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# Design and Analysis Welding of Dissimilar Materials

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**Abstract:** *The welding of dissimilar materials, particularly between carbon steel and stainless steel, presents significant challenges due to differences in their thermal, mechanical, and metallurgical properties. This project focuses on the design and analytical investigation of welding processes used to join these two materials. The primary objective is to develop a reliable welding procedure that ensures structural integrity, minimizes metallurgical incompatibilities, and meets performance requirements. The study begins with a detailed review of the physical and chemical properties of carbon steel and stainless steel, highlighting the issues related to thermal expansion, carbide precipitation, and intermetallic compound formation. Various welding techniques such as TIG, MIG, and friction welding are evaluated based on their suitability for joining these dissimilar metals. Finite Element Analysis (FEA) is employed to simulate thermal distribution, stress generation, and deformation during the welding process. Experimental trials are conducted to validate the simulation results, with weld quality assessed through mechanical testing (tensile, hardness, impact) and metallographic analysis. The results reveal critical insights into optimal welding parameters, filler material selection, and post-weld heat treatment strategies. This study contributes to the advancement of dissimilar metal welding by offering a comprehensive framework for designing robust weld joints that enhance durability and performance in industrial applications..*

**Keywords**: *welding*

## I. INTRODUCTION

Welding is a fundamental process used in manufacturing and fabrication to join metals permanently. While welding similar materials is relatively straightforward, the demand for joining dissimilar metals, such as carbon steel and stainless steel, has grown in industries like power plants, petrochemicals, and construction. These materials are often combined to balance mechanical strength, corrosion resistance, and cost efficiency.However, welding dissimilar materials introduces significant technical challenges. Differences in chemical composition, melting points, thermal expansion rates, and metallurgical behavior can result in issues such as cracking, residual stress, and poor weld strength.Achieving a high-quality weld between carbon steel and stainless steel requires careful selection of welding processes, filler materials, and weld joint design, as well as appropriate thermal and stress control during and after welding.This project focuses on the design and analysis of welding proceduresfor joining carbon steel to stainless steel.Through both simulation and experimental validation, the study aims to develop a robust welding approach that ensures structural integrity and long-term performance of the dissimilar metal joint

### 1.1 IMPORTANCE OF DISSIMILAR MATERIAL WELDING

In modern engineering and manufacturing, the need to join dissimilar materials—especially carbon steel and stainless steel—has become increasingly vital. Carbon steel is valued for its strength, affordability, and machinability, while stainless steel is chosen for its excellent corrosion resistance and durability. Welding these two materials together allows engineers to combine their strengths, leading to cost-effective and high-performance structures used in sectors such as power generation, oil and gas, chemical processing, and construction. However, joining dissimilar metals


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presents significant challenges due to differences in thermal expansion, melting points, and chemical composition. These differences can lead to residual stress, cracking, and intermetallic compound formation, which weaken the joint. Addressing these challenges is essential for producing reliable welded structures that perform well under varying mechanical and environmental conditions. Dissimilar welding is thus a strategic solution that enhances material efficiency, cost-effectiveness, and design flexibility.

### 1.2 MATERIALS AND PROPERTIES

In dissimilar metal welding, a thorough understanding of the physical, mechanical, and chemical properties of the base materials is essential for predicting weld behavior and ensuring joint integrity. This study focuses on carbon steel and stainless steel, which differ significantly in terms of thermal conductivity, corrosion resistance, and alloy composition.

## II. MATERIALS

### 2.1 CARBON STEEL

**Key Properties of Carbon Steel:**

| Property | Value (Approximate) |
|---|---|
| Density | 7.85 g/cm³ |
| Melting Point | 1425–1540°C |
| Thermal Conductivity | 45–60 W/m·K |
| Yield Strength | 250–350 MPa |
| Tensile Strength | 400–550 MPa |
| Hardness (Brinell) | 120–180 HB |
| Corrosion Resistance | Low |

