A

Project Report

On

EFFECT OF POST WELD HEAT TREATMENT ON MECHANICAL AND METALLURGICAL CHARACTERIZATION OF DISSIMILAR WELDED JOINTS

Submitted for the partial fulfillment of the requirement for the degree

of

Bachelor of Technology in

Mechanical Engineering

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(Batch: 2019-2023)

DECLARATION

This is to certify that the project report entitled **"Effect of post weld heat treatment on mechanical and metallurgical characterization of dissimilar welded joints"** which is submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Mechanical Engineering, Meerut Institute of Engineering & Technology, during the academic year 2022-2023 comprises only our own work. The work has not been submitted to any other institute for any degree or diploma. Wherever we have used supporting material (data, theoretical analysis, figures, and text) from other sources, we have given due credit by citing the references for the details, in the text of the report. We have followed the guidelines provided by the institute in preparing the project report.

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CERTIFICATE

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Abstract

In this work, the effect of post weld heat treatment on TIG welded joints of Mild steel and EN31 with filler SS308 and MS70S2 was analyzed. Mild steel and EN 31 can be effectively joined by employing the compatible filler metals, namely SS308 and MS70S2. The utilization of these specific filler materials ensures a robust and reliable bond between the two types of steel. Based on the results obtained from the tensile and hardness tests, it is evident that the strength of the welded joint is initially lower than that of the base metals, specifically mild steel and EN31. However, significant improvements can be achieved through the application of a heat treatment process. After subjecting the welded joint to a normalizing treatment, a remarkable change is observed. The hardness of the joint decreases by approximately 7.08% for SS308 Filler. Both the hardness and tensile strength of the welded joint using SS308 and MS70S2 filler are observed to increase significantly after undergoing normalizing and quenching heat treatment processes. Based on the SEM image analysis, it is evident that the weld defect in the joint is less than 2%, which is a positive indication of the welding quality. Additionally, the formation of precipitates is found to be minimal when using SS308 filler, while a small amount is observed when MS70S2 filler is employed. The tensile strength of a TIG weld with filler SS308 was obtained as 296.85 MPa. After annealing, normalizing, and quenching, the tensile strength increases to 324.57 MPa, 369.26 MPa, and 402.24 MPa, respectively. And the tensile strength of a TIG weld with filler MS70S2 is obtained as 202.74 MPa. After annealing, normalizing, and quenching, the tensile strength increases to 264.14 MPa, 296.33 MPa, and 348.19 MPa, respectively. The hardness of a TIG weld with filler SS308 is obtained as 254 HV. After annealing, the hardness decreases to 236 HV, and after normalizing and quenching, the hardness increases to 319 HV and 392 HV, respectively. The hardness of a TIG weld with filler MS70S2 is obtained as 219 HV. After annealing, the hardness decreases to 227 HV, and after normalizing and quenching, the hardness increases to 268 HV and 311 HV, respectively.

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CHAPTER-1

1 INTRODUCTION

The welding process can be carried out on the same or unequal metal. Welding of different metals includes different types of metals containing different chemical compositions. Including different mechanical properties during the welding process, and in two different metal microstructures can affect the welding current, not like welding current, holding time, welding force, etc. when it becomes a structure or component of a machine or undergoes repair processing. The chemical composition of metals is outstanding. The difference in metal chemical composition may be due to many factors such as aging, oxidation, and the like. Research on the mechanical properties of welding is important because the welded structure can be installed in highly sensitive and dangerous places. The problem of forming intermetallic compounds can be triggered, which can affect the quality of the weld.

Currently, welding is widely used in various industries. It is an engineering and technological method employed to join materials under different conditions [1]. Gas Metal Arc Welding (GMAW) is utilized for bonding Stainless Steel 304H. GMA welding involves the use of a continuous copper coated wire. MIG welding is preferred due to its numerous advantages over traditional welding methods [2]. Stainless Steel 304H is extensively employed in industries such as chemical, petrochemical, biomedicine, and nuclear reactors due to its high tensile strength, corrosion resistance, and ductility [3,4]. The flow rate of the shielding gas is a crucial welding parameter that affects the properties of the welded joint, as well as the shape and penetration pattern during the welding process [5,6]. Shielding gas plays a vital role in producing strong, tough, and corrosion-resistant welded joints [7]. It safeguards the molten metal pool from atmospheric contamination, stabilizes the arc, and facilitates uniform metal transfer [8].

Modernity requires rapid production structures. Welding is an efficient process in which two materials of the same or different structure are permanently added together. Many industrial/commercial structures are composed of different structural materials, or different components require different welding techniques.

These conditions result in uneven metal welding. An excellent weld is a weld with sufficient tensile strength and flexibility so that the joint for the welded joint does not fail. The main problem with uneven metal welded joints is the formation of intermetallic compounds in the weld zone. These intermetallic compounds should be related to problems related to crack sensitivity, ductility, corrosion, and the like. This makes the study of microstructures important for the study of the formation of intermetallic compounds, indicating residual stresses in developed regions. Due to the reduced temperature, the toughness may undergo a brittle transition, which may later cause weld failure due to such brittleness. An intermediate layer of nickel or vanadium is used to avoid the formation of intermetallic compounds.

During the welding process, the two metals are typically added together into the workpiece by melting or filling, and when the molten metal cools, it takes the shape of a solid joint. There are different ways to add uneven metals; one of them is composite inclusive. As the name suggests, insert another material between the two metals facing each other to complete the process.

There are different welding methods for including uneven metals such as explosive welding, cold welding, ultrasonic welding, diffusion welding, friction welding, electron beam welding, arc welding and resistance spot welding. Explosive welding is done by moving the metals together. With any type of explosive, metal fragments are accelerated at very high speeds. Explosive welding process Explosive welding has some advantages. It is a simple process that can be attached to a large surface without affecting the actual and actual performance of the metal. There are also limitations that allow it to weld only simple geometries, causing noise and large vibrations due to explosions.

1.1 Shielded Metal Arc Welding (SMAW)

Shielded Metal Arc Welding (SMAW), also known as stick welding or manual metal arc welding, is a popular and widely used welding process. It involves creating an electric arc between a coated electrode (welding rod) and the workpiece to melt the base metal and create a weld joint. As shown in fig.1, The electrode consists of a metal core wire covered with a flux coating. The flux coating serves multiple purposes, including providing shielding gases, stabilizing the arc, introducing alloying elements, and creating a protective slag layer over the weld. SMAW offers versatility as it can be performed in various positions and is suitable for different base metals. It is a portable process, making it convenient for on-site work. While it requires skill and practice to achieve high-quality welds, SMAW is cost-effective and less affected by outdoor conditions, making it widely used in construction, maintenance, fabrication, and various other applications.

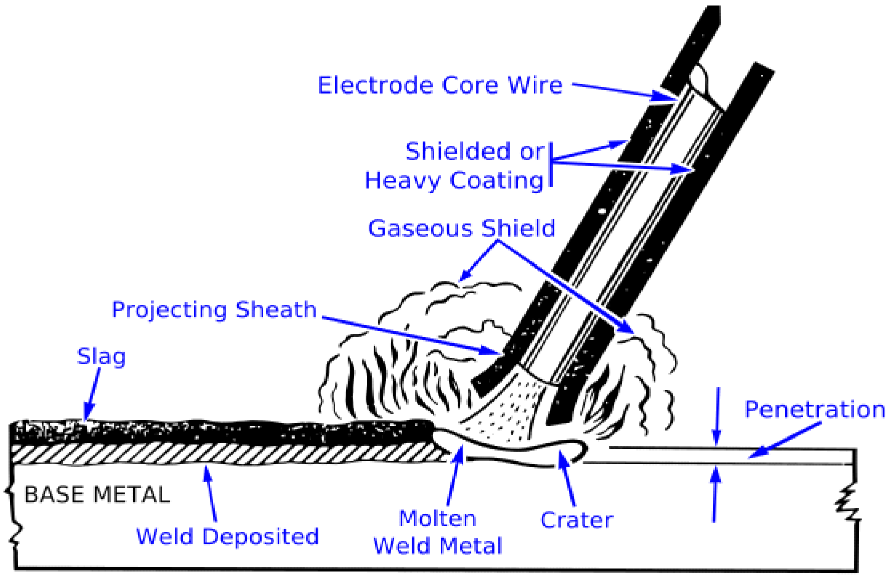


Figure 1: Shielded Metal Arc Welding [10]

SMAW is the oldest and most popular method of metal joining. Medium quality welding can be carried out at low speeds with good uniformity. SMAW is primarily used for low cost, flexibility, portability and versatility. The equipment and electrodes are very low and very simple.

1.2 Tungsten Inert Gas Welding

Tungsten Inert Gas (TIG) Arc Welding, also known as Gas Tungsten Arc Welding (GTAW), is an arc welding process that utilizes a non-consumable tungsten electrode and an inert gas shield. TIG welding is commonly used for welding non-ferrous metals, such as aluminum, magnesium, and stainless steel, as well as some ferrous metals.

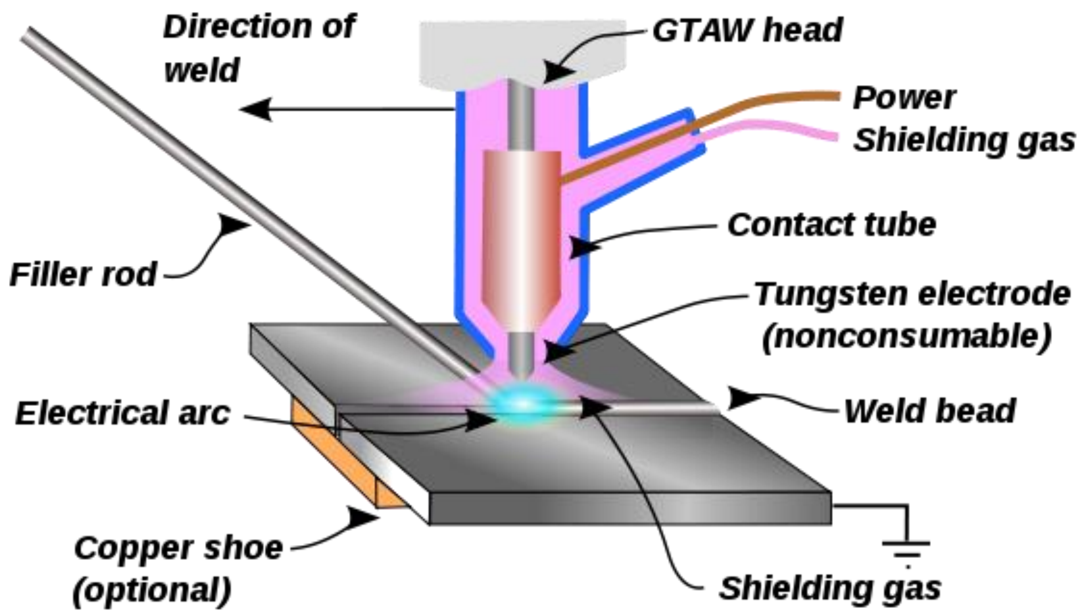


Figure 2: Tungsten inert gas welding [11]

TIG welding requires a power source, a TIG torch, a tungsten electrode, and a shielding gas supply as shown in fig.2. The power source provides the electrical current necessary for the welding process. The TIG torch holds the tungsten electrode, controls the flow of shielding gas, and often includes additional controls for adjusting welding parameters. The tungsten electrode is a non-consumable electrode made of pure tungsten or tungsten alloy, which remains intact during the welding process. The shielding gas, typically argon or a mixture of argon and helium, is used to protect the weld area from atmospheric contamination. TIG welding is widely used in industries such as aerospace, automotive, electronics, and fabrication, where high-quality welds and precise control are required. It is particularly suitable for applications involving thin materials, critical joints, or materials that require exceptional weld integrity.

1.2.1 Electric Arc Welding

Arc welding is defined as the sustained electrical discharge through an ionized gas. The discharge is initiated by an avalanche of electrode emitted from the hot cathode and maintained by thermal ionization of hot gas. The electrical discharge through an ionized gas reduces a good amount of heat energy which is employed for joining various metals and allows by fusion. A welding arc is a high current up to 2000Amp and low voltage 10-50volt discharge. It can be considered as a flexible conductor carrying electrical charge in a vector motion and a plasma jet in purely kinetic motion.Fig.3 shows the component of arc welding. Arc is initiated by providing a conducting path between the electrode and a job or by ionizing the gap between two. By momentarily touching the electrode with the job and taking it away. By scratching the electrode with the job. Scratching is initiated a little distance away from the point where the welding is to be started and during stretching the electrode is brought to the proper place of starting the welding.in this case steel wool is kept pressed between the electrode and the job. When the welding current is switched on, the steel wool provides a conducting path for the arc to establish. This method can be used in atomic submerged arc welding sets and automatic MIG welding machine.

