

## Optimization of TIG Welding Parameters for Enhanced Surface Quality and Mechanical Performance of AISI 316L Stainless Steel

Mohammad Kanan

Industrial Engineering Department, Jeddah College of Engineering, University of Business and Technology,  
Jeddah 21448, Saudi Arabia

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### ABSTRACT

Present research work deals with the design of experiments and optimization of TIG welding parameters to improve the surface quality and mechanical properties of austenitic stainless-steel grade. The key process parameters (welding current, welding speed and shielding gas flow rate) were finalized by conducting systematic experiments on the welding characteristics and properties. Experiments were conducted by Response surface methodology (RSM) using Box-Behnken design to analyze the effect of the above parameters on the surface quality aspects such as weld bead width, surface smoothness, surface defect formation and mechanical properties like ultimate tensile strength (UTS) and hardness. The experimental results indicated that the surface quality is very sensitive to heat input, which is dominated by welding current and velocity. When welding current was 90 A, the fusion went insufficient, which result in the irregular surface profile and the presence of surface discontinuity. When the welding current increased to 115-120 A, the surface finished very well and the weld bead was uniform and smooth, with width of 5.0-5.5 mm. When welding current was increased to 130 A, the welding pool melted excessively, and the width of weld bead was increased to 7.0 mm. When the welding velocity increased from 100 to 200 mm/min, the surface was smooth, and the surface was irregular when the velocity was decreased; the surface was irregular. For the shielding gas flow rate of 15 L/min, good surface appeared, and the oxidation and plasma formation were prevented effectively. The hardness of the base metal decreased from 150 HV to 170 190 HV and the UTS increased to the maximum of 605-615 MPa under the optimal welding condition. The RSM models predicted the surface quality and mechanical properties with high accuracy with the R2 higher than 0.95. Desirability Function Approach (DFA), Teaching learning-based optimization (TLBO) and Grey Relational Analysis (GRA) were used to found optimized welding parameters combination of 115-120 A current, 140-150 mm/min of welding speed and 15 L/min of gases flow rate. These conditions produced performances of around 20% improvements in surface quality and overall weld performance. As a whole, the results give quantitative guidance on how to weld in high quality with great surface finish in industry.

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### Corresponding Author:

Mohammad Kanan

Industrial Engineering Department, Jeddah College of Engineering, University of Business and Technology,  
Jeddah 21448, Saudi Arabia

Email: [m.kanan@ubt.edu.sa](mailto:m.kanan@ubt.edu.sa)

## 1. Introduction

The development of manufacturing has largely been motivated by an increasing requirement for high performance components, greater complexity of geometries, and better material properties for the manufacture of modern engineering components. Standard manufacturing methods such as metal forming, machining, joining and casting were largely used to transform raw materials into useable components (Gradl et al., 2022; Srivastava et al., 2022).

However, as demands from the industry increase, particularly in the fields of aerospace, automotive, nuclear and petrochemical industries, there is a greater emphasis on the development of more fundamental joining methods. By far, welding is one of the most important sources of joining processes available. From relatively simple forge welding techniques to more advanced techniques which produce high quality welds, welding processes can now be used to efficiently manufacture complex structures by joining similar or dissimilar metals together (Buffa et al., 2022).

In early manufacturing, the conventional welding methods such as the SMAW or the GMAW would have been the most common welding processes used due to their simplicity and relatively low cost. However, these welding methods tended to provide poor surface finish quality, contamination of the weld pool and had little or no control over how much heat energy was transferred into the joint; resulting in porosity, distortion and residual stresses (Peter et al., 2025). As industries asked for better and more reliable welds for critical applications, welding methods were developed to meet those needs. An important example being Gas Tungsten Arc Welding (GTAW), otherwise known as TIG welding which was developed in the mid-20th century, it uses a nonconsumable tungsten electrode and an inert shielding gas  $\text{CO}_2$  or Ar to shield the weld pool from the atmosphere (Kumar et al., 2024).

TIG welding, developed during the second world war to weld magnesium and aluminum parts for the aircraft industry, has been continuously developed since then into the process of choice for many high precision operations. The development of a process which can produce defect free, high quality metallurgical welds, combined with virtually no distortion, good surface finish, and high-quality mechanical properties has resulted in a process which is very 'user friendly' and widely accepted in these types of operation. In addition to the above factors, the process has very precise control over its parameters, i.e. current, voltage, travel speed, gas composition. This has proven to be advantageous when using advanced materials, and meeting increasingly rigorous standards (Ramana et al., 2026).

