

**THE EFFECT OF FILLER MATERIALS ON WELD STRENGTH IN DISSIMILAR
METAL WELDING.**

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CERTIFICATION

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DEDICATION

This work is dedicated to God Almighty for his strength, guidance and support throughout my academic years in the prestigious University of Benin.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Welding is an essential fabrication process in various industries, including automotive, aerospace, shipbuilding, and construction. It is a method used to join metals or thermoplastics through coalescence, usually involving the application of heat or pressure. The welding of similar metals, such as steel-to-steel or aluminum-to-aluminum, is relatively well-understood, with established techniques and filler materials to ensure strong and reliable welds. However, welding dissimilar metals (those with different chemical compositions and physical properties) introduces additional challenges due to the inherent differences in melting points, thermal conductivity, and expansion rates.

Dissimilar metal welding (DMW) has gained increasing attention in recent years due to its potential to optimize material properties in critical applications. For instance, in the automotive industry, lightweight materials like aluminum are welded to stronger metals such as steel to produce fuel-efficient vehicles without compromising safety. In the aerospace industry, DMW enables the combination of materials like titanium and aluminum, offering a balance between strength, heat resistance, and weight reduction.

The role of filler materials is particularly important in DMW, as they act as intermediaries between the base metals, helping to form a stable joint. The choice of filler material influences not only the mechanical strength of the weld but also its resistance to corrosion, heat, and stress. Incompatible filler materials can lead to poor weld strength, the formation of brittle intermetallic compounds, or cracking. This study seeks to explore how different filler materials affect weld strength in DMW, with the ultimate goal of identifying the optimal materials for specific dissimilar metal combinations.

1.2 History and Evolution of Dissimilar Metal Welding

The practice of welding metals together dates back thousands of years, with evidence of basic forge welding techniques found in ancient Egypt and Mesopotamia. However, the ability to join dissimilar metals only became feasible with advancements in material science and welding technologies during the Industrial Revolution. As the demand for new alloys and metal combinations grew, particularly in the shipbuilding and railroad industries, engineers began experimenting with ways to join metals like copper, steel, and aluminum.

By the mid-20th century, the introduction of modern welding techniques such as gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and submerged arc welding (SAW) revolutionized the field of dissimilar metal welding. These techniques provided better control over heat input, allowed for the use of different filler materials, and reduced the incidence of defects in the weld joint. In recent decades, the development of advanced technologies like laser welding and friction stir welding has further enhanced the ability to join metals with vastly different properties.

Today, DMW is employed across numerous industries, from the construction of hybrid metal pipelines in the oil and gas industry to the fabrication of multi-metal components in the aerospace sector. With the increasing demand for lightweight, durable, and high-performance materials, the need to perfect the art of dissimilar metal welding has never been greater.

1.3 Problem Statement

While the welding of dissimilar metals offers significant advantages, it remains a complex and challenging process. The primary issue arises from the differences in the physical, mechanical, and metallurgical properties of the metals being welded. Metals with different thermal expansion rates, melting points, and conductivity levels tend to react unpredictably when exposed to the intense heat of welding. This can result in weak weld joints, excessive residual stress, and the formation of brittle intermetallic compounds that compromise the structural integrity of the weld.

A key factor influencing weld strength in DMW is the selection of filler materials. The filler material must be compatible with both base metals to ensure a strong bond. However, improper filler material selection can lead to weld defects such as cracking, porosity, and corrosion, especially when joining metals with widely varying properties. The lack of clear guidelines on optimal filler materials for specific dissimilar metal combinations further complicates the process, leading to inconsistent results.

This study addresses the problem of filler material selection in DMW by investigating how different filler materials affect weld strength, particularly when joining metals like aluminum, steel, copper, and nickel-based alloys. By exploring the mechanical and microstructural properties of these welds, the research aims to provide insights into the most effective filler materials for achieving strong and reliable joints in dissimilar metal welding.

1.4 Aim and Objectives of the Study

The aim of this study is to evaluate the effects of various filler materials on weld strength in dissimilar metal welding. Specifically, the study seeks to identify the most suitable filler materials for enhancing the mechanical properties and durability of weld joints between different metal combinations.

The objectives of the study are as follows:

- To test the mechanical properties (e.g., tensile strength and toughness) of dissimilar metal welds using different filler materials.
- To provide recommendations on the optimal filler materials for specific dissimilar metal pairings, based on experimental results.

1.5 Research Questions

To guide the investigation, the following research questions have been formulated:

- How do different filler materials affect the mechanical properties (e.g., strength, toughness) of dissimilar metal weld joints?
- How does heat input during the welding process influence the weld strength when using different filler materials?
- Which filler materials are most effective in preventing defects such as cracking or porosity in dissimilar metal welds?
- What are the optimal filler materials for welding specific dissimilar metal combinations (e.g. Galvanized steel to Stainless steel, aluminum to steel, copper to stainless steel)?

1.6 Theoretical Framework

The theoretical framework for this study is grounded in the principles of materials science and welding metallurgy. The welding of dissimilar metals introduces complexities due to variations in the chemical and physical properties of the metals. The formation of a weld between two dissimilar metals involves both fusion of the base metals and interaction with the filler material. To understand how filler materials impact weld strength, it is essential to consider several key concepts:

Thermal Expansion and Conductivity: Metals with different thermal expansion rates can expand and contract at different rates during welding. If not properly managed, this can lead to residual stress and deformation in the weld joint. Understanding the thermal properties of both the

base metals and the filler material is crucial for predicting the behavior of the weld during heating and cooling cycles.

Intermetallic Compound Formation: When dissimilar metals are welded together, there is a risk of forming brittle intermetallic compounds at the weld interface. These compounds, such as Fe-Al intermetallics in aluminum-to-steel welding, can drastically reduce the mechanical properties of the weld. The selection of filler materials that can reduce or mitigate the formation of these compounds is critical to ensuring weld strength.

Heat-Affected Zone (HAZ): The area surrounding the weld, known as the heat-affected zone, is subject to changes in microstructure due to the heat of the welding process. The properties of the filler material and the control of heat input play a major role in determining the extent of these changes and their impact on the overall weld strength.

Solidification and Cooling Rates: The cooling rate of the weld has a significant impact on its final structure and mechanical properties. Faster cooling can lead to the formation of smaller grains, which generally improve strength, but can also increase brittleness. The filler material can influence the cooling rate by modifying the thermal properties of the weld pool.

The combination of these factors forms the basis for the analysis of how filler materials affect weld strength in dissimilar metal welding. By investigating the interplay between these theoretical principles and experimental results, this study will provide insights into the optimal selection of filler materials.

1.7 Scope of the Study

The scope of this study focuses on the welding of selected dissimilar metal pairs that are commonly used in industrial applications, specifically:

Aluminum to Stainless Steel: This combination is widely used in automotive and aerospace industries due to the need for lightweight and corrosion-resistant structures.

Carbon Steel to Copper: Common in electrical and thermal applications where high conductivity is required, such as in power generation systems.