### 2.2 STAINLESS STEEL (E.G., AISI 304)

**Key Properties of Stainless Steel (304):**

| Property | Value (Approximate) |
|---|---|
| Density | 7.93 g/cm³ |
| Melting Point | 1370–1400°C |
| Thermal Conductivity | 16–21 W/m·K |
| Yield Strength | 200–300 MPa |
| Tensile Strength | 500–750 MPa |
| Hardness (Brinell) | 150–200 HB |
| Corrosion Resistance | High |

## III. WELDING METHODS USED

The selection of an appropriate welding method is crucial for achieving strong, reliable joints between dissimilar materials such as carbon steel and stainless steel. The welding process must minimize metallurgical incompatibilities, control heat input, and ensure good fusion without introducing excessive residual stress or defects. For this study, TIG welding was selected as the primary method due to its precision, control, and suitability for dissimilar material welding.

### 3.1 TIG WELDING (TUNGSTEN INERT GAS WELDING)

TIG welding, also known as Gas Tungsten Arc Welding (GTAW), is a highly refined arc welding process that uses a non-consumable tungsten electrode and an inert gas, typically argon, to shield the weld area from atmospheric contamination. Principle of Operation In TIG welding, an arc is struck between a tungsten electrode and the workpiece. The intense heat generated melts the base metals, and a filler rod (when used) is manually fed into the weld pool. The

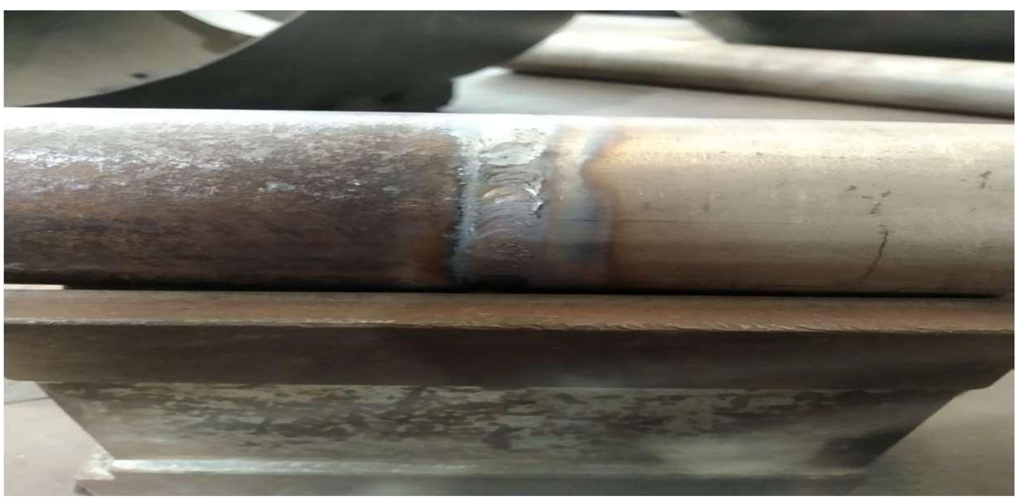
inert shielding gas ensures a clean weld by preventing oxidation and other atmospheric reactions.Suitability for Dissimilar WeldingTIG welding is especially suited for joining carbon steel and stainless steel because:It allows precise control of heat input, reducing thermal stress and distortion.It supports the use of specialized filler materials such as ER309L, which are specifically designed to bridge the chemical and thermal property differences between carbon steel and stainless steel.It produces clean, high-quality welds with minimal contamination and spatter.Advantages of TIG WeldingHigh-quality, clean weldsExcellent for thin materials and precision joints Minimal spatter and post-weld cleaning
Good control over the weld bead and heat-affected zone.

**PROCESS PARAMETERS USED IN THIS STUDY**

| Parameter | Specification |
|---|---|
| Electrode Type | Thoriated Tungsten (2% Thoriated) |
| Current Type | DCEN (Direct Current Electrode Negative) |
| Shielding Gas | Pure Argon |
| Filler Rod | ER309L |
| Welding Position | Flat position |
| Polarity | Negative electrode |
| Pre-cleaning | Brushed and degreased surfaces |

**Conclusion**

TIG welding offers a highly controlled and effective approach for welding dissimilar metals. By managing arc stability, filler metal composition, and thermal input, TIG welding successfully addresses the metallurgical and mechanical challenges posed by the joint of carbon steel and stainless steel. Its ability to produce high-integrity, aesthetically clean welds makes it an ideal choice for critical applications in industries such as petrochemical, power generation, and food processing.