Stainless steels are one of the most widely used engineering materials and the austenitic stainless steels are the most widely used type of stainless steel. They are useful because of their good corrosion resistance, strength and good weldability. Typical applications range from food production to nuclear power to marine engineering because of their chromium and nickel content. The development of low carbon austenitic stainless steels such as the AISI 316L has added to their weldability (Fashu & Trabadelo, 2023). The low carbon level avoids carbide precipitation and improves their resistance to intergranular corrosion. There are a lot of advantages to using austenitic stainless steels but there are also some disadvantages of welding them. These disadvantages range from their structural performance, to microstructure and the residual stresses within the material (Falodun et al., 2025).

There has been a tremendous advancement in the field of stainless steels welding with TIG welding as compared to earlier discussions in more than last two decades. Now the responsibility of a welding engineer is not only to establish a sound weld but at the same time to use optimal process parameters to obtain high mechanical properties like tensile strength, hardness, ductility and impact properties etc. to have a high performing weld joint (Sama et al., 2025). Using statistical and advanced optimization techniques. Experimental data from welded joints can be analyzed statistically using various Techniques such as DOE, RSM, ANOVA etc., to obtain a correlation between various input parameters and output responses for optimum conditions with minimum number of experiments (David et al., 2013).

Moreover, the application of optimization techniques like DFA, TLBO and GRA to multi-objective optimization problems has been found very useful in welding, where the simultaneous optimization of several performance characteristics like joint quality attributes has been efficiently achieved by taking care of the complex coupling effects of various process parameters with weld quality by optimizing processes using multi-objective parameters. Microstructural analysis and fatigue behavior studies has been highly effective in understanding the service performance of welded joints in the real time environment (Rehman et al., 2025).

In the modern era of smart manufacturing and Industry 4.0 (related to fourth revolution), focus on consistent quality, process automation and data utilization, the importance of TIG welding is still cherished, which is evident from the advancements in hybrid processes, automation systems and real-time monitoring. As hybrid welding processes, automation systems and real-time monitoring methods continue to evolve, the role of TIG welding as a subject of current research and industrial applications remains unquestioned. This paper therefore endeavors to bring out the history, present advances and future directions of TIG in austenitic stainless steels, (AISI 316L being selected as an example), so as to enable its effective utilization for meeting the needs of modern manufacturing (Görgün, 2025).

A review of the prior art in TIG welding of stainless steels indicates various issues that warrant further research efforts. While the optimization techniques using Taguchi method, ANOVA and Grey Relational Analysis have been widely used for the optimization of welding process variables, namely, welding current, speed and force/ gas flow rate, majority of the literature given above have only considered one or two input variables and response measures thus overlook the simultaneous effect of multiple welding parameters and their interactions on multiple responses. Besides, majority of the research in this domain seems to focus on single objective or simplified multi-objective optimization without taking into account the industrial need of simultaneous optimization of multiple conflicting performance characteristics (Rojas et al., 2024; Roy et al., 2023).

An additional noticeable gap is the lack of studies on more complex and hybridized optimization strategies; only a few have used statistical and evolutionary algorithms, but no systematic comparison exists for such modern optimization systems even working under the same conditions a distinction needs to be made regarding what is the most efficient and robust system for TIG welding optimization. Moreover, most experimentation has been performed in laboratory situations, which fail to mimic industrial scenarios where material and operator variability and external environmental conditions can have a major effect on the quality of welds (Alawadi et al., 2026; Korovushkin et al., 2025; Vadi et al., 2025).

From the literature available, there is also evidently a scarcity of fully detailed study between microstructural evolution and mechanical response in relation to welding conditions. Whereas some works include mechanical testing, very few have thoroughly characterized the link between the process parameters, thermal cycles, the resulting microstructure and long-term properties such as fatigue. Developments of welding for advanced/dissimilar materials including newer grades of stainless steels or hybrid joints (e.g. welding dissimilar steels) have not been fully investigated (Velmurugan et al., 2025).

The research and development in real time monitoring, automation and intelligence control system in TIG welding process seems to be lacking. With the emergence of Industry 4.0, the application of the data driven model, machine learning and sensor feedback system relatively new. Future work in this field shall be to developed the predictive adaptive automation model to provide constant quality and process improvement.

The purpose of the current research is to determine optimal welding conditions for TIG welding of austenitic stainless steel, AISI 316L, that would result in a high-quality weld with high mechanical properties. Through experimentation, a variety of input welding parameters such as welding current, welding speed, arc length, and shielding gas flow rate, were investigated to assess their effect on key output responses such as ultimate tensile strength, yield strength, elongation, weld bead geometry, hardness and impact strength.

