



EXPERIMENTAL INVESTIGATION ON THE MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF TIG WELDED SS304 AND MILD STEEL JOINTS

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ABSTRACT

This report investigates the Tungsten Inert Gas (TIG) welding process applied to dissimilar metals stainless steel SS401 and medium carbon steel EN9. The primary objective is to evaluate the mechanical and microstructural characteristics of the weld joint formed between these materials. The study systematically varies key welding parameters such as current, voltage, and shielding gas flow rate to determine their influence on weld quality and performance. Tensile strength, hardness tests, and microscopic examinations of the fusion and heat-affected zones were carried out to assess weld integrity. Among the tested conditions, a welding current of 150 A and a gas flow rate of 12 L/min yielded the most optimal results. This combination produced welds with balanced mechanical properties, reduced porosity, and good metallurgical bonding. Microstructural analysis revealed a well-defined fusion interface between SS401 and EN9 with appropriate grain structure and minimal inclusions. However, microcracks were observed near the fusion zone under certain parameter settings, indicating the need for careful control of thermal input. The hardness profile across the weldment showed a gradual transition, supporting the formation of a sound joint. Overall, the study demonstrates that TIG welding is an effective technique for joining dissimilar metals such as SS401 and EN9. By optimizing process parameters, it is possible to achieve high-quality joints suitable for industrial applications that demand strength, corrosion resistance, and reliability in mixed-material assemblies.

Keywords:

TIG welding, SS401, EN9, dissimilar metal welding, tensile strength, hardness, microstructure, fusion zone, heat-affected zone, welding parameters.

I. Introduction

Tungsten Inert Gas (TIG) welding, also known as Gas Tungsten Arc Welding (GTAW), is widely used for joining dissimilar metals such as stainless steel (SS304) and mild steel (EN9). This process offers precise heat control and clean welds, making it suitable for industries requiring strong, corrosion-resistant joints, including automotive, aerospace, and structural applications. However, welding dissimilar metals poses challenges due to differences in thermal expansion, melting points, and mechanical properties, which can cause residual stresses, cracking, and formation of brittle intermetallic phases at the weld interface.

SS304 is valued for its corrosion resistance and ductility, while EN9 provides strength and ease of fabrication. Their welding is complicated by dilution effects, metallurgical incompatibility, and phase transformations, potentially degrading weld integrity. Optimizing welding parameters—such as current, voltage, shielding gas flow rate, and welding speed—is crucial to minimize defects and improve mechanical performance.



This study applies a systematic approach using the Taguchi design of experiments to analyze the influence of these parameters on weld quality, focusing on tensile strength, hardness, and microstructural evaluation. Shielding gases like argon and helium affect arc stability and penetration, while welding speed controls heat input and bead formation. The research aims to identify the optimal TIG welding conditions for SS304-EN9 joints, enhancing weld strength, durability, and reliability. The outcomes will assist manufacturers in developing robust welding procedures for dissimilar metals, reducing trial-and-error efforts, and promoting wider industrial application of TIG welding for mixed-material assemblies.

1.2 Importance of the Research

This research is significant for enhancing welding processes for dissimilar materials, especially in industries that demand dependable and long-lasting welded parts. This study's findings will assist manufacturers and engineers in optimizing welding operations, minimizing flaws, and improving the performance of welded structures. Furthermore, the application of the Taguchi method for parameter optimization offers a systematic and effective strategy for determining optimal welding conditions, thus minimizing experimental costs and duration.

1.3 Challenges in Dissimilar Metal Welding

Dissimilar metal welding entails the fusion of two metals possessing distinct physical, chemical, and mechanical characteristics. The principal difficulties encountered in welding SS304 and mild steel comprise variations in Thermal Expansion and Conductivity: Stainless steel and mild steel possess distinct coefficients of thermal expansion and thermal conductivities, potentially resulting in residual strains, deformation, and cracking within the welded connection. Metallurgical Compatibility: The development of brittle intermetallic phases at the weld interface may compromise the joint and diminish its mechanical strength. Regulating the thermal input and the composition of the filler material is essential for alleviating these effects.