Nickel-Based Alloys to Steel: Used in high-temperature and corrosive environments, particularly in the chemical and oil industries.

Galvanized Steel to Stainless Steel: Used in construction, automotive or industrial projects where galvanized steel components are to be joined.

The study will primarily examine the effects of different filler materials, including Electrode and binding wire, as well as stainless steel fillers, on the mechanical properties of the weld. The research will also focus on the metallurgical changes that occur in the weld joint, particularly the formation of intermetallic compounds and the characteristics of the heat-affected zone.

The experimental work will involve testing the mechanical properties of the weld joints, including tensile strength, toughness, and hardness.

1.8 Justification of the Study

The increasing demand for strong and lightweight materials in industries such as automotive, aerospace, and construction has highlighted the importance of dissimilar metal welding. As manufacturers seek to optimize the performance of metal components, the ability to reliably weld dissimilar metals has become essential. However, the challenges associated with achieving strong and durable welds between dissimilar metals remain significant, particularly in terms of selecting the appropriate filler material.

This study is justified by the need to provide practical insights into filler material selection for dissimilar metal welding. Despite advances in welding technologies, there is still a lack of comprehensive data on how different filler materials influence weld strength, particularly in terms of microstructural changes and the formation of intermetallic compounds. By focusing on commonly used dissimilar metal combinations, this research aims to bridge the gap between theory and practice, offering recommendations that can improve weld performance in real-world applications.

The findings from this study will be valuable to industries that rely on dissimilar metal welding, providing guidelines on the optimal selection of filler materials to enhance weld strength and durability. Furthermore, the study will contribute to the broader field of materials science by expanding the understanding of how filler materials interact with base metals in complex welding scenarios.

1.9 Limitations of the Study

While this research aims to provide a comprehensive analysis of the effect of filler materials on weld strength in dissimilar metal welding, there are certain limitations that must be acknowledged:

Material Selection: Study will focus on a limited set of dissimilar metal pairs: Galvanized steel to Stainless steel. While this pair is common in industrial applications, the results may not be fully generalizable to other metal combinations, such as titanium to copper or magnesium to stainless steel.

Filler Material Selection: Only a specific range of commercially available filler materials will be tested, which includes Electrode and Binding wire. The study will not explore experimental or newly developed filler materials, which may perform differently under the same conditions.

Welding Techniques: The research will focus primarily on conventional welding methods such as gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW). Advanced techniques

like friction stir welding and laser welding, which may offer different advantages for dissimilar metal welding, are beyond the scope of this study.

Time Constraints: Due to the limited timeframe for this study, only short-term mechanical testing (e.g., tensile strength and hardness) will be performed. Long-term studies involving fatigue, thermal cycling, and corrosion behavior would provide additional insights but are outside the scope of this research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The welding of dissimilar metals has become increasingly important in various industries where the ability to combine materials with different properties offers enhanced performance. However, the differences in thermal expansion, melting points, and chemical composition between dissimilar metals present significant challenges, particularly in achieving strong and durable weld joints.

This chapter provides a comprehensive review of the existing literature on dissimilar metal welding, with a focus on the role of filler materials in influencing weld strength. The review covers welding techniques commonly used for dissimilar metals, the properties and selection criteria for filler materials, and factors that affect weld quality and strength. It also discusses previous research on filler materials in dissimilar metal welding and highlights gaps in the literature that this study aims to address.

2.1 Overview of Welding Techniques for Dissimilar Metals

Various welding techniques are used to join dissimilar metals, each with its advantages and limitations. The choice of welding technique depends on the properties of the base metals, the desired characteristics of the weld joint, and the application in which the weld will be used. The most commonly used techniques for dissimilar metal welding include:

2.11 Gas Tungsten Arc Welding (GTAW/TIG): GTAW is a precision welding process that uses a non-consumable tungsten electrode to create the weld. This process is widely used for dissimilar metal welding because it provides excellent control over heat input and minimizes the formation of intermetallic compounds. GTAW is particularly suitable for metals like aluminum, stainless steel, and copper.

2.12 Gas Metal Arc Welding (GMAW/MIG): GMAW uses a consumable wire electrode and a shielding gas to create the weld. This method is more efficient and faster than GTAW, making it suitable for large-scale production. However, GMAW can introduce more heat into the weld, which may lead to the formation of intermetallic compounds or weld defects when joining dissimilar metals.

2.13 Friction Welding: Friction welding is a solid-state process that joins metals by applying mechanical friction to generate heat, allowing the materials to fuse without melting. This technique

is advantageous for dissimilar metal welding because it avoids the formation of brittle intermetallic compounds that can occur in fusion welding.

2.14 Laser Beam Welding: Laser welding uses a high-energy laser beam to fuse materials together. It offers precise control over the weld zone and is particularly useful for dissimilar metals with different melting points. Laser welding is becoming increasingly popular in industries like aerospace and electronics, where high-precision welds are required.

2.2 Comparative Analysis of Welding Techniques

In dissimilar metal welding (DMW), selecting the appropriate welding technique is critical for achieving strong, reliable joints. The performance of each technique varies based on the metals being joined, the filler materials used, and the desired characteristics of the weld. Below is a comparative analysis of the four primary welding techniques used in DMW:

Welding Techniques	Advantages	Disadvantages	Best for Dissimilar Metal Pairs
Shielded Metal Arc Welding(SMAW)	<ul style="list-style-type: none"> • Low equipment cost • Portability • High versatility: Can be used to weld a wide range of Metals. 	<ul style="list-style-type: none"> • Limited penetration • Slag formation • Low welding speed 	<ul style="list-style-type: none"> • Galvanized to Stainless Steel • Cast iron to Galvanized steel
Gas Tungsten Arc Welding (GTAW)	<ul style="list-style-type: none"> • Precise control over heat input • High-quality welds with minimal defects 	<ul style="list-style-type: none"> • Slower process • Requires high skill level 	<ul style="list-style-type: none"> • Aluminum to Stainless Steel • Copper to Steel
Gas Metal Arc Welding (GMAW)	<ul style="list-style-type: none"> • High deposition rate • Suitable for large-scale production 	<ul style="list-style-type: none"> • Higher heat input can cause distortion • Less control over heat 	<ul style="list-style-type: none"> • Aluminum to Steel • Carbon Steel to Copper

Friction Welding	<ul style="list-style-type: none"> • Avoids molten phase, reducing intermetallic compounds • High-strength joints 	<ul style="list-style-type: none"> • Limited to linear or rotational welds • Requires special equipment 	<ul style="list-style-type: none"> • Titanium to Steel • - Aluminum to Copper
Laser Welding	<ul style="list-style-type: none"> • High precision • Low heat input minimizes defects 	<ul style="list-style-type: none"> • High cost of equipment • Sensitive to joint preparation 	<ul style="list-style-type: none"> • Aluminum to Nickel Alloys • Steel to Copper

The choice of technique depends on various factors, including the properties of the base metals, the desired quality of the weld, and the industrial application. For instance, GTAW is preferred for high-precision applications like aerospace components, where weld quality is critical. On the other hand, GMAW is favored for large-scale production due to its efficiency, though it may result in more weld defects if not properly controlled.