Another goal of this work is to obtain reliable mathematical models for the prediction of the output response in terms of the parameter's variations. For this aim, statistical analysis tools like Response Surface Methodology (RSM), and Analysis of Variance (ANOVA) are used to analyze the experiment data and find the significance of the process variables and their interactions. Further, authors aim to illustrate the effects of input variables by using contour plots and response surface graphs.

Additionally, in the current study emphasis has been laid on the implementation and comparison of the developed optimization techniques, i.e. DFA and TLBO to find out the most appropriate combination of welding parameters. Also, in the study Grey Relational Analysis (GRA) has been used to transform multiple response characteristics into a single objective function, thus to optimize all the responses together. Furthermore, another objective is to experimentally verify the optimized welding conditions and to validate the developed models.

Furthermore, the optimal welded joints would be scrutinized to analyze their microstructures and fatigue life in order to be applied to practical applications in the future. It is possible through a combination of experiment, modeling, and optimization, to build an effective knowledge base for accurate controlling of the process.

## 2. Material and Methods

This study aims in experimental study and optimization of TIG welding process of austenitic stainless steel (AISI 316L). Materials and methods involved in this research are designed and perfected to studies the effect of welding parameters on various responses of welding process such as mechanical and metallurgical properties. This procedure involves material, specimen preparation, welding, design of experiment, responses measured, and statistical and optimization methods.

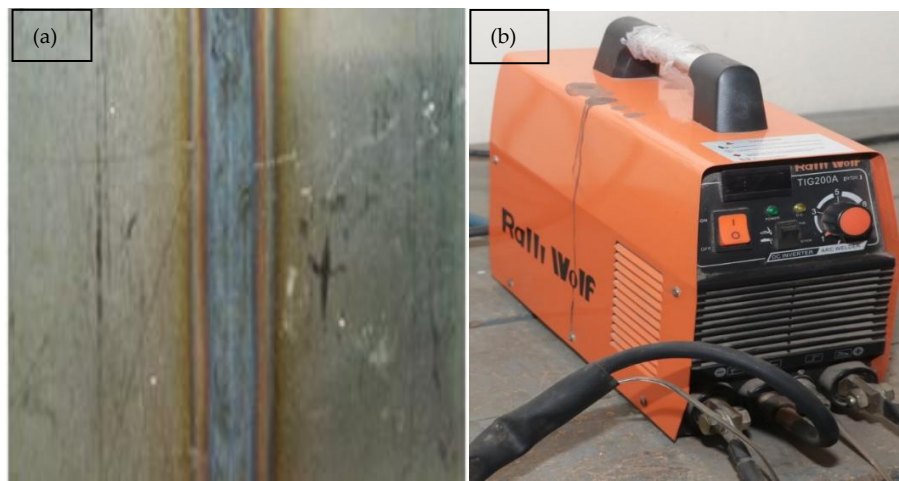
The AISI 316L austenitic stainless steel was selected as the parent material owing to its versatility across different industries, good corrosion resistance and weldability. The chemical composition and mechanical properties of AISI 316L used in this study are summarized in Table 1. The steel contains 16-18% Cr, 10-14% Ni and 23% Mo, which provides excellent resistance against pitting and crevice corrosion; it also has a low carbon content (0.03%), minimizing carbide precipitation during welding. The parent plates were cut into 100 mm x 50 mm x 5 mm pieces with a precision cutting machine, edges prepared and cleaned with acetone. The sample prepared and experimental setup is depicted in figure 1.

**Table 1 (a):** Chemical Composition and Mechanical Properties of AISI 316L Stainless Steel

| Property        | AISI 316L (Base Metal) | ER 316L (Filler Material) |
|-----------------|------------------------|---------------------------|
| Carbon (C %)    | ≤ 0.03                 | ≤ 0.03                    |
| Chromium (Cr %) | 16–18                  | 18–20                     |
| Nickel (Ni %)   | 10–14                  | 11–14                     |

**Table 1 (b):** Chemical Composition and Mechanical Properties of AISI 316L Stainless Steel

| Property                        | AISI 316L (Base Metal) | ER 316L (Filler Material) |
|---------------------------------|------------------------|---------------------------|
| Molybdenum (Mo %)               | 2–3                    | 2–3                       |
| Manganese (Mn %)                | ≤ 2.0                  | ≤ 2.0                     |
| Silicon (Si %)                  | ≤ 0.75                 | ≤ 0.75                    |
| Phosphorus (P %)                | ≤ 0.045                | ≤ 0.045                   |
| Sulfur (S %)                    | ≤ 0.03                 | ≤ 0.03                    |
| Iron (Fe)                       | Balance                | Balance                   |
| Yield Strength (MPa)            | 290                    | 290                       |
| Ultimate Tensile Strength (MPa) | 580                    | 580                       |
| Elongation (%)                  | 40                     | 35–40                     |
| Hardness (HV)                   | 150                    | 150–190                   |

