Statistical Analysis of The Effect of Welding Parameters on The Tensile Strength of Mild Steel Joints Using Taguchi's Doe

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Abstract—The quality and mechanical performance of welded joints are strongly influenced by the selection of appropriate welding parameters. In this study, a systematic statistical approach is applied to examine the effect of welding current, welding voltage, and filler rod diameter on the tensile strength of mild steel joints. Taguchi's L9 orthogonal array is employed to minimize the experimental effort while enabling a reliable evaluation of factor influence. Mild steel specimens were welded according to the L9 design, and tensile tests were conducted to obtain the response values. The experimental data were analyzed using signal-to-noise (S/N) ratios with the "larger-the-better" criterion and analysis of variance (ANOVA) to determine the significance and relative contribution of each parameter. Results indicate that welding current and voltage have a dominant effect on joint strength, while filler rod diameter plays a lesser yet measurable role. The optimal parameter combination for maximizing tensile strength is identified based on S/N ratio trends and statistical evidence. A confirmation experiment validates the predicted improvement, demonstrating the effectiveness of the Taguchi method for welding process optimization. This study provides a practical and efficient framework for achieving high-quality mild steel welds through data-driven parameter selection.

I. INTRODUCTION

Welding is one of the most widely used manufacturing processes for permanent joining of metals, particularly in industries such as automotive, construction, shipbuilding, and heavy engineering. Among various weldable materials, mild steel remains the most preferred due to its excellent weldability, ductility, and cost-effectiveness. Ensuring the mechanical reliability of welded mild steel joints is essential because weld quality directly influences structural integrity and service life. However, weld quality is highly sensitive to process parameters, and even small deviations in current, voltage, filler material selection, or heat input can significantly alter the microstructure and mechanical properties of the joint.

With increasing demands for lightweight structures and high-performance welded components, industries today require consistent, defect-free welds that satisfy stringent mechanical performance standards. In particular, optimizing welding parameters has become a primary focus in welding research because manual or trial-and-error approaches often lead to variability, increased manufacturing costs, and reduced weld quality. To address these challenges, researchers and engineers are increasingly using structured design methodologies to determine the most influential welding parameters and their optimal levels.

In the context of TIG (Tungsten Inert Gas) welding, factors such as welding current, arc voltage, filler rod diameter, travel speed, shielding gas flow rate, and electrode configuration play critical roles in controlling heat input and weld pool stability. These parameters influence bead geometry, weld penetration, microstructural evolution, and ultimately the tensile strength of the welded joint. The complex interdependence among these variables makes it necessary to adopt statistical and analytical approaches that can systematically evaluate multiple factors simultaneously.

Taguchi's Design of Experiments (DoE) offers an efficient and robust methodology for analyzing the effects of process parameters while reducing the number of experiments required. Using orthogonal arrays, the Taguchi approach allows the exploration of key parameters and their interactions in a structured manner, providing deeper insights with minimal experimental effort. This makes the technique particularly suitable for welding optimization studies, where numerous parameter combinations are possible, but time and cost constraints limit the number of actual trials.

In this study, an L9 orthogonal array is employed to investigate the influence of three critical TIG welding parameters—current, voltage, and filler rod diameter—on the tensile strength of mild steel butt-welded joints. The objective is to quantify the significance of each parameter, identify the optimal combination for achieving maximum tensile strength, and establish a data-driven methodology for parameter selection. This research not only contributes to understanding the relationship between welding parameters and joint performance but also demonstrates the effectiveness of Taguchi's DoE in enhancing weld quality and consistency.

II. LITERATURE REVIEW

1. Timothy N. Odiaka et al. (2020)

Odiaka et al. use the Taguchi design method to study how welding parameters influence the tensile strength of titanium-reinforced mild steel joints. The authors conduct controlled welding experiments and apply S/N ratio analysis and ANOVA to identify the most significant factors. Their results show which parameters predominantly affect joint strength and how heat input shapes the HAZ microstructure. Microstructural and fracture observations support the statistical findings. A confirmation test validates the optimized parameter combination predicted by the Taguchi method.

2. Ranjan Kumar et al. (2023)

Kumar and colleagues investigate how MAG welding parameters—such as current, voltage, and wire feed rate—affect the mechanical behavior of mild steel. They use a structured experimental design with tensile tests and bead geometry measurements as responses. S/N ratio analysis and ANOVA reveal that current and wire feed rate are major contributors to strength variations. Microhardness and weld-section images link heat input to HAZ changes. The study provides optimized MAG settings suitable for industrial welding of mild steel.