2.3 Detailed Analysis of Filler Material Properties

Filler materials are crucial in dissimilar metal welding, as they act as a bridge between the two base metals and influence the overall strength and durability of the weld. The selection of an appropriate filler material is influenced by several factors, including the chemical composition of the base metals, the welding technique, and the operating conditions of the final component (e.g., temperature, corrosion exposure).

The following table outlines common filler materials used in DMW, their properties, and typical applications:

Filler Material	Chemical Composition	Advantages	Disadvantages	Common Applications
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Nickel-Based Alloys	Nickel (Ni) with elements like Chromium (Cr), Molybdenum (Mo)	- High strength - Excellent corrosion resistance	- High cost - Can be prone to cracking in some metals	Steel to Nickel - Stainless Steel to Copper
Aluminum-Silicon Alloys	Aluminum (Al) with Silicon (Si)	- Reduces cracking - Good fluidity in the weld pool	- Limited use in high-temperature applications	- Aluminum to Stainless Steel - Aluminum to Copper
Copper-Based Alloys	Copper (Cu) with Zinc (Zn), Tin (Sn), or Nickel (Ni)	- Excellent electrical and thermal conductivity	- Prone to porosity - Poor mechanical strength at high temperatures	- Steel to Copper - Copper to Aluminum
Stainless Steel Fillers	Iron (Fe), Chromium (Cr), Nickel (Ni), Manganese (Mn)	- High corrosion resistance - Good ductility	- Prone to intermetallic compound formation in some metal pairs	- Stainless Steel to Carbon Steel - Steel to Nickel Alloys

Each filler material has unique properties that determine its suitability for different metal combinations. For example, nickel-based alloys are commonly used for welding dissimilar metals in high-temperature or corrosive environments due to their excellent strength and resistance to oxidation. However, the high cost of these fillers makes them less desirable for large-scale applications. Aluminum-silicon alloys, on the other hand, are effective in reducing cracking when welding aluminum to stainless steel but are not suitable for high-temperature environments due to their lower melting point.

2.4 Factors Affecting Weld Strength

Achieving strong welds between dissimilar metals depends on multiple factors, including the filler material, heat input, cooling rate, and metallurgical properties of the metals involved. The following factors play a significant role in determining the overall strength of the weld:

Non-uniform Thermal Expansion: Dissimilar metals often have vastly different coefficients of thermal expansion. During the welding process, one metal may expand or contract more than the other, leading to residual stresses and the potential for cracking. This is especially critical when

welding metals like aluminum and steel, which have significantly different thermal expansion rates. The proper selection of filler materials, as well as control over the heat input, can help mitigate these effects.

Melting Point Differences: The melting points of the base metals are another important consideration in dissimilar metal welding. Metals like aluminum and copper have much lower melting points than steels, which can result in uneven melting or incomplete fusion if not properly controlled. Filler materials with a melting point closer to that of the base metals can help to bridge this gap, ensuring a more uniform weld.

Intermetallic Compound Formation: When dissimilar metals are welded, there is a high likelihood of forming intermetallic compounds at the weld interface. These compounds are often brittle and can severely reduce the mechanical properties of the weld. For example, welding aluminum to steel often results in the formation of brittle Fe-Al intermetallic phases, which can lead to cracking. Filler materials that minimize or prevent the formation of these compounds are essential for improving weld strength.

Heat Input and Cooling Rate: The amount of heat applied during welding and the rate at which the weld cools are critical factors that affect the microstructure of the weld. Excessive heat input can lead to the formation of large grains or promote the dilution of the filler material into the base metals, both of which can reduce the weld strength. Conversely, rapid cooling can increase the brittleness of the weld. Optimizing the heat input and cooling rate, along with selecting the appropriate filler material, is crucial for achieving strong welds.

Weld Defects (Cracking, Porosity, and Distortion): Weld defects such as cracking, porosity, and distortion can significantly reduce the strength of the weld. Cracking often occurs due to thermal stresses caused by differences in expansion rates between the metals. Porosity can be introduced if gases are trapped during the solidification process, while distortion can occur if the heat input is not properly controlled. The right combination of filler material and welding technique can help to minimize these defects.

2.5 Common Challenges in Dissimilar Metal Welding

Welding dissimilar metals presents unique challenges due to the inherent differences in their chemical, physical, and mechanical properties. These challenges can result in various issues that compromise weld integrity, strength, and durability. Below are some of the most common challenges encountered in dissimilar metal welding:

Formation of Brittle Intermetallic Compounds: One of the most significant challenges in dissimilar metal welding is the formation of brittle intermetallic compounds at the weld interface. Intermetallic compounds are chemical combinations of two or more metals that tend to form during

the fusion of dissimilar metals, particularly those with highly reactive elements such as aluminum, copper, and steel. These compounds often have poor ductility and toughness, leading to a reduction in weld strength and making the joint more susceptible to cracking.

For example, when welding aluminum to steel, Fe-Al intermetallic compounds can form, which are brittle and reduce the mechanical properties of the weld. Proper filler material selection and controlled heat input are critical in minimizing the formation of these compounds.

Differences in Thermal Expansion: Dissimilar metals often have different coefficients of thermal expansion, which can lead to internal stresses during the welding process. When heated, metals expand at different rates; during cooling, the contraction rates also vary. This can cause residual stresses to build up in the weld joint, leading to distortion, cracking, or even complete failure of the weld.

The thermal expansion mismatch is particularly problematic when welding metals like aluminum and steel, where the difference in thermal expansion is significant. Proper control of the heat input and cooling rate, along with the use of compatible filler materials, can reduce the effects of thermal expansion mismatch.

Corrosion Resistance: Dissimilar metal welds are often more susceptible to galvanic corrosion, which occurs when two dissimilar metals are in electrical contact with each other in the presence of an electrolyte, such as water. One of the metals acts as an anode and corrodes faster, while the other acts as a cathode and corrodes slower. This issue is commonly seen in metals like aluminum and steel, where the anodic aluminum corrodes more rapidly in the presence of moisture.

To mitigate corrosion in dissimilar metal welds, corrosion-resistant filler materials, such as nickel-based alloys, can be used. Additionally, applying protective coatings and careful design of the welded component can help reduce the risk of galvanic corrosion.

Differences in Melting Points: The difference in melting points between dissimilar metals can complicate the welding process. Metals with lower melting points, such as aluminum, tend to melt more quickly, while metals with higher melting points, like steel, may not fully melt at the same temperature. This can result in incomplete fusion, weak joints, or excessive melting of one metal.

For instance, when welding copper to steel, copper melts at a much lower temperature than steel. Managing the heat input and using filler materials that help to bridge the temperature gap can improve weld quality. Laser welding and friction welding techniques are often used to overcome the challenges posed by differences in melting points.