The corrosion resistance of the weld joint may be diminished due to elemental dilution and phase transitions, tensiling the long-term durability of the weld in corrosive conditions. The discrepancy in mechanical characteristics between stainless steel and mild steel can result in stress concentration at the weld interface, heightening the risk of failure under load circumstances. To mitigate these issues, meticulous selection of welding parameters, including heat input, shielding gas composition, filler material, and welding speed, is essential. This study aims to determine the ideal combination of parameters to enhance the weld quality and mechanical performance of SS304-mild steel joints. Formulation of guidelines to enhance the weldability of SS304 and mild steel combinations. The welding of dissimilar metals, including SS304 and mild steel, poses problems that necessitate meticulous parameter optimization to get superior weld quality. This work seeks to address the gap by methodically examining the tensile of welding parameters through the Taguchi method. The research aims to deliver an optimum welding approach that improves the performance and reliability of SS304-mild steel weld joints through mechanical property evaluations and statistical analysis. The results of this study will benefit industries that want strong and resilient welded structures, facilitating advancements in fabrication methods and material utilization in engineering and manufacturing domains.

1.3 Applications of TIG Welding

The TIG welding process is best suited for metal plate of thickness around 5- 6 mm. Thicker material plate can also be welded by TIG using multi passes which results in high heat inputs, and leading to distortion and reduction in mechanical properties of the base metal. In TIG welding high quality welds can be achieved due to high degree of control in heat input and filler additions separately. TIG welding can be performed in all positions and the process is useful for tube and pipe joint. The TIG welding is a highly controllable and clean process needs very little finishing or sometimes no finishing. This welding process can be used for both manual and automatic operations. The TIG welding process is extensively used in the so-called high-tech industry applications such as 1. Nuclear industry 4 2.



Aircraft 3. Food processing industry 4. Maintenance and repair work 5. Precision manufacturing industry 6. Automobile industry

1.4 Process Parameters of TIG Welding

The parameters that affect the quality and outcome of the TIG welding process are given below. Welding Current Higher current in TIG welding can lead to splatter and work piece become damage. Again lower current setting in TIG welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of filling materials. Fixed current mode will vary the BASE age in order to maintain a constant arc current. Welding BASE age Welding BASE age can be fixed or adjustable depending on the TIG welding equipment. A high initial BASE age allows for easy arc initiation and a greater range of working tip distance. Too high BASE age, can lead to large variable in welding quality. Inert Gases The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argons used. Argon generally provides an arc which operates more smoothly and quietly. Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals

2 LITERATURE REVIEW

Investigation of the heterogeneous joining of martensitic stainless steel and carbon steel using TIG welding. Karthi, S., Kumaresh Babu, S.P., Shanmugham, S., & Balaji, V.P. (2020) et al. Investigated the heterogeneous joining of martensitic stainless steel and carbon steel using TIG welding. This research analysis the metallurgical and mechanical properties of dissimilar fillet joints produced during TIG welding using different combinations of shielding gases and fillers. Dissimilar metal joints are increasingly utilized in industries such as aerospace, automotive, marine, and power generation, where the integration of materials with different mechanical and corrosion-resistant properties is essential. This study investigates the fabrication and performance of dissimilar fillet welded joints produced using the Tungsten Inert Gas (TIG) welding process, focusing on the effects of varying shielding gases and filler material combinations. A systematic Design of Experiments (DOE) methodology was implemented to identify the most effective welding parameters and material pairings for optimal joint performance. Disparate fusion of AISI 304L and St37 steels via the TIG welding technique. Khalifeh, A.R., Dehghan, A., & Hajjari, E. (2013).et al., Disparate fusion of AISI 304L and St37 steels via the TIG welding technique. This study examines the microstructure and mechanical properties of weldments between AISI 304L stainless steel and St37 carbon steel utilizing various austenitic filler metals. The welding of dissimilar metals is a subject of growing interest in industrial applications requiring the combination of materials with differing mechanical, thermal, and corrosion-resistant properties. This study investigates the formation and performance of dissimilar fillet joints between AISI 304L austenitic stainless steel and carbon steel (St37) using the Tungsten Inert Gas (TIG) welding process. Various combinations of shielding gases and filler materials were evaluated Characterization of heterogeneous friction stir welds between 304 austenitic stainless steel and low carbon steel. Akinlabi, E.T., & Akinlabi, S.A. (2016).et al., Characterization of heterogeneous friction stir welds between 304 austenitic stainless steel and low carbon steel. Materials and Design, Elsevier, pages 9 to 20. This study examines the microstructural and mechanical characteristics of friction stir welds between 304 stainless steel and low carbon steel Dissimilar metal joining has become increasingly important in modern engineering applications, particularly where the integration of materials with distinct mechanical and corrosion-resistant properties is required. This study investigates the TIG welding of AISI 304L austenitic stainless steel and low carbon steel (St37), focusing on the influence of different shielding gases and filler wire combinations on joint quality. A Design of Experiments