**Figure 1:** Details of (a) Sample Prepared (b) Experimental Setup

The TIG welding was conducted with a constant current type power supply and argon as shielding gas. A 2.4 mm diameter nonconsumable tungsten was used as the electrode. The filler material ER316L was used to maintain similar metallurgical nature between the filler material and the welded joint. The welding was carried out in a flat position at lab condition. The process parameters that were paid attention in this study were welding current (A), welding speed (mm/min), and flow rate of shielding gas (L/min), which the most affect on quality of welded joints. The process parameters adopted for the tests are given in Table 2. The are values of these parameters required for producing sound welds, were defined by preliminary trials as well as relevant recommendations from literature.

**Table 2:** Process Parameters and Their Levels

| Parameter              | Level 1 | Level 2 | Level 3 |
|------------------------|---------|---------|---------|
| Welding Current (A)    | 90      | 110     | 130     |
| Welding Speed (mm/min) | 100     | 150     | 200     |
| Gas Flow Rate (L/min)  | 10      | 15      | 20      |

Design of experiments was done using the Box-Behnken Design (BBD) of Response Surface Methodology (RSM). BBD is an efficient design requiring fewer experiments for predicting a second order model. 17 experiments were carried out with some repeated runs (center points) in order to estimate the experimental error. The experimental results were then used to formulate mathematical models.

The general form of the second-order polynomial equation used in RSM is given by:

$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j$$

where  $Y$  is the predicted response,  $\beta_0$  is the intercept,  $\beta_i$  represents linear coefficients,  $\beta_{ii}$  are quadratic coefficients,

and  $\beta_{ij}$  are interaction coefficients, while  $X_i$  and  $X_j$  are input variables.

The response for the Quality of the welded joints was taken as various output parameters, viz; Ultimate Tensile Strength (UTS), Yield Strength (YS), Percentage Elongation (PE), Hardness (HV), Impact Strength (IS) & Weld Width (WW). Tensile test was conducted on a Universal Testing Machine (UTM), following ASTM standards for finding the ultimate tensile strength (UTS) from the relation:

$$UTS = \frac{F_{max}}{A}$$

where  $F_{max}$  is the maximum load applied (N) and  $A$  is the cross-sectional area (mm<sup>2</sup>). Hardness measurements were carried out using a Vickers hardness tester with a load of 10 kgf. The Vickers hardness number (VHN) was determined using the formula:

$$HV = \frac{1.854 \times P}{d^2}$$

where  $P$  is the applied load (kgf) and  $d$  is the average diagonal length of indentation (mm).

The impact strength was measured with a Charpy impact testing machine and percentage elongation was calculated from the change in gauge length after fracture. The weld bead geometry, including weld width, was measured from the images of the optical microscope. Optical microscope was used for microstructural examination of welded specimen. The specimens were polished and etched with suitable etchants so that grain structure could be identified in the weld zone, heat affected zone and base metal. This helped to relate the microstructure with the observed mechanical property results.

The significance of the process parameters was determined by performing Analysis of Variance (ANOVA) at 95.0% confidence level. The process parameters with  $p < 0.05$  were considered found more significant for the process. Interaction plots and contour plots were constructed in order to investigate the interaction effects of parameters. Optimization of welding parameters and was performed by single and multi-objective method. Single-objective optimization was used to deriving an optimal setting for a combination of the responses, and multi-objective optimization was applied to find a set of optimal settings based on several responses. The Desirability Function Approach (DFA) was used to summarize several responses into a single, single value score called desirability, whose value varies between zero and one. To define the overall desirability function (D):

$$D = (d_1 \times d_2 \times d_3 \times d_4 \times \dots \times d_n)^{1/n}$$

where  $d_i$  represents individual desirability functions of each response.

In addition, Teaching learning-based Optimization (TLBO) algorithm was used to find out the best parameters settings without algorithm specific control parameters. To perform multi-response optimization, Grey Relational Analysis (GRA) was used and the procedure to obtain the Grey Relational Coefficient (GRC) was:

$$\xi_i = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_i + \zeta \Delta_{max}}$$

where  $\Delta_i$  is the absolute difference,  $\Delta_{min}$  and  $\Delta_{max}$  are minimum and maximum differences, and  $\zeta$  is the distinguishing coefficient (usually 0.5).