Weldability of Base Metals: The weldability of individual metals varies greatly, and some metals are inherently more difficult to weld than others. For example, metals like titanium and magnesium are more reactive and require special welding environments, such as inert gas atmospheres, to

prevent oxidation during welding. When welding these metals to more easily weldable metals, such as steel, the difference in weldability can complicate the process. The selection of compatible filler materials and the use of specialized welding techniques, such as friction welding or TIG welding in an inert atmosphere, can help improve the weldability of challenging metal combinations.

Differences in Mechanical Properties: Metals joined by dissimilar metal welding often have vastly different mechanical properties, such as hardness, tensile strength, and ductility. These differences can lead to uneven stress distribution across the weld joint, which can cause premature failure under mechanical loads.

For instance, welding a high-strength metal like steel to a softer, more ductile metal like aluminum can result in stress concentrations at the weld interface, leading to cracking or failure. The use of filler materials that offer a balance between the mechanical properties of the base metals can help alleviate these issues.

2.6 Previous Studies on Filler Materials in Dissimilar Metal Welding

Numerous studies have been conducted on the impact of filler materials on weld strength and quality in dissimilar metal welding. These studies provide important insights into how different filler materials behave in various metal combinations, offering guidelines for improving weld strength and durability.

Study on Aluminum-Stainless Steel Welding:

A study conducted by Zhang et al. (2018) focused on the welding of aluminum to stainless steel using different aluminum-based filler materials. The study found that using aluminum-silicon alloy fillers significantly reduced the formation of brittle Fe-Al intermetallic compounds, thereby improving the mechanical properties of the weld. Additionally, the researchers highlighted the importance of controlling heat input to minimize distortion and cracking.

Nickel-Based Fillers for High-Temperature Applications:

Huang et al. (2020) investigated the use of nickel-based filler materials in welding nickel alloys to steel for high-temperature applications. The study found that nickel-based fillers offered superior resistance to oxidation and high-temperature corrosion compared to other fillers. The researchers also noted that the filler material's ability to form ductile phases helped prevent cracking, even in high-stress environments.

Copper-Steel Dissimilar Metal Welding:

Smith et al. (2019) explored the welding of copper to steel using various filler materials. The study demonstrated that brass fillers, which contain a mix of copper and zinc, provided the best results in terms of weld strength and corrosion resistance. The researchers also found that excessive heat input led to porosity in the welds, underscoring the importance of heat control in copper-steel welding.

Cooling Rates Effects on Weld Microstructure:

Research by Patel and Singh (2021) examined the effect of cooling rates on the microstructure and mechanical properties of dissimilar metal welds. The study found that slower cooling rates promoted the formation of larger grains in the weld, which reduced the weld's overall strength. Conversely, faster cooling rates improved strength but increased the risk of brittleness. The research concluded that optimizing the cooling rate was critical for balancing strength and ductility in dissimilar metal welds.

These studies highlight the critical role that filler materials play in determining the success of dissimilar metal welds. By selecting appropriate filler materials and controlling welding parameters such as heat input and cooling rate, manufacturers can significantly improve the strength and reliability of dissimilar metal joints.

2.8 Case Studies of Real-World Applications

Real-world case studies demonstrate the practical applications and challenges of dissimilar metal welding in various industries. Below are two notable examples:

Automotive Industry: Aluminum-Steel Joints: In the automotive industry, lightweight materials like aluminum are frequently welded to steel to reduce vehicle weight and improve fuel efficiency. A case study involving a major automobile manufacturer found that the use of aluminum-silicon filler material improved the strength and corrosion resistance of aluminum-to-steel joints, leading to longer-lasting components. However, the study also highlighted the need for precise heat control to prevent the formation of brittle intermetallic compounds at the weld interface.

Aerospace Industry: Titanium-Steel Welding: In the aerospace sector, dissimilar metal welding is used to join high-performance materials like titanium to steel for use in aircraft components. A case study on a titanium-steel weld used in jet engine components revealed that nickel-based fillers provided the best results in terms of heat resistance and weld strength. The study also emphasized the importance of post-weld heat treatment to relieve residual stresses and improve the microstructure of the weld.

2.9 Standards and Regulations in Dissimilar Metal Welding

Welding dissimilar metals is a highly specialized process, and the quality and safety of welded joints are critical, especially in industries such as aerospace, automotive, construction, and energy. To ensure the reliability of these welds, several international organizations have developed standards and guidelines that regulate dissimilar metal welding practices, including the selection of filler materials, welding procedures, and testing methods. Below are some of the most relevant standards and regulations:

American Welding Society (AWS) Standards:

- The AWS D1.1 Structural Welding Code provides guidelines for welding steel structures, but it also includes provisions for welding dissimilar metals, particularly when steel is involved. The AWS D1.1 specifies the use of filler materials that are compatible with the base metals and outlines the necessary procedures for ensuring strong, defect-free welds.
- AWS A5.10 is the standard for welding aluminum and aluminum alloys, which includes provisions for dissimilar metal welding involving aluminum. This standard provides specifications for filler materials that reduce cracking and improve joint strength when welding aluminum to other metals.

ISO Welding Standards:

- The International Organization for Standardization (ISO) has developed several standards that apply to dissimilar metal welding. ISO 15614-6 provides guidelines for the qualification of welding procedures for metallic materials, including dissimilar metal welding. This standard covers both fusion and solid-state welding processes and provides requirements for testing and evaluating welds.
- ISO 18274 specifically addresses nickel and nickel alloy welding, which is often used in dissimilar metal welding due to its corrosion resistance and high-temperature performance. This standard provides specifications for nickel-based filler materials, ensuring that they meet the required mechanical and chemical properties for welding dissimilar metals.

European Standards (EN):

- The EN 1011 series of standards provides comprehensive guidelines for welding metallic materials in Europe. EN 1011-3 focuses on the welding of aluminum and its alloys, offering detailed instructions on how to handle dissimilar metal welding involving aluminum. This standard emphasizes the selection of appropriate filler materials to minimize the formation of intermetallic compounds and weld defects.
- EN ISO 9606-1 specifies the qualification requirements for welders who perform dissimilar metal welding. It ensures that welders are trained to use the correct techniques and filler materials to produce high-quality welds.

ASME Boiler and Pressure Vessel Code (BPVC): The ASME BPVC Section IX outlines the requirements for welding and brazing qualifications, including procedures for welding dissimilar metals in critical applications such as pressure vessels, boilers, and pipelines. This code specifies the testing and certification requirements for welders, as well as the approval of welding procedures and filler materials for use in high-pressure and high-temperature environments.

Industry-Specific Guidelines: In addition to general welding standards, many industries have developed their own guidelines for dissimilar metal welding. For example, the NACE (National Association of Corrosion Engineers) has guidelines for preventing galvanic corrosion in dissimilar metal welds, particularly in the oil and gas industry. These guidelines help engineers select filler materials and protective coatings to minimize the risk of corrosion when dissimilar metals are joined in corrosive environments.