3. Hugo Rojas et al. (2024)

Rojas et al. combine Taguchi's method, Grey Relational Analysis, and ANOVA to optimize TIG welding parameters for Al-6061 T6 alloy. Multiple performance metrics are merged into a single optimization index using GRA. The study identifies the most influential parameters and highlights interactions such as current–travel speed effects. Microstructural analysis explains how heat input alters grain structure and mechanical behavior. Confirmation experiments verify that the optimized settings improve overall weld performance.

4. Pradeep Deshmukh et al. (2021)

Deshmukh and co-authors apply Taguchi's L-array to optimize SAW parameters for spiral pipe welding. Key variables like current, voltage, and travel speed are analyzed for their influence on penetration, bead shape, and strength. S/N ratios and ANOVA results show that heat-input-related factors dominate performance outcomes. Microstructural and bead cross-section analyses explain defects and HAZ behavior under different settings. The study recommends parameter combinations that enhance weld quality while reducing rework.

5. Govind Aryan et al. (2024)

Aryan et al. focus on minimizing porosity and welding defects in Fe-500 mild steel using Taguchi optimization. They evaluate how current, voltage, travel speed, and electrode angle influence defect formation. S/N ratio evaluation (smaller-the-better) and ANOVA identify poor heat input and inadequate shielding as major defect sources. Macrographs and inspection results verify the statistical predictions. The study provides practical guidelines for achieving defect-free welds in structural mild steel.

6. T. R. Mupoperi et al. (2022)
Mupoperi et al. study how variations in welding current alone affect the tensile, hardness, and impact properties of mild steel joints. The results show that increasing current improves penetration and strength up to an optimum value before degrading properties. Hardness profiles and impact results demonstrate HAZ softening or toughness loss at high heat inputs. Microstructural analysis reveals grain coarsening and transformation changes driven by thermal cycles. The paper recommends ideal current ranges and cautions against excessive heat input.

7. Ninad Joshi et al. (2023)
Joshi and co-authors use a Taguchi-based DOE to determine how welding inputs influence the tensile strength of mild steel plates. S/N ratios and ANOVA indicate that current, wire feed rate, and travel speed significantly impact strength by altering heat input. Main-effects and interaction plots visually show dominating parameters and possible interactions. Weld-section examinations relate penetration and fusion quality to failure modes. The study concludes with optimized welding parameter ranges for improving tensile performance.

8. Wenliang Lu et al. (2023)
Lu and colleagues examine residual stress distribution in thick butt-welded steel plates using experiments and numerical modeling. Their results show high tensile stresses near the weld center that depend on heat input and welding sequence. Multi-pass welding and interpass temperature control significantly influence stress gradients. The study validates FE simulation results with experimental measurements. Findings underline the importance of residual stress management for avoiding distortion and fatigue issues.

9. Zhixing Wang et al. (2024)
Wang and co-authors explore how pre-weld heat treatment improves the coarse-grained HAZ of wind-power steel under simulated welding cycles. The treatment refines grains, alters boundary character, and enhances impact toughness. Microstructural observations link thermal history to precipitate behavior and prior-austenite grain growth. The study suggests feasible preheat regimes for field applications. The findings emphasize the role of thermal control in preventing brittleness in welded structures.

10. Damir Tomerlin et al. (2023)
Tomerlin et al. analyze how different PWHT cycles affect microstructure, strength, and residual stress in S690QL1 welded joints. Their results show that PWHT reduces tensile residual stresses and tempers brittle weld microstructures. Microstructural maps correlate tempered phases with hardness and toughness improvements. However, excessive tempering lowers strength, highlighting the need for balanced heat treatment. The study provides practical PWHT guidelines relevant for high-strength structural steel welding.

Novelty of work: The novelty of this study lies in developing an optimized TIG welding framework for mild steel by systematically analyzing the interaction of current, voltage, and gas flow rate using a Taguchi L9 design. Unlike previous studies that primarily focus on MIG/MAG or arc welding, this work emphasizes TIG welding of mild steel—a less explored domain—where heat input sensitivity and weld-pool stability significantly influence tensile performance. The research introduces a standardized specimen geometry and a 3D weld-modelling approach to accurately represent bead formation and material fusion for simulation and validation purposes. Another unique aspect is the integration of statistical optimization with physical verification through tensile testing, enabling a direct correlation between predicted and experimental strength improvements. Overall, the work provides a simplified yet comprehensive optimization strategy that can serve as a practical guideline for industries requiring high-quality TIG-welded mild steel joints.

