INVESTIGATION OF MECHANICAL PROPERTIES OF TIG AND MIG WELDED JOINTS OF LOW CARBON STEEL

2023
MASTER THESIS
MECHANICAL ENGINEERING

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Master Thesis

KARABUK
November 2023

I certify that in my opinion the thesis submitted by Waad Abdullah Taeeb TAEEB titled “INVESTIGATION OF MECHANICAL PROPERTIES OF TIG AND MIG WELDED JOINTS OF LOW CARBON STEEL” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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Waad Abdullah Taeeb TAEEB

ABSTRACT

M. Sc. Thesis

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Institute of Graduate Programs
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November 2023, 47 pages

This research focuses on the mechanical properties of welded joints of low carbon steel (type A285 Gr.C) with an 8mm thickness, employing two welding methods: TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas). After a series of tests and analyses, it was concluded that MIG welding exhibits superior properties than TIG welding, thanks to its automatic feeding speed. Hardness tests revealed a hierarchy in hardness values; the base metal has the highest value, followed by the heat-affected zone, and the fusion zone shows the lowest value. Tensile tests showed higher results for MIG welding than TIG welding; the ultimate tensile strength reached 492.4 MPa for MIG and 489.6 MPa for TIG. Furthermore, the bending tests demonstrated that MIG welding exhibited more excellent resistance than TIG welding, with resistance values of 10086.77N and 10007.87N, respectively. With these features, the MIG method is superior to the TIG method.

This research contributes to the advancement of engineering applications by offering insightful information about the mechanical behaviour of welded joints and useful recommendations for welding technique selection in industries utilising low-carbon steel assemblies.

Keywords : MIG, TIG, heat affected zone, fusion zone, bending strength, tensile strength, hardness.

Science Code : 91438

ÖZET

Yüksek Lisans Tezi

DÜŞÜK KARBONLU ÇELİKLERİN TIG VE MIG KAYNAKLI BİRLEŞTİRMELERİNİN MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

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Kasım 2023, 47 sayfa

Bu araştırma, iki kaynak yöntemi kullanılarak, 8 mm kalınlığında düşük karbonlu çelikten (A285 Gr.C tipi) kaynaklı bağlantıların mekanik özelliklerine odaklanmaktadır: TIG (Tungsten İnert Gaz) ve MIG (Metal İnert Gaz). Bir dizi test ve analiz sonrasında MIG kaynağının, otomatik besleme hızı sayesinde TIG kaynağına göre üstün özellikler sergilediği sonucuna varılmıştır. Sertlik testleri, sertlik değerleri arasında bir hiyerarşi olduğunu ortaya çıkarmış olup en yüksek değer ana metalde, ardından ısıdan etkilenen bölge, en düşük değer ise füzyon bölgesinde görülmüştür. Çekme testleri MIG kaynağı için TIG kaynağından daha yüksek sonuçlar göstermiş olup maksimum çekme mukavemeti MIG için 492,4 MPa'ya ve TIG için 489,6 MPa'ya ulaşmıştır. Ayrıca eğme testleri, MIG kaynağının sırasıyla 10086,77N ve 10007,87N değerleriyle TIG kaynağından daha iyi sonuçlar sergilediğini göstermiştir. Bu özellikleriyle MIG yönteminin TIG yöntemine göre daha üstün olduğu görülmektedir. Bu araştırma, kaynaklı bağlantıların mekanik davranışı hakkında aydınlatıcı bilgiler ve düşük karbonlu çelik aksamların kullanıldığı endüstrilerde kaynak tekniği seçimi için faydalı tavsiyeler sunarak mühendislik uygulamalarının ilerlemesine katkı sağlamaktadır.

Anahtar Kelimeler: MIG, TIG, ısıdan etkilenmiş bölge, ergime bölgesi, eğilme dayanımı, çekme dayanımı, sertlik

Bilim Kodu **:** 91438

ACKNOWLEDGMENT

Special thanks and respect to my supervisor, Assist. Prof. Dr. Bilal ÇOLAK, for all the help, support, and understanding he provided me throughout the study period.

I would also like to thank my parents, who sacrificed a lot for me, my dear brothers and sisters, and my dear wife for their continued support and encouragement. I would also like to thank my dear friend Kahelan Faisal Hamood Melhi Alhemyari for his support.

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ABBREVIATIONS

MIG	: Metal Inert Gas
TIG	: Tungsten Inert Gas
GMAW	: Gas Metal Arc Welding
HAZ	: Heat-Affected Zone
WFS	: Wire Feed Speed
FZ	: Fusion Zone
Amps	: Amperes
ASME	: American Society of Mechanical Engineers
SMAW	: Shielded Metal Arc Welding
V	: Voltage
Amp.	: Amperes
MPa	: Megapascal
ASTM	: American Society for Testing and Materials
HV	: Hardness Vickers
AISI	: American Iron and Steel Institute
WZ	: Welding Zone
BM	: Base Metal

PART 1

INTRODUCTION

Welding is a crucial part of today's industrial environment since it combines materials to create solid and reliable structures. Developed in the 1940s for use in WWII aircraft production, MIG welding employs a consumable wire electrode in conjunction with a shielding gas to rapidly connect metal. For this reason, it finds application in many manufacturing processes and even in vehicles. In the 1930s, TIG welding was developed to meet the demands of the aviation industry. It makes precise, high-quality welds using inert gases and an electrode made from tungsten that isn't meant to be consumed. This is ideal for the nuclear and aerospace sectors due to their rigorous requirements and usage of thin components. Although MIG welding offers speed and diversity, sectors prioritising precision and striving for outstanding weld outcomes select TIG welding instead. Although both technologies are vital in many sectors, MIG is typically preferred for its speed, while TIG is more popular for its accuracy and superior welding performance. [1,2].

There are many methods for joining low-carbon steel sheets. The most popular and flexible are fusible core and metal welding by arc [3]. Type A285 Gr.C. low-carbon steel TIG and MIG welded joints are the subject of this mechanical investigation. This study has the potential to shed light on the mechanical properties and structural soundness of welded connections. The usage of welded joints is widespread in the industrial sector. Because of its superior welding characteristics, low-carbon steel is the primary material under investigation here. This study aims to document the effects of TIG and MIG welding on the material's mechanical characteristics. The effect of various welding processes on the flexibility, strength, and integrity of welded joints is investigated in detail in this thesis. This research examines the details of TIG and MIG welding on low-carbon steel, especially type A285 Gr.C., by collecting and evaluating data on mechanical characteristics, durability, tensile force, bending behaviour, etc. These welded connections will have their mechanical properties studied in detail.

By providing suggestions for improving the performance and reliability of welded structures, our study contributes to engineering applications and deepens our understanding of welding processes overall [3]. The study's conclusions and suggestions on the choice, optimisation, and application of welding methods can be highly beneficial for industries that employ low-carbon steel assemblies.

PART 2

LITERATURE REVIEW

Açar investigated how different shielding gas combinations affect the mechanical and microstructural properties of AISI 316 austenitic stainless steel using MIG welding. Investigating the effects of shielding gas types on weld joints, including their macro and microstructures in both weld metal and the heat-affected zone, the review focuses explicitly on tensile, bending, and hardness tests as indicators of mechanical behaviour. The joints that were welded utilizing 100% Ar shielding gas had the best tensile strength, according to the study's findings. The welded samples' tensile strength dropped as H2 was added to the Ar gas at a higher concentration. Various studies conducted in 2021 offer insights into the correlations between protective gas types and the resultant structural and mechanical properties of welded stainless steel [5]

Arora et al. conducted circumferential weld joint welding simulations with the TIG method at various positions. High distortion and residual stress were caused by the high temperature generated in TIG welding joints and at inclined positions. They used Finite Element Methodology's welding simulation to design a good welding joint in regulated residual stress and deformation. TIG-welded SS304 grade material was used in the experiments, and the MSC marc program was used in conjunction with Finite Element Analysis (FEM) to forecast temperature, residual stresses, and distortion with different cylinder, voltage, and pressure [7]

Asibeluo and Emifoniye stated that the influence of temperature as a function of current on the mechanical characteristics of an A36 carbon steel welded joint employing shielded metal arc welding is the main topic of this research project (SMAW) [8]. Given that A36 steel melts at a temperature of around 1426–1470°C, a welding current range of 70A–120A was selected to provide a range of heat input. Hardness, impact, and microstructure tests determined the welded joint's mechanical parameters. The cooling cycle was primarily responsible for controlling the welded microstructure. Less time was needed for solidification at 70A or low current. Littler grains are encouraged by the quick cooling. At 120A, the time required for solidification increases; therefore, the cooling rate slows down, yielding coarse grains. The coarsest grain size was measured at 120A, where the toughness and hardness values were 11 Joules and 60BH, respectively, suggesting decreased toughness and strength.