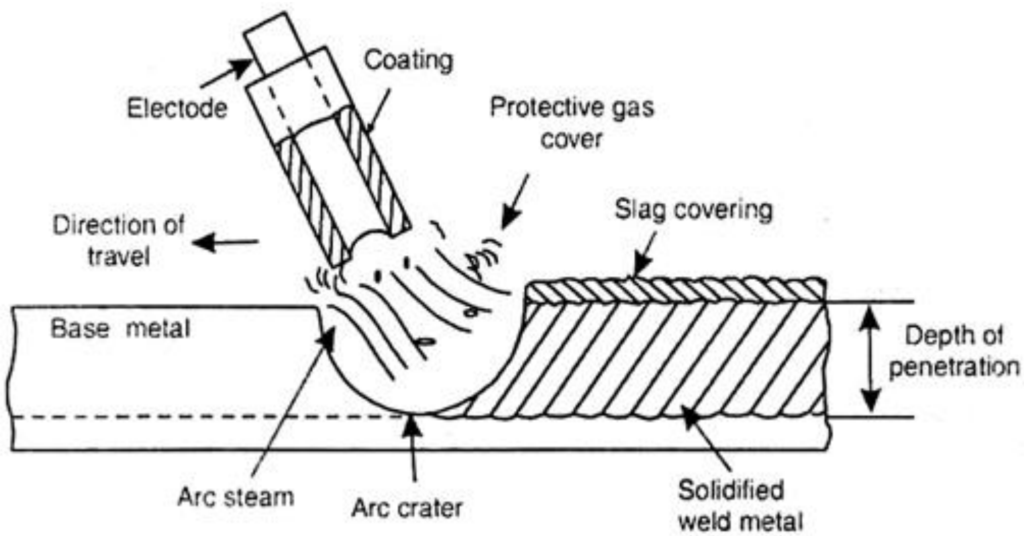


Figure 3: Arc Welding [12]

1.3 Resistance Welding

Resistance welding is a type of welding that uses pressure and electric current to join metal parts. In resistance welding, the parts to be joined are held together between two electrodes and an electric current is passed through them. The resistance of the parts to the current generates heat, which melts the metal and creates a weld.

There are several types of resistance welding, including:

Spot welding: the most common type of resistance welding, which uses two opposing electrodes to apply pressure and electric current to a small area of metal.

Seam welding: similar to spot welding, but the electrodes move along the joint, creating a continuous weld.

Projection welding: used to join metal parts with raised sections or projections, where the projections concentrate the electric current and generate heat.

Resistance welding is a fast and efficient process, capable of joining large numbers of parts quickly and with high accuracy. It is commonly used in the automotive, aerospace, and electronics industries, among others. However, it is generally only suitable for joining metals with relatively low melting points, such as steel and aluminum.

1.4 MATERIALS CONSIDERATIONS

1.4.1 Steel alloy

Steel alloy is a type of metal that is made by combining iron with other metallic and non-metallic elements in varying proportions. These additional elements can include carbon, manganese, silicon, nickel, chromium, vanadium, tungsten, and many others. By adding these elements, the properties of steel can be altered, making it stronger, more durable, and more resistant to corrosion and other environmental factors.

The resulting steel alloys have a wide range of properties and uses, ranging from common construction materials to high-strength, high-temperature applications in industries such as aerospace and automotive manufacturing. Different steel alloys are used for different applications, depending on the specific requirements of the end product.

Steel alloys are typically classified according to their carbon content, with low-carbon steels having less than 0.3% carbon, medium-carbon steels havingbetwee0.3%and0.6% carbon, and high-carbon steels having more than 0.6% carbon. In addition to carbon, alloying elements can also be added in various proportions to achieve specific properties such as increased strength, improved corrosion resistance, or better heat resistance.

1.4.2 Types Of Steel Alloy

There are many different types of steel alloys, each with its unique properties and characteristics. Here are some common types of steel alloys:

1.4.2.1 *Carbon Steel:*

This is the most commonly used type of steel alloy, which has a carbon content ranging from 0.06% to 1.5%. Carbon steel can be further categorized into low carbon steel, medium carbon steel, and high carbon steel, depending on the amount of carbon content.

1.4.2.2 *Stainless Steel:*

This is a corrosion-resistant steel alloy that contains chromium, nickel, and other elements. Stainless steel is commonly used in household appliances, cutlery, and construction materials.

1.4.2.3 *Alloy Steel:*

This is a steel alloy that contains other elements such as nickel, copper, manganese, and silicon, in addition to carbon and iron. Alloy steel is known for its strength, toughness, and durability and is used in a wide range of applications, including automotive and aerospace industries.

1.4.2.4 *Tool Steel:*

This is a type of steel alloy that is specifically designed for making tools. Tool steel is known for its high hardness, wear resistance, and toughness and is used for making cutting tools, dies, and molds.

1.4.2.5 *High-Speed Steel:*

This is a type of tool steel that is specifically designed for making cutting tools that operate at high speeds. High-speed steel contains elements such as tungsten, molybdenum, and cobalt, which give it high hardness and heat resistance.

1.4.2.6 *Weathering Steel:*

This is a type of steel alloy that is designed to resist corrosion and weathering. Weathering steel is commonly used in outdoor structures such as bridges and sculptures

1.5 Filler Rod Material

The filler rod material used in TIG welding (GTAW) can vary depending on the type of metal being welded and the application. Generally, the filler rod material should be compatible with the base metal being welded and have similar mechanical and chemical properties.

Some common filler rod materials used in TIG welding include:

Mild Steel: Mild steel filler rods are commonly used in TIG welding applications that involve welding mild steel. They are typically made of low-carbon steel and are often coated with copper to improve their conductivity and prevent oxidation.

Stainless Steel: Stainless steel filler rods are used in TIG welding applications that involve welding stainless steel. They come in a variety of grades and can be either straight or coiled.

Aluminum: Aluminum filler rods are used in TIG welding applications that involve welding aluminum. They are typically made of an aluminum alloy and may be either pure aluminum or contain other metals such as silicon or magnesium to improve their strength and durability.

Copper: Copper filler rods are used in TIG welding applications that involve welding copper or copper alloys. They are often used in electrical applications, as copper has excellent electrical conductivity.

In addition to these materials, there are also specialized filler rod materials available for welding other types of metals, such as titanium, nickel, and cobalt. The selection of the appropriate filler rod material depends on the specific requirements of the welding application

1.6 BIMETALLIC WELDS

The bimetallic weld joint as shown in fig.4 plays a crucial role in the design of pressurized water reactors (PWRs) and boiling water reactors (BWRs). These reactors require the connection of heavy section low alloy steel to stainless steel, especially in areas where the system interfaces with various nozzles of the reactor pressure vessel and steam generator. Bimetallic weld joints are commonly employed in steam generators of power plants, connecting ferritic low alloy steels like SA 508 to austenitic stainless steels such as SS 304. In power plant steam generators, austenitic stainless steel tubes are utilized in high-temperature sections that demand exceptional creep strength and resistance to oxidation [14]. These sections require materials with superior properties to withstand the harsh operating conditions.

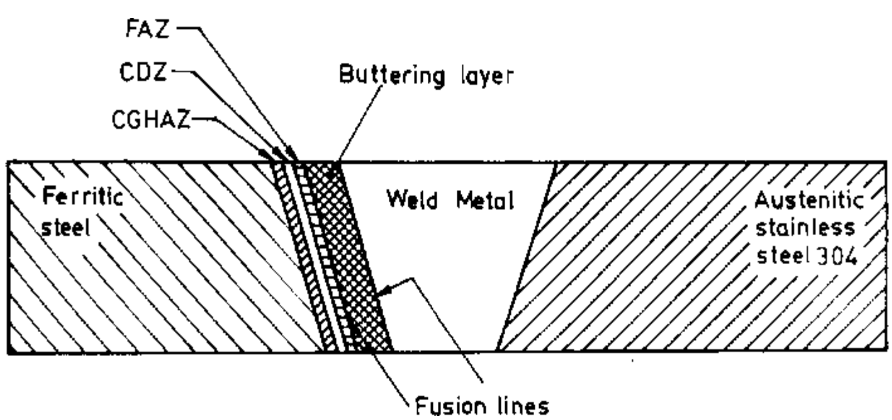


Figure 4: Bimetallic austenite-ferrite weld configuration with a buttering layer and different zones [14]

1.6.1 *Bimetallic Welds in working condition*

Bimetallic weld joints between austenitic stainless steel and chromium-molybdenum ferritic steel, which have a low carbon content, find extensive usage in numerous high-temperature applications within energy conversion systems [15].

During the start-up and shutdown processes of power plants, thermal cycling plays a significant role in causing early maintenance failures in bimetallic welded joints. These cyclic stresses are further intensified by residual weld stress, external loads, and internal steam pressure, ultimately leading to the failure of repaired bimetal welded joints. To prolong the service life of these joints and reduce the magnitude of cyclic thermal stress, one approach is to increase the coefficient of thermal expansion (CTE) of the composite component.

One method involves utilizing a three-metal structure, which includes an intermediate material with a CTE that falls between the CTEs of the base metal and the stainless steel. By incorporating this intermediate material, the difference in thermal expansion characteristics between the base metal and the weld metal in the bimetallic welded joint can be mitigated, thereby reducing the occurrence of cyclic thermal stresses during the power plant's operational cycles, including multiple starts and shutdowns. These cyclic thermal stresses are considered the primary cause of untimely maintenance failures in bimetallic welded joints within power plants [15].

As the bimetallic weld (BMW) joints have experienced premature failures before reaching their intended design life, numerous studies have been undertaken to investigate the transition from fermentation to fermentation [16]. These studies have revealed that these joints encounter significant thermal stresses during temperature variations, primarily due to disparities in the coefficients of thermal expansion [17]. Among the joint regions, the interfacial zone between the weld metal and the ferritic steel is particularly prone to failure. Welding-related failures are commonly observed in nearly all utilized austenitic-ferritic dissimilar alloys [18].

1.6.2 Causes of failure in bimetallic welds

In the power generation industry, different components and systems operate under varying conditions, necessitating the use of suitable materials for each application. Components that operate at high temperatures typically employ stainless steel, while those operating at low temperatures are typically made of ferritic steel. As a result, bimetallic welded joints are employed to connect stainless steel tubes in the steam generator to other components or systems, such as the control assembly, using dissimilar materials such as ferritic and austenitic steels. However, bimetallic welded joints often experience failures, which can be attributed to one or more of the following reasons [19].

- Residual stresses present in the BMWs
- Carbon migration.
- Preferential oxidation at the interface
- Effect of Post-Weld Heat Treatment
- Thermal stresses arise in bimetallic welded joints (BMW) due to significant disparities in coefficients of thermal expansion (CTE) between the joined materials.

1.6.3 Thermal Stresses

In various sectors of the nuclear industry, a wide range of materials are utilized in different elements and structures. These materials experience significant mechanical and thermal loads during operation. The combination of variable thermal and mechanical stresses can result in higher stress levels in regions of stress concentration within the components, leading to the formation of cracks [20].To accurately assess the stress in the stress concentration regions of a structure, a geometric simulation factor is established. This factor takes into account the material properties, geometry, and temperature distribution of the structure. The structure is divided into multiple free elements "i," each having the same thermal expansion. The free thermal expansion, εi, of each element is calculated using the following formula:

$$\varepsilon i = \alpha i . \ \Delta Ti \qquad (1)$$

In the formula mentioned, αi represents the thermal expansion coefficient of the respective element, and ΔTi represents the temperature increment experienced by that particular element.

1.6.4 Residual Stresses

Due to the mismatch in thermal expansion coefficients between ferritic steel and austenitic steel, high residual stresses are concentrated at the interface between the ferritic steel and the weld metal. This leads to uneven welded joints near the interface, with ferrite being the most susceptible to failure in both the base metal and the welds [21]. In power plant steam generators, dissimilar metal joints are commonly used between ferritic and austenitic steel tubes. Analysis of failures and literature investigations of diffusion-welded joints have revealed that a significant number of failures occur in the heat-affected zone (HAZ) region of the corroded steel side in such dissimilar welded joints. The presence of residual stress in the welded joint is one of the primary factors contributing to the unsatisfactory performance of the joint.