These standards and regulations provide a framework for ensuring that dissimilar metal welding processes are conducted safely and effectively. By following these guidelines, manufacturers can reduce the risk of weld failure, ensure compliance with industry standards, and improve the overall quality and performance of welded joints.

2.10 Future Trends in Filler Materials and Welding Technology

As industries continue to push the boundaries of material science and engineering, the demand for advanced dissimilar metal welding technologies is increasing. Emerging trends in filler materials and welding techniques are aimed at improving weld quality, reducing costs, and expanding the range of materials that can be welded together. Below are some of the key trends shaping the future of dissimilar metal welding:

Development of New Filler Materials: Advances in materials science are leading to the development of new filler materials specifically designed for dissimilar metal welding. These materials are engineered to minimize the formation of brittle intermetallic compounds, improve corrosion resistance, and enhance the mechanical properties of the weld. For example, hybrid filler materials that combine elements from both base metals are being developed to reduce thermal expansion mismatches and improve weld compatibility.

Another promising area of research is the development of nano-reinforced filler materials. These materials incorporate nanoparticles into the filler material, which can improve the mechanical properties of the weld by refining the grain structure and increasing the toughness and strength of the joint.

Additive Manufacturing and Welding: Additive manufacturing (AM), also known as 3D printing, is revolutionizing the welding industry by enabling the production of complex, multi-material components. Some AM processes, such as Directed Energy Deposition (DED), involve

depositing material layer by layer to form a weld. This technology allows for precise control over the composition of the material being deposited, enabling the seamless integration of dissimilar metals in a single component. The combination of additive manufacturing and dissimilar metal welding opens up new possibilities for producing lightweight, high-performance structures in industries such as aerospace and automotive. Researchers are exploring the use of AM to create functionally graded materials (FGMs), where the composition of the material gradually changes from one metal to another, reducing the risk of thermal expansion mismatches and intermetallic formation.

Advances in Welding Techniques: New welding techniques, such as friction stir welding (FSW) and laser-arc hybrid welding, are gaining popularity for dissimilar metal welding applications. These techniques offer better control over heat input and minimize the formation of defects in the weld.

Friction Stir Welding: This solid-state welding process uses mechanical friction to join materials without melting them. FSW is particularly effective for welding dissimilar metals like aluminum and steel because it avoids the molten phase, where most defects and intermetallic compounds form.

Laser-Arc Hybrid Welding: This technique combines the precision of laser welding with the efficiency of arc welding, providing greater flexibility in welding dissimilar metals with different melting points. It allows for deeper penetration and faster welding speeds while maintaining control over the heat input.

Smart Welding Systems: Advances in automation and artificial intelligence (AI) are leading to the development of smart welding systems that can optimize the welding process in real-time. These systems use sensors and machine learning algorithms to monitor the welding parameters (e.g., heat input, cooling rate) and adjust them to ensure consistent weld quality. In the context of dissimilar metal welding, smart systems can help reduce the risk of weld defects by dynamically adjusting the welding conditions based on the properties of the base metals and filler materials.

Robotic welding systems are also becoming more sophisticated, allowing for greater precision and repeatability in dissimilar metal welding applications. These systems can be programmed to weld complex geometries and use advanced techniques like laser welding or friction stir welding to join materials that would be difficult to weld manually.

Sustainable Welding Practices: As environmental concerns become more prominent, there is a growing emphasis on developing sustainable welding practices. This includes reducing the use of hazardous filler materials and minimizing waste during the welding process. Researchers are exploring eco-friendly filler materials that are free from harmful elements like lead and cadmium, which are commonly used in some soldering and brazing processes.

Additionally, sustainable welding techniques that use less energy, such as friction welding, are gaining traction in industries looking to reduce their carbon footprint. These techniques not only produce strong, high-quality welds but also require less heat and energy, making them more environmentally friendly.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methodology employed in this research to evaluate the effect of filler material (electrode plus binding wire) on the weld strength in dissimilar metal welding between galvanized steel and stainless steel. The research is experimental, involving controlled welding and mechanical testing of weld joints to determine their strength and performance. This chapter covers the research design, materials and equipment used, welding procedures, testing methods, data collection, and analysis techniques. The procedures followed were designed to ensure the reliability, accuracy, and repeatability of the experimental results.

3.2 Research Design

This study employs an experimental research design, focusing on evaluating the mechanical properties (tensile strength and hardness) of welds formed between galvanized steel and stainless steel. The research aims to determine how the selected filler material (electrode plus binding wire) affects the weld strength. The experimental procedure includes:

- **Material Selection:** Galvanized steel and stainless steel pipes are welded using a consumable electrode and binding wire.
- **Welding Process:** The welding is conducted using electric arc welding with specific welding parameters.
- **Testing and Analysis:** Weld strength is assessed using a Universal Testing Machine (UTM) for tensile strength analysis.
- **Data Analysis:** Experimental results are analyzed statistically, comparing weld performance based on mechanical properties.

3.3 Materials and Equipment

3.3.1 Base Metals

- **Galvanized Steel**



Fig 3.1: galvanized steel pipe

Galvanized steel is a type of carbon steel that has been coated with a layer of zinc to protect it from corrosion. The composition of galvanized steel is approximately:

Element	Percentage Composition (%)
Iron(Fe)	97.5 - 99.0
Carbon (C)	0.04 - 0.30
Manganese (Mn)	0.25 -1.40
Zinc (Zn)	0.01- 0.50
Silicon(Si)	0.00 - 0.04

Table 3.1: Percentage composition of Galvanized steel.

The galvanized steel pipes used in this study have the following dimensions:

Length: 17 cm

Diameter: 1¼ inch

- **Stainless Steel**

Stainless steel is an alloy of iron with chromium and nickel, providing excellent corrosion resistance. The composition of stainless steel (AISI304) is:

Element	Percentage Composition (%)
Iron(Fe)	65 -70
Chromium (Cr)	18 -20
Nickel(Ni)	8 - 10
Carbon (C)	≤0.08
Manganese (Mn)	≤2.00
Silicon (Si)	≤1.00

Table 3.2: *Percentage composition of Stainless steel.*

The stainless steel pipes used have:

Length: 17 cm

Diameter: 1¼ inch



Fig 3.2: *Stainless steel pipe.*

Sourcing of Base Metals

Galvanized steel and stainless steel are commonly sourced from:

- Local steel suppliers and fabrication workshops.
- Steel manufacturing plants that produce pipes and sheets.
- Industrial scrap yards and recycling centers.

3.3.2 Filler Material

- **Electrode (E6013 Welding Electrode)**

The electrode used in this experiment is E6013, a commonly used mild steel electrode for arc welding. It is coated with a flux that stabilizes the arc and prevents oxidation. The composition of an E6013 electrode is:

Element	Percentage composition (%)
Iron(Fe)	95 -98
Carbon (C)	0.10 - 0.15
Manganese (Mn)	0.30 - 0.60
Silicon (Si)	0.20 - 0.35
Titanium dioxide (TiO ₂)	10 - 12
Sodium(Na)/Potassium(K)	1 - 3

Table 3.3: *Percentage composition of Electrode (E6013 welding Electrode).*

Purpose:

The electrode provides the molten filler metal necessary to join the dissimilar base metals.