Meng et al. used mild steel plates of 300×50×2.5mm and 300×50×2.0mm in dimension as the base metals for bead-on-plate welding and butt welding, respectively. The welding wire was ER50-6 with a diameter of 1.2mm for mild steel. The shielding gas was pure argon gas with 9.5 L/min flux for the TIG torch and a mixed gas of 87%Ar-13%CO2 with 19 L/min flux for the MAG torch, respectively. A TIG-MAG hybrid arc welding process was proposed to achieve high-speed welding [9]. The influences of hybrid arc welding parameters on welding speed and weld appearance were studied through orthogonal experiments, and the microstructures and mechanical properties of the weld were tested and compared with those of the conventional MAG weld. The TIG-MAG hybrid arc welding speed could reach up to 3.5 m/min for bead-on-plate welding of 2.5 mm thick mild steel plate under the condition of high-quality weld appearance and 4.5 m/min for butt welding of 2 mm thick mild steel plate, respectively. The mechanical properties of the hybrid arc weld were not lower than those of the conventional MAG weld. The stable hybridisation obtained by balancing TIG and MAG welding currents and proper wire-electrode distance was critical in stabilising the welding process. This study revealed that TIG-MAG hybrid welding produced welded connections with higher tensile strength, micro-hardness, and a smaller HAZ when compared to standard MAG welding [9].

Chen et al. developed separate adaptive mathematical heat source models for the TIG and MIG welding processes. The results show that these modifications could reflect the heat flux distribution on the workpiece with varied torch angles. It shows that more and more heat energy is deposited in the front of the weld pool to pre-heat adjacent areas with decreasing temperatures, and the peak temperature of the thermal cycle is reduced together. The TIG-MIG hybrid welding process is calculated and discussed based on the above models without considering the interaction of two arcs. Moreover, because of the tailing arc, the length of the high-temperature zone in the weld pool extends compared to a single MIG. It also shows the excellent potential of TIG-MIG hybrid welding in high-speed welding due to the force effect of the tailing arc on the weld pool. The following research should be focused on the influence of attractive or repulsive forces between two arcs, which will change the force and heat distribution of arcs on the workpiece. The fluid flow in the weld pool should also be considered, as it is an essential factor influencing the heat and mass transfer mechanisms. The results of the experiment indicate that little penetration and distortion of the weld bead occurs at welding speeds of 0.3 m/min, 125 A welding current, and 13.5 V arc voltage. Additionally, it demonstrates that when the HAZ area decreases, the peak temperature drops. The reduction in peak temperature is caused by the fact that as the welding torch angle goes from 90° to 60°, less heat will be transmitted to the weld pool boundary, resulting in a fall in maximum energy density [10].

Kumar et al. examined the strength of the joint and the product's lifespan, which are significantly impacted by the joining processes used and how they affect the metallurgical qualities of the metal. The three types of welding techniques—arc, metal, and tungsten inert gas (TIG)—are used in AISI 1024 in the current project. Destructive procedures are used to test how these three treatments affect the steel alloy series. Evaluations include the microstructure, hardness, and tensile strength at the base plate, HEZ, and joints. The base plate's ultimate tensile strength of 906 MPa was found to be relatively higher than that of the other specimens. Of the weld specimens, the TIG specimen had the highest tensile strength of 765.721 MPa, while the MIG specimen had the lowest strength of 496.820 MPa. The Arc weld specimen had the most insufficient strength of 337.120 MPa, which may have been caused by the heat treatment applied after the weld [11].

Kumar et al. examined how various welding methods affect the mechanical characteristics and microstructure of the welds. In contrast to arc and tungsten inert gas (TIG) welding, the weld zone (WZ) in metal inert gas (MIG) welding has a more significant martensite proportion. In comparison to arc welding (190 ± 12 HV), TIG welding (142 ± 10 HV), friction stir welding (FSW) (202 ± 10 HV), and base metal

(BM) (108 ± 14 HV), the micro-hardness of the WZ was found to be greatest following MIG welding (220 ± 14 HV). Comparing the joints made with MIG welding to those made with arc and FSW, the former showed a greater tensile strength (371 ± 10 MPa). The parent metal's ductility was 42 ± 2%, but the presence of martensite during fusion welding resulted in decreased ductility for the MIG and arc joints, at 13 ± 2% and 17 ± 3%, respectively. Because the WZ contains refined, equiaxed recrystallised grains, the FSW joint exhibits greater yield and tensile strengths (356 ± 8 MPa) and higher elongation (22 ± 4%) than fusion-welded joints. The contact between the base metal and the HAZ has a lower hardness than the WZ, where the fracture occurs. After fusion and FSW, the WZ contains compressive and tensile residual stress, respectively. This research calculates the direction of preceding austenite (γ) in the MIG weld join using analytical techniques. The texture of the high temperature γ phase is simulated for the various welding procedures. The martensite also grains from the MIG weld, including the orientation relationship (OR) of the Kurdjumov-Sachs (Ksingle bondS). Researchers found evidence of ferrite's texture memory effect in the heat-affected zone (HAZ) after MIG welding. This research calculates the direction of preceding austenite (γ) in the MIG weld join using analytical techniques. The texture of the high temperature γ phase is simulated for the various welding procedures. The martensite also grains from the MIG weld, including the orientation relationship (OR) of the Kurdjumov-Sachs (Ksingle bondS). Researchers found evidence of ferrite's texture memory effect in the heat-affected zone (HAZ) after MIG welding [12].

In their study, Cui et al. combined the advantages of TIG welding with those of metal inert gas (MIG) to create an alternative welding process called TIG-MIG. Combining the two welding methods is wise as it will increase productivity and quality. To better understand how the arc interacts with the particle and the weld pool in TIG-MIG hybrid welding, a detailed transient model was developed to represent their behaviour. In the weld reservoir and arc space, we analysed and reproduced factors, including electromagnetic force, temperature field, quantity of metal vapour, flow fluid, and current density. Researchers found that when using a TIG arc, arc temperature increased, and metal vapour content decreased. The advantages of hybrid TIG-MIG welding over single-MIG welding are smaller upper arc temperatures and larger plasma velocity levels. Outcomes for the weld bead cross-section, droplet deflection angle, arc temperature change, and droplet transfer speed agreed with the experiments' findings. The results of the calculations demonstrated that adding the TIG arc raised the arc temperature and reduced the amount of metal vapor. The maximum arc temperature and plasma velocity amplitudes in TIG-MIG hybrid welding were less than in single-MIG welding.

Hybrid TIG-MIG welding, created by Han et al., blends the best features of both metal inert gas welding and TIG welding. It is capable of producing exceptional weld joints in a timely manner, meeting the demands of contemporary industry. For TIG-MIG hybrid welding, electromagnetic theory, fluid dynamics, and heat transfer were used to build a transient model of how the arc and droplets interact [13].

Hybrid TIG-MIG welding, created by Han et al., blends the best features of metal-inert gas welding and TIG welding. It is capable of producing exceptional weld joints in a timely manner, meeting the demands of contemporary industry. For TIG-MIG hybrid welding, electromagnetic theory, fluid dynamics, and heat transfer were used to build a transient model of how the arc and droplets interact. The study examined the arc space's temperature field, flow field, electromagnetic force, pressure, and current density characteristics. The study compared and analysed single-TIG and MIG-MIG hybrid arc-droplet interactions, as well as heat and force distributions on the workpiece, using numerical simulation and experimental methods to explore and clarify TIG-MIG hybrid arc-droplet interaction mechanisms and the effect of the arc-droplet on the workpiece. The findings demonstrate that introducing TIG welding significantly affects MIG welding [14].

Owunna et al. studied the TIG based on welding current, voltage, gas flow rate L/min, and temperature, an experimental design matrix with thirteen (13) centre points, six (6) axial points, and eight (8) factorial points—resulting in twenty (20) experimental runs—was created based on the Design of Experiment (DOE). The FEM simulation produced a maximum bead penetration of 8.44 mm with corresponding input variables of 190 A, 19 V, 18 L/min, and 298.44 oC. In contrast, the welding experiment produced a maximum bead penetration of 7.942 mm with corresponding input variables of 155 A, 22 V, 15.50 L/min, and 278.46 oC [15]. Compared to traditional gas tungsten arc welding (GTAW), the testing findings showed that cusp-type magnetic field (CMF) aided gas tungsten arc welding (GTAW) produces joints with superior mechanical and metallurgical qualities. The penetration depth was enhanced by 13%, and the breadth of the weld beads was reduced by 4% on average in cusp-type magnetic field (CMF) aided welds. When the cusp-type magnetic field (CMF) was present, the workpiece's temperature sensor revealed a significant drop in temperature for the same amount of heat input. Compared to traditional gas tungsten arc welding (GTAW), hardness was noticeable due to 12% and 15% better grain refinement in the heat-affected zone (HAZ) at the fusion border and base metal, respectively. It was found that, for the welding runs conducted in this investigation, there was no significant difference in the bead penetration variation between the experimentally achieved weld bead penetration and the finite element projected bead penetration [15].

