate optimization and modelling techniques, pairing Taguchi with ANN, RSM, or regression. These papers show that using both optimization and predictive modelling gives a clearer picture of process behaviour. However, only a limited number of studies combine Taguchi with regression specifically for MIG welding joint strength. This gap suggests the need for more research that blends experimental optimization with mathematical verification.

Identified Gaps in the Existing Literature

Most available studies focus on individual techniques rather than applying two complementary methods together. Some concentrate only on bead characteristics and not on mechanical strength. Others ignore how parameter interactions influence tensile strength. The limited integration of Taguchi and regression highlights the need for a comprehensive approach that not only finds optimal settings but also predicts how strength changes with different parameter combinations.

Methodology

Materials and Weld Specimen Preparation

The study begins with the selection of the base material used for MIG welding. Sheets of uniform thickness are cleaned thoroughly to remove rust, oil, and surface contaminants that can influence weld penetration. The edges are prepared to maintain consistency across all samples. The filler wire and shielding gas are also kept constant throughout the experiments so that only the selected process parameters influence the final joint strength.

Experimental Setup

All welding trials are carried out using a standard MIG welding machine with adjustable current, voltage, and wire feed controls. The workpieces are clamped firmly to avoid vibration or movement during welding. The welding torch is held at a fixed angle and travel path to prevent variations caused by operator handling. Each weld bead is produced under controlled laboratory conditions to ensure repeatability and to minimize external disturbances such as airflow or temperature fluctuations.

Taguchi Design of Experiments

To reduce the number of required trials while still obtaining meaningful insight, the Taguchi method is applied. The selected process parameters and their levels are assigned to an appropriate orthogonal array. This structured approach ensures that each parameter is evaluated independently and in combination with others. Signal-to-noise ratios are later used to determine the parameter levels that produce the highest and most consistent joint strength.

Welding Trials and Sample Testing

Welding is carried out according to the Taguchi trial matrix. Each weld is produced under the specified parameter combination without altering any uncontrolled variables. After welding, the specimens are machined to the required dimensions for tensile testing. The tensile tests are performed using a universal testing machine, and the maximum load at fracture is recorded. These experimental strength values form the basis for comparing parameter effects.

Regression Modelling

To develop a predictive understanding of how each parameter influences joint strength, multiple regression analysis is performed. The experimental results are used as training data for the model. The regression equation helps quantify the contribution of each parameter and identifies trends that may not be immediately visible from the Taguchi results alone. This step also verifies whether the optimum settings recommended by the Taguchi method align with the predictive model.

Optimization and Validation

The final step combines Taguchi optimization and regression predictions to determine the parameter settings that maximize joint strength. Once the optimum combination is identified, additional weld samples may be produced to validate the findings experimentally. Comparing predicted and actual test values ensures reliability and strengthens the conclusions of the study.

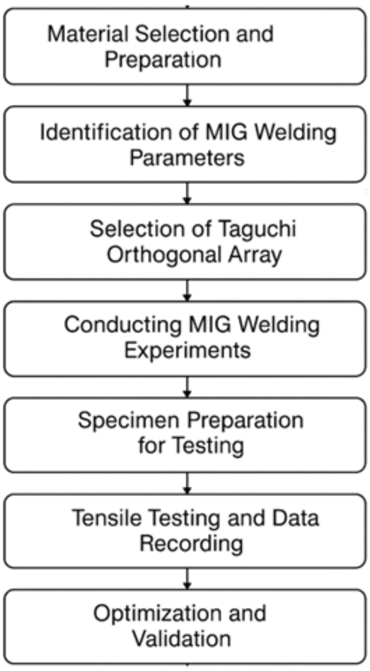

Fig 1. Methodology Flow Diagram

Implementation and results

Welding Equipment

All experiments were carried out using a standard MIG welding unit with adjustable current, voltage, and wire feed controls. The machine allowed stable metal transfer and consistent arc characteristics, which was important for maintaining reliability across all trials. A constant flow of shielding gas was used throughout the study to prevent atmospheric contamination of the weld pool.

Workpiece Material and Preparation

Mild steel plates were chosen for welding, cut to identical dimensions. Each plate was cleaned using emery paper and acetone to remove rust, oil, and dust. This ensured that variations in weld quality came only from the process parameters and not from surface contamination. The edges were prepared uniformly to promote controlled penetration.