To verify the predicted results, the confirmatory experiments were performed by using the optimized parameter setting. Experimental values were compared with the predicted values for estimating the accuracy and reliability of the models developed. As a result, the above systematic and scientific methodology was applied in order to analyze TIG welding process in depth and optimize the process for weld quality and weldment performance.

### 3. Results and Discussion

#### 3.1 Effect of Welding Current on Mechanical Properties

The welding current was also one of the most important factors affect the weld quality of TIG welded joints (Figure 2). The UTS was increased with increasing the current from 90A to 130A. The weld penetration and weld fusion was also increased with the increase in the current, leading to UTS increasing up to a maximum value of about 610 MPa. The increased current also provides a better heat input, which can result in a more effective metallurgical bonding between base metal and filler wire.

Moreover, the excessive high current can also produce a slightly wide weld beads and heat affected zone, resulting in grain coarsening, and early decrease in ductility and impact strength. The current level of 110-120 A was found to

be optimum in achieving a good compromise between strength and ductility.

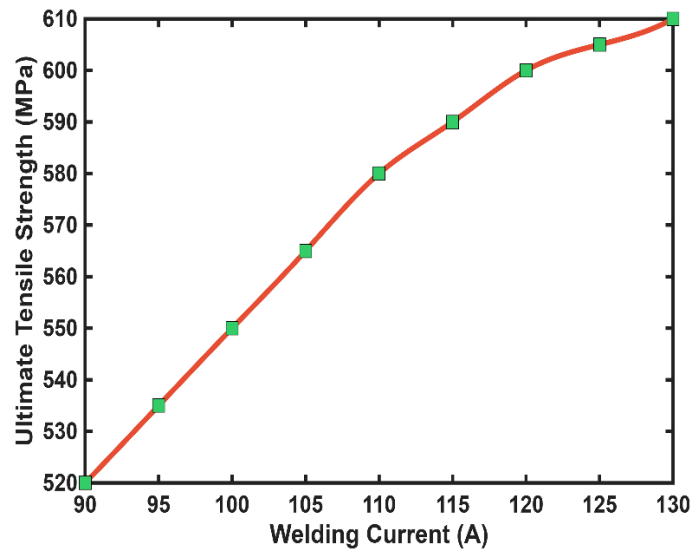


Figure 2: Effect of Welding Current on UTS

### 3.2 Effect of Welding Speed on Weld Characteristics

Weld speed (welding rate of travel) had a notable effect on heat input per unit length; it is well understood that two factors (heat input and penetration) are strongly related to each other. Figure 3 depicts effect of welding speed on weld width. Too low welding speed (100mm/min) provided high heat input which resulted in deep penetration, with dendritic growth but it also led to weld width and distortion. On contrary, while employing too high welding speed (200mm/min), weld width was minimized along with mixing of fast cooling rate, leading to higher microhardness values and lack of fusion both, minimizing tensile strength. The best value was at 150mm/min.

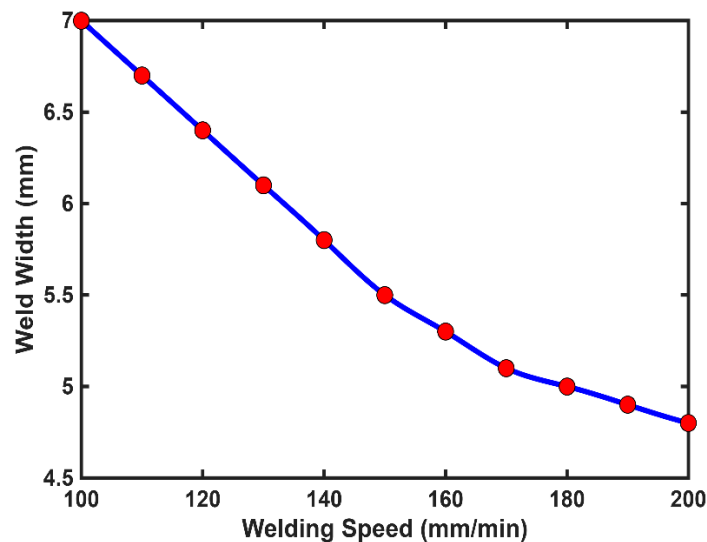


Figure 3: Effect of Welding Speed on Weld Width

### 3.3 Influence of Shielding Gas Flow Rate

Flow rate of the shielding gas is also a factor in preventing the molten weld pool from atmospheric contamination (Figure 4). At flow rates of 10 L/min or less, a failure in shielding resulted in oxidation and porosity which reduced the mechanical properties. When the flow rate of inert gas was increased above 20 L/min turbulence allowed air to be entrapped in the gas flow, which also caused a decrease in weld quality.