A specific type of pipe welded joint, as seen in the Rapid Proliferation Test Reactor (FBTR) in India, is manufactured using 2.25Cr-1Mo ferritic steel and AISI 316 stainless steel. In these joints, the use of an Inconnel-82 buttering layer has been investigated to mitigate residual stresses. X-ray diffraction (XRD) is employed to determine the distribution of residual stress in these welded joints. The study demonstrates that the Inconnel-82 buttering layer can effectively reduce the residual stress in the ferritic steel HAZ, thereby helping to mitigate or alleviate the residual stress in the dissimilar welded joint [21-23].

1.6.5 Carbon migration from the ferritic steel

In the temperature range, carbide migration occurs at the weld metal interface, from ferritic steel to aesthetic stainless steel. The aging of the alloy 800H / 2.25Cr-lMo steel joint was studied, in which 783, 866 and 950K were welded at different times with Inconel 82, and the carbon concentration was measured by EPMA [24].

According to Larson Miller type equivalency given by

$$P = T(C + \log_{10} t) \tag{3}$$

In the equation mentioned, P represents the equivalent parameter, T denotes the absolute temperature in Kelvin, C signifies the kinetics of continuous carbon migration dependence, and t represents the exposure time at temperature t. Through the analysis of these findings, it was determined that the continuous value of C is 8.4, which is lower than the typical value of 20. This value is often suitable for describing the creep rupture properties of carbon and low alloy steels.

The process of carbon migration involves the decomposition of carbides present in ferritic steels, which then migrate from the ferritic steel into the weld metal. The driving force behind this migration is primarily a carbon concentration gradient or, more precisely, a difference in carbon activity between the low chromium (Cr) ferritic steel and the weld metal, which is rich in Cr.

When carbon migrates across the interface between the weld metal and ferritic steel, it precipitates as carbides due to the low solubility and preferential trapping of carbon in the weld metal. Based on the width of the carbonized layer, a time-temperature relationship similar to the Larsen-Miller equivalency was established. This relationship was defined through metallographic etching techniques.

$$P' = K/T + \log t \tag{4}$$

where P' represents the equivalency parameter, K denotes a material constant that is determined specifically for each weld joint, T represents the absolute temperature, and t signifies the exposure time.

1.6.5.1 *Effect of Post-Weld Heat Treatment*

Post-weld heat treatment (PWHT) is commonly employed to reduce or eliminate residual stress that arises from the welding process. In addition to this, the effect of PWHT on the microstructure of the weld metal/ferritic steel interface in the medium- and long-term was investigated using accelerated laboratory aging techniques. The study discovered that, after aging under accelerated temperature conditions and simulating the operating environment, the size and distribution of cracks remained largely similar. This suggests that PWHT does not significantly impact the long-term failure mechanism [19].

1.7 Processing Parameter of TIG Welding

The processing parameters of TIG welding include the following:

Welding current: the amount of electric current used to heat the metal and create the weld. The welding current is typically controlled by the welder using a foot pedal or other control device.

Welding voltage: the electric potential difference between the tungsten electrode and the workpiece. The welding voltage affects the heat input and penetration of the weld.

Gas flow rate: the rate at which the inert gas is delivered to the welding area to shield the weld from atmospheric contamination. The gas flow rate is typically controlled by a regulator.

Electrode type and diameter: the diameter of the tungsten electrode and its shape (pointed or rounded) can affect the arc stability and the shape of the weld.

Filler metal type and diameter: the type of filler metal and its diameter can affect the strength and quality of the weld.

Travel speed: the rate at which the welder moves the torch along the joint. The travel speed can affect the heat input and the penetration of the weld.

Arc length: the distance between the tungsten electrode and the workpiece. The arc length can affect the stability and quality of the arc.

Optimizing these parameters can help achieve a high-quality TIG weld with good mechanical properties and minimal defects. However, the optimal parameters can vary depending on the type of metal being welded, the thickness of the material, and other factors, so it's important to select the appropriate parameters for each welding application.

1.7.1.1 *Direct current reverse polarity (DCRP)*

In TIG welding, Direct Current (DC) with Reverse Polarity is commonly used. This means that the electrode or tungsten is connected to the negative terminal of the welding machine, and the workpiece is connected to the positive terminal.

When using DC Reverse Polarity in TIG welding, the heat is concentrated at the tungsten electrode and then transferred to the workpiece. This results in deeper penetration and higher welding speeds, making it ideal for welding thicker materials.

However, DC Reverse Polarity can also cause tungsten electrode erosion due to the high heat concentration at the tip of the electrode. To minimize this effect, it's important to use the appropriate electrode size and shape, and to properly adjust the welding parameters such as the amperage and gas flow rate.

Overall, DC Reverse Polarity is a useful technique in TIG welding for achieving deeper penetration and higher welding speeds, but it requires careful consideration of the welding parameters and electrode selection to ensure optimal results.

1.7.1.2 *Direct current straight polarity (DCSP)*

Direct Current (DC) with Straight Polarity is not commonly used in TIG welding. In this case, the workpiece is connected to the negative terminal of the welding machine, and the electrode or tungsten is connected to the positive terminal. DC Straight Polarity in TIG welding is used in certain cases where a shallow weld depth and faster travel speed is required. However, it produces less heat and penetration compared to DC Reverse Polarity, making it less effective for welding thicker materials. In addition, using DC Straight Polarity can cause the tungsten electrode to ball up and reduce the control of the arc. To minimize this effect, it's important to use a smaller electrode size and lower welding currents. Overall, DC Straight Polarity in TIG welding is less commonly used than DC Reverse Polarity, and should only be considered for specific applications where shallow weld depth and faster travel speeds are required.

1.7.1.3 *Alternating current (AC)*

Alternating Current (AC) is commonly used in TIG welding for welding aluminum and other non-ferrous metals. In AC TIG welding, the electrode or tungsten alternates between positive and negative polarity at a rate of 60 cycles per second (60 Hz) in North America, or 50 Hz in other parts of the world.

AC TIG welding allows for a combination of both DC Reverse Polarity and DC Straight Polarity benefits, as the positive polarity provides deeper penetration while the negative polarity provides better cleaning action to remove oxide layers on the metal surface. This results in a smoother and more consistent weld. However, AC TIG welding requires careful adjustment of the balance control and frequency control on the welding machine to achieve optimal results. The balance control adjusts the percentage of time that the electrode is in positive or negative polarity, while the frequency control adjusts the rate of polarity change. In addition, AC TIG welding requires the use of a high-frequency starting system to establish the arc without touching the tungsten electrode to the workpiece, as this can contaminate the tungsten and the weld.

Overall, AC TIG welding is a versatile process that allows for effective welding of aluminum and other non-ferrous metals, but requires careful control of the welding parameters and the use of a high-frequency starting system for optimal results.

1.8 Applications OF TIG Welding

1.8.1 Aerospace

TIG welding is widely used in the aerospace industry because of its ability to produce high-quality welds with precise control over the heat input. It is used for welding critical components such as engine parts, airframes, and fuel tanks.

1.8.2 Automotive:

TIG welding is used in the automotive industry for welding exhaust systems, roll cages, and suspension components. It is also used for welding aluminum and other lightweight materials used in the production of race cars.

1.8.3 Medical:

TIG welding is used in the medical industry for welding medical devices and equipment, including surgical instruments and implantable devices. The precision and control offered by TIG welding make it ideal for welding small and intricate parts.

1.8.4 Pipe welding:

TIG welding is used in pipe welding applications, including welding of stainless steel, carbon steel, and exotic metals such as Inconel and Titanium. It is used in the construction of pipelines for the transportation of gas and oil, as well as in the food and beverage industry for welding of sanitary piping.

1.8.5 Jewelry making

TIG welding is also used in the jewelry industry for welding of precious metals such as gold and silver. The precision and control offered by TIG welding make it ideal for welding small and intricate parts of jewelry.

1.8.6 Artistic welding:

TIG welding is used in the creation of metal sculptures and artistic pieces. The precise control and ability to weld a variety of metals make it a popular choice for artists who work with metal.

1.9 Advantages

TIG (Tungsten Inert Gas) welding has several advantages over other welding processes:
Precise and high-quality welds: TIG welding produces high-quality welds with precise control of the heat input and the filler material, resulting in strong and aesthetically pleasing welds.
Versatility: TIG welding can be used to weld a wide range of materials, including steel, stainless steel, aluminum, copper, brass, and titanium.
No spatter or slag: TIG welding does not produce spatter or slag, resulting in a cleaner weld that requires less post-weld cleaning.
Low distortion: TIG welding produces low levels of heat input, resulting in minimal distortion of the workpiece.
Narrow heat-affected zone: TIG welding produces a narrow heat-affected zone, reducing the risk of thermal damage to the surrounding material.
No flux required: TIG welding does not require flux, resulting in a cleaner and more precise weld.
Welds thin materials: TIG welding can be used to weld thin materials with precision and control, resulting in strong and reliable welds.
Overall, TIG welding is a versatile process that produces high-quality welds with precise control, minimal distortion, and no spatter or slag, making it ideal for a wide range of applications.

1.10 Heat Treatment

Heat treatment refers to a combination of heating and cooling processes applied to a material, typically a metal or alloy, in order to alter its physical and mechanical properties. The primary objective of heat treatment is to improve the material's strength, hardness, toughness, ductility, and other desired characteristics while maintaining its overall integrity.

Heat treatment processes involve controlled heating and cooling cycles, which are performed under specific temperature conditions. Here are some common heat treatment techniques:

Annealing: Annealing is a process that involves heating the material to a specific temperature and holding it there for a certain period, followed by slow cooling. It is used to reduce internal stress, improve machinability, soften the material, and enhance its ductility.

Quenching: Quenching is a rapid cooling process that involves immersing the heated material into a quenching medium, such as water, oil, or air. This process hardens the material by transforming its microstructure, typically resulting in increased strength and hardness.

Tempering: Tempering is performed after quenching and involves reheating the quenched material to a temperature below its critical point, followed by controlled cooling. Tempering reduces the brittleness caused by quenching and enhances toughness and ductility while maintaining some of the hardness obtained through quenching.

Normalizing: Normalizing is a process similar to annealing but involves air cooling instead of furnace cooling. It is used to refine the grain structure of the material, improve its mechanical properties, and enhance machinability.

Case hardening: Case hardening is a heat treatment method used to increase the hardness of the surface layer of a material while maintaining a tough and ductile core. Common case hardening techniques include carburizing, nitriding, and carbonitriding.

Stress relieving: Stress relieving is a heat treatment process performed to reduce residual stresses within a material caused by previous manufacturing processes. It involves heating the material to a specific temperature and allowing it to cool slowly, which helps relieve internal stresses and minimize the risk of deformation or cracking.

CHAPTER 2

2 LITERATURE REVIEW

A. Joseph et al., (2005) [21], Failure analysis and literature investigations of diffusion welded joints have shown that a large number of failures have occurred in the heat affected zone (HAZ) region of the corroded steel side of such different welded joints. The residual stress present in the welded joint is one of the main factors leading to dissatisfaction of the welded joint. This study shows that the Inconel-82 buttering Layer for dissimilar welded joints can be used to reduce the residual stress in the Feritic steel HAZ, thus facilitating the butter to avoid/reduce the residual stress failure of the gate weld.

Shamsul Baharin Jamaludi et al., (2013) [27], Experiments were conducted to join stainless steel 304 to mild steel using gas tungsten arc welding (GTAW) technique. The results indicated that the yield strength and tensile strength of the welded specimens, when using a mild steel welding electrode, were slightly lower compared to the specimens welded using a stainless steel welding electrode. However, both types of welded samples exhibited satisfactory strength in the welded joint. Interestingly, all of the welded samples failed at the mild steel base metal, indicating that the regions encompassing the stainless steel base metal, fusion zone, and heat-affected zone were stronger than the mild steel base metal.

J. Rodriguez et alet al., (2015) [28] A study was conducted involving the friction stir welding (FSW) of 6-mm-thick mild steel and Ni-based alloy 625 plates. The FSW process utilized a tool rotational speed of 300 rpm and a travel speed of 100 mm/min. The researchers performed microstructural characterization using various techniques such as optical microscopy, scanning and transmission electron microscopy, and energy dispersive X-ray spectroscopy (EDS).

The findings of the study indicated that the FSW of mild steel and Ni-based alloy 625 resulted in welds that were free from volumetric defects. The welds exhibited different microstructures. In the case of the mild steel, the heat-affected zone (HAZ) displayed three distinct regions. However, the thermo-mechanically affected zone (TMAZ) was not observed in the steel due to the concealment of deformation history resulting from allotropic transformation. The observed phase transformations in the HAZ were similar to those observed in traditional welding processes and were attributed to the influence of high temperatures experienced during the thermal cycle.

Huseyin Uzun et al., (2005) [29] In an experiment, the bonding of aluminum and mild steel was investigated using the friction welding process. The results revealed that the hardness of the welded materials was lower than that of the parent materials. This decrease in hardness can be attributed to the thermal effects associated with the friction welding process.