Durgaprasad is in charge of the organisation. Gas tungsten arc welding (GTAW) on low-carbon steel is investigated in this research by using a magnetic field. The cusp-type magnetic field (CMF) was created by carefully positioning rectangular samarium cobalt permanent magnets. There was an external magnetism field involved. To thoroughly examine the effects of cusp-type fields of magnetism (CMFs) on the microstructure and morphology of the weld joints, we employed optical microscopes, field-emission scanning electron microscopy, and X-ray diffraction. Using gas-tungsten arc welding (GTAW) with a cusp-type magnetic field (CMF) assists in producing joints with superior mechanical and structural properties compared to typical GTAW, according to the test results. A 13% increase in penetration depth and a 4% decrease in weld bead width were the typical outcomes of welds helped by cusp-type magnetic fields (CMFs). Compared to traditional GTAW, there was a noticeable increase in hardness due to 12% and 15% better grain refinement in the heat-affected zone (HAZ) at the fusion border and base metal, respectively [16].

PART 3

THEORETICAL BACKGROUND

Bridge construction and gasoline tank production are only two of the many corporate welding operations that rely on steel made from carbon. Multiple forms of stress, including tensile, compressive, bending, and fatigue, are experienced by these applications. Many elements affect the weld's stress resistance, such as the weld joint's shape and design, welding procedure, welding direction, and metallurgical properties of the base metal. These metallurgical properties encompass the material's microstructure and corrosion resistance [1].

Using a carbon electrode, a Frenchman named August.D. Merntz first put the concept of arc welding into practice in 1881 AD. Carbon has high heat resistance, but the welding electrode's high carbon diffusion in the welding joint makes welding more difficult. Electric arc welding was invented using a carbon electrode by a scientist (Bernard's) in 1886 AD. This invention was used in Europe to repair steam boilers by electric arc welding. Still, the carbon electrode during welding results in a welding line with a high percentage of carbon, which leads to the breaking of the welding line. Then, continued experiments by scientists on a metal electrode, and the Russian scientist (Kofen) succeeded in 1889 AD in inventing a metal electrode instead of the carbon electrode. Its uses were limited until the First World War began, and the demand for welding increased to repair military equipment [17, 18].

In 1895 AD, a metal electrode not covered with smelting aid (flux) began, which did not guarantee a high quality of welding, but it eliminated the increase in carbon in the welded joint. In 1905 AD, metal electrodes covered with asbestos powder began, improving the quality of the welding process. Since then, there has been a significant development in the quality of the powders as the welding process developed and the manual electric arc welding process started. Then, the automatic implementation of electric welding was invented[19].

3.1. ARC WELDING PROCESS

About (90%) of all smelting welding processes are used, making it one of the most used welding techniques. In this method, electrical energy is converted into thermal energy, which is used in the local melting of the ends of the welding joint[20].

Electric arc welding includes a group of welding methods in which the fusion occurs by heating through an electric discharge (arc) between the electrode and the base metal. The welding process can be carried out without using a welding electrode or a welding electrode, depending on the thickness of the welded metal and the gap between the parts to be welded[21].

Although the electric arc with metal electrodes (tungsten or metal not covered with flux) is the most common type of electric arc welding, there are situations where the electric arc generated between the carbon electrode and the welded material is preferable. It is non-consumable since its only purpose is to produce the heat required to melt the filler metal at both ends of the welding connection[22].

When compared to other electrodes, the carbon electrode is exceptionally inexpensive. Because the carbon electrode operates at a higher temperature and emits a light (white glow) that might harm the handle, unique handles that are cooled by air flowing around the nozzle of the handle are required for use with the carbon electrode. In continuous welding procedures, water is sometimes utilised for cooling, with the welders protecting themselves from heat using a shield[23].

3.1.1. Parameters of Welding [32]

Many parameters are used in welding processes, including:

3.1.1.1. Welding Current

The most critical factor in the arc welding process that affects the electrode bum off-rate, fusion depth, and weldment shape is the welding current; when welding thick metals, a high current can be used since the current offers depth of penetration. The proper selection of current is essential for welding since an excessively high current might burn the metal, while an excessively low current causes insufficient penetration.[32]

3.1.1.2. Welding Speed

TIG is a manual process that involves moving the filler metal and welding torch while isolating the welding zone from polluting air. The welder's skill determines the welding speed.

MIG welding’s speed can be adjusted by using the reel within the bag of the machine. An increase in welding speed leads to a decrease in heat input. Heat input was effective in decreasing the grain size of the fusion zone (FZ) and the heat-affected zone (HAZ), but it had no effect on the grain size of the base metal.

3.1.1.3. Shielded Gas

Welding gases prevent atmospheric oxidation during welding. It helps arc ignition. Protection gas significantly affects welding penetration. It isolates the electric arc created when an electric current flows through a non-consumed electrode like tungsten. Argon gas weighs 1.4 times air and ten times helium. This permits argon gas to isolate the welding pool (molten pool), monitor the electric arc, and manage the welding pool. Argon gas ignites the turn easier than helium.

The efficiency of the welding process is thus determined by the use of shielding gas.

3.1.1.4. Welding Angle

The welding angle is the area between the two welding joints, and it can be in the form of a letter (V) or the shape of the letter (U). There is no need to prepare the welding joint's edges if the metal's thickness is (3.2) mm or less. Also, it is possible to take advantage of the welding joint of the type Butt joint and lap joint, as well as of the corner joint type in welding processes.

3.1.1.5. Weld Joints

The failure of welded joints is caused by several elements, not only the welding procedure; hence, any welded design must consider these issues. The welding process also causes changes in mechanical, metallurgical, and metallic characteristics, which requires standard conditions to eliminate them[33].

Overlap, butt, and corner welding joints are used in engineering. The square butt joint is preferred for thin sheets in stainless steel welding. To achieve total weld permeability, thick joints (5-13 mm) must be prepared to fill with filler metal.

3.1.2. CONDITIONS FOR WELDING[34]

3.1.2.1. Source of Energy

Energy is supplied in heat by a flame, electrical arc, radiant energy, or prepared mechanically in the form of (friction, ultrasonic waves, vibration, or explosion, as in solid-state welding). In limited welding operations, pressure transforms the weld area from elasticity to plasticity. In the case of fusion welding, the metal part to be welded will melt from the region exposed to the electrode.

3.1.2.2. Protection From Surface Contamination

The presence of surface contamination on the surface of the part to be welded can be in the form of harmful organic substances or gases absorbed from the air or the base metal; usually, these compounds are oxides. When the heat is supplied from the power source, it will effectively remove the organic compounds, and this heat will remove the substances that can evaporate and are located on the surface of the base metal; only the oxide layer remains, which is still drawn by heat and must be removed by other methods. The presence of surface contamination on the surface of the welded part can be in the form of harmful organic substances or gases absorbed from the air. When the heat is supplied from the power source, it will effectively remove the organic compounds, which will remove the substances that can evaporate located on the base metal's surface.

3.1.2.3. Protection from Atmospheric Contamination

The shielding gases such as argon and helium protect the welding pool from atmospheric pollution, especially the oxygen and nitrogen in the air.

3.1.3. THE ZONES OF WELDING JOINT

The welding joint consists of three parts, as shown in Figure 3.3.[35]:

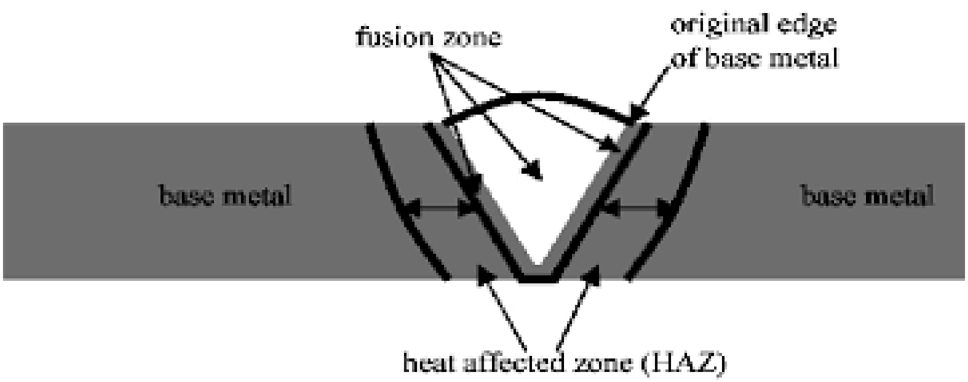


Figure 3.1. The zones of a welding joint.