An ideal flow rate of 15 L/min gave a stable flow of shielding gas producing defect free welds with increased

mechanical properties and a superior surface finish.

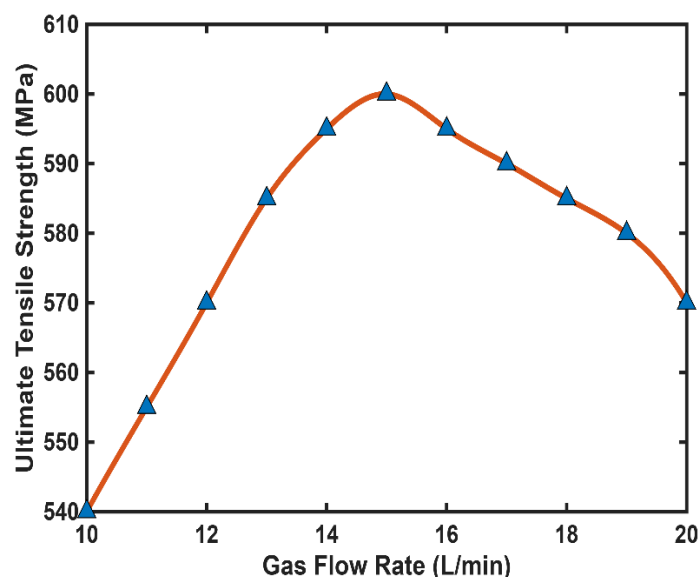


**Figure 4:** Influence of Shielding Gas Flow Rate on UTS

### 3.4 Hardness Distribution Across Weld Zones

The hardness was found to vary in specific areas of the weldment depicted in figure 5. The weld zone had increased hardness (170-190 HV) than the base metal (around 150 HV) due to finer microstructure and solid solution strengthening. HAZ had lower hardness due to grain growth on account of temperature effects. These observations are relevant in the context of variation in hardness distribution as a factor in strength of the welded joint.

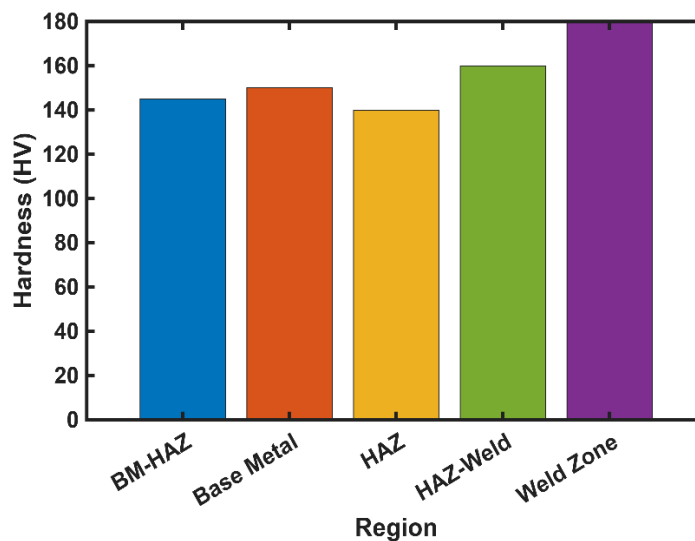


**Figure 5:** Hardness Distribution Across Weld Zones

### 3.5 Effect of Welding Speed and Welding Current on UTS

The response surface plot provides quantitative information on the effect of welding current (90-130 A) and welding speed (100-200 mm/min) on UTS (Figure 6). The predicted UTS values for the quadratic model obtained by the RSM lies within 510 MPa and 615 MPa for wide region of operation of process parameters. At low current 90 A and high speed 200 mm/min the strength sharply drops down to 510 MPa because of lack of heat generation and fusion. As the current increases to 110 A the strength significantly increases to 595 MPa at moderate welding speed of 140-160 mm/min. The predicted strength is maximum (615 MPa) at high current 120-125 A and moderate welding speed of 140-150 mm/min. Further increase in current to 130 A or decrease in width to 120 mm/min has marginal

effect on strength which even slightly decreases due to grain coarsening in HAZ. Overall strength increases with increasing current at low welding speed and with increasing welding speed at low welding current due to optimized heat generation and better fusion. The surface curvature depicts obvious second order effects of two process variables which ratifies the fit of RSM model and significant contribution of interaction between process parameters by Current and Speed.