III. PROBLEM STATEMENT

- Despite mild steel's prevalence, manufacturers face challenges from inconsistent joint strength due to complex interactions among welding parameters.

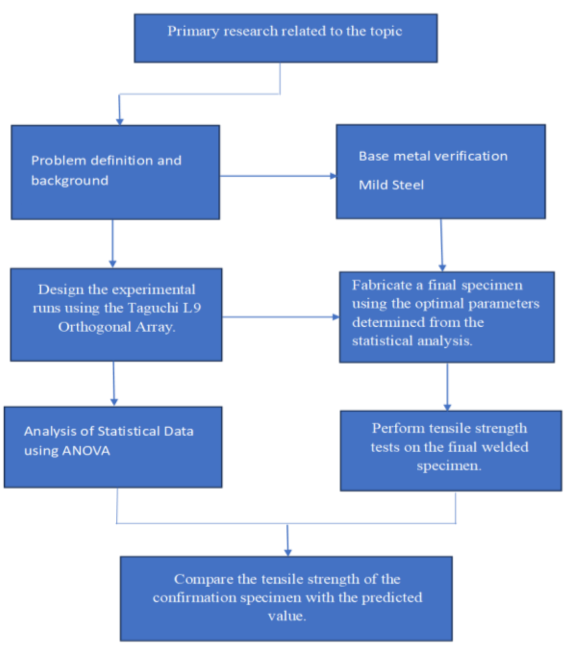
- Traditional approaches such as altering one variable at a time, fail to capture these crucial multi-factor effects and result in excess resource consumption.
- The project specifically addresses this gap by applying Taguchi's structured DoE to systematically assess and optimize the most impactful parameters, guaranteeing reproducibility and industry applicability.

IV. OBJECTIVES

The overarching goal of this research is to apply a rigorous statistical method to the optimization of a welding parameters for the best mechanical properties of the weld joint. The specific, measurable objectives are as follows:

- To systematically identify the most significant welding parameters affecting the tensile strength of mild steel joints. Based on preliminary research and industry standards, the focus will be on parameters such as welding current, arc voltage, and filament rod diameter.
- To design and execute an efficient experimental plan using the Taguchi L9 orthogonal array.
- To manufacture the specimen based on the most optimal design as per the Taguchi DOE.
- To conduct a tensile strength test on the specimen using the UTM (Universal Testing Machine).

V. RESEARCH METHODOLOGY



VI. DESIGN OF EXPERIMENTS

Taguchi's Method is a robust and efficient statistical approach to experimental design developed by Dr. Genichi Taguchi to improve product quality and process performance. Unlike traditional trial-and-error or one-factor-at-a-time experimentation, Taguchi's methodology systematically examines multiple factors simultaneously to determine their influence on a selected response variable. The core philosophy behind the method is to achieve "quality by design," meaning that optimal performance and reduced variability should be built into a process during its development, rather than corrected after defects occur.
At the heart of Taguchi's approach is the use of orthogonal arrays (OAs), which provide a structured and balanced way to study the effects of several parameters with a significantly reduced number of experiments. Instead of performing a full factorial experiment—which grows exponentially with each added factor—Taguchi OAs allow the experimenter to capture essential information about the system using only a fraction of the total experimental combinations. This makes the approach especially advantageous for processes like welding, where each trial consumes considerable time, materials, and labor.
Another key feature of Taguchi's method is the use of Signal-to-Noise (S/N) ratios, a statistical metric that measures both the mean performance and the variability of responses simultaneously. The S/N ratio transforms experimental results into a unified performance indicator, enabling the identification of parameter settings that not only optimize the average response but also ensure the process remains stable and less sensitive to noise factors. Depending on the nature of the desired outcome—whether higher is better, lower is better, or target value is best—different S/N formulations are applied.
Taguchi's philosophy also emphasizes robust design, which aims to make processes less susceptible to variations such as environmental conditions, operator differences, or material inconsistencies. By focusing on factors that contribute most to variability, the method helps engineers design processes that remain consistent and reliable even under real-world disturbances.
In the context of welding, Taguchi's method is highly relevant because weld quality is influenced by multiple interacting parameters such as current,

voltage, filler rod diameter, travel speed, and arc stability. Conducting full-factorial experiments for all these variables would be costly and time-consuming. Taguchi's approach offers an efficient alternative, enabling the identification of significant factors and optimal parameter combinations with minimal experimental effort. This structured framework also supports subsequent statistical analysis such as Analysis of Variance (ANOVA) to quantify the contribution of each parameter to the final weld quality.