3.1.3.1. Base Metal

It is the metal or alloy on which the welding process is intended, such as ferrous alloys (low, medium, and high carbon steels), stainless steel, cast iron, and nonferrous alloys such as copper and aluminium alloys, and this is the part where it does not effect by the heat of welding.

3.1.3.2. Heat Affected Zone (HAZ)

It is the part of the base metal that did not melt during the welding process. Still, this part's microstructure, mechanical, and metallurgical properties were changed due to the welding process's heat. The changes that occur in this area can be studied by mechanical and metallurgical testing.

3.1.3.3. Fusion Zone

It is the area in which the welding process occurs and is confined between the two edges of the parts to be welded. Welding needs the flux, a layer covering the welding electrode. The protection of the welding zone, which includes the heat-affected zone (HAZ) and fusion zone (FZ), from the pollution of gases in the air by forming slag (oxide layer + organic materials) above the welding zone. This layer is removed by cleaning operations later.

3.1.4. Tungsten Inert Gas Welding (TIG)

In this method, an electric arc is generated between the tungsten electrode and the material, and this arc heat is used for the welding. The tungsten metal does not melt with the arc’s heat. When necessary, filler metal is added to the fusion zone, similar to oxyacetylene welding. Figure (3-1) represents a simplified idea of the tungsten electrode welding method using an inert gas (argon or helium) to protect the welding zone [24].

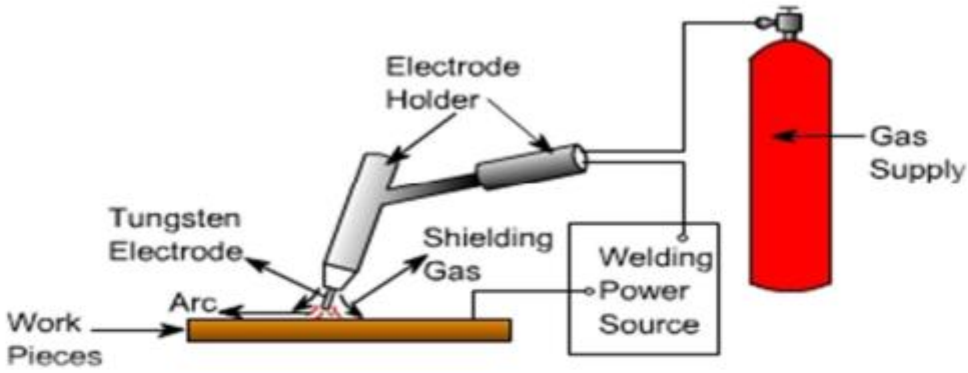


Figure 3.2. Representation of the TIG welding process [6].

3.1.4.1. Equipment of TIG

- Power Supply Unit: DC or AC sources are used in the TIG welding method. These sources must be characterised by the ability to control the amount of current used, especially at low values, to maintain a stable arc in thin plate welding. It is preferable to use reverse polarity to provide high deposition, good metal cleaning, and electric arc stability [25].
- The Voltage Intense: The voltage intense is the voltage that exists between the workpiece and the electrode during welding. The arc length determines the response for a particular electrode. If the arc voltage variation and, consequently, the arc length, are kept constant, the welding will be quite smooth. Arc lengths shouldn't, in general, exceed electrode diameters [26].
- Welding Torch: In gas tungsten arc welding (GTAW), two types of welding torches are used: the air-cooled welding torch and the water-cooled welding torch[27].
  - Air-cooled welding torch
  - Some of these types of torches are used for less than 50 amps. The bigger ones are used for general purposes, with a current that may reach 150 amps. The air-cooled welding torches contain nozzles with a diameter of about 6.5 mm for gas injection made of ceramic [28].
- Water-cooled welding torch: This type of torch can be used up to 1000 Amps. The water pipes in the water-cooled torch are controlled by a valve installed inside the machine. Also, these torches are manufactured in varied sizes

depending on the maximum value of the current used. The welding gun contains a set of rubber tubes that connect to the welding gun as a gas supply **tube, water supply tube, and return water tube beside the electric cable.**

- **Tungsten Electrodes:** The electric arc is generated between the tungsten electrode which does not melt and does not enter the welding pool and the workpiece.

Tungsten is one of the metals with a high melting point (3410 °C), low electrical resistance and good thermal conductivity, as well as ease of electronic emission. Electrodes are available in different diameters ranging from 1.5-4.5 mm and are made of pure tungsten or its alloy containing 1-2% thorium or exceedingly tiny amounts of zirconium. These added elements help the electrode to withstand high current and have good electronic emission, keep the nozzle cool, and reduce the movement of the arc around the electrode tip, but do not facilitate the integration of its elements into the welding joint [29].

3.1.4.2. Advantages of the TIG [30]

- It produces superior-quality welds with deficient levels of diffusible hydrogen, so there is less danger of cold cracking.
- It does not give weld spatter or slag inclusions, which makes it particularly suitable for applications that require a high degree of cleanliness (e.g., pipework for the food and drinks industry, semiconductor manufacturing, etc.).
- It can be used with filler metal and on thin sections without filler, producing welds at relatively high speed.
- It enables welding variables to be accurately controlled and is particularly good for controlling weld root penetration in all welding positions.
- It can weld almost all weldable metals, including dissimilar joints, but is not generally used for those with low melting points, such as lead and tin. The method is especially useful in welding reactive metals with stable oxides such as aluminium, magnesium, titanium, and zirconium.
- The heat source and filler metal additions are controlled independently; thus, it is perfect for joining thin base metals.

3.1.4.3. Disadvantages of the TIG [30]

- It gives low deposition rates compared with other arc welding processes.
- More agility and welder coordination are needed than MIG/MAG welding.
- It is less economical than MMA or MIG/MAG for sections thicker than ~10mm.
- It isn't easy to fully shield the weld zone in draughty conditions, so it may not be suitable for site/field welding.
- Tungsten inclusions can occur if the electrode is allowed to contact the weld pool.
- The process has no cleaning action and a low filler or base metal contaminants tolerance.

3.1.5. Metal Inert Gas Welding (MIG)

The metal is melted with an arc between the welding electrode attached to the welding gun and the part in the fusion zone. In 1920, MIG welding tests failed due to irregularity in welding wire speed, but in 1950, gas welding worked [31]. As in the TIG method, in the MIG method, an inert gas such as argon or helium is used to isolate the welding pool from the atmosphere.

This technique works on thin and thick sheets of steel, aluminium, magnesium, copper, and other metal sheets. This method can also be used for rapid welding of ferrous and non-ferrous metals. Figure 3-2 shows metal arc welding using shielding gas.

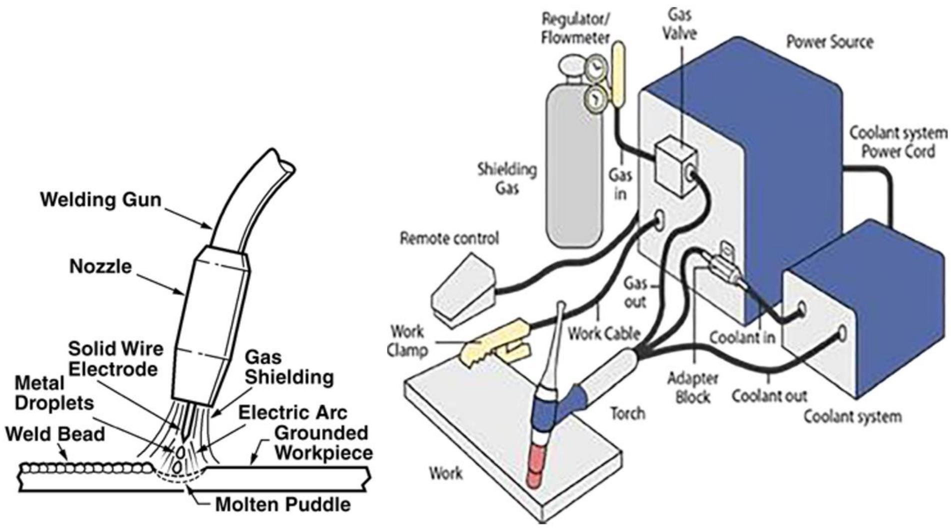


Figure 3.3. A simplified drawing of MIG welding.