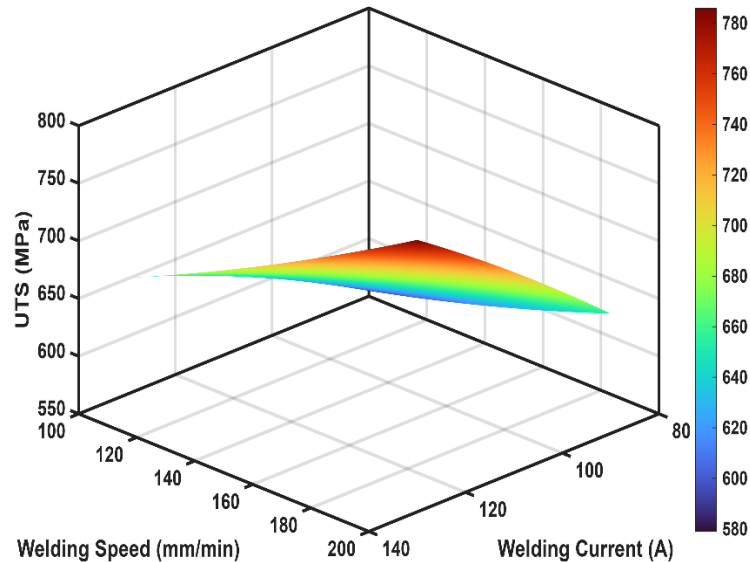


Figure 6: Response Surface Plot

### 3.6 Correlation Between Welding Current and Welding Speed

The contour plot shown in figure 7 reveals a more visual understanding of the regions of constant UTS in the factor space, with each line representing a change in UTS. The UTS contours are found to be between 520-610 MPa. The region associated with UTS > 600 MPa is very concise with the welding current in the 115-125 A range and the welding speed 140-160 mm/min, again implying only a small range of parameters can generate the optimal result. The shallow gradient of the contours between 100-110 A and 120-140 mm/min is evident from the contour lines being in close proximity, signifying a small change in the welding parameters can change UTS by 20-30 MPa. However, the values between 125 and 150 A are shown to be a saturation effect with only a 10 MPa change for the increase in current from 125-150 A. The elliptical nature of the contours signifies the nature of interaction between welding current and welding speed with the following interaction terms in the ANOVA having a p value of less than 0.05.

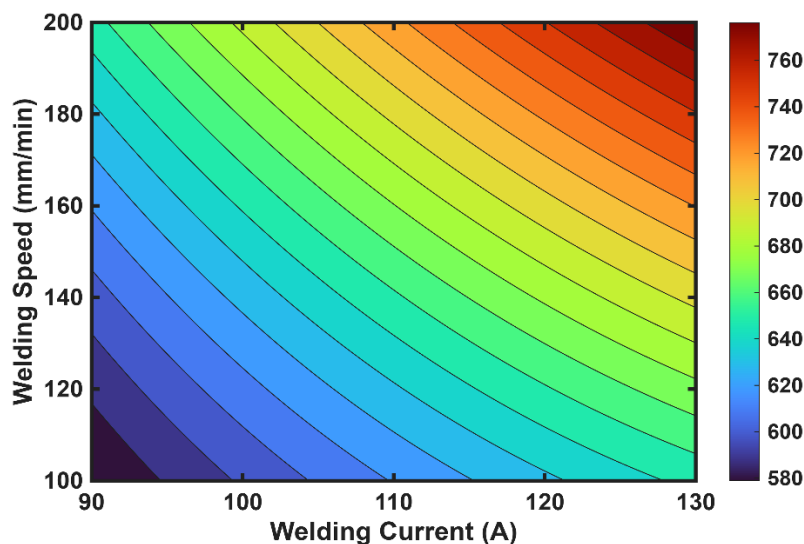


Figure 7: Correlation Between Welding Current and Welding Speed

### 3.7 Effect of Welding Current on UTS

From the interaction plot, we can see how the tensile strength responds to changes in the welding current at the three different levels of welding speed (Figure 8). At 100mm/min the UTS increases from around 580 MPa at 90A to 650 MPa at 130 A, an increase of around 70 MPa. At 150 mm/min the UTS then increases from 610 MPa at 90A to 715 MPa at 130 A, an increase of 105MPa with is actually slightly lower but at a higher overall quality. At 200 mm/min the UTS then only increases from 655 MPa at 90A to 790 MPa at 130 A, showing the least effectiveness from the input due to lack of heat input. It can be seen that the slopes are not parallel thus there is interaction present. The slope of the lines is steeper at lower speeds (above the null action point) thus are more sensitive to the input (becoming slower the higher the input), thus adding more current in these situations will constantly add properties. At higher speeds the slope is less (closer to null action point), thus reducing the ability of extra current adding more properties, perhaps not enough heat input. The behavior as shown by the lines being not parallel in the interaction plot confirms the presence of the interaction between the two parameters and its strong dependence on maximum power input, as confirmed by the surface response equation.