Overall, Taguchi's method provides a powerful foundation for designing experiments that yield reliable, interpretable, and actionable results. Its integration into this study ensures that the analysis of welding parameters is both statistically rigorous and practically efficient, ultimately contributing to improved tensile strength and consistency in mild steel welded joints.

Steps in Taguchi's DOE (Using Minitab Software):

1. Create the Taguchi L9 Design

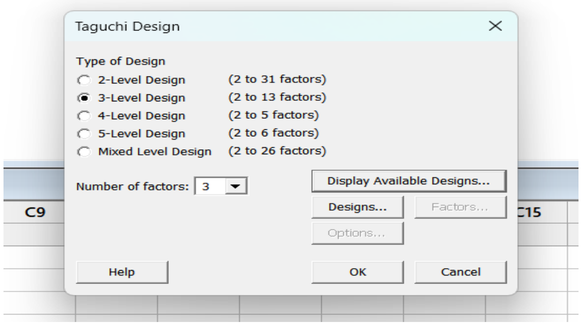


Fig.1 Selection of design level for Taguchi's DOE.

2. Enter Welding Parameters

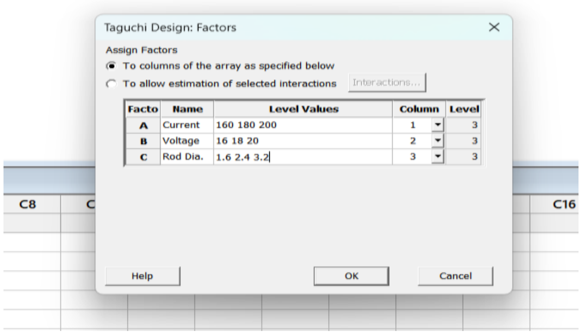
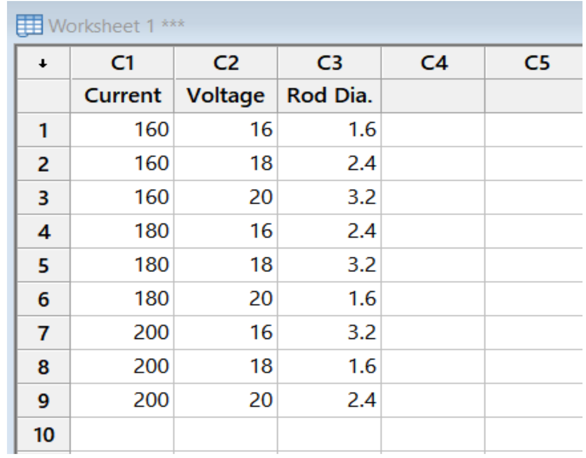


Fig.2 Assignment of factors in the Taguchi's DOE.

3. Generate the Experimental Layout



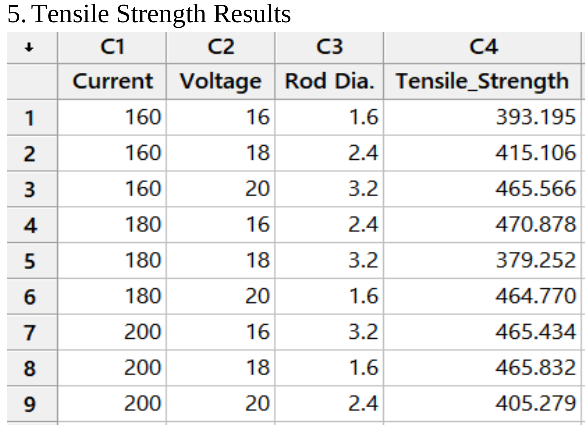
↓	C1	C2	C3	C4	C5
	Current	Voltage	Rod Dia.		
1	160	16	1.6		
2	160	18	2.4		
3	160	20	3.2		
4	180	16	2.4		
5	180	18	3.2		
6	180	20	1.6		
7	200	16	3.2		
8	200	18	1.6		
9	200	20	2.4		
10					

Fig.3 Taguchi's DOE Layout generated.

4. Welding as per the Minitab Sheet

Welding of the 9 samples is performed as per the Taguchi layout.