3.1.5.1. Main Equipment of MIG

- Power Source: The primary objective of the power source is to furnish the system with appropriate electrical power. Moreover, the performance of the power source plays a crucial role in the welding process, influencing factors such as arc ignition, the stability of molten electrode material transfer, and the generation of spatter. This will optimise the static and dynamic characteristics of the power source. It is essential to enhance its suitability for the specific welding procedure [4].
- Wire Feed: Ensuring rapid start and stop of wire feed and maintaining a consistent wire feed speed is essential for high-quality welding. Any alterations in the hose's curvature, which contains the wire inside, can adversely affect the stability of the wire feed speed. It is imperative to avoid significant variations in wire speed to prevent unwanted fluctuations in welding data [4].
- Welding Machine Accessories: This group depends on the type of equipment used and includes a cable for the current used to perform the welding process and a control cable to connect the switch of the welding torch gun with the control unit [4].
- Welding Gun or Torch: The gun operations are feeding wire, transmitting welding current, and shielding gas. It has several types:

A- Light-duty gun with a power of 200 Amps.
B- Heavy-duty guns have a maximum power of 400-500 Amps; a cooling unit must be used if it is more than 500 Amps.
C- The welding gun with a wire coil at the bottom.

3.1.5.2. Advantages of the MIG

- Continuous wire feed.
- Automatic self-regulation of the arc length.
- High deposition rate and the minimal number of stop/start locations.
- High consumable efficiency.
- Heat inputs in the range 0.1-2.0kJ/mm.
- Low hydrogen potential process.
- Welder has good visibility of the weld pool and joint line.
- Little or no post-weld cleaning.
- Can be used in all positions (dip transfer).
- Good process control possibilities.
- Wide range of applications.

3.1.5.3. Disadvantages of the MIG

- No independent control of filler addition.
- Difficult to set up optimum parameters to minimise spatter levels.
- Risk of lack of fusion when using dip transfer on thicker weldments.
- High level of equipment maintenance.
- Higher equipment cost than MMA (manual metal arc) welding.
- Site welding requires special precautions to exclude draughts that may disturb the gas shield.
- Joint and part access is less than MMA or TIG welding.
- Cleanliness of base metal slag processes can tolerate more significant contamination.

3.2. THE AIM OF THE RESEARCH

The aims of the current work are to:

- Examination of mechanical properties (strength, hardness, and bending resistance) of TIG and MIG welded samples made of low-carbon steel.
- Investigating the fracture behaviour and flexibility of the welded samples under tensile and bending loading and how it varies between TIG and MIG welding processes
- Providing valuable insights and practical guidance for selecting, optimising, and applying welding techniques in industries relying on assemblies of low-carbon steel.

PART 4

EXPERIMENTAL WORK

This chapter includes the details of the experimental procedures used in this research. This work aims to reveal the mechanical properties of TIG and MIG-welded joints made of low-carbon steel (A 285 Gr.C). The weldings were conducted at the Petroleum Training Institute in Baiji, Iraq.

4.1. THE EQUIPMENT USED

All the equipment that has been used in our work are as follows.

- American welding machines were used for MIG welding (Fig.4.2) and TIG welding (Fig.4.3).

Figure 4.1. Welding machine (MIG/MAG).

Figure 4.2. Welding machine (TIG).

- The welded samples were cut by a COOFIX Chinese-brand electric cutting machine.
- The welded samples were smoothed and polished with a French-type (Mecapol P200 Controlab) electric smoothing and polishing device at various stages, using correction papers and polishing cloth with alumina solution in distilled water consisting of multi-dimensional granules.
- The dimensions of the plates were measured by a Japanese-brand (Fowler) digital vernier calliper.

4.2. THE MATERIAL USED

Sheet metal made of 8 mm-thick low-carbon steel, grade A-285M Gr.C, was utilised. This grade has many uses, including bridge structures, fuel tanks, and steam boilers. The standard chemical composition of the used metal in welding according to the American classification (AWS) is shown in the first row of Table (4.1). According to the spectroscopy test done at the Specialized Institute for Engineering Industries in Iraq, the chemical composition of the used alloy is shown in the second row of Table (4.1).

Table 4.1. Chemical composition of the used alloy (A-285M Gr. C).

Element	C%	Cu%	V %	Mn%	P%	S%	Si%
Standard Alloy	0.17 max	0.02 min	0.005	0.9 max	0.025 max	0.025 max	0.40 max
material used	0.132	0.154	0.033	0.842	0.002	0.013	0.051

Table 4.2. Chemical composition and strength of the welding wire (ER 70 S-6).

Element	Wt.%
C	0.07-0.15
Si	0.80-1.20
Mn	1.4
Mo	0.02
Cr	0.04
Cu	0.29
P	0.011
NI	0.13
Tensile Strength (MPa)	498

4.3. WELDING AND TESTS OF THE SAMPLES

The MIG welding process was performed as a direct current reversed polarity (DCRP) welding method, and a welding wire of type ER 70 S-6 (SG2) with a diameter of 1.2 mm was used. The TIG welding process was also carried out on a sample. The diameter of the tungsten electrode is 2.4 mm, and the electrode alloy is EWTH-2. Many types of gases are mixed for specific situations or atmospheres. Pure argon was preferred as a shield gas because it is the best gas in stable atmospheres [36]. Other welding parameters are in Table 4.3.

Table 4.3. Welding Parameters.

Welding type	I (Amp)	V (V)	Type of shielding gas	Shielding gas flow rate (L/min)
TIG	**150**	**20**	**Argon**	**12**
MIG	**180**	**25**	**Argon**	**10**

The samples were securely attached to a table by their edges so there would be no distortion due to cooling after welding, as shown in Figure 4.4.

Figure 4.3. Fixing the sample on the welding table.

After welding the samples, dye penetrant tests were conducted to detect surface flaws such as cracks, porosity, laps, seams, and other surface-breaking defects in the samples. This NDT method is an essential technique used in various industries to ensure the integrity of materials and components without damaging them. The dye penetrant test (PT) consists of three spray bottles. The first step of this test is cleaning the sample's surface using one of the cleaner spray bottles. The next step is to use the spray bottle of paint (penetrant) and leave it for five minutes. Utilising the third spray bottle, commonly called the developer, necessitates prior cleaning of the sample surface with a piece of cloth. This step is integral in removing the applied paint from the sample, ensuring a clear and unobstructed examination, as shown in Figure 4.5. The dye penetrant testing showed that the welded samples were free of defects. Then, the samples were cut with a metal cutting device and examined.

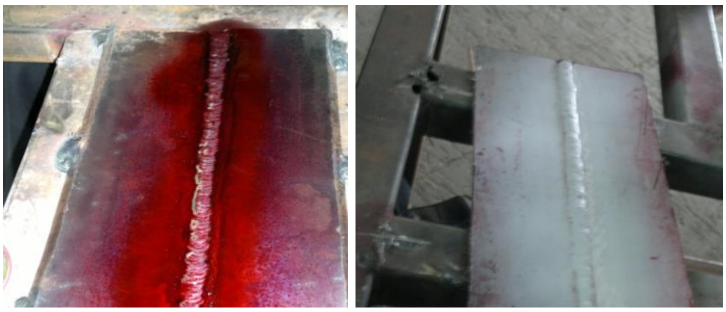


Figure 4.4. The method of Dye penetrant test (PT).

4.4. HARDNESS MEASUREMENTS

The microhardness of the samples was measured in g/cm2 units with the Metkon brand Vickers hardness measuring device (Figure 4.7). The device contains a pyramidal diamond stitching tool at an angle 136° between the two opposite sides, with a load from 25g to 1000g. It contains a camera and a computer through which the microstructure can be observed and photographed, as a constant load of 500g for 5 seconds for all samples. Then, it was lifted automatically, and the dimensions of the resulting impact were measured on the sample's surface in the two axes in opposite directions to conduct a hardness test in three areas where we took many points. The average of these three measurements was calculated for the welding zone, the heat-affected zone (HAZ), and the base metal.

Figure 4.5. Vickers hardness device.

4.5. TENSILE TEST

This study applied tensile tests with a load of 100 kN to the samples to see the mechanical properties such as ultimate tensile strength, yield strength, and elongation. These samples were machined according to ASTM A370 specifications before the tests. The stress-strain diagram was displayed on the computer screen, as shown in the figures (5.4 and 5.6) in the results and discussion part, and the relevant data were computed.

Figure 4.8 shows the tensile-tested samples. The tests were carried out with the MTS (100kN Servo hydraulic dynamic test device) brand device at KBÜ Margem Laboratories, shown in (Figure 4.9).

Figure 4.6. The samples after tensile test.

Figure 4.7. MTS device.