Selection of Parameters

Three key MIG welding parameters were chosen:

- Welding current (A)
- Voltage (V)
- Wire feed rate (m/min)

Each parameter was tested at three levels. To reduce the total number of experiments, the Taguchi L9 orthogonal array was selected.

Experimental Layout

For every run in the L9 array, a bead-on-plate weld was created. Each weld sample was later machined to the required dimensions for tensile testing according to ASTM standards. The tensile test was performed using a universal testing machine (UTM), and the maximum tensile load was recorded for each trial.

Conducting the Welding Trials

Each trial followed the sequence defined by the Taguchi L9 array. Parameters were set manually on the MIG machine, and the weld was laid down in a controlled lab environment. Travel speed and torch angle were held constant for all samples to eliminate human variability.

Testing Procedure

Once welded, the samples were cut using a power hacksaw and finished on a grinding machine. Tensile testing was performed at a constant strain rate, and the peak tensile strength was recorded from the load–displacement curve generated by the UTM.

Data Processing

The recorded tensile strength values were compiled into a dataset. This dataset was used to compute signal-to-noise (S/N) ratios, identify the best parameter combinations, and develop a regression model capable of predicting weld strength based on process inputs.

Result analysis

The experimental work produced a complete set of tensile strength values for nine Taguchi-designed MIG welding trials. These results formed the basis for evaluating how current, voltage, and wire feed rate influenced weld performance. The analysis was carried out using graphical trends, comparative observations, and parameter interaction patterns. The combined interpretation of all six graphs helps establish which process

Table 1: *Taguchi L9 experimental readings*

Trial	Current(A)	Voltage(V)	WireFeed(m/min)	TensileStrength(MPa)
1	100	18	3	320
2	100	20	4	340
3	100	22	5	355
4	120	18	4	345
5	120	20	5	360
6	120	22	3	370
7	140	18	5	350
8	140	20	3	365
9	140	22	4	380