Additionally, the tensile strength of the welded rods was found to be lower than that of the parent rods. This reduction in strength was attributed to incomplete welding.

The study introduced a finite difference method, which proved to be a valuable tool for analyzing and optimizing weld parameters. The findings from this study contribute to a better understanding of the friction welding process and can aid in the development of improved welding parameters.

A.N Cherepanov et al., (2016) [30] A research study was conducted on weld joints between VT1-0 titanium and AISI 321 austenitic stainless steel using laser welding. To improve the quality and strength properties of the joints, two types of explosively welded four-layered composite inserts (SS-Cu-Nb/Ta-Ti) were employed. These inserts had different barrier layers, which included refractory metals. Microstructural analyses, utilizing both optical and electron microscopy, revealed that the produced joints were defect-free and exhibited a narrow heat-affected zone. A severely deformed zone with an average depth of 60 μm was observed at the interface between the copper and stainless steel layers. The strength of the resulting compositions was found to be higher than that of VT1-0 titanium and was primarily influenced by the materials used in the composite insert. The composition containing niobium foils demonstrated the highest values of ultimate tensile strength (UTS = 476 MPa) and yield strength (YS = 302 MPa). It should be noted that in all cases, failure occurred at the weakest component of the composition, which was the copper plate.

M. Sireesha et al., (2002) and A.K. Bhaduri et al., (1999) [31-32], By enhancing the coefficient of thermal expansion of the composite element, it is possible to prolong the operational lifespan of the joint by minimizing the magnitude of cyclic thermal stress. A potential approach in this regard involves employing a filler material that possesses a coefficient of thermal expansion (CTE) situated between that of carbon steel and stainless steel. Investigations have demonstrated that such joints experience significant thermal stresses during temperature variations, attributable to dissimilarities in their thermal expansion coefficients. [33].

Mitchell et al., (1978) and Christoffel et al., (1956) [34-35], examinations have revealed that carbon migration occurs from regions of elevated temperatures to those of lower temperatures. This phenomenon is accountable for the breakdown of bimetal weld joints due to carbon migration.

J. N. Dupont et al., (2007) [36], The filler material utilized is SS 308L. This welding filler shares a similar composition to SS 308, except for a deliberate reduction in carbide precipitation potential between particles. To achieve this, the carbon content is limited to a maximum of 0.30%. SS 308L is particularly well-suited for welding stainless steels such as 304, 321, and 347. It is specifically designed for applications requiring low-temperature conditions, making it an ideal wire choice.

R. Chhibber et al., (2006) [37], Stainless steel 304L finds application in primary boiler tubes, which are typically procured as rectangular blocks. Bimetal welded joints are extensively employed in various high-temperature applications within energy conversion systems, involving the coupling of large stainless steel and carbon steel components. In steam power plants, the boiler components are subjected to lower temperatures due to economic considerations, as the primary boiler tubes and heat exchangers are primarily constructed from carbon steel. Conversely, components such as heaters operating at higher temperatures, particularly the final stages of the superheater and reheater, require enhanced resistance to creep and thermal stress. For this reason, these components are typically fabricated using stainless steel.

A. M. Meyer et al., (2001) [38], The welding of 11-12% chromium steel presents a long-standing challenge concerning the formation of turbulent particles in the heat-affected zone of ferritic stainless steel. Introducing austenite at the ferrite grain boundaries during high-temperature conditions can potentially impede grain growth. This research paper explores the prospect of weld metal diffusion contributing to increased carbon or nitrogen levels in the heat-affected zone, thereby promoting the stabilization of austenite at the grain boundaries. Furthermore, employing an Inconel-82 buttering layer in dissimilar welded joints can aid in reducing residual stress within the heat-affected zone of the trivalent steel. Hence, decreasing the buttering layer thickness can assist in mitigating or minimizing failures associated with residual stress in the welded joint.

Husain Mehdi et al., (2016), [39], The mechanical characteristics of welded joints were examined using friction stir welding, which is significantly influenced by the collective impacts of the metal composition and the operational variables.

Graham Gedge, (2008) [40], Stainless steel exhibits exceptional qualities that make it an optimal material choice for explosion-resistant structures. It possesses high strength, effective energy absorption properties, and remarkable flexibility. The stress-strain curve of stainless steel in the plastic range ensures remarkable plastic resistance similar to that of carbon steel. However, stainless steel demonstrates a more pronounced sensitivity to strain compared to carbon steel. This means that stainless steel can achieve comparable strength under rapid tensile rates, particularly at a strain of 0.2%. Over the past two decades, research initiatives have aimed to explore and harness the strain rate effects in austenitic, duplex stainless steels, as well as stainless steel designs in anti-knock structures.

P.K. Sharma et al., (2006) [41], Stainless steel finds extensive applications worldwide in the production of both structural and non-structural components. These steels are composed of alloys containing iron, chromium, nickel, and varying amounts of molybdenum. The corrosion resistance of stainless steel is primarily attributed to its chromium content, which can be further improved by the addition of molybdenum and nitrogen. Nickel is commonly added to achieve desired mechanical properties and attain the appropriate microstructure in the steel. Furthermore, other alloying elements may be incorporated to enhance specific characteristics of stainless steel, such as elevated temperature performance, increased strength, or specialized processing capabilities.

Deepak Bhandari et al., (2017) [42], It has been examined that bimetal welded joints are extensively employed in numerous high-temperature applications within energy conversion systems, involving the coupling of sizable stainless steel and carbon steel components. In steam power plants, economic considerations dictate that the boiler components, including the primary boiler tubes and heat exchangers, are designed to withstand lower temperatures. These components are predominantly fabricated using carbon steel. Conversely, components such as heaters operating in the final stages of the superheater and reheater function at elevated temperatures, requiring enhanced resistance to creep and thermal stress. Consequently, these components are constructed using stainless steel materials to optimize their performance under high-temperature conditions.

R. Kacar et al., (2004), [43], The construction of the equipment necessitates welding between the bimetallic part and the bimetallic stainless steel (SS). When soldering with the SS-LAS interface, the bimetallic component is soldered to a minimum depth of 2 mm after removing the SS cladding. This process facilitates welding from LAS to LAS. For the SS portion, a pure austenitic SS steel buffer layer and corrosion-resistant SS are employed for the removal and storage of the welded composite. The pure austenitic layer is created using bimetallic welding consumables, which serve as the buffer layer for LAS and provide the necessary mechanical properties and weld metal for the desired chemical composition. On the other hand, corrosion-resistant SS consumables, made of stainless steel, are used for the branching of the bimetallic and SS weld deposits during the welding process.

2.1 RESEARCH GAP FROM LITERATURE REVIEW

Extensive research has been conducted in the field of gas tungsten arc welding, investigating the influence of various parameters on the mechanical properties and microstructural changes of welded materials. Some researchers have utilized optimization techniques like Taguchi design of experiments and analysis of variance to optimize the tungsten arc welding process. Furthermore, the use of ANSYS software tools has been employed to compare theoretical results with actual testing outcomes.

While welding analysis of SS-202 and SS-304 has been extensively studied using tungsten inert gas welding and other welding processes, the mechanical characterization of welded joints between Mild steel and EN31 with different filler metals using tungsten inert gas welding has not been reported yet. Therefore, this study aims to address this gap by comparing the effect of two filler rods on the welded joint between Mild steel and EN31, providing valuable insights into the mechanical properties of these joints.

CHAPTER-3

3 OBJECTIVE OF PRESENT WORK

Bimetallic parts are employed in equipment manufacturing to meet diverse functional material requirements, such as strength, corrosion resistance, or heat resistance.

The objective of this study is to investigate the influence of post-heat treatment on the mechanical properties and microstructural analysis of the welded joint between mild steel and EN31. Two different filler metals, namely SS308L and MS, were utilized in the welding process, which involved tungsten inert gas welding. Through the examination of post-heat treatment effects, this research aims to provide valuable insights into improving the mechanical properties and microstructural characteristics of the welded joint between these two materials.

3.1 BASE MATERIALS

Bimetallic welded joints find extensive application in energy conversion systems, particularly in large-scale stainless steel and carbon steel structures. In steam power plants, the boiler components are often made of carbon steel due to economic considerations, as they are exposed to lower temperatures. On the other hand, specific parts like superheaters require materials with enhanced creep strength and oxidation resistance. The pressure vessel and primary boiler typically utilize SS 202 and SS304 materials. These steels are commonly received in the form of rectangular blocks, which are subsequently used to fabricate the necessary components for the energy conversion systems.

3.2 FILLER MATERIALS

In this study, the welding of mild steel and EN31 was performed using SS308 and MS70S2 filler rods. SS308 is an alloyed austenitic steel known for its excellent oxidation resistance, creep resistance, and high temperature strength. The reduced nickel content in SS308L enhances its resistance to sulfur attack at elevated temperatures. This steel exhibits ductility and toughness, making it suitable for fabrication and machining processes. Additionally, it is well-suited for applications in cryogenic environments, making it a suitable choice for this study.

3.3 CHEMICAL COMPOSITION

Chemical composition of base material and filler material are given in table 1 and 2 respectively.

Table 1: Chemical composition of base material [13]

Type of Stainless steel	**C**	**Mn**	**Si**	**Cr**	**Ni**	**P**	**S**
Mild Steel	0.05-0.25	0.25-1.5	1.0	0	8.0-12.0	0.04	0.05
EN31	1.1	0.5	0.75	0.35	10.5	0.025	0.025

Table 2:- Chemical composition of Filler material [13]

Type of Stainless steel	**C**	**Mn**	**Si**	**Cr**	**Ni**	**P**	**S**
SS308	0.08	2.0	1.0	19.0-21.0	10.0-12.0	0.045	0.03
MS70S2	0.11	1.5	1.0	0.12	0.09	0.025	0.025

3.4 MECHANICAL AND PHYSICAL PROPERTIES

Mechanical physical properties of base and filler material as shown in table 3.

Table 3:- Mechanical and physical properties of base and filler materials [13]

Type of steel	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Thermal coeff. (10^{-6}m/m°C)	Density (g/cm3)
Mild Steel	400	300	200	11-12	8-8.5
EN31	900	590-690	210	11.2-11.7	7.8
SS308	577	448-460	190-210	17.2-18.4	7.7-8.03
MS70S2	532	380-450	214	11.4-12	7.85

3.5 WIRE FEED SYSTEM

To introduce the filler wire into the weld pool, a push wire feed system is employed. This system consists of two drive rollers that can be adjusted according to the diameter of the wire electrode, ensuring a steady and seamless feed. The feeding rate into the weld was set at 4 cm/min.

3.6 GROOVE PREPARATION

In the market, 16 mm thick plates of both mild steel and EN31 stainless steel were obtained. A single V-groove with a 60-degree angle was prepared between these two plates. To ensure proper alignment and minimize distortion after welding, a base plate made of mild steel and EN31 stainless steel was welded to hold both plates in the desired position. The base plates were fully machined, and then welding was performed using a filler rod. Subsequently, the welded joint was machined again to achieve the required geometry.

3.7 SHIELDING GAS

A commercially available shielding gas, argon 99.97, was utilized for the welding process. A gas flow rate of 10 liters/min was selected after conducting tests on the plate. This specific flow rate was chosen because it resulted in favorable weld properties.

3.8 SPECIMEN DIMENSIONS

ASTM E8 standard samples were subjected to tensile testing to assess the mechanical properties of various welds involving Mild steel and EN31 shown in fig.5.