4.6. BENDING TEST

To perform the bending tests, a Zwick/Roell Z600 brand device with a maximum load of 600kN was used at KBÜ Margem Laboratories (Figure 4-11). While performing the bending test, the prepared samples are exposed to pressure at three points: two fixed points at the bottom of the sample and the third being the pressure point applied to the sample. This test determines the material's ductility, bending strength, and fracture strength according to the applied pressure until it reaches 90°. As the material bent, the maximum force was measured using a computer connected to the device.

Figure 4.10. shows the state of the samples machined according to ASTM A370 specifications after the bending test.

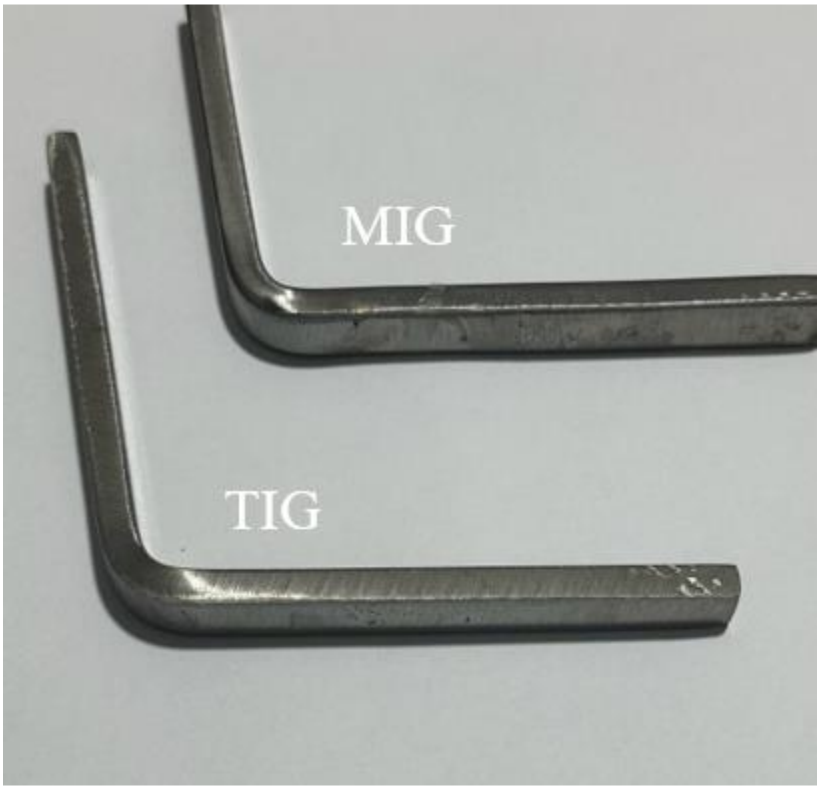


Figure 4.8. Samples after bending test.

Figure 4.9. Zwıck/Roell Z600 bending device

PART 5

RESULTS AND DISCUSSION

This chapter investigates the mechanical properties of the two welding methods, TIG and MIG, applied on low carbon steel type A285 Gr.C.

5.1. RESULTS OF THE HARDNESS MEASUREMENTS

The hardness assessment was conducted on the welded joints produced by TIG and MIG welding techniques on low-carbon steel type A285 Gr.C. The Vickers hardness (HV) measurements were taken at various points along the welded joints to evaluate the hardness distribution, as shown in Figure 5.1.

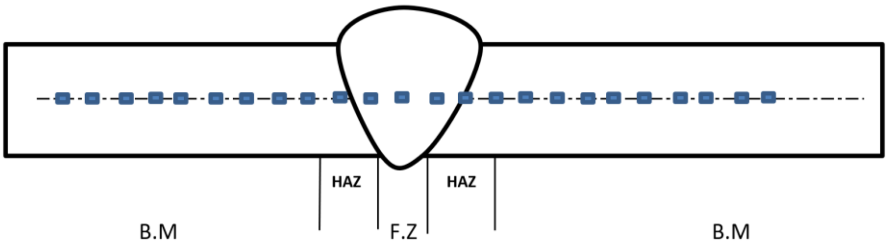


Figure 5.1. Taken points of TIG and MIG welded samples.

5.1.1. TIG

The TIG welding sample had hardness Vickers (HV) values that varied between 104 and 174 HV. The base metal (B.M) surface had the maximum Vickers hardness (174 HV), while the fusion zone (F.Z) surface had the lowest (104 HV). These results indicate a broader range of hardness values in the TIG weld, suggesting potential microstructural differences and mechanical property variations in distinct joint zones, as shown in Figure 5.2. (A) and the average of the three samples is shown in Figure 5.2. (B).

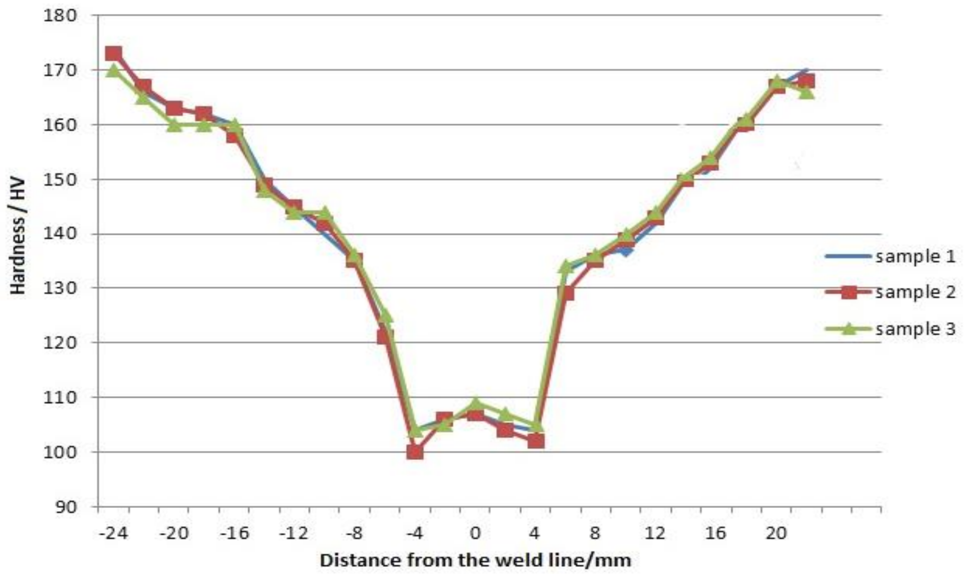
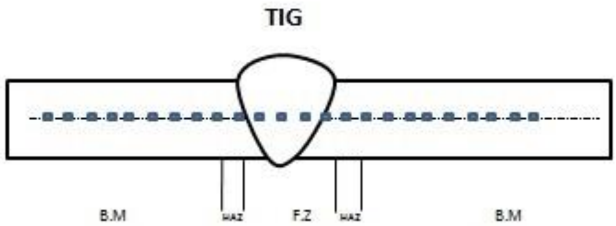


Figure 5.2. (A) The three samples of microhardness value for different points for TIG welding.



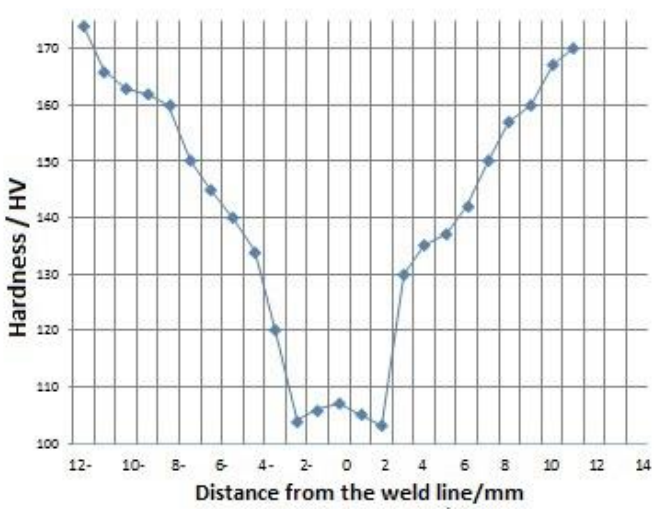


Figure 5.3. (B) The average of microhardness value for different points for TIG welding.

The results of the hardness test for TIG welding show a clear pattern in the various zones where the welding process has an impact. First, for the base metal, the maximum hardness point of 174 signifies the strong deformation resistance that the unaltered material possesses. Well-processed base metals with an organized microstructure and ideal mechanical qualities are predicted to have this degree of hardness. But there is a discernible drop in hardness as we approach the heat-affected zone (HAZ). The lowest point in the base metal (104 in the HAZ) indicates how the welding procedure affected the material. During welding, the HAZ has notable temperature variations but does not completely melt. In comparison to the unaltered base metal, this causes modifications to the microstructure, such as phase transitions or grain development, which lowers the hardness. As we enter the welding zone, we see that the hardness rating is at its lowest, 100 HV. The extreme heat produced during welding is responsible for this decline in hardness because it causes the material in this zone to melt completely and then solidify quickly. Lower hardness levels are the outcome of a less organized and softer microstructure formed by the cooling rates connected with welding.