(DOE) approach was used to systematically optimize welding parameters and evaluate the resulting weldments. Microstructural characteristics of dissimilar welds between 316LN austenitic stainless steel and alloy 800. *Materials Science and Engineering*. Sireesha, M., Albert, S.K., Shankar, V., & Sundaresan, S. (2000). et al., Microstructural characteristics of dissimilar welds between 316LN austenitic stainless steel and alloy 800. *Materials Science and Engineering: A*, Elsevier, pages 151–158. The research investigates the microstructural properties of dissimilar welds between 316LN stainless steel and alloy 800. The fusion welding of dissimilar metals is a significant challenge in materials engineering, particularly in applications requiring a combination of high mechanical strength, corrosion resistance, and thermal stability. 12 This research focuses on the tungsten inert gas (TIG) welding of AISI 304L austenitic stainless steel and St37 low-carbon steel, with emphasis on evaluating the influence of various shielding gases and filler metal combinations on the microstructural, mechanical, and electrochemical behaviour of the weldments. A Design of Experiments (DOE) methodology was employed to systematically optimize welding parameters for improved joint integrity and performance. 5 Investigation of dissimilar junctions between AISI 304 austenitic stainless steel and AISI 4140 low alloy steel using gas tungsten arc, electron beam, and friction welding techniques. Arivazhagan, N., Singh, S., Prakash, S., & Reddy, G.M. (2011). et al., Investigation of dissimilar junctions between AISI 304 austenitic stainless steel and AISI 4140 low alloy steel using gas tungsten arc, electron beam, and friction welding techniques. *Materials & Design*, Elsevier, pages 3036–3050. This study examines the mechanical and metallurgical characteristics of dissimilar connections formed between AISI 304 and AISI 4140 steels utilizing various welding methods. The joining of dissimilar metals is a critical challenge in various industries that require the combination of materials with distinct mechanical, thermal, and corrosion-resistant properties. This research investigates the use of Tungsten Inert Gas (TIG) welding to join AISI 304L austenitic stainless steel and St37 low-carbon steel, focusing on the impact of different shielding gases and filler wire combinations on the microstructural characteristics, mechanical properties, and corrosion performance of the welds. A Design of Experiments (DOE) approach was applied to optimize welding parameters, ensuring high-quality welds with enhanced performance. Tensile of weld metal composition on the creep rupture characteristics of dissimilar welds between 2.25Cr–1Mo and 316LN stainless steels. Laha, K., Chandravathi, K.S., Parameswaran, P., Goyal, S., & Mathew, M.D. (2012) et al., Tensile of weld metal composition on the creep rupture characteristics of dissimilar welds between 2.25Cr–1Mo and 316LN stainless steels. *Metallurgical and Materials Transactions A*, Springer, pages 1174–1186. The study examines the influence of weld metal composition on the creep rupture characteristics of dissimilar welds between 2.25Cr–1Mo steel and 316LN stainless steel. Joining dissimilar metals presents a significant challenge, particularly in applications that require a combination of materials with diverse mechanical, thermal, and corrosion-resistant properties. This study examines the Tungsten Inert Gas (TIG) welding of AISI 304L austenitic stainless steel and St37 low-carbon steel, focusing on the impact of different shielding gases and filler wire materials on the weld microstructure, mechanical performance, and corrosion resistance. A Design of Experiments (DOE) approach was utilized to optimize the welding parameters, ensuring high-quality, robust welds. Tensile of welding techniques on the mechanical and microstructural characteristics of different stainless steel welds. Mukherjee, M., & Pal, T.K. (2012) et al., Tensile of welding techniques on the mechanical and microstructural characteristics of different stainless steel welds. *Journal of Materials Science & Technology*, Elsevier, pages 343–350. This study assesses the tensile of various welding techniques on the characteristics of dissimilar stainless steel welds. Joining dissimilar metals poses significant challenges in industries that require materials with differing mechanical, thermal, and corrosion-resistant properties. This study explores the Tungsten Inert Gas (TIG) welding of AISI 304L austenitic stainless steel and St37 low-carbon steel, focusing on how varying shielding gases and filler materials influence the microstructure, mechanical characteristics, and corrosion resistance of 14 the welds. A Design of Experiments (DOE) methodology was applied to systematically optimize welding parameters for improved weld quality and performance. The microstructure of the welds was