The flux coating produces a shielding gas during welding to prevent oxidation and contamination.

Why Electrode:

- Readily available, widely used for arc welding.
- Compatible with both galvanized steel and stainless steel, ensuring good fusion.

- **Binding Wire(Filler wire):**

Binding wire (also known as tie wire) is commonly made of low-carbon steel. It is used to reinforce welds by acting as an additional filler material.

The chemical composition is:

Element	Percentage composition (%)
Iron(Fe)	98 - 99
Carbon (C)	0.04 -0.10
Manganese (Mn)	0.25 - 0.50
Silicon (So)	0.02 - 0.06

Table 3.4: *Percentage composition of Binding wire.*

Purpose:

Used as an additional filler material to strengthen the weld and improve ductility.

Fig 3.4: Binding wire used as filler in welding.

Why Binding/Tie wire:

- Low cost and easy to handle, making it ideal for use with galvanized steel.
- Helps reduce porosity and cracking in the weld zone.



Fig 3.4: *Binding wire used as filler in welding.*

Why These Filler Materials (Electrode and binding wire) Were Chosen:

- Readily available and cost-effective compared to advanced filler materials.

- Compatible with both galvanized steel and stainless steel, ensuring good fusion and mechanical properties.
- Ease of use in manual arc welding applications, making it suitable for general fabrication.

3.3.3 Welding Equipment

The welding process was conducted using Electric Arc Welding (Shielded Metal Arc Welding - SMAW), which employs a consumable electrode and binding wire to fuse metals together. The equipment used includes:

Welding Machine: A 220V, 200A Electric Arc Welding Machine was used, capable of producing a stable arc for welding.

Electrode Holder and Ground Clamp: Essential for maintaining proper electrical conductivity.

Protective Gas: None, since SMAW uses a flux-coated electrode, eliminating the need for shielding gas.

Safety Equipment: Welding helmet, gloves, and protective clothing to ensure safe welding practices.

3.4 Welding Process and Parameters

3.4.1 Welding Parameters

The following parameters were selected to ensure a high-quality weld for joining galvanized steel and stainless steel:

Parameter	Value
Welding Process	SMAW(Manual Arc Welding)
Electrode type	E6103
Current type	Direct Current (DC)
Welding Current	120 - 140A
Arc Voltage	22 -24 V

Electrode Diameter	2.5mm
Travel Speed	3 - 5mm/sec
Heat Input	~1.2KJ/mm
Joint Configuration	Butt Joint (Pipe-to-Pipe)

Table 4.1: *Welding parameters for dissimilar metal welding.*

3.4.2 Experimental Procedure

3.4.2.1 Preparation of Base Metals

Cutting:

The galvanized steel and stainless steel pipes were cut into 17 cm lengths using a metal cutting saw.

Surface Cleaning:

The galvanized coating on the edges of the steel pipe was removed using a grinder to prevent contamination during welding.

Stainless steel surfaces were cleaned with acetone to remove oils and dirt.

Beveling:

A 45-degree bevel was machined at the pipe edges to ensure better penetration and fusion.

3.4.2.2 Joint Configuration

A butt joint configuration was selected, where the two pipes were aligned end-to-end and welded along the circumference. This configuration provides good structural integrity and is commonly used in pipe welding applications.

3.4.2.3 Number of Weld Specimens

To ensure reliability and repeatability, multiple samples were prepared:

3 specimens welded using E6013 electrode with additional binding wire.

Each set was tested for tensile strength.

3.5 Testing of Weld Strength

3.5.1 Tensile Strength Test (Using Universal Testing Machine - UTM)

Objective:

To determine the maximum load capacity of the weld before failure.

Procedure:

- i. Welded specimens were clamped into the Universal Testing Machine (UTM).
- ii. A gradual tensile force was applied along the pipe's axis.
- iii. The ultimate tensile strength (UTS) was recorded at the point of weld failure.
- iv. The fracture surface was analyzed to determine failure mode (brittle vs. ductile).

3.6.2.1 Interpretation of result:

A low CV would indicate consistent tensile strength values, meaning the filler material (electrode + binding wire) provides stable weld performance and a high CV will prove otherwise.

3.7 Ensuring Reliability and Accuracy

To ensure that the experimental results were reliable and reproducible, the following measures were implemented:

Repeatability:

Multiple samples (n=3) were tested for each welding configuration to ensure consistency.

The welding parameters were kept constant across all samples.

Minimizing Operator Variability:

The same operator conducted all welding and testing procedures to reduce human error.

3.8 Limitations of the Study

Despite the comprehensive experimental approach, the study had certain limitations:

- **Limited Range of Filler Materials:**

The study focused on only one filler material (E6013 electrode + binding wire).

Other filler materials, such as nickel-based or aluminum-silicon fillers, were not tested due to unavailability.

- **Restricted Welding Techniques:**

Only Shielded Metal Arc Welding (SMAW) was used.

Advanced techniques such as TIG (Tungsten Inert Gas) or MIG (Metal Inert Gas) welding were not explored.

- **Limited Filler Material Choices:**

Only electrode + binding wire was tested, restricting comparisons with other filler materials.

- **Controlled Laboratory Conditions:**

The study was conducted under laboratory conditions, meaning environmental factors (e.g., outdoor exposure, humidity) were not considered.

In real-world applications, factors such as corrosion resistance and long-term durability could affect weld performance.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and analyzes the results obtained from the tensile strength test conducted on three welded specimens. The test aims to determine the ultimate tensile strength (UTS) of the weld joint between galvanized steel and stainless steel pipes using an electrode and binding wire as filler materials.

The failure load (force required for fracture) and the UTS values were recorded for each sample and analyzed to assess the weld quality and strength consistency.

4.2 Data Collection and Analysis

Data collection in this study involved recording mechanical properties such as tensile strength and hardness for each welded sample. The results were documented systematically to evaluate the effect of the filler material (E6013 electrode with a binding wire) on weld strength. Statistical methods were applied to compare the weld quality between the two filler material configurations.

4.2.1 Tensile Strength Measurement

Test Setup:

The welded specimens were secured in the Universal Testing Machine (UTM). A gradually increasing tensile load was applied until failure occurred.

Recorded Data:

- Maximum load before failure (in Newtons, N)
- Ultimate Tensile Strength (UTS)
- Fracture location (weld zone, heat-affected zone, or base metal)



Figure 4.2: *Universal Testing Machine (UTM)*

Formula for Ultimate Tensile Strength (UTS):

$$UTS = F/A$$

Where:

UTS = Ultimate Tensile Strength (MPa)

F = Maximum Load (N)

A = Cross-sectional Area (mm²).

NOTE: The cross-sectional area (A) of the welded joint is determined based on the geometry of the pipes being welded. Since the galvanized steel and stainless steel pipes are cylindrical with an outer diameter of 1¼ inches (31.75 mm), and they are welded in a butt joint configuration, we assume that the cross-sectional area is equal to the cross-sectional area of the pipe wall at the weld interface.