5.1.2. MIG

The hardness Vickers (HV) values ranged from 93 to 173 HV in different regions of the MIG welding sample. The highest recorded hardness Vickers (HV) measurement was in a base metal (BM), 173 HV, while the lowest was in a fusion zone (FZ), 93 HV. According to Figure 5.3(A), these results of the three samples reveal that the MIG weld exhibits a wide range of hardness, which suggests that the structural integrity and material qualities vary at different places. The average of the three samples is shown in Figure 5.3. (B).

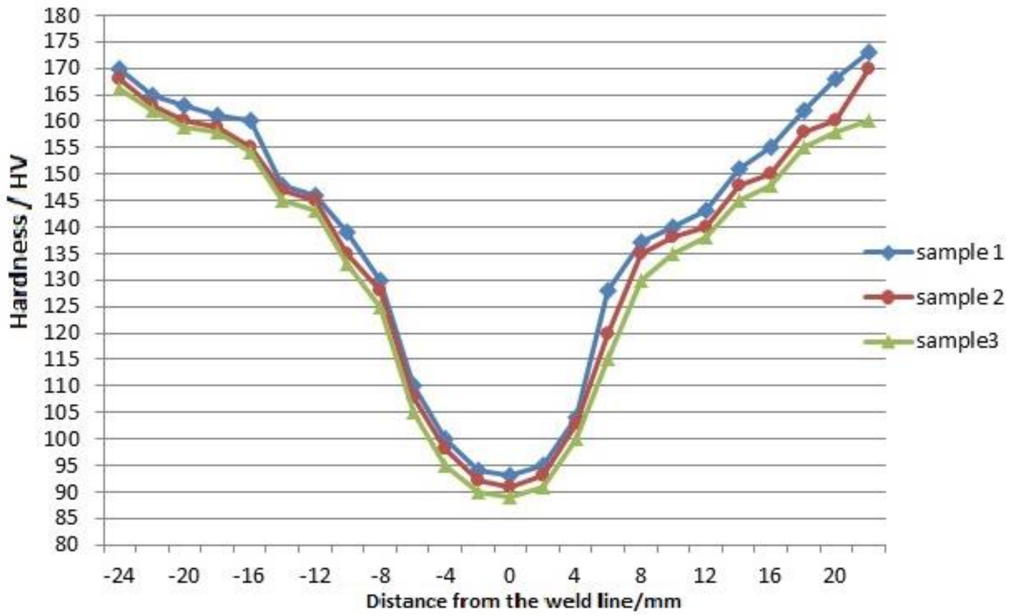
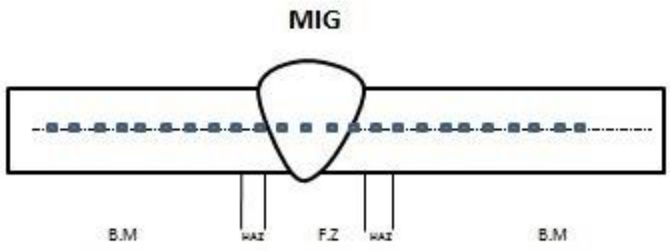


Figure 5.4. (A) Microhardness values of three samples over many MIG welding locations.



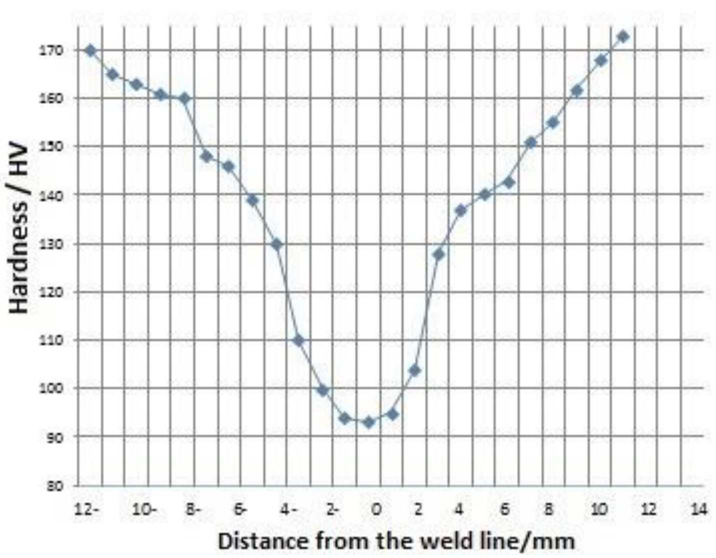


Figure 5.5. (B) Microhardness values averaged over many MIG welding locations.

The grain size is the reason for getting a substantial difference between the value of the fusion zone (FZ) and base metal (BM). In the fusion zone (FZ), grain size is larger than other zones, which gives it the lowest value of hardness Vickers (HV)

5.2. RESULTS OF THE TENSILE TEST

The tensile tests were performed on the welded joints created using TIG and MIG welding techniques with low carbon steel type A285 Gr.C. The investigation centred on each weld's mechanical properties—peak load, ultimate tensile stress, and yield strength. The investigation into the tensile properties of the TIG and MIG welding samples reveals distinct mechanical behaviours in their respective welds. The results highlight the unique mechanical attributes of each welding method, as seen in Table 5.1.The results above showed that MIG welding gives more resistance to breakage compared to TIG welding. This is because the weld speed of the filler metal can be controlled, and thus, the heat input can be controlled in the welding joints.

Table 5.1. Results of tensile test for TIG and MIG welded samples.

Type of welding	Samples dimensions	Yield Strength (MPa)	Ultimate tensile strength (Mpa)
TIG	15X7.75	348.1	489.6
MIG	15.50X7.60	360.2	492.4

Because welding speed is inversely proportional to heat input, a lower heat input will speed up the cooling process and minimise the area impacted by heat. On the other hand, a greater heat input will result in a slower cooling rate, which will cause the HAZ within the same material to expand. Moreover, the HAZ becomes larger as the welding process slows down. Larger, coarser grains may form due to the cooling process that the metal in the Heat Affected Zone (HAZ) undergoes. These larger grains may serve as stress concentration sites, increasing the material's susceptibility to the start and spread of cracks, which would ultimately fail in the zone.

5.2.1. TIG

The TIG weld exhibited a yield strength of 348.1 MPa and an ultimate tensile strength of 489.6 MPa. These figures indicate the weld's ability to endure stress before exhibiting plastic deformation, displaying moderate strength and stress resistance, as shown in Figure 5.4.

Figure (5-5) displays the tensile sample of the TIG welding after tensile test.

MIG welds work well with larger projects with thick metals that need longer, continuous runs.

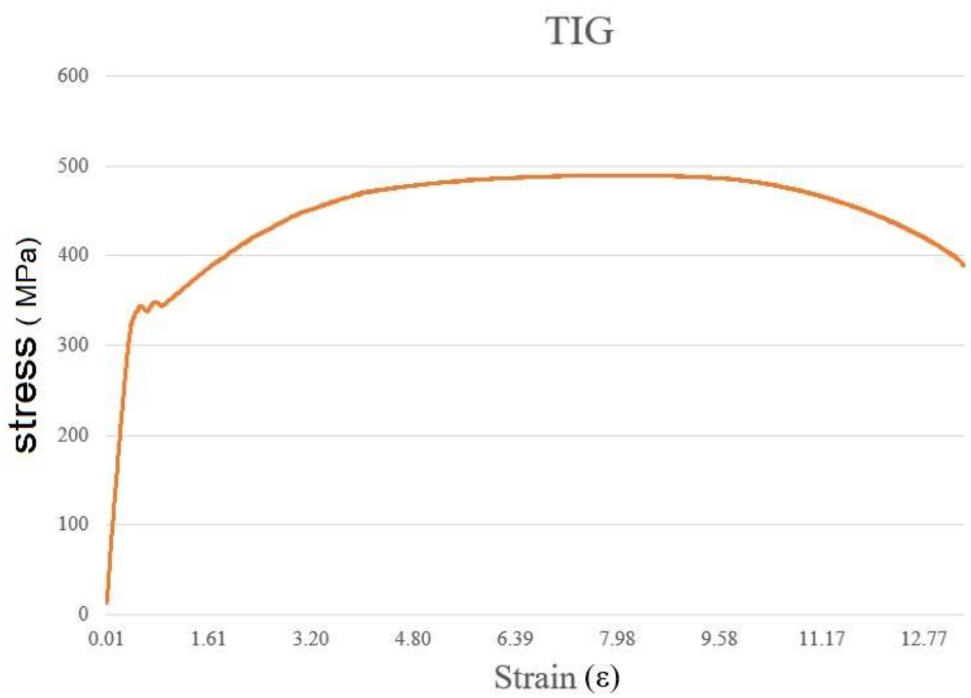


Figure 5.6. Tensile test curve of TIG welded samples.