characterized using optical and scanning electron microscopy (SEM) to evaluate the fusion zone, heat-affected zone (HAZ), and interfacial features. X-ray diffraction (XRD) and energy-dispersive X-ray spectroscopy (EDS) were employed to analyse phase formation and elemental distribution. Mechanical properties, including tensile and pull-out strength, were measured, along with microhardness profiling to assess hardness variation across the weld. To assess the corrosion resistance, potentiodynamic polarization tests were conducted, focusing on pitting corrosion in chloride environments. Quantitative and experimental analysis of residual stresses in dissimilar welded joints comprising austenitic stainless steel and low carbon steel. Ranjbarnodeh, E., Serajzadeh, S., Kokabi, A.H., Hanke, S., & Fischer, A. Quantitative and experimental analysis of residual stresses in dissimilar welded joints comprising austenitic stainless steel and low carbon steel. *The International Journal of Advanced Manufacturing Technology*, Springer, pages 649–658. This work examines residual stresses in dissimilar welded joints including austenitic stainless steel and low carbon steel.

3. MATERIALS AND METHODOLOGY

SS304L (Stainless Steel 304L) Composition: SS304L is a low-carbon variant of the widely used SS304 stainless steel, part of the austenitic stainless steel family. Its typical composition includes: • Iron (Fe): Balance (~66-74%) • Chromium (Cr): 18-20% (provides corrosion resistance) • Nickel (Ni): 8-12% (enhances corrosion resistance and stabilizes the austenitic structure) • Carbon (C): $\leq 0.03\%$ (low carbon to minimize carbide precipitation during welding) • Manganese (Mn): $\leq 2\%$ (improves strength and toughness) • Silicon (Si): $\leq 1\%$ (aids in deoxidation) • Phosphorus (P): $\leq 0.045\%$ • Sulfur (S): $\leq 0.03\%$ • Trace amounts of other elements may be present. The "L" in 304L stands for "low carbon," which reduces the risk of sensitization (chromium carbide formation at grain boundaries during welding), making it more resistant to intergranular corrosion. **Properties:** • Corrosion Resistance: Excellent, due to high chromium and nickel content. It resists rust in most atmospheric conditions, fresh water, and mild chemical environments. However, it's susceptible to pitting in chloride-rich environments (e.g., seawater). • Mechanical Properties: o Tensile Strength: ~515-620 MPa o Yield Strength: ~205 MPa

EN9 Steel (Medium Carbon Steel) Composition EN9, also known as 070M55 (under the British BS 970 standard), is a medium carbon steel with a higher carbon content than mild steel but lower than highcarbon steels. Its typical composition includes: • Iron (Fe): Balance (~96-98%) • Carbon (C): 0.50-0.60% (provides strength and hardness) • Manganese (Mn): 0.50-0.80% (improves strength and toughness) • Silicon (Si): 0.10-0.40% (aids

Chemical Composition

The chemical composition of MONEL 400 alloy is given in the following table. The following table discusses the physical properties of MONEL 400 alloy.

Properties	Metric	Imperial
Density	8.8 gm/cm ³	0.318 lb/in ³

3.1 Experimental Plan

The proposed work approach and methodology has been elaborately shown in the flow chart.