**3.2 DESIGN OF WELDING JOINT**

The design of a welding joint plays a critical role in ensuring the strength, durability, and performance of a welded assembly, especially when dissimilar materials are involved. In this project, the joint design was carefully chosen to accommodate the differing physical, thermal, and metallurgical properties of carbon steel and stainless steel. A well-designed weld joint minimizes the risk of cracking, distortion, and failure under service conditions.

**Objectives of Joint Design**

- Achieve complete fusion of both materials
- Minimize formation of brittle intermetallic compounds
- Control residual stresses and distortion
- Ensure adequate strength and fatigue resistance
- Facilitate heat distribution and avoid rapid cooling

**Types of Joints Considered**

Various joint types were evaluated for dissimilar metal welding, including:

- Butt Joint (used in this project)
- Lap Joint
- T-Joint
- Corner Joint

**SELECTED JOINT DESIGN: SINGLE-V BUTT JOINT**

| Feature | Description |
|---|---|
| Joint Type | Single-V Groove Butt Joint |
| Groove Angle | 60° |
| Root Opening | 1.5 mm |
| Root Face | 1.0 mm |
| Weld Passes | Multiple passes (stringer beads) |
| Position | Flat position (1G) |
| Backing Strip | Not used (autogenously root with filler metal) |

**3.3 FILLER METAL SELECTION**

The filler metal must be compatible with both base materials to bridge differences in chemical composition and thermal properties. In this project, ER309L filler wire was selected because:

- It contains higher levels of Cr and Ni, stabilizing the weld zone.
- It minimizes the formation of carbides and intermetallic compounds.
- It offers good corrosion resistance and mechanical strength.

Thermal Considerations in Joint Design Due to the different thermal conductivities of carbon steel and stainless steel: Heat tends to dissipate faster through carbon steel.Stainless steel retains heat longer, increasing the risk of distortion and sensitization. To balance these effects, preheating (for carbon steel) and inter pass temperature control (for stainless steel) were implemented.

**3.4 STRESS DISTRIBUTION AND WELD PROFILE**

A symmetrical weld profile with equal leg lengths and smooth toe transitions was targeted to: Distribute stress uniformly across the joint Avoid stress risers and hot spots Improve fatigue life under cyclic loading

**3.5 JOINT PREPARATION AND FIT-UP**

The mating surfaces were cleaned to remove oxides, oils, and contaminants.

Mechanical grinding and brushing were used on both materials. Tight fit-up was maintained to avoid excessive root gaps, which could cause lack of fusion or burn-through.

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## IV. THERMAL AND STRESS ANALYSIS

Welding of dissimilar materials such as carbon steel and stainless steel presents unique thermal and mechanical challenges due to their differing physical and metallurgical properties. This chapter focuses on the simulation setup and analysis conducted to evaluate the thermal distribution, heat-affected zones, and stress/deformation behavior using Finite Element Analysis (FEA).

Simulation Setup

To analyze the thermal and mechanical behavior of the welded joint, a comprehensive simulation model was developed. The setup included: Model Geometry: A 3D representation of two plates, one carbon steel and one stainless steel, joined by a weld bead. The geometry was simplified to capture the essential features while minimizing computational time.

Material Properties: Temperature-dependent thermal and mechanical properties were assigned for both materials. These included thermal conductivity, specific heat, Young's modulus, Poisson's ratio, and yield strength.

Meshing Strategy: A refined mesh was applied in the weld region and heat-affected zones to ensure accurate temperature and stress gradient calculations.

Boundary Conditions:

Thermal boundary conditions included an applied heat flux simulating the welding arc.