Step-by-Step Calculation

1. Given Data

Outer Diameter of Pipe (D_o) = 31.75 mm

Pipe Wall Thickness (t) = 2 mm (Assumed for standard galvanized and stainless steel pipes)

Inner Diameter of Pipe (D_i) is calculated as:

$$D_i = D_o - 2 \times t$$

$$D_i = 31.75 - (2 \times 2) = 27.75 \text{ mm}$$

2. Formula for Cross-Sectional Area of a Pipe Wall

The cross-sectional area of a hollow cylinder (pipe) is given by:

$$A = \pi/4(D_o^2 - D_i^2)$$

3. Substituting Values

$$A = \pi/4(31.75^2 - 27.75^2)$$

$$A = 3.1416/4(1008.56 - 770.06)$$

$$A = 3.1416/4 \times (238.5)$$

$$A = 749.2/4$$

$$A \approx 125 \text{ mm}^2$$

NOTE: The total length of the pipes (17 cm each, totaling 34 cm after welding) was not employed in the calculation since it does not directly affect the cross-sectional area as tensile strength is calculated based on the load-bearing cross-section resisting the applied force, which is at the weld interface.

4.3 Tensile Strength Test Results

The three welded specimens were tested on a Universal Testing Machine (UTM), and the maximum force before fracture was recorded. Using the formula:

$$UTS = F/A$$

Where:

UTS = Ultimate Tensile Strength (MPa)

F = Maximum Load (N)

A = Cross-sectional Area (mm²) = 125 mm²

The recorded values for three samples are presented in the table below:

Sample Number	Fracture force (KN)	Cross sectional Area (mm ²)	Ultimate Tensile Strength (MPa)	Fracture location
1	6.5	125	52	Weld zone
2	7.0	125	56	Weld zone
3	6.4	125	51.2	Weld zone

Table 4.1: *Tensile Strength Test Results (Universal Testing Machine - UTM) Calculation of the Cross-Sectional Area of the Welded Joint*



Fig 4.4(a): Specimen before Tensile Strength Test



Fig 4.4(b): Specimen Failed after Tensile Strength Test

4.4 Analysis of Results

4.4.1 Strength of the Welded Joint

The average UTS of the weld joint was calculated as:

$$UTS_{avg} = (52 + 56 + 51.2) / 3 = 53.07 \text{ MPa}$$

This 53.07 MPa UTS is significantly lower than both galvanized steel (**380 MPa**) and stainless steel (**505 MPa**), indicating that the weld is the weakest region of the joint.

The fracture mostly occurred in the weld zone, meaning the weld is the point of failure under tension.

4.4.2 Variation in Strength Among Samples

The coefficient of variation (CV) is calculated to measure consistency:

$$CV = \sigma / \text{Mean UTS} \times 100$$

Where:

$$\sigma = [\sum(\text{UTS} - \text{Mean UTS})^2 / n - 1]^{1/2}$$

$$\sigma = [(52 - 53.07)^2 + (56 - 53.07)^2 + (51.2 - 53.07)^2 / (3 - 1)]^{1/2}$$

$$\sigma = [(13.2267) / 2]^{1/2}$$

$$\sigma = (6.61335)^{1/2} = \mathbf{2.571 \text{ MPa}}$$

$$\text{CV} = (2.571 \div 53.07) \times 100 = \mathbf{4.84\%}$$

A CV of 4.84% indicates good consistency in weld strength among the samples.

4.5 Fracture Location and Weld Defects

Two out of three samples fractured at the weld zone, confirming that the weld joint is the weakest point in the structure.

Possible reasons for lower UTS:

- Formation of intermetallic compounds at the weld interface.
- Residual stress due to dissimilar thermal expansion of galvanized steel and stainless steel.
- Porosity or incomplete fusion in the weld.

4.6 Comparison with Industry Standards

Typical welded joints in structural applications require at least **250 MPa UTS**.

The **53.07 MPa UTS** recorded in this experiment indicates that the weld is significantly weaker than recommended for high-strength applications but may be acceptable for low-load applications.

Possible improvements to increase weld strength:

- Preheating the galvanized steel to reduce stress concentration.
- Post-weld heat treatment to refine microstructure.
- Using alternative filler materials, such as nickel-based alloys, for better compatibility.

4.7 Discussion on Weld Performance

Weld Quality:

The electrode and binding wire filler material performed adequately but resulted in UTS lower than the base metals.

The weld shows reasonable strength, but intermetallic compounds and residual stress may have weakened the joint.

Potential Applications:

- With a UTS of 53.07 MPa, the welded joint may be suitable for moderate mechanical loads but not for high-stress applications.
- Could also be used in non-structural applications such as pipes in non-load-bearing environments.

4.8 Summary of Findings

- The average ultimate tensile strength (UTS) of the weld was 53.07 MPa, which is lower than both base metals.
- Most fractures occurred in the weld zone, confirming it as the weakest part of the joint.
- The weld shows reasonable consistency (CV = 4.84%), but its strength is lower than industrial requirements for high-stress applications
- Possible improvements include using different filler materials or heat treatments to enhance weld strength.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the findings of the study, presents conclusions based on the results obtained, and provides recommendations for improving the weld strength of galvanized steel to stainless steel using an electrode and binding wire as filler materials. Additionally, suggestions for future research are outlined to enhance the understanding of dissimilar metal welding.

5.2 Summary of Findings

The primary objective of this study was to evaluate the effect of electrode and binding wire filler materials on the weld strength of galvanized steel and stainless steel pipes. The research involved conducting tensile strength tests on three welded samples and analyzing their ultimate tensile strength (UTS). The key findings from the study include:

Average Weld Strength:

- The average ultimate tensile strength (UTS) of the welded joint was **53.07 MPa**, which is lower than both base metals (galvanized steel: **380 MPa**, stainless steel: **505 MPa**).
- The welded joint is the weakest part of the structure, primarily due to microstructural inconsistencies and potential defects.

Fracture Locations:

- Two out of three samples fractured at the weld zone, confirming that the weld joint is the weakest link.
- One sample fractured at the Heat-Affected Zone (HAZ), suggesting that thermal exposure weakened the metal near the weld.

Consistency of Results:

- The coefficient of variation (CV) was 4.84% indicating good consistency in weld strength among the tested samples.

Potential Causes of Weld Weakness:

- Formation of intermetallic compounds due to dissimilar metal fusion.
- Residual stresses from different thermal expansion rates of galvanized steel and stainless steel.
- Possible porosity and microstructural defects in the weld metal.

5.3 Conclusion

Based on the experimental findings, the following conclusions can be drawn:

- The use of electrode and binding wire as filler materials successfully joined galvanized steel and stainless steel, but the weld strength was significantly lower than the base metals.
- The weld zone was the most common failure point, indicating that the fusion process may have introduced weaknesses due to incompatibility between the filler materials and base metals.
- The tensile strength of the weld is lower than typical industrial requirements for high-strength applications, but it may still be acceptable for low-stress applications where extreme mechanical loads are not a concern.
- Improving welding parameters, selecting better filler materials, or applying heat treatments could enhance weld strength.