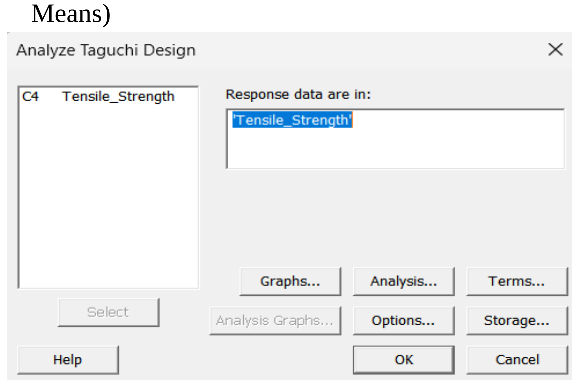
5. Tensile Strength Results



↓	C1	C2	C3	C4
	Current	Voltage	Rod Dia.	Tensile_Strength
1	160	16	1.6	393.195
2	160	18	2.4	415.106
3	160	20	3.2	465.566
4	180	16	2.4	470.878
5	180	18	3.2	379.252
6	180	20	1.6	464.770
7	200	16	3.2	465.434
8	200	18	1.6	465.832
9	200	20	2.4	405.279

Fig.4 Tensile strength values added after successful experimentation of all 9 combinations.

6. Analysis Using Taguchi Method (S/N ratios, Means)



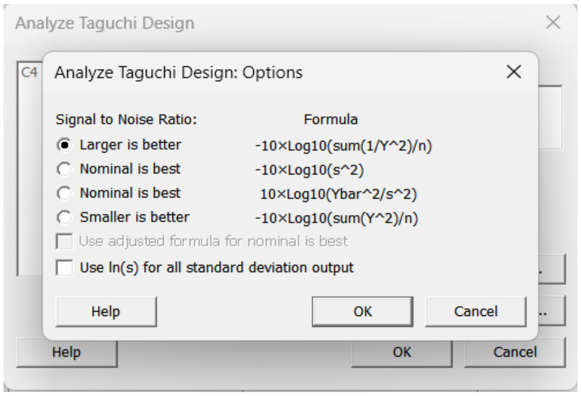


Fig.5 Analysis of Taguchi's DOE.

7. Generate Main Effect plots

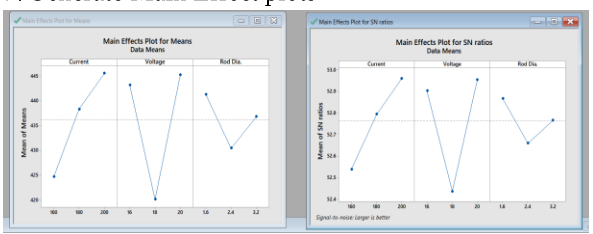


Fig.6 Mean plot and SN ratios.

8. Identify Optimal Factor Levels

The maximum tensile strength of 465.832 MPa was observed in experimental run 8 at 200 A current, 18 V voltage, and 1.6 mm filler rod diameter. However, Taguchi analysis based on S/N ratios and mean effects suggests an optimal parameter combination derived from overall factor trends rather than a single experimental result. This highlights that the statistically optimal condition may differ from the best observed trial, emphasizing the robustness of Taguchi's optimization approach.

VII. MANUFACTURING OF THE COMPONENT

The preparation of tensile test specimens for this study was carried out in accordance with the ASTM E8M-04 standard, ensuring consistency and reliability in mechanical testing. The manufacturing process involved material selection, specimen fabrication using laser cutting, edge preparation, welding, and post-processing prior to tensile testing.

Fig.7 Specimen after successful completion of experimentation.

VIII. CONCLUSION

- The study investigated the effect of TIG welding parameters: current, voltage, and filler rod diameter; on the tensile strength of mild steel joints using a Taguchi L9 design.
- The experimental results showed that tensile strength is highly influenced by welding conditions, with the maximum value of 465.832 MPa obtained at 200 A current, 18 V voltage, and 1.6 mm filler rod diameter.
- Analysis of means and signal-to-noise (S/N) ratios indicated that welding current has the most significant positive effect on tensile strength, followed by voltage and filler rod diameter.
- While current showed a consistent increasing trend, voltage exhibited a non-linear influence, and smaller filler rod diameter resulted in better weld performance.
- Based on Taguchi optimization, the optimal parameter combination was identified as 200 A, 20 V, and 1.6 mm, representing the most robust setting derived from overall trends.
- In conclusion, the results confirm that appropriate selection of TIG welding parameters significantly improves joint strength.
- The Taguchi method proved effective in identifying optimal conditions with minimal experiments, providing a reliable approach for enhancing weld quality and consistency in mild steel applications.

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