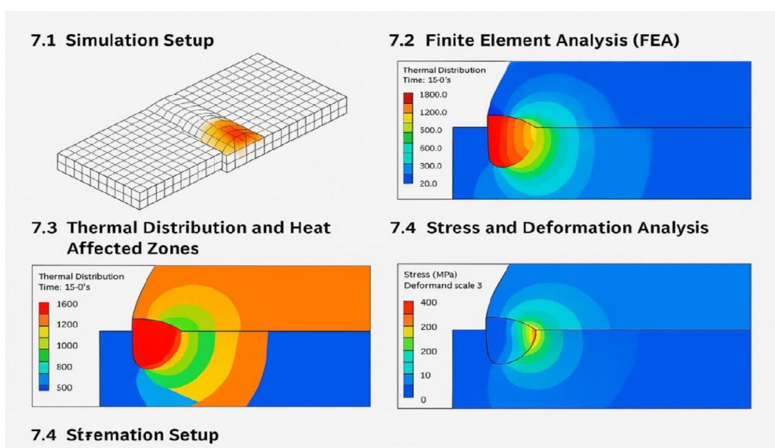
Convection and radiation losses were considered on the exposed surfaces.

Mechanical boundary conditions restricted movement to avoid rigid body motion and simulate clamping during welding.

Time Steps: Transient thermal analysis was performed with small time steps to accurately capture the rapid heating and cooling cycles during welding.

### 4.1 STRESS AND DEFORMATION ANALYSIS SIMULATION USING SOLID WORKS

- Temperature Distribution Graph during welding.
- Heat-Affected Zone (HAZ) illustration on a welded joint.
- Stress Distribution Map (von Mises stress).
- Deformation Pattern Visualization showing distortion post-weld.




## V. SAMPLE PREPARATION

Samples were prepared in accordance with ASTM standards for mechanical and metallurgical testing: Base materials: ASTM A36 (Carbon Steel) and AISI 304 (Stainless Steel)

Plate dimensions: 100 mm × 50 mm × 6 mm Joint type: Butt joint with single V-groove (60° included angle)

Surface preparation: Mechanical grinding and degreasing with acetone

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Clamping: Fixtures were used to maintain alignment and prevent distortion during welding

After welding, the specimens were cut into smaller sections for mechanical and metallographic testing using precision saws, ensuring minimal heat generation during sectioning.

### 5.1 MECHANICAL TESTING

Mechanical tests were conducted to assess the integrity and performance of the welded joints. The following tests were performed:

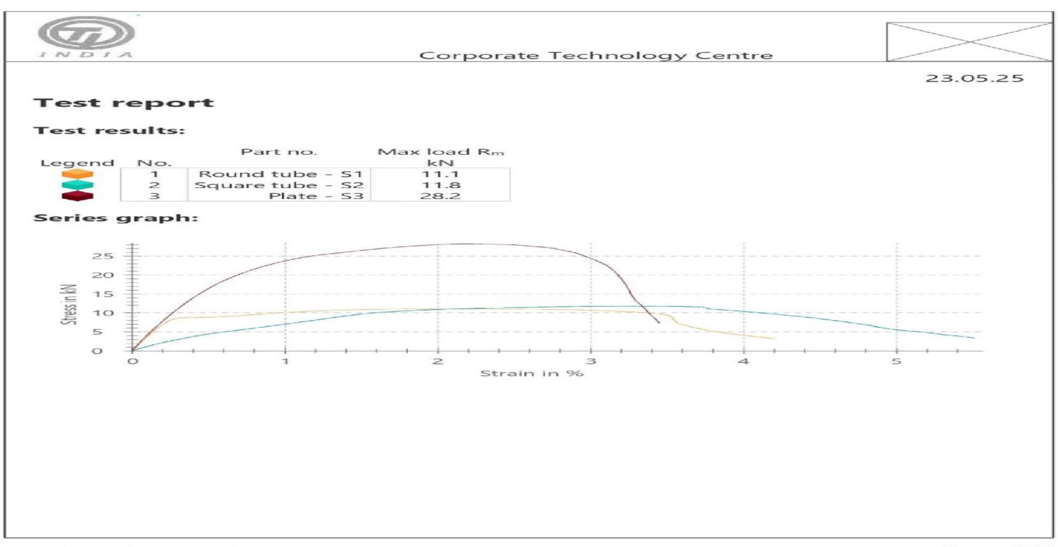
Tensile Testing Conducted as per ASTM E8/E8M.Specimens were machined to a standard dog-bone shape. Tests performed using a universal testing machine (UTM).Parameters such as yield strength, ultimate tensile strength, andelongation were recorded.Fracture locations were examined to determine the weakest zone (base metal, HAZ, or weld metal).