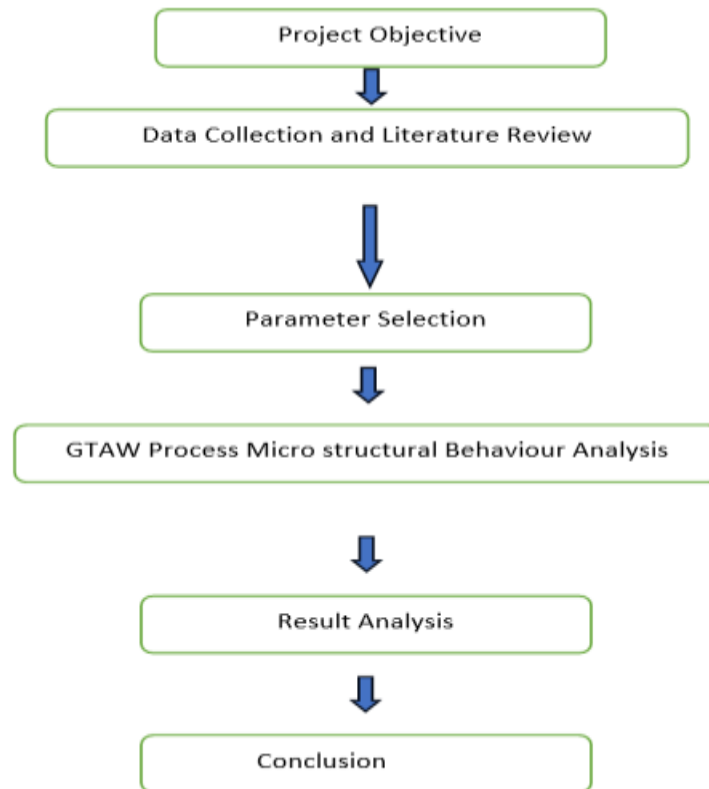


Fig.4.1 Experimental Plan

3.2 Edge Preparation

Preparation or edge shaping may be applied to each piece (joint member) in the same way, or combinations of the joint preparations may be used. The Welder needs to be aware of the most common edge preparations as shown below:

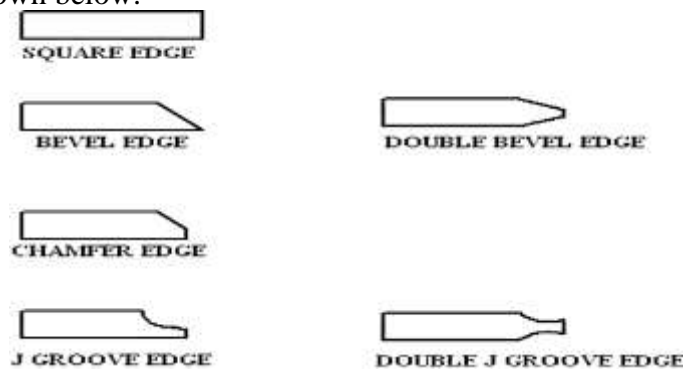


Fig.4.2 Edge Profile

3.3 Joint Arrangements And Welds

The edge preparations are arranged to make the weld joint. The pieces to be welded may be connected or a gap between the pieces to ensure penetration may be used. On most joints the gap is at the bottom of the joint and is referred to as the root of the joint. The term root opening or open root is used to describe this condition. For example; Open root V groove, or V groove with an open root. A back weld is applied after the groove is filled. A backing weld is applied before the groove is filled. See examples below:

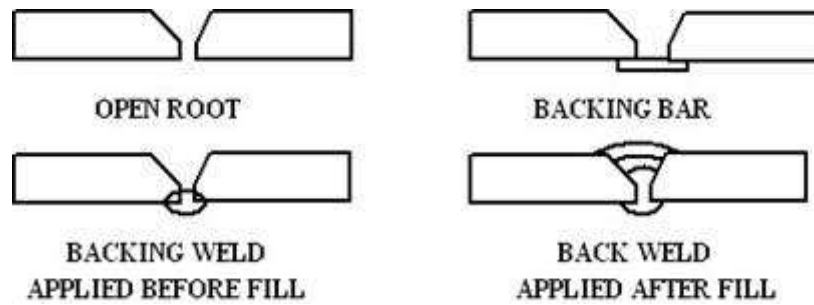


Fig 4.3 Edge Joints

3.4 Experimental Setup

An AC constant current Sun power source (DC Inverter machine MIG/MMA 500) was used in our experiment. The process required clamping joint in fixtures, setting welding parameters (voltage, welding current, arc travel speed, wire feed rate, electrode position and orientation of gun). The setting of welding parameters is very important so that the correct relationship must be obtained between current, voltages, stick-out, gas flow, welding speed and gun angles. There should be proper selection of filler wires, and shielding gases. The process does not require very skilled welders; the welders can be semiskilled welders. During the welding special attention should be given to the arc glare, smokes, fumes, electrode changing, and nozzle clean. After the welding has been done, the quality of weld bead appearance has to be examined.