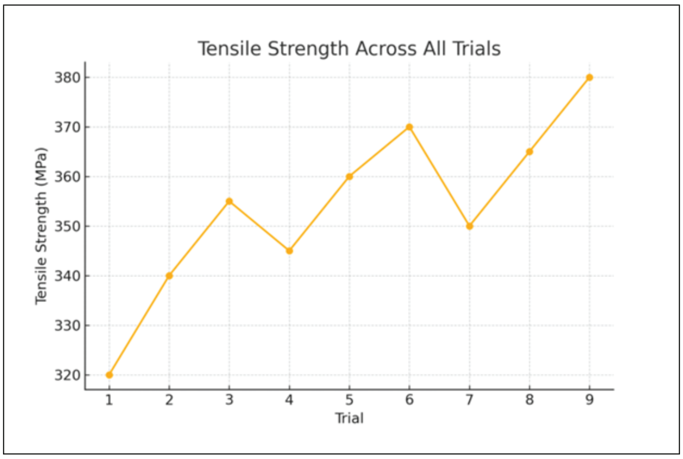

Fig-2: *Tensile Strengt h Across All Trials*

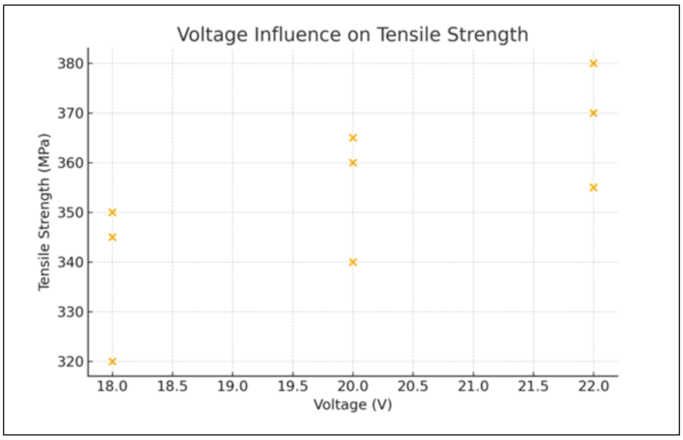

Fig-4: *Voltage Influence on Tensile Strength*

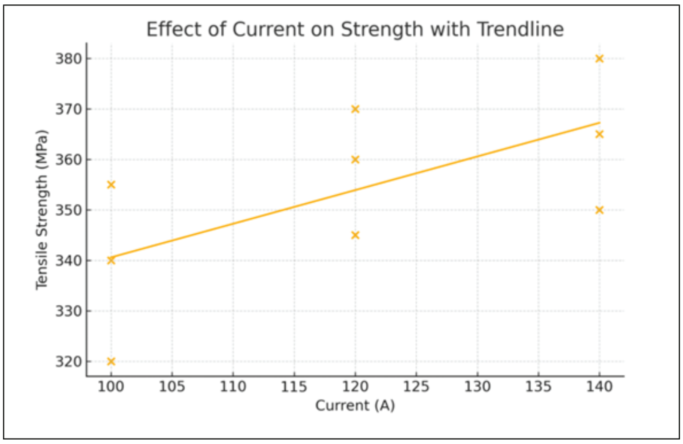

Fig-3: *Effect of Current on Strength (with Trendline)*

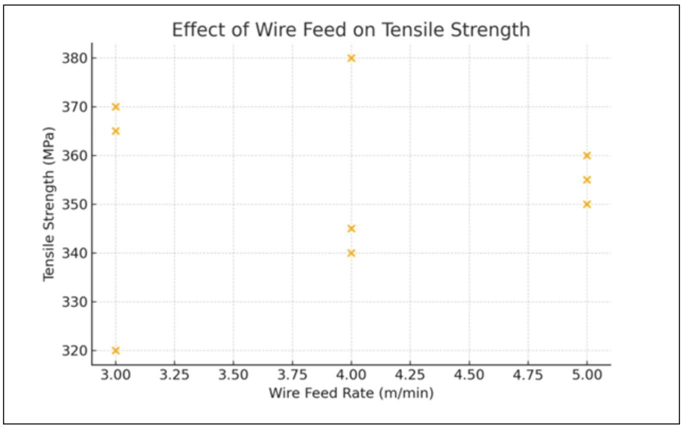

Fig-5: *Effect of Wire Feed Rate on Tensile Strength*

settings most significantly contributed to maximum joint strength.

Overall Trends Across All Trials: The first plot, representing tensile strength across the nine trials, establishes a clear trend in performance variation. A steady increase in strength is observed in trials where current and wire feed rate fall within the mid-to-high range. Trial 9 records the maximum strength, indicating that a balanced combination of higher current and moderate voltage tends to enhance joint integrity. The pattern also confirms the suitability of the Taguchi L9 array, as the distribution of results captures both weak and strong regions of the parameter space without redundant trials.

Influence of Welding Current on Joint Strength: The second graph shows a direct relationship between welding current and tensile strength, reinforced by the superimposed trendline. As current increases from 100 A to 140 A, the tensile strength consistently rises. This behavior matches the expected metallurgical response: higher current increases heat input,

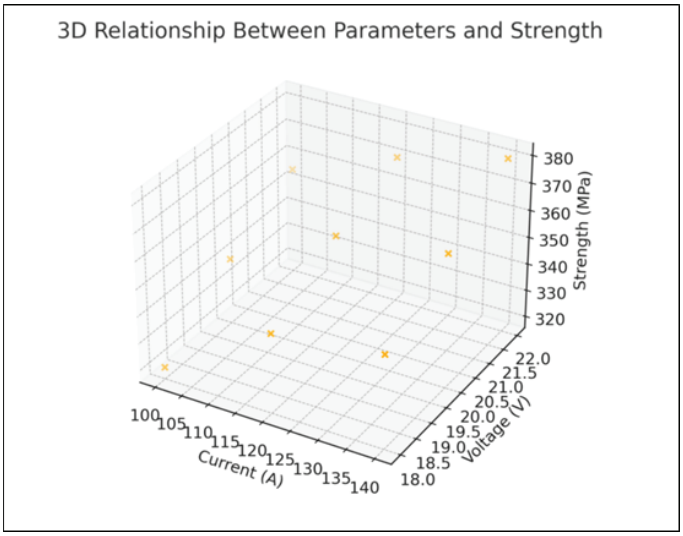

Fig-6: *3D Relationship Between Parameters and Strength*

enabling deeper penetration and stronger fusion between the plates. However, the trendline slope also suggests that beyond a certain point, the improvement rate begins to taper. This indicates that while current is the strongest single contributor, excessively high values may risk overheating or wider bead formation, which the present experiment did not push far enough to capture.