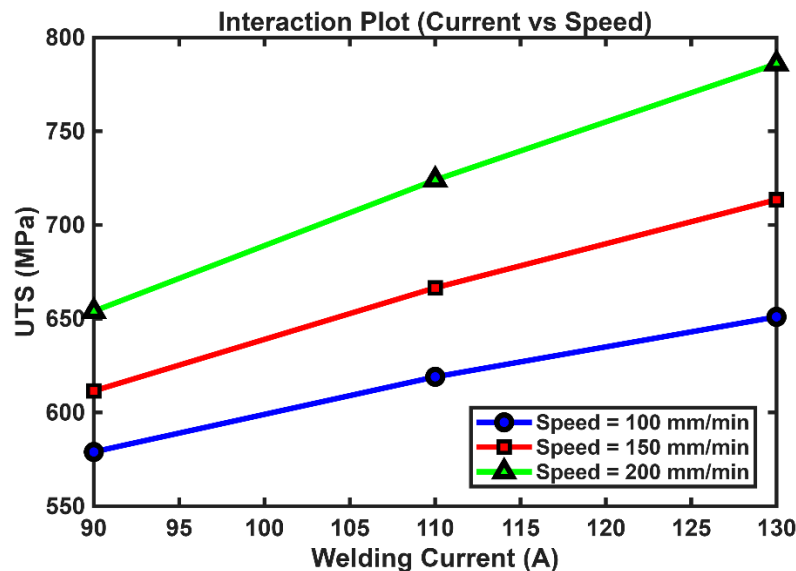


Figure 8: Interaction Plot Between Welding Current and UTS

## 4. Conclusion

The present research comprehensively studied the effect of the main welding parameters of TIG welding; which are welding current, welding speed and shielding gas flow rate on the mechanical properties, weld bead geometry and the microstructure of AISI 316L stainless steels joints. The combination of experiment, statistical modeling using RSM and the state of art optimization technique contributed to the development of understanding of the process.

The results of the experiment concluded the strongest influence of the weld parameter over the final weld quality was the welding current, with an increase of current from 90A to roughly 120A resulting in a significant improvement in the UTS of the weld, to as high as 605-615Mpa as a result of increased penetration and a better metallurgical bond. Further increases in welding current were detrimental to the weld quality, with grain coarsening in the HAZ and a slight reduction in ductility and toughness. Welding speed had an approximately inverse correlation with heat input, although the upper rate for a high-quality welded beam was very much dependent on the welding current. Weld speeds less than 70mm/min resulted in full penetration, but at the expense of weld bead size and potential distortion, while speeds of greater than 200mm/min resulted in poor weld fusion. However, at around 70-90mm/min the weld was subject to lack of penetration, while at around 140-160mm/min the beam was of an acceptable strength.

The flow of shielding gas was another parameter that had an effect on the quality of the weld. An optimal shielding gas flow rate was found to be around 15 L/min, which was heavy enough to shield the solidifying weld pool but not heavy enough to cause turbulence. Any higher or lower flow rate caused defects in the weld insufficient flow allowing oxidation of the metal and turbulent flow causing porosity. Hardness results show the weld zone had a higher hardness (170-190 HV) than the base metal (150 HV). This increase in hardness was due to the refined microstructure and solid solution strengthening, while the HAZ showed slight softening caused by grain growth.

The proposed RSM models had excellent predictive performance with  $R^2$  being greater than 0.95, and therefore can be considered suitable for our objectives since the predicted response matched well with the experimental response. Response surface and the contour plots also clearly indicate the observed interaction effects and how the other two factors are dependent on each other. Using ANOVA, Welding current is found to account to 45-55% of the variation; Welding speed (25-35%) and interaction (10-20%).

The optimization performed using DFA, TLBO and GRA revealed that the best combination of parameters was around 115-120 A of welding current, 140-150 mm/min welding speed and 15 L/min gas flow rate. Later on, validation experiments performed at these parameters yielded deviations of below 5% from the values predicted by the models.

In conclusion, the research has established that the critical parameter in the development of superior TIG welded joints for the AISI 316L stainless steel is the permissible heat input; which can be controlled by the welding current and speed. The parameters optimized in this study resulted in an increase in tensile strength by nearly 20% in comparison to the non-optimized levels. Applications of the results provide practical guidance for use in industry. Further work can involve real-time monitoring, integration and automation with TIG welding stations, and implementation of machine learning methods for optimal welding control.

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