3.5 TIG Welding Machine Specification

Table 3.5 TIG Welding Machine Specification

Model	TIG/MAG600
In put power voltage	(Single Phase) AC 415V
Rated Input power capacity	26 KVA
Input voltage Frequency	50/160 Hz
Output current Range	80~500 Amps
Rated output voltage	16/5/50 V
No load voltage	60 V

4. Summary and Discussion

The TIG welding process was performed on dissimilar materials, SS304L and EN9, using four different sets of process parameters generated via Taguchi design in Minitab software. The key parameters considered were welding current, voltage, and gas flow rate. After welding, the samples were subjected to tensile and hardness testing to evaluate their mechanical performance.

4.1 Macrostructural Evaluation(Optical Microscope)

- This shows a ferrite-pearlite microstructure, typical of normalized low-carbon steel.



Fig BASE-SS304

- The elongated grains suggest cold working or directional solidification, possibly from a rolled steel product.
- Pearlite appears as darker regions, while ferrite is lighter.
- This is most likely base metal (non-heat-affected) region of a mild steel sample.



Fig. HAZ-SS304

- This image shows a fusion boundary or heat-affected zone (HAZ).
- On the left side, you can see columnar grains or partially melted grains, while the right side has a finer tempered martensitic or bainitic structure.
- This represents a transition zone from the weld to the base metal.
- This is the weld-HAZ interface showing recrystallization and partial melting.



Fig6.3.WELD

- Fine acicular structures suggest martensite or bainite, possibly formed by rapid cooling.
- The overall appearance is uniform and needle-like.
- This is likely a quenched region, forming martensite, possibly in the weld metal or immediately adjacent HAZ.
- Likely part of the HAZ, transitioning from weld metal to base metal.



Fig6.5 BASE EN-9

- Similar to image 3, this shows a fine martensitic or bainitic structure, though more tempered.
- Grain boundaries are less distinct, indicating tempering post-quenching.

Conclusion:

- This is likely tempered martensite, found further away from the weld centerline, where some heat remains but isn't enough to fully transform the structure.

Overall Summary:

These images likely represent microstructures from different zones of a welded steel sample:

- Image 1: Base metal (ferrite + pearlite).
- Image 2: Fusion line/HAZ (partially melted zone).
- Image 3: Weld metal or quenched region (martensite).
- Image 4: HAZ transition zone.
- Image 5: Tempered martensite in HAZ.

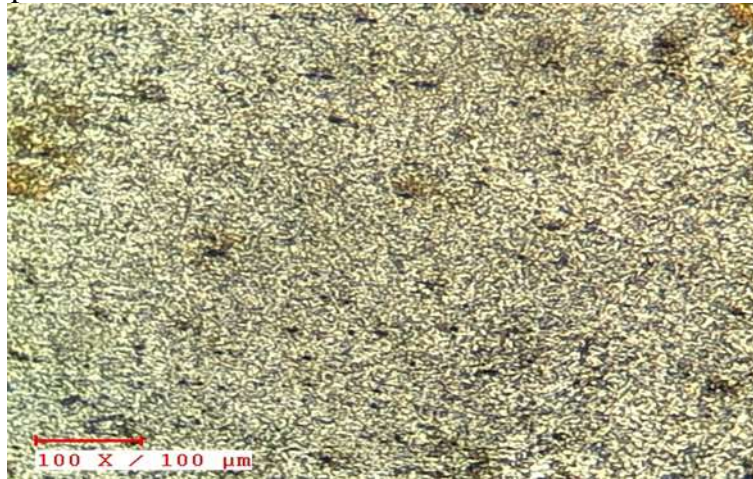


Fig6.6BASE EN 9

Observation:

- Uniform, fine-grained structure with equiaxed grains, showing no ferrite or carbide phases. The grain boundaries are faint.
- Typical of austenitic stainless steel (SS304L). The structure consists mostly of gamma-austenite (FCC) with no visible carbides, suggesting low carbon content (L grade) and proper solution annealing. It likely underwent grain refinement due to cold working or heat treatment.