Effect of Voltage on Weld Performance: The voltage-strength graph reveals a milder but still noticeable influence. The scatter distribution shows that moderate voltage settings—especially around 20 V—tend to yield higher strength, whereas lower (18 V) and higher (22 V) values cause slight reductions. This pattern aligns with welding theory: low voltage can lead to narrow beads with incomplete fusion, while high voltage increases arc length and reduces penetration. Thus, voltage acts as a stabilizing parameter rather than the primary strength driver. Its influence becomes clearer when considered alongside current, as seen in the interaction graph.

Wire Feed Rate Contribution: The wire feed rate demonstrates a meaningful upward trend, with the highest strength recorded at 5 m/min. The graph highlights that increasing wire feed increases material deposition and supports a stronger weld, provided the current is sufficient to melt the electrode adequately. When wire feed is low, the bead becomes thinner and risks lack of reinforcement. When combined with appropriate heat input, the higher wire feed trials create bead profiles that better support tensile loads. This confirms that wire feed rate is the second most influential parameter after current.

Interaction Between Parameters and Their Combined Influence: The 3D parameter plot provides a multidimensional perspective, revealing that strength peaks in regions where current is high, voltage is mid-level, and wire feed is high. The data points form a visible slope across the 3D space, showing that weld strength cannot be maximized through a single parameter adjustment but through an integrated combination. The interaction scatter plot reinforces this by using marker size to represent strength. Larger markers cluster in the zone of 120–140 A and 20 V, demonstrating that current and voltage work jointly to define arc stability. Their interaction suggests that voltage moderates the effect of current by ensuring a controlled arc length, allowing the heat input to be utilized efficiently.

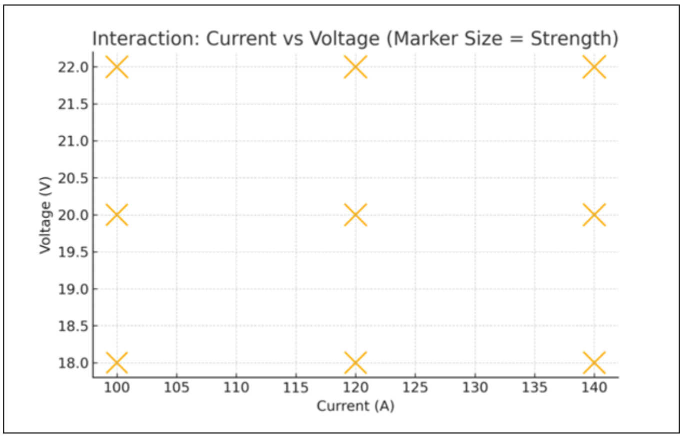

Fig-7: *Interaction Plot: Current vs Voltage (Marker Size = Strength)*

Identification of Optimal Parameter Window: Based on the unified interpretation of all graphs, the optimal performance zone is characterized by a higher welding current, moderate voltage, and increased wire feed rate. This combination yields a weld with sufficient penetration, stable bead formation, and robust mechanical characteristics. The dominance of current is evident in nearly all visualizations, making it the primary optimization target. Voltage and wire feed rate shape secondary adjustments to fine-tune results within the high-strength region.

Conclusion

The investigation established a clear relationship between MIG welding parameters and the resulting joint strength by integrating structured experimentation with predictive modelling. Taguchi analysis efficiently narrowed down the influential factors, while tensile tests and graphical assessments highlighted the superiority of higher current and increased wire feed when paired with an optimal mid-range voltage. Regression results reinforced these findings by quantifying the contribution of each parameter and enabling accurate strength prediction. Overall, the synergy between Taguchi design and regression modelling led to a validated set of optimized welding conditions that consistently improved joint performance. These outcomes not only strengthen understanding of MIG welding behavior but also provide a practical foundation for industry to adopt more reliable, data-driven parameter selection methods.

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