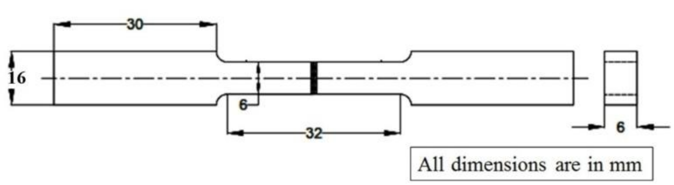
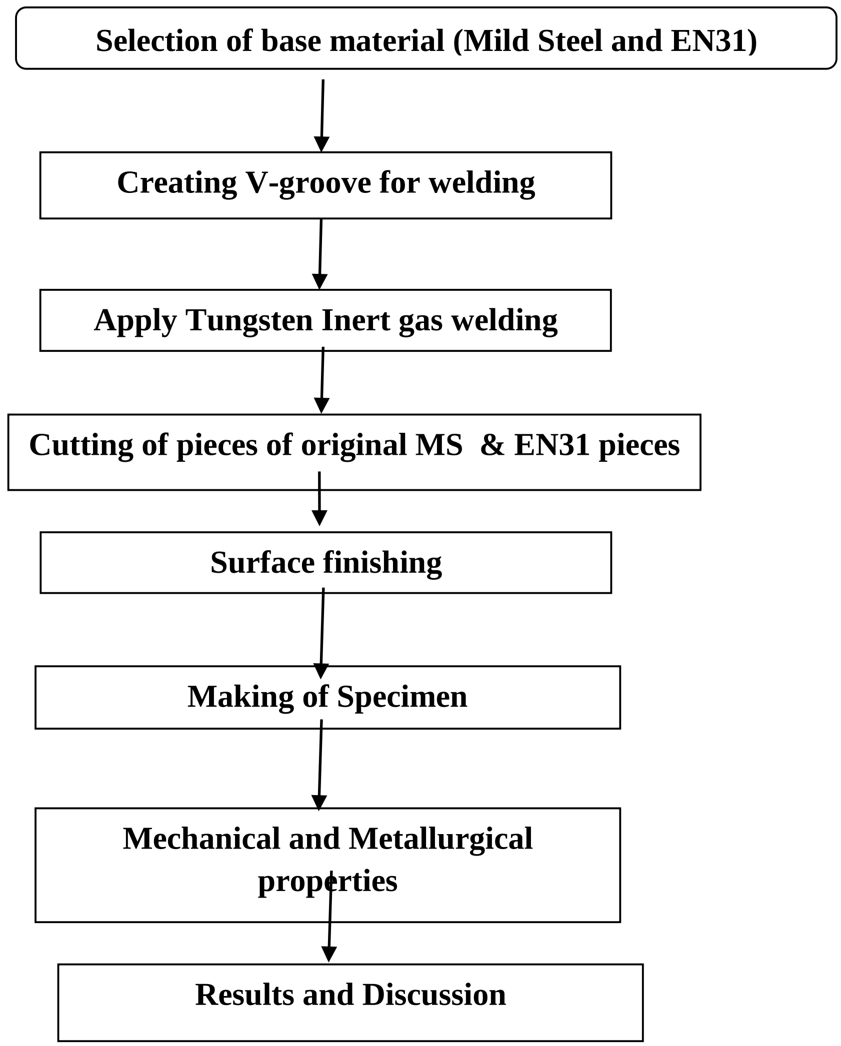


Figure 5: ASTM E8 standard test specimen

CHAPTER-4

4 RESEARCH METHODOLOGY

In methodology different steps are followed and these steps are firstly shown by a flow chart then these are discussed in detail.



4.1 SELECTION OF MATERIAL

Initially, the primary challenge was to determine the appropriate material for the operation. After careful consideration, MS (mild steel) and EN31 plates measuring 200x100x22mm were chosen for the project, as shown in fig.6.

Figure 6: Base pate before welding (200 x 50 x 16 mm)

4.2 CREATING GROOVE FOR WELDING

V-shaped groove is created in the material for the welding purposes as shown in fig.7. This groove is created by the help of shaper machine; a v shape groove is created the angle which is generated by the shaper machine is 45^0 the tool used in shaper machine is carbide tool.

Figure 7: (a) Grooving operation, (b) V groove

4.3 TUNGESTEN ARC WELDING

Tungsten Inert Gas (TIG) welding, also referred to as Gas Tungsten Arc Welding (GTAW), is a welding technique that employs a non-consumable tungsten electrode to generate an electric arc and a shielding gas to safeguard the weld region against atmospheric impurities. In TIG welding, the tungsten electrode, which is highly resistant to heat, is used to create the arc. The electrode is connected to a power source, which provides the necessary electrical energy for the welding process. The electrode does not melt during the welding process but instead generates intense heat through the arc. Tungsten Inert gas welding during experiment is shown in fig.8.

To protect the weld area from oxidation and contamination, an inert gas, such as argon or helium, is used as a shielding gas. The shielding gas is directed through a nozzle around the electrode and the weld pool, forming a protective atmosphere that prevents atmospheric gases from reacting with the molten metal.TIG welding offers precise control over the welding process and is commonly used for welding thin materials, as well as for welding critical joints that require high-quality and aesthetically pleasing welds. It allows for greater control of heat input, which minimizes distortion and ensures high weld integrity.TIG welding is widely used in industries such as automotive, aerospace, and manufacturing, where high-quality welds and precise control are essential. It is particularly suitable for welding materials like stainless steel, aluminum, and other non-ferrous metals. The welding parameters as shown in table 4.

Figure 8: Tungsten Inert gas welding during experiment

Table 4: Welding parameters

Type	**Current (A)**	**Voltage (V)**	**Wire feed (cm/mint)**
Welding	195	23	4

4.3.1 Safety

Like any other arc welding methods, TIG welding carries potential hazards if adequate precautions are not followed. Welders must don appropriate protective gear such as heavy leather gloves and long-sleeved jackets to protect against excessive heat and sparks. Since TIG welding produces minimal smoke, the arc's brightness can be more intense than in other metal arc welding processes, making the operator more susceptible to eye and skin irritation.

To prevent such risks, it is essential to wear a dark visor helmet to shield against UV radiation and maintain proper eye and skin protection.

4.4 SURFACE FINISHING

After welding fig.9(a), the welding plate was in turn into first Shaper shown in fig .9(b)and then Surface Grinder. The carbide tool was used to make the whole surface plate similar, means uniform thickness throughout. The plate was surface finished from both the side. The thickness obtained was 12 mm shown in fig.9(c).

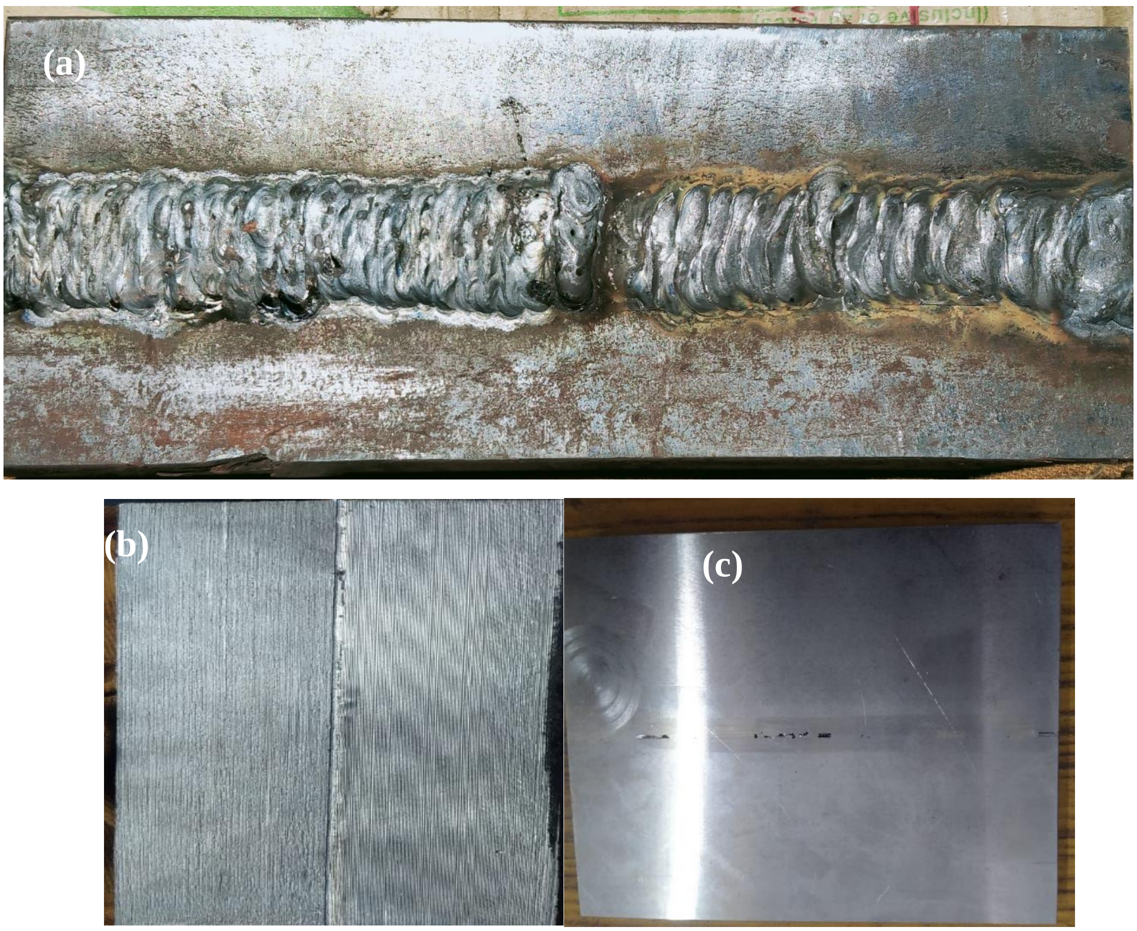


Figure 9 : (a) Workpiece after welding, (b) after shaper, (c) after surface finishing

4.5 CREATING SPECIMENS OF SS-304, MS, AND WELDMENT

The strips are formed after cutting of material are converted into the specimens of given dimensions (ASTM E8) shown in fig.11, these specimens are formed on Surface Grinder.

Figure 10 :-During Preparation of specimen

Figure 11: Tensile test specimen as per ASTM E8 standard

4.6 Heat Treatment of Specimens

Heat treatment is performed as shown in fig.12 to alter the physical and mechanical properties of materials, such as metals and alloys, by controlled heating and cooling processes. It improves their strength, hardness, toughness, ductility, and other characteristics, enhancing their performance, durability, and suitability for specific applications.

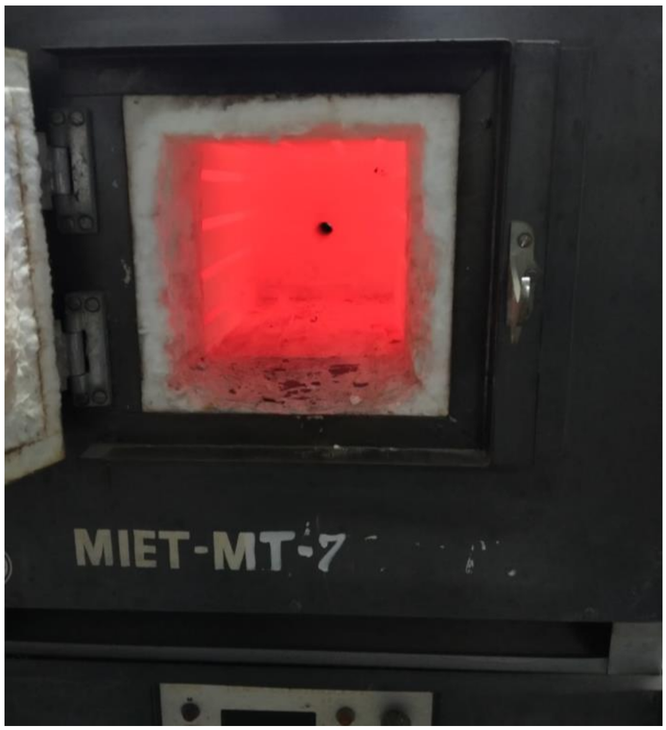


Figure 12: During heat treatment

4.6.1 Annealing

In the annealing process, the specimen is heated to a temperature of 860°C and maintained at that temperature for 1 hour. After the holding time, the material is gradually cooled down to room temperature inside the furnace. This slow cooling process allows for the desired structural changes and relaxation of internal stresses within the material, resulting in improved ductility, reduced hardness, and refined grain structure.

4.6.2 Quenching

First, the specimen is heated to a temperature of 860°C and held at that temperature for 1 hour. This allows for the desired transformation or microstructural changes to occur within the material. After the soaking period, the specimen is rapidly cooled by immersing it in water. The rapid quenching in water promotes a high cooling rate, resulting in the desired hardening and transformation of the material's microstructure. This process is commonly known as water quenching or water hardening.

4.6.3 Normalizing

In the normalizing process, the specimen is heated to a temperature of 860°C and held at that temperature for 1 hour. This allows for the complete transformation and homogenization of the material's microstructure. After the soaking period, the specimen is cooled in the ambient atmosphere, which means it is allowed to cool naturally in the surrounding air. This slow cooling process helps to achieve a more uniform and controlled cooling rate, allowing the material to undergo structural changes and obtain a refined grain structure. Normalizing is often used to improve the mechanical properties and machinability of the material.

4.7 TENSILE TESTING OF SPECIMENS

The specimens which are formed after welding are divided into two parts one is weld specimen with filler SS308 and other MS70S2 both of these specimen along with Mild steel and EN31 specimens are tested on universal testing machine to find out their tensile strength and made 5-5 specimens for each. Specimen during Tensile Testing is shown in fig.13.