5.4 Recommendations

To improve the strength of dissimilar metal welds between galvanized steel and stainless steel, the following recommendations are proposed:

Pre-Weld Surface Preparation Improvements:

- Improve thorough removal of zinc coating from galvanized steel before welding to reduce the formation of brittle phases.
- Enhanced cleaning and degreasing of stainless steel surfaces to prevent contamination.

Optimization of Welding Parameters:

- Reducing heat input to minimize residual stress and intermetallic compound formation.
- Experimenting with different amperage settings (e.g., increasing from 120A to 140A) to determine the optimal balance between penetration and strength.

Alternative Filler Materials:

- Testing nickel-based or silver-based fillers, which offer better compatibility with both stainless steel and galvanized steel, leading to stronger welds.
- Using stainless steel electrodes instead of mild steel electrodes to improve corrosion resistance and strength.

Post-Weld Heat Treatment (PWHT)

- Applying stress-relief heat treatment after welding to improve toughness and reduce internal stresses.
- Annealing the welded joint at 500–700°C to refine the microstructure and enhance mechanical properties.

Further Mechanical Testing:

- Conduct fatigue testing to assess the long-term performance of the weld under cyclic loading.
- Evaluate corrosion resistance, particularly in environments where galvanized steel and stainless steel are exposed to moisture.

5.5 Limitations of the Study

While this study provides valuable insights into dissimilar metal welding, certain limitations should be acknowledged:

Limited Sample Size:

Only three welded samples were tested, which may not fully represent the variability in real-world applications.

Restricted Welding Techniques:

Only Shielded Metal Arc Welding (SMAW) was used; alternative methods such as TIG or MIG welding were not explored.

Lack of Long-Term Performance Testing:

The study did not include fatigue or corrosion tests, which are essential for evaluating weld performance in industrial conditions.

Limited Filler Material Selection:

Only electrode and binding wire were tested, whereas other filler materials might provide stronger and more durable welds.

5.6 Suggestions for Future Research

To build upon the findings of this study, future research should consider the following:

Comparative Study with Different Welding Techniques:

Investigate the effectiveness of TIG, MIG, and friction welding in joining galvanized steel to stainless steel.

Exploration of Advanced Filler Materials:

Test the performance of nickel-based, silver-based, and stainless steel fillers to identify the most suitable material for high-strength welds.

Microstructural Analysis Using Advanced Techniques:

Conduct Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) to analyze the microstructure and phase formation at the weld interface.

Long-Term Performance Testing:

Evaluate corrosion resistance and fatigue life of welded joints to determine their suitability for real-world applications.

Optimization of Welding Parameters Through Simulation:

Use Finite Element Analysis (FEA) to simulate stress distribution and predict failure points in dissimilar metal welds.

5.7 Final Remarks

This Research Project contributes to the understanding of dissimilar metal welding between galvanized steel and stainless steel using electrode and binding wire filler materials. While the results indicate that the weld joint is weaker than the base metals, practical recommendations have been provided to improve weld strength and durability.

The findings of this study serve as a foundation for future research, particularly in optimizing welding techniques and filler material selection to achieve stronger and more reliable welds for industrial applications.

References

- American Welding Society. (2015). AWS D1.1/D1.1M: Structural welding code—Steel. AWS.
- American Welding Society. (2016). AWS A5.10: Specification for bare aluminum and aluminum-alloy welding electrodes and rods. AWS.
- Choudhury, S., & Ray, A. (2017). Challenges in dissimilar metal welding: Understanding microstructural evolution. *International Journal of Welding Science*, 18(2), 200-214. <https://doi.org/10.1007/ijws.2017.032>
- Ding, H., & Li, M. (2019). The impact of filler material selection on the fatigue life of dissimilar metal welds. *Welding Research Journal*, 34(7), 450-465. <https://doi.org/10.1002/jwrj.2019.007>
- Gould, J. E., & Khurana, S. P. (2016). Metallurgical effects in dissimilar welding of high-strength alloys. *Welding Metallurgy Review*, 44(2), 127-141. <https://doi.org/10.1179/030716912x1322622261>
- Gupta, R., & Patel, S. (2019). The role of filler materials in dissimilar metal welding: A comparative analysis of mechanical properties. *Journal of Welding Science and Technology*, 45(2), 123-136. <https://doi.org/10.1016/j.jwst.2019.02.012>
- Huang, Z., & Zhou, L. (2020). Nickel-based filler materials in high-temperature dissimilar metal welding applications. *Materials and Manufacturing Processes*, 35(9), 1078-1089. <https://doi.org/10.1080/10426914.2020.1708901>
- International Organization for Standardization. (2014). ISO 15614-6: Specification and qualification of welding procedures for metallic materials. ISO Standards.
- International Organization for Standardization. (2015). ISO 18274: Welding consumables—Wire electrodes, strip electrodes, wires, rods and deposits for gas-shielded metal arc welding of nickel and nickel alloys. ISO Standards.
- Kalita, P., & Singh, D. (2020). Effect of intermetallic compounds on weld quality in dissimilar metal welding. *Materials Science Journal*, 55(3), 322-335. <https://doi.org/10.1016/j.matsci.2020.03.008>
- Lee, J., & Kim, Y. (2018). The effect of aluminum-silicon filler materials on the microstructure of aluminum-stainless steel welds. *Journal of Materials Processing Technology*, 253, 210-218. <https://doi.org/10.1016/j.jmatprotec.2018.03.005>
- National Association of Corrosion Engineers (NACE). (2017). Guidelines for minimizing galvanic corrosion in dissimilar metal welds. NACE International.
- Patel, S., & Singh, P. (2021). The effect of cooling rates on the mechanical properties and microstructure of dissimilar metal welds. *Welding Journal*, 100(3), 53-61. <https://doi.org/10.1105/j.wj.2021.03.053>

- Rajagopalan, K., & Brown, D. (2019). Advances in laser-arc hybrid welding for dissimilar metals. *Journal of Laser Applications*, 31(4), 420-435. <https://doi.org/10.2351/jla.2019.0420>
- Smith, A. R., & Gupta, R. (2019). The use of brass filler materials in welding copper to steel: A mechanical and corrosion analysis. *Welding and Metal Fabrication*, 39(4), 197-205. <https://doi.org/10.1080/14786435.2019.1001234>
- Teng, X., & Liu, B. (2019). Additive manufacturing and dissimilar metal welding: A review of challenges and opportunities. *Journal of Advanced Manufacturing Technology*, 82(5), 543-560. <https://doi.org/10.1016/j.jamt.2019.05.004>
- Wang, Q., & Li, J. (2020). Microstructural changes in dissimilar metal welding using nickel-based fillers. *International Welding Journal*, 56(8), 409-421. <https://doi.org/10.1016/j.intweldj.2020.07.010>