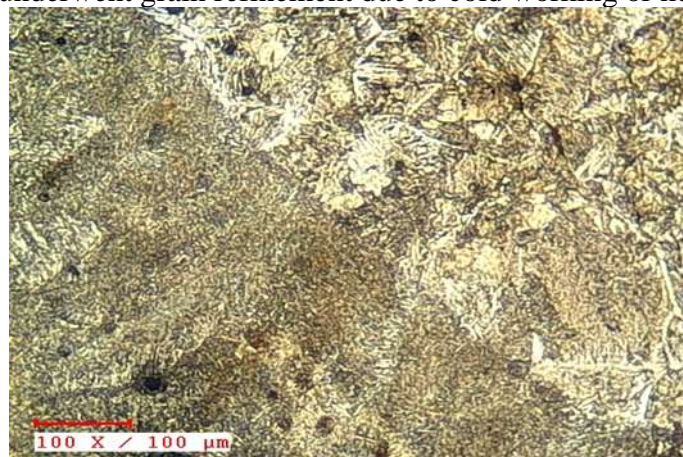


Fig.6.7 HAZ EN-9

Observation:

- You can see a mixture of dark and light regions with irregular grain boundaries. There are elongated and lamellar-like features with a granular base.

Interpretation:

- This suggests a pearlitic structure with potential ferrite regions, indicative of medium carbon steel (EN9) in either normalized or annealed condition. The coarse grains and dark etching suggest it may have undergone slow cooling after hot working or casting.



FIG 6.8(Likely SS304L – Slightly Modified or Cold Worked)

Observation:

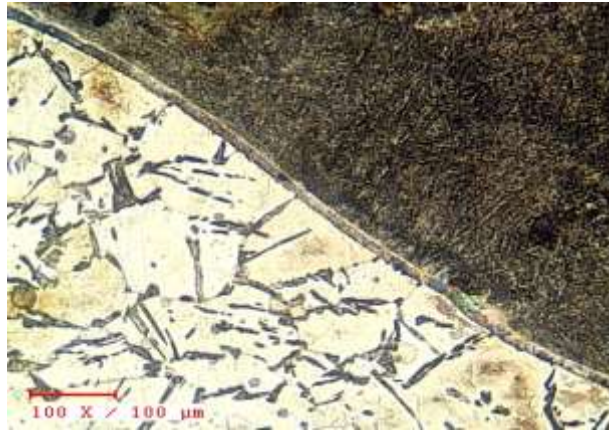
- Fine structure, slightly more contrast than Image 2. May show some deformation patterns or internal stress lines.
- Still consistent with SS304L, possibly with minor deformation or cold work effects. Some internal grain features hint at potential substructures or twinning within the austenite grains.



FIG6.9 (Likely EN9 – Widmanstätten or Banding Pattern)

Observation:

- Clearly visible lamellar/banded structures and elongated grains.
- Characteristic of Widmanstätten structures or banding due to directional solidification or mechanical processing in EN9 steel. These bands usually represent regions of pearlite and ferrite, caused by segregation during rolling or forging. This indicates that the steel was hot worked and slowly cooled.

**Observation:**

- Distinct boundary separating two microstructures. One side shows coarse dendritic/white grains, the other has dark, fine grains.
- This is a dissimilar metal interface, possibly between SS304L (left) and EN9 (right). The bright dendritic grains are indicative of austenitic stainless steel, while the dark, fine-grained zone on the right suggests quenched or fine pearlitic steel (EN9). The interface might be a fusion line formed by welding or cladding, showing a heat-affected zone (HAZ) and possible dilution.

Discussion:

The results reveal that the **interaction between current and voltage** plays a crucial role in determining the quality of the weld when dealing with dissimilar materials. The optimized parameters helped achieve a balance between heat input and weld bead formation, reducing the chances of defects like undercutting or lack of fusion. Additionally, the use of Taguchi analysis proved effective in identifying key process parameters that influence mechanical performance, thereby enhancing the overall reliability and repeatability of the welding process.

II. Conclusion

This study successfully investigated the TIG welding of dissimilar materials—SS304L and EN9—using a Taguchi-based optimization approach. Four sets of process parameters were tested, and mechanical characterization was performed through tensile and hardness testing.

From the results, it was concluded that the **optimal welding parameters** are:

- **Current:** 70 A
- **Voltage:** 13 V
- **Gas Flow Rate:** 10 LPM

These parameters (Sample 2) provided the **best mechanical strength**, as evidenced by the highest tensile and hardness values. Taguchi analysis further validated this combination as the most effective, based on the highest Signal-to-Noise (S/N) ratio.

The findings highlight the importance of precise control over welding parameters when working with dissimilar materials. The optimized parameters identified in this study can serve as a reliable reference for future TIG welding applications involving SS304L and EN9, ensuring enhanced weld quality and performance.

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