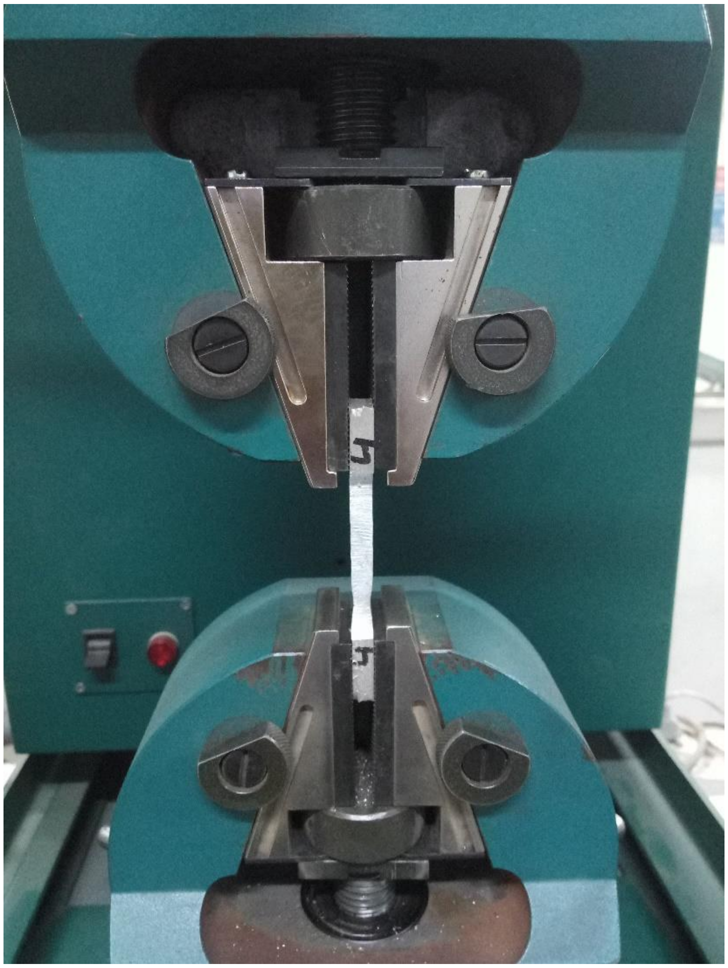


Figure 13: Specimen during Tensile Testing

4.8 MICROHARDNESS TEST

Hardness is defined as the resistance offered by the metal for localized plastic deformation. It has been defined as the resistance exhibited by metal. The Vickers hardness value is obtained by dividing the load by the square millimeter area of the indentation. The sample was polished on 2000 grit sandpaper and then polished using alumina powder. The sample was fixed on stability and weight on a micro-hardness tester. The load applied to the treated sample was 200 grams at 10 seconds at room temperature shown in fig.14.

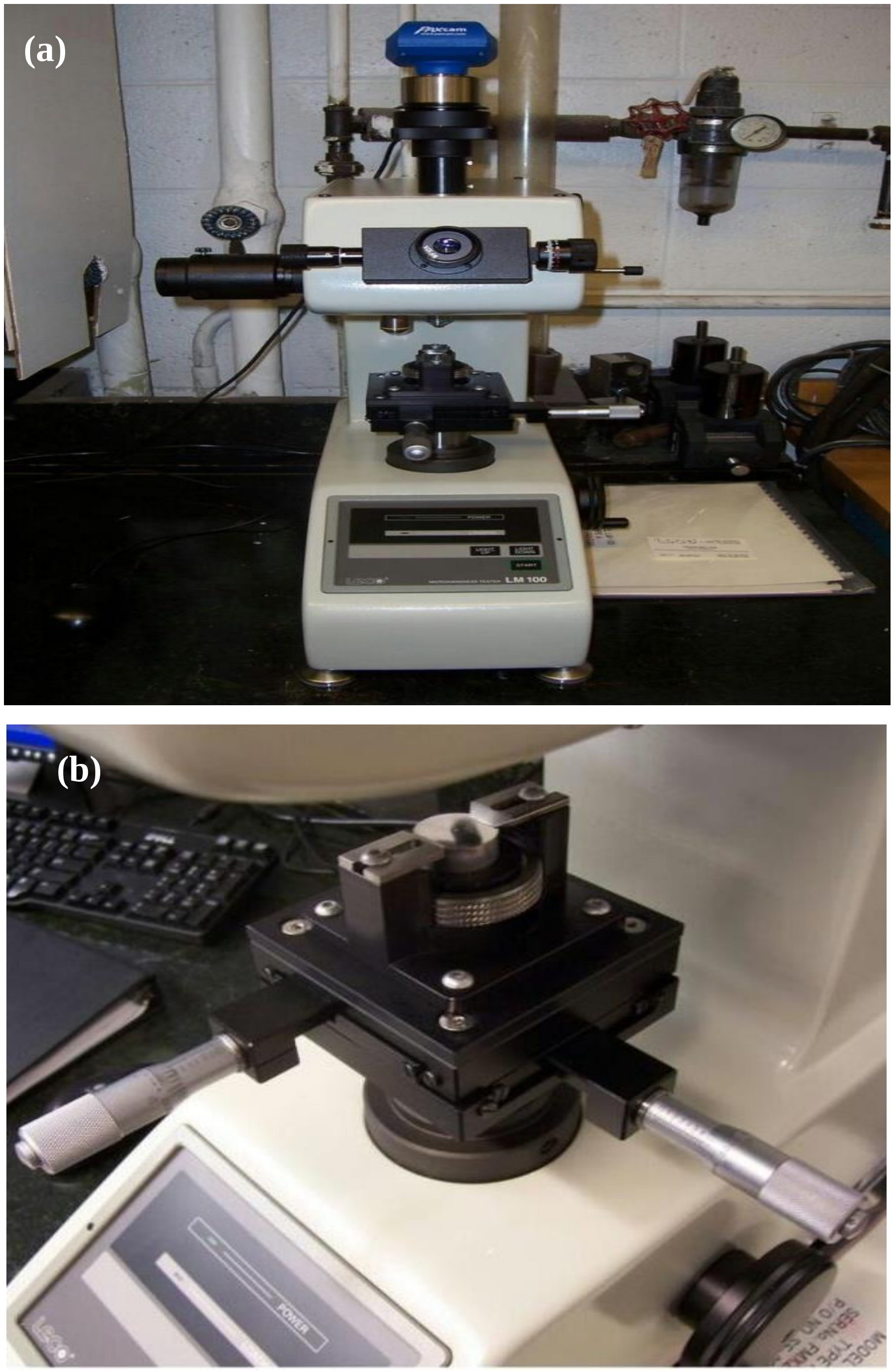


Figure 14: (a) Vickers micro hardness tester, (b) Micro hardness testing process

4.9 MICROSTRUCTURE TESTING

Checking the microstructure of the material provides information to determine if the structural parameters are within a particular specification. The results of the analysis are used as criteria for acceptance or rejection.

In the analysis, microstructural examinations are typically performed using optical or scanning electron microscopy to increase the properties of the material. The number or size of these facilities can be measured according to acceptance criteria. These exams are often subjected to failure analysis to determine the type of material used to assist and determine what process with proper processing can evaluate metallurgical exams.

- Reduced and disintegrated, grain size, mutual erosion or excessive corrosion
- Depth of α in titanium alloy
- Spheroidization percentage
- Inclusion ratings.
- Volume fraction of particles in different phases or in the second stage of the metal

Figure 15: SEM machine

4.9.1 Sample Preparation

In order to identify and evaluate the microstructure of the material, it is very important to carefully and properly prepare the test sample. The different steps in preparing a sample for microstructure inspection include:

- Select a representative sample of the material
- Sample sections to avoid changing or destroying structures of interest
- Mounting the section without the destruction of test samples
- Grinding the sample surface to obtain a flat sample with minimal damage
- Polished the mounted and ground sample.

4.9.2 Sectioning

To avoid changing or destroying the structure of the material, carefully disconnect the test sample. If using an abrasive saw, it is important to keep the sample cool with coolent or lubricated so that it does not burn or overheat. However, no matter how careful the friction is seen or the electrical discharge machining, there will be a small amount of deformation on the surface of the sample. This deformation should be removed in the subsequent preparation phase.

4.9.3 Mounting

There are test samples that are divided into suitable sizes that are placed in a plastic or epoxy material to facilitate processing and grinding and polishing steps. Increasing the medium should be consistent with the hardness and wear resistance of the sample. Thermosetting phenolic are like Bakelite specific mounting materials, and thermoplastic materials such as methyl methacrylate (Lucite). Mounting involves placing the sample into a mold and mixing it with a suitable powder. When the mold is heated and the pressure is pressed to a suitable level, there is a media setting or treatment. Remove the installed sample from the mold. If the structure of the sample of interest is changed using heat or pressure, then castable cold mounting materials such as epoxies are employed.

4.9.4 Grinding

Grinding is performed after mounting to eliminate any surface damage caused during the sectioning process and to achieve a smooth, flat surface. Typically, water-lubricated abrasive wheels are utilized, along with a sequence of increasingly finer abrasive grits. This step ensures the creation of a flat surface that is nearly devoid of any disrupted or distorted metal resulting from earlier sample preparation stages.

4.9.5 Polishing

The polishing stage removes the last layer of twisted metal. It leaves a properly prepared sample ready to check for existing features such as insert content or any porosity.

4.9.6 Etching

The final step that can be used is etching to show the microstructure of the test sample. This step reveals particles, twins and other phase particles that are not visible without sampling.

CHAPTER 5

5 RESULTS AND DISCUSSIONS

5.1 Effect of heat treatment on mechanical properties of TIG welded joint with filler SS308

The welded joint of mild steel and en31 with filler ss308 shows tensile strength of 296.85 MPa and hardness value of 254 HV. The joint efficiency is 51.47%. On doing heat treatment namely annealing the hardness decreases to 236 HV because during annealing the existing grain structure breaks down, and new, strain-free grains are formed. These new grains have a lower dislocation density, which leads to a decrease in hardness. Tensile strength increases by 8.5% compared to weld. The joint efficiency is 56.25% as demonstrated in table 5.

In case of normalizing the hardness increase by 25.6% as compared to weld and 35.16 as compared to annealed. The hardness increases because Normalizing promotes the formation of a finer and more uniform grain structure compared to the original structure.The formation of pearlite, a lamellar structure consisting of alternating layers of ferrite and cementite, contributes to the increase in hardness. the joint efficiency is 63.99

Table 5: Mechanical properties of TIG welded of MS and EN31 with filler SS308

Specimens	Tensile strength (MPa)	% Strain	Joint efficiency (%)	Hardness (HV)
weld	296.85	8.28	51.47	254
Annealing	324.57	10.37	56.25	236
Normalizing	369.26	9.41	63.99	319
Quenching	402.24	5.19	69.71	392

In case of quenching the hardness increase by 53.5% as compared to weld and 66.1% and 22.8 as compared to annealing and normalizing respectively. Hardness increases due to formation of martensite. Tensile strength increases by 35.5% and the joint efficiency is 69.71%.

5.2 Effect of heat treatment on mechanical properties of SS308

The welded joint of mild steel and en31 with filler MS702 shows tensile strength of 202.74 MPa and hardness value of 219 HV. The joint efficiency is 38.1%.

On doing heat treatment namely annealing the hardness decreases to 227 HV because during annealing the existing grain structure breaks down, and new, strain-free grains are formed. These new grains have a lower dislocation density, which leads to a decrease in hardness. Tensile strength increases by 3.625% compared to weld. The joint efficiency is 38.1%.

In case of normalizing the hardness increase by 22.37% as compared to weld and 18.06% as compared to annealed. The hardness increases because Normalizing promotes the formation of a finer and more uniform grain structure compared to the original structure. The formation of pearlite, a lamellar structure consisting of alternating layers of ferrite and cementite, contributes to the increase in hardness. the joint efficiency is 55.7%.

In case of quenching the hardness increase by 42.009% as compared to weld and 37.004% and 16.04 as compared to annealing and normalizing respectively. Hardness increases due to formation of martensite. Tensile strength increases by and the joint efficiency is 71.74% revealed in table 6.

Table 6: Mechanical properties of TIG welded of MS and EN31 with filler MS70S2

Specimens	Tensile strength (MPa)	% Strain	Joint Efficiency (%)	Hardness (HV)
weld	202.74	14.81	38.1	219
Annealing	264.14	16.09	49.65	227
Normalizing	296.33	11.27	55.70	268
Quenching	348.19	4.02	65.44	311

5.3 MICROSTRUCTURE ANALYSIS

5.3.1 TIG welded joint with filler SS308

The microstructure of the weld metal is typically austenitic, which is characterized by a face-centered cubic crystal structure. The weld metal exhibits a dendritic grain structure, where the grains grow from the fusion zone towards the heat-affected zone (HAZ). These dendrites have a distinct branching pattern.