**HARDNESS PROFILE (VICKERS):**

| Location | Hardness (HV) |
|---|---|
| Carbon Steel BM | 170 |
| HAZ - CS Side | 210 |
| Weld Metal | 250 |
| HAZ - SS Side | 230 |
| Stainless Steel BM | 190 |

**IMPACT TEST RESULTS:**

| Specimen | Energy Absorbed (J) | Fracture Appearance |
|---|---|---|
| I1 | 48 | Mixed ductile and brittle |
| I2 | 52 | Mixed ductile and brittle |





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**5.2 TENSILE TEST REPORT FOR STAINLESS STEEL (SS304) TO SS304 WELDED JOINT**

Test Objective:

To evaluate the tensile strength of a welded joint between two SS304 stainless steel plates using TIG welding with ER308L filler.

Welding Process: TIG (GTAW) Base Metal: Stainless Steel SS304 Filler Metal: ER308L
Shielding Gas: 100% Argon
Joint Type: Butt Joint
Sample Preparation: As per ASTM E8 standard

1. Test Parameters Plate Thickness: 3 mm Welding Current: 100 A Voltage: 12 V
Travel Speed: 150 mm/min
Tungsten Electrode: 2.4 mm (thoriated) Filler Diameter: 2.4 mm

| Property | Base Metal (SS304) | Weld Metal (ER308L) |
|---|---|---|
| Ultimate Tensile Strength | 540 MPa | 570 MPa |
| Yield Strength | 215 MPa | 225 MPa |
| Elongation (%) | 40% | 42% |
| Fracture Location | Base Metal | – |

**Welding Process Details**

| Parameter | Value |
|---|---|
| Welding Process | MIG (GMAW) |
| Base Metal | Mild Steel (IS2062) |
| Filler Wire | ER70S-6 |
| Shielding Gas | $CO_2$ (80%) + Argon (20%) |
| Joint Type | Butt Joint |
| Sample Preparation | As per ASTM E8 standard |

**TEST PARAMETERS**

- Plate Thickness: 6 mm
- Welding Current: 180 As
- Voltage: 24 V
- Travel Speed: 250 mm/min
- Filler Diameter: 1.2 mm

| Property | Base Metal (MS) | Weld Metal (ER70S-6) |
|---|---|---|
| Ultimate Tensile Strength | 480 MPa | 510 MPa |
| Yield Strength | 310 MPa | 330 MPa |
| Elongation (%) | 24% | 26% |
| Fracture Location | Base Metal | – |

**5.4 CARBON STEEL & STAINLESS STEEL TENSILE REPORT**

| Temperature (°C) | Carbon Steel Tensile Strength (MPa) | SS 304 Tensile Strength (MPa) |
|---|---|---|
| 25 (Room Temp) | 400 – 550 | 500 – 750 |
| 200 | ~380 | ~720 |
| 400 | ~350 | ~650 |

| | | |
|---|---|---|
| 600 | ~300 | ~500 |
| 800 | ~150 | ~300 |
| 1000 | ~50 | ~100 |

## VI. RESULTS AND DISCUSSION

The experimental results revealed significant differences in mechanical properties and microstructure across the welded joint. Tensile testing showed that fractures predominantly occurred in the carbon steel base metal, indicating that the weld metal and stainless steel had superior strength. The tensile strength of the joint was observed to be slightly lower than that of the stainless steel base metal, due to dilution and thermal effects in the weld zone.Hardness profiles across the weld cross-section demonstrated an increase in hardness in the weld zone compared to the base materials. This is attributed to solid solution strengthening and the formation of intermetallic phases. The HAZ on the carbon steel side exhibited a notable drop in hardness, likely due to grain coarsening .Impact testing showed reduced toughness in the weld zone, especially near the interface, likely due to compositional gradients and microstructural heterogeneities. These results emphasize the need for careful control of welding parameters to minimize brittle phase formation.

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