The welded joint fabricated using the TIG process with SS308L filler exhibited increased strength due to two factors: grain refinement and the unique metal composition. Firstly, the process of welding led to grain refinement within the joint, resulting in smaller and more closely packed grains. This grain refinement enhanced the strength of the joint. Secondly, the specific metal composition of the SS308L filler, which typically contains higher amounts of chromium and nickel, contributed to the improved strength. These alloying elements promote solid solution strengthening and formation of stable precipitates, ultimately leading to higher strength values in the welded joint [48].

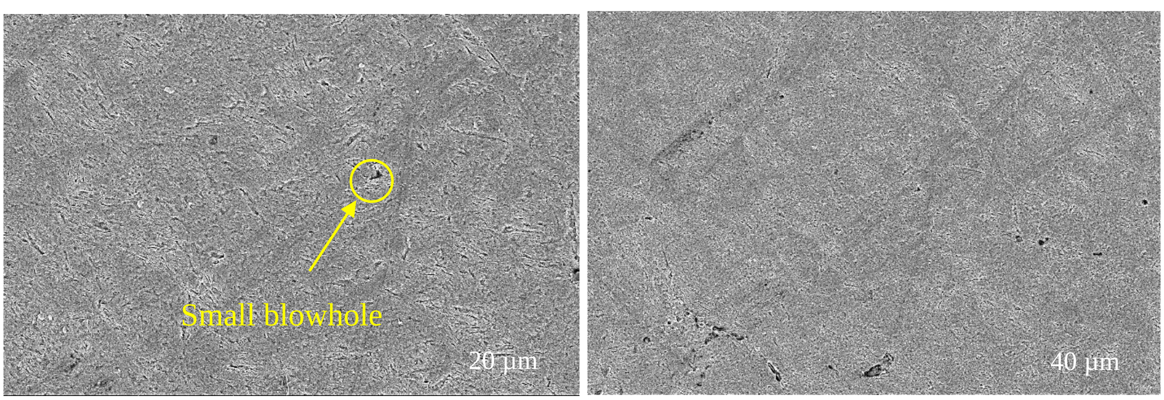


Figure 16: SEM images of TIG welded joint with filler SS308

The microstructure of a weldment is affected by the amount of heat applied, the parameters used during processing, and the chemical composition of the filler material. Typically, a higher heat input results in a coarser grain structure in the welded metal, as it leads to a slower cooling rate. Conversely, a lower heat input promotes a finer microstructure, as it facilitates a faster cooling rate. [48].

Due to proper fusion of filler metal with base micro-hardness value at the center of the welded zone was found maximum (267 HV) with filler material SS308. The HAZ typically exhibits coarser grain structure compared to the base metal due to the heat input.

5.3.2 TIG welded joint of MS70S2

MS70S2 filler metal typically forms a microstructure consisting of ferrite and pearlite. Ferrite is a ductile phase, while pearlite is a lamellar structure composed of alternating layers of ferrite and cementite.The weld metal exhibits a columnar or equiaxed grain structure, depending on the welding parameters, heat input, and cooling rate during solidification.

During the welding process, a blow defect occurred, which is clearly visible in the scanning electron microscope (SEM) image. A blow defect is a type of welding imperfection that arises when trapped gases or contaminants in the weld pool are not properly expelled during solidification. These trapped gases form voids or cavities within the weld metal, leading to structural weaknesses and potential failure points. In the SEM image, the blow defect appears as a distinct void or cavity within the welded region [47].

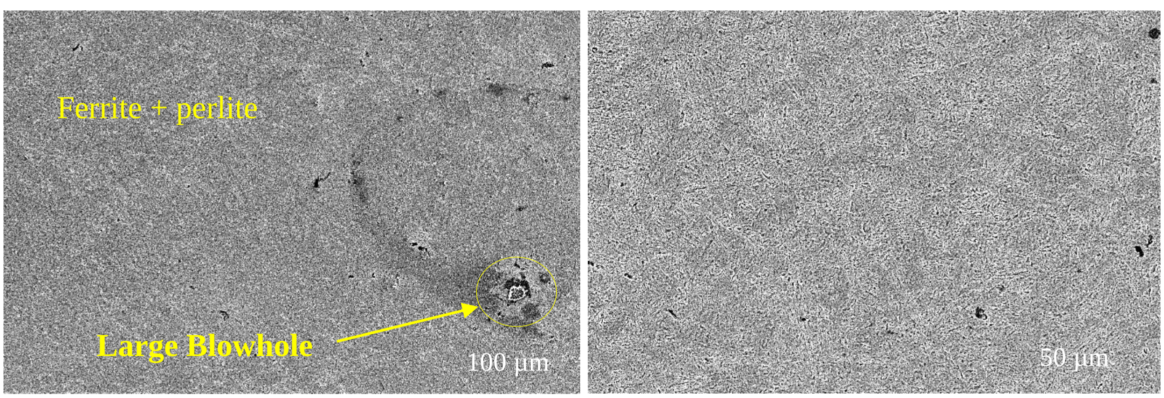


Figure 17: SEM images of TIG welded joint with filler MS70S2

5.4 Effect of post weld heat treatment with filler SS308

5.4.1 Normalizing

The normalized SS308 filler metal retains its austenitic microstructure after normalization. Austenite is characterized by a face-centered cubic (FCC) crystal structure, which provides good ductility and corrosion resistance. The microstructure appears predominantly pearlite, as evident from the black areas. Additionally, a few austenite grains can be observed. The variation in microstructure is attributed to a more rapid cooling rate during the normalization process [45]. From the SEM image of normalized SS308, it is clear that the carbon content is approximately 0.3%. The austenite transforms at a constant temperature of 860°C to form a lamellar mixture of ferrite and cementite, known as pearlite, through the eutectoid transformation process. Ferrite appears white, while pearlite appears dark or lamellar under the microscope [59]. So, there is approximately 37.5% pearlite and rest are other including ferrite as shown in fig.18.

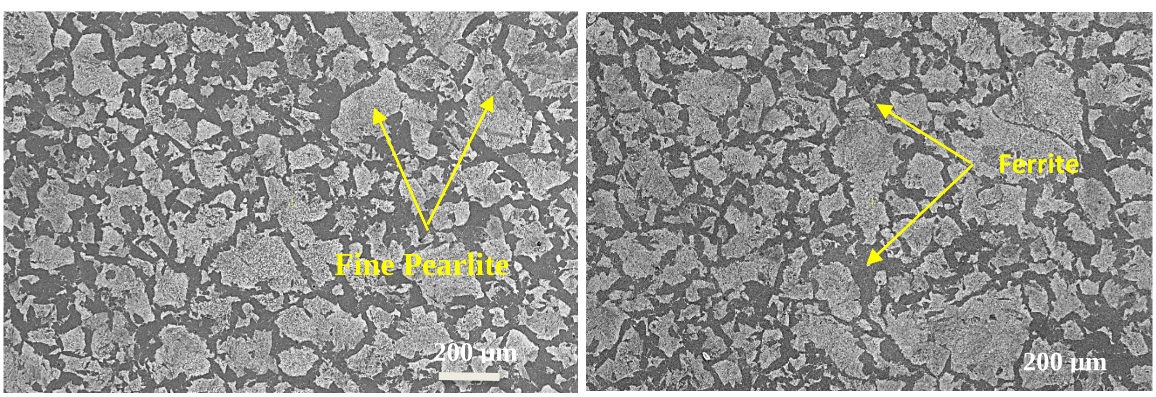


Figure 18: Effect of Normalizing on SEM images of TIG welded joint with filler SS308

5.4.2 Annealing

In Annealing, the alloy is treated by heating to a temperature of about 50°C above upper critical temperature of hypoeutectoid for compositions less than the eutectoid, or, for compositions in excess of the eutectoid, 50°C above lower critical temperature [48] (to form austenite and Fe3C phases).

According to the composition We heat the specimen till 860 c. The specimen is subsequently subjected to furnace cooling, where the heat-treating furnace is deactivated, allowing both the furnace and the steel to gradually cool down to room temperature over a span of several hours. During this annealing process, the resulting microstructure consists of coarse pearlite, along with any proeutectoid phase present, which exhibits relatively favorable characteristics such as softness and ductility.

The formation of pearlite begins with the nucleation of cementite at the grain boundaries of homogeneous austenite, which is the high-temperature phase of iron. The nucleation of cementite occurs due to the segregation of carbon at the grain boundaries. In the case of coarse pearlite, the transformation occurs relatively slowly, allowing for the growth of larger pearlite colonies. These colonies consist of alternating layers or lamellae of ferrite and cementite shown in fig.19. The lamellae are relatively thick and can be easily distinguished under a microscope.

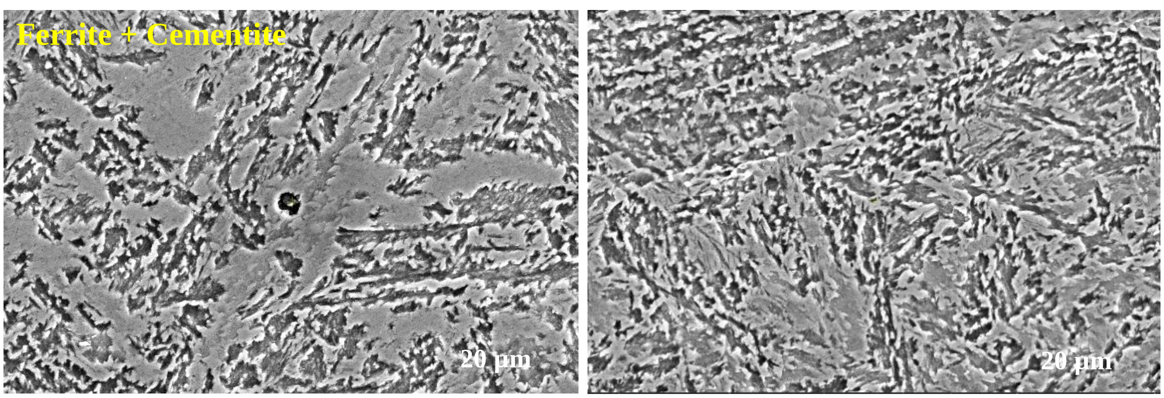


Figure 19: Effect of Annealing on SEM images of TIG welded joint with filler SS308

5.4.3 Quenching

The microstructure consists of needle like structure as shown in fig.20 which is very huge in amount. In Quenching the specimen undergoes a very rapid rate of colling. As such the austenite transformed to martensite. These structures are formed due to the rearrangement of atoms during the diffusion less transformation [45]. The needle-like structure provides the characteristic hardness and strength associated with martensite.

The hardness test results indicate a clear increase in hardness, as evidenced by the values obtained: from an initial hardness of 254 HV (Hardness Value) to an improved hardness of 392 HV.

For 0.6% carbon the structure is lath martensite and for 0.6% to 1.0 % the structure is mixed and for 1.0% to 1.4% plate martensite. In our sample the carbon is content is 0.46 % and hence the microstructure is lath martensite [47]. The hardness of martensite depends on the carbon content in the austenite. Martensite with hardness below 55Rc have some amount of ductility and more than 60 Rc are generally brittle.

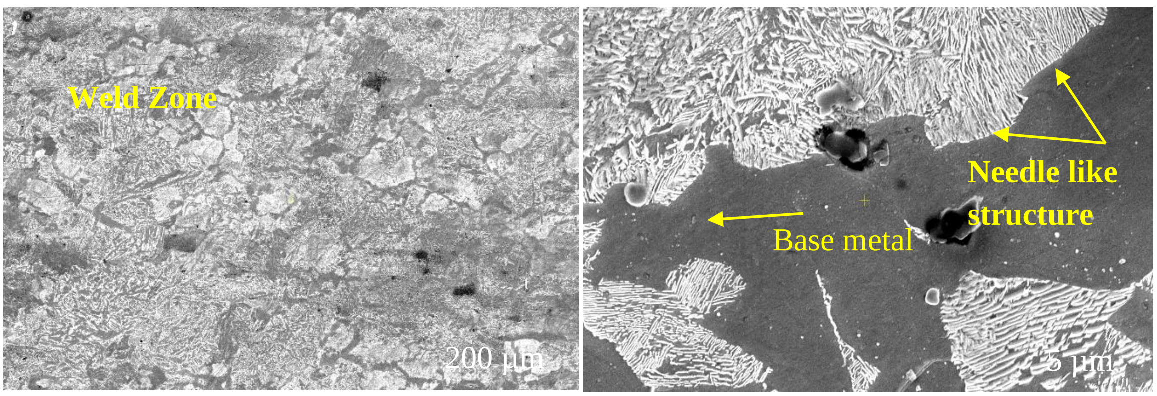


Figure 20: Effect of Quenching on SEM images of TIG welded joint with filler SS308

5.5 Effect of post weld heat treatment with filler MS70S2

5.5.1 Normalizing

Typically, when normalizing, a fine pearlite microstructure is formed. However, due to the 0.11% carbon content in MS70S-2, the resulting pearlite tends to be relatively coarse pearlite shown in fig.21[47]. Let's delve into the reasons behind this occurrence:

Pearlite is a lamellar structure comprising alternating layers of ferrite and cementite. Its formation is influenced by the cooling rate during the transformation from austenite to a two-phase microstructure of ferrite and cementite.

In the case of MS70S-2, which has a carbon content of 0.11%, this relatively higher carbon concentration provides a stronger driving force for carbon diffusion and subsequent cementite precipitation. During the normalizing process, the cooling rate is generally slower compared to other heat treatment methods like quenching. This slower cooling rate allows for a more gradual transformation of austenite into pearlite. The slower cooling rate provides ample time for carbon atoms to diffuse and combine, forming cementite particles. Consequently, the pearlite microstructure that forms during normalizing in MS70S-2 tends to have larger cementite particles and wider ferrite layers, resulting in a relatively coarser pearlite morphology [47].

During the normalizing process of MS70S-2, some precipitation of additional phases occur as shown in fig.21. This can be attributed to the presence of different elements in the base metal, as MS70S-2 itself has a relatively low content of alloying elements. The limited amount of alloying elements in MS70S-2 filler metal result in the formation of fewer alloying element-rich phases during solidification and subsequent heat treatment. As the base metal contains a higher concentration of alloying elements compared to the filler metal, these elements can contribute to the formation of precipitates during normalizing

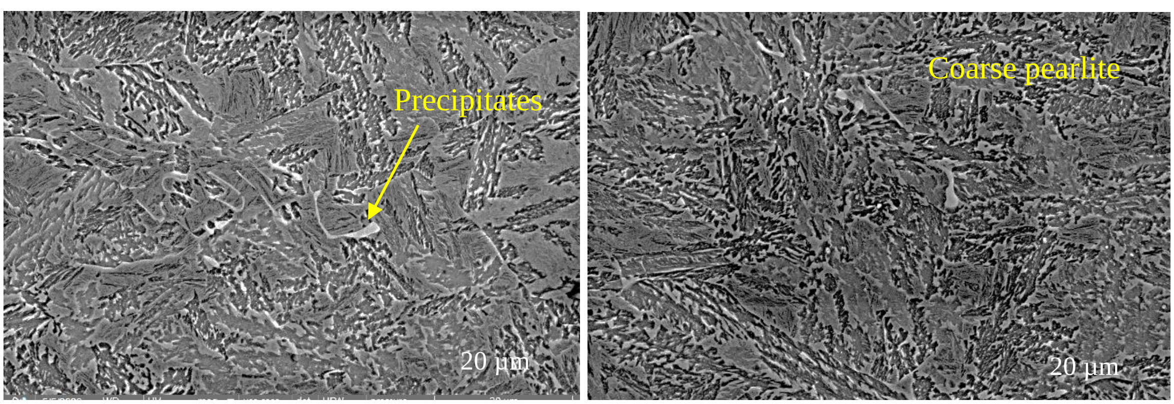


Figure 21: Effect of Normalizing on SEM images of TIG welded joint with filler MS70S2

5.5.2 Annealing

It seems that these films predominantly consist of ferrite, accompanied by clusters of pearlite, while exhibiting microstructural inconsistencies. When the specimen was heated to a temperature of 860°C, a process called annealing, it caused a transformation from a structure known as Body-Centered Cubic (BCC) to Face-Centered Cubic (FCC), as explained by Calister in 2007. This transformation resulted in the specimen now being in the austenite state. Looking at the image we can observe that the grains in the material have a uniform distribution, meaning they are evenly spread out and consistent. Additionally, the grains appear larger in size. As a result, the material is both ductile, meaning it can be easily stretched without breaking, and magnetic, indicating it has magnetic properties.

Even though the 0.11% carbon steels contain a relatively small amount of carbon, at extremely high temperatures of 860°C, the formation of ferrite starts to occur. As much as the carbon percentage steel occurs it begin to precipitate out ferrite at much lower temperature [49]. As the annealing temperature increases the size of the precipitates increase and tensile strength of also tends to increase with the annealing temperature. The hardness of the material generally decreases as the annealing temperature increases, and this decrease is attributed to the changes in the size of precipitates. When the annealing temperature is increased, the precipitates tend to coarsen shown in fig.22, leading to a reduction in the precipitation hardening effect. It was observed that the difference in hardness between samples annealed at 850°C and 900°C was relatively small [50].

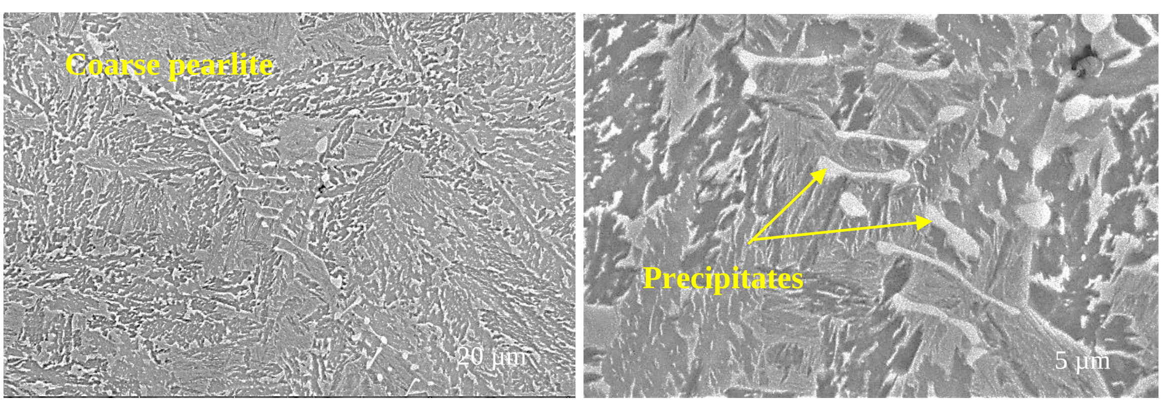


Figure 22: Effect of Annealing on SEM images of TIG welded joint with filler MS70S2

5.5.3 Quenching

During the process of quenching, austenite transforms into martensite, which is a specific crystalline structure. In a visual representation or figure, the retained martensite appears bright or lighter in color [46].

For 0.6% carbon the structure is lath martensite and for 0.6% to 1.0 % the structure is mixed and for 1.0% to 1.4% plate martensite. In our sample the carbon is content is 0.46 % and hence the microstructure is lath martensite [47]. The hardness of martensite depends on the carbon content in the austenite. Martensite with hardness below 55Rc have some amount of ductility and more than 60 Rc are generally brittle.

From the hardness test we found that the Hardness value is 348.19. When the steel is cooled to some lower temperature, both the phases will contract, but the volume contraction of martensite is greater than that of austenite. Retained austenite (R-A) shown in fig.23 varies from surface to center in a hardened steel component. It is less at or near the surface and more in the center.

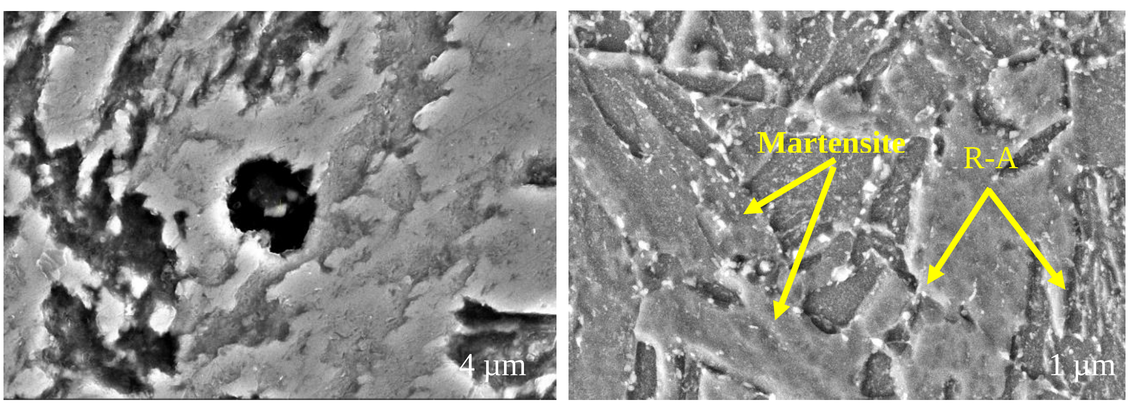


Figure 23: Effect of Quenching on SEM images of TIG welded joint with filler MS70S2

5.6 Conclusions

- Mild steel and EN 31 can be effectively joined by employing the compatible filler metals, namely SS308 and MS70S2. The utilization of these specific filler materials ensures a robust and reliable bond between the two types of steel.
- Based on the results obtained from the tensile and hardness tests, it is evident that the strength of the welded joint is initially lower than that of the base metals, specifically mild steel and EN31. However, significant improvements can be achieved through the application of a heat treatment process. After subjecting the welded joint to a normalizing treatment, a remarkable change is observed. The hardness of the joint decreases by approximately 7.08% for SS308 Filler. Both the hardness and tensile strength of the welded joint using SS308 and MS70S2 filler are observed to increase significantly after undergoing normalizing and quenching heat treatment processes.
- Based on the SEM image analysis, it is evident that the weld defect in the joint is less than 2%, which is a positive indication of the welding quality. Additionally, the formation of precipitates is found to be minimal when using SS308 filler, while a small amount is observed when MS70S2 filler is employed.
- The tensile strength of a TIG weld with filler SS308 was obtained as 296.85 MPa. After annealing, normalizing, and quenching, the tensile strength increases to 324.57 MPa, 369.26 MPa, and 402.24 MPa, respectively. And the tensile strength of a TIG weld with filler MS70S2 is obtained as 202.74 MPa. After annealing, normalizing, and quenching, the tensile strength increases to 264.14 MPa, 296.33 MPa, and 348.19 MPa, respectively.
- The hardness of a TIG weld with filler SS308 is obtained as 254 HV. After annealing, the hardness decreases to 236 HV, and after normalizing and quenching, the hardness increases to 319 HV and 392 HV, respectively. The hardness of a TIG weld with filler MS70S2 is obtained as 219 HV. After annealing, the hardness decreases to 227 HV, and after normalizing and quenching, the hardness increases to 268 HV and 311 HV, respectively.

5.7 Future Scope

The future scope of studying the effect of post-weld heat treatments on the mechanical and metallurgical characterization of dissimilar welded joints holds significant potential for advancements in the field. Here are some potential areas of exploration within this research scope:

- Optimization of heat treatment parameters: Future studies can focus on determining the optimal heat treatment parameters, such as temperature, duration, and cooling rate, for dissimilar welded joints. Understanding the influence of these parameters on the mechanical and metallurgical properties can help in developing guidelines for achieving desired outcomes.
- Microstructural analysis: Investigating the microstructural changes induced by different post-weld heat treatments can provide valuable insights into the evolution of phases, grain structure, and defects in dissimilar welded joints. Techniques like electron microscopy, X-ray diffraction, and hardness testing can be employed to analyze and compare the microstructural characteristics of treated and untreated joints.
- Mechanical properties evaluation: Future research can delve into assessing the mechanical properties, including tensile strength, hardness, impact toughness, and fatigue resistance, of dissimilar welded joints subjected to various post-weld heat treatments. This can help in understanding how heat treatment influences the mechanical behavior and performance of the joints, enabling the identification of optimum treatment strategies for specific applications.
- Residual stress analysis: Residual stresses play a crucial role in the performance of welded joints. Future studies can explore the effect of different post-weld heat treatments on residual stress distribution in dissimilar welded joints. This can involve using techniques like X-ray diffraction, neutron diffraction, or finite element analysis to quantify and compare residual stresses in treated and untreated joints.
- Numerical modeling and simulation: Computational modeling and simulation techniques can complement experimental investigations by providing a deeper understanding of the underlying mechanisms involved in the effect of post-weld heat

treatments on dissimilar welded joints. Numerical simulations can help predict the microstructural and mechanical changes induced by heat treatments, facilitating the optimization of treatment parameters.

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