Figure 5.7. TIG sample after the tensile test.

5.2.2. MIG

In contrast, the MIG weld displayed a slightly higher yield strength of 360.2 MPa and an ultimate tensile strength of 492.4 MPa. These values suggest increased resistance to deformation, signifying higher strength capabilities in the MIG welding sample, as shown in Figure 5.6.

Figure (5-7) displays the tensile sample of the MIG welding after tensile test.

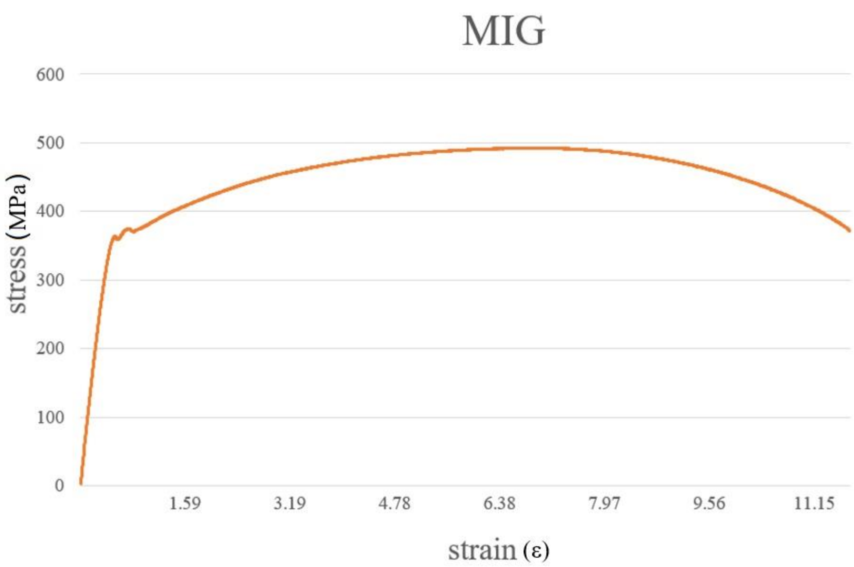


Figure 5.8. Tensile test curve of MIG welded samples.

Figure 5.9. MIG sample after the tensile test.

The (MIG) welding method gave better properties compared to the (TIG) welding method because the (MIG) welding process is automated in the feeding speed.

In TIG welding, the welder must use one hand to control the flame and the other hand to feed filler material onto the weld. In MIG welding, the weld is produced by continually feeding a wire electrode through the spool gun.

TIG welding is slower than MIG welding when it comes to welding thicker metals. TIG can be a preferable choice if the metal you're utilising is thin.

The tensile tests were performed on the welded joints created using TIG and MIG welding techniques with low carbon steel type A285 Gr.C. The investigation centred on each weld's mechanical properties—peak load, ultimate tensile stress, and yield strength. The investigation into the tensile properties of the TIG and MIG welding samples reveals distinct mechanical behaviours in their respective welds. The study revealed the following information:

- TIG Welding Results:
  Yield Strength: 348.1 MPa
  Ultimate Tensile Strength: 489.6 MPa
- MIG Welding Results:

Yield Strength: 360.2 MPa

Ultimate Tensile Strength: 492.4 MPa

- Yield Strength: A key mechanical property that indicates the stress at which a material starts to distort plastically is yield strength. In this study, the yield strength of MIG welding was somewhat greater (360.2 MPa) than that of TIG welding (348.1 MPa). Better structural integrity is shown by a higher yield strength, which implies that materials welded by MIG are less likely to plastically deform under strain.
- Ultimate Tensile Strength: A material's ultimate tensile strength indicates the highest stress it can withstand before breaking. The ultimate tensile strength values obtained for the two welding methods are similar, with MIG welding exhibiting a little greater strength (492.4 MPa) than TIG welding (489.6 MPa). This suggests that MIG welding results in welded seams that are more resistant to tensile pressures and are thus less prone to fail under harsh circumstances.
- Control of Welding Wire Feeding: The capacity of MIG welding to regulate the feeding of the welding wire is mentioned as a reason for its superiority. This control is important because it makes it possible to regulate the filler material deposition precisely, which produces a more uniform and controlled weld bead. This more precise control is frequently helpful in producing reliable, high-quality welds, especially in situations where accuracy and repeatability are crucial.

Conclusion: The marginally better performance of MIG welding, along with its improved control over welding wire feeding, suggests that MIG welding may, in fact, offer advantages in terms of structural strength and consistency, even though the differences between TIG and MIG welding in yield strength and ultimate tensile strength are relatively small, one welding procedure is not always "better" than another; additional considerations include the particular application, the kind of material, and the welding circumstances. Every technique has advantages and is frequently selected in accordance with the specific needs of the welding project.

5.3. RESULTS OF BENDING TEST

The bending test was performed on welded joints created by TIG and MIG welding techniques using low-carbon steel type A285 Gr.C. The investigation included the determination of critical parameters: maximum flexure angle, maximum load (Fmax), and deflection at Fmax (dL at Fmax), as shown in Table 5.2.

Table 5.2. Bending results.

Type	Span (mm)	Maximum flexure angle (°)	F_{max} (N)	dL at F_{max} (mm)
MIG	50	90°	10086.77	16.87928
TIG	50	90°	10007.87	13.41593

After the welded samples bent 90º, both TIG and MIG samples had no cracks or fail, which means the base metal and the filler metal of TIG and MIG welded samples were melted well.

5.3.1. TIG

In contrast, the TIG welding sample showed a slightly lower maximum load (Designation) of 10007.8 N, resulting in a lower deflection at a maximum load (dL at Fmax) of 13.41 mm. This suggests that the TIG weld experienced less deformation at the same load as the MIG weld, implying potentially different mechanical behaviours, as shown in Figure 5.10.

Figure (5-11) displays the tensile bent of the TIG welding after the bending test.

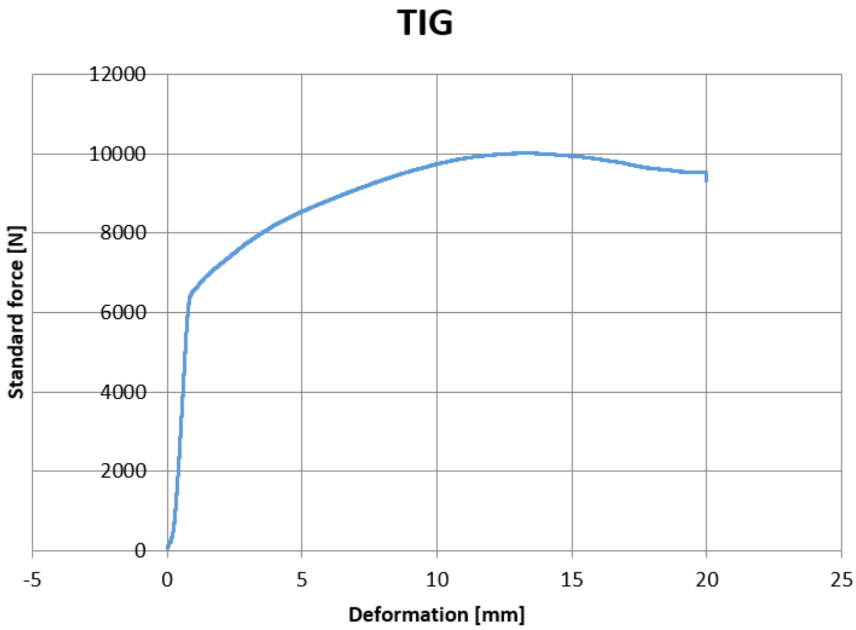


Figure 5.10. Bending test curve of TIG welded samples.

Figure 5.11. TIG sample after the bending test.

5.3.2. MIG

The MIG welding sample displayed a higher maximum load (Designation) of 10086.7 N, resulting in a more significant deflection at a maximum load (dL at Fmax) of 16.88

mm. This indicates the weld's ability to withstand higher loads before exhibiting considerable deformation, as shown in Figure 5.8.

Figure (5-9) displays the tensile bent of the MIG welding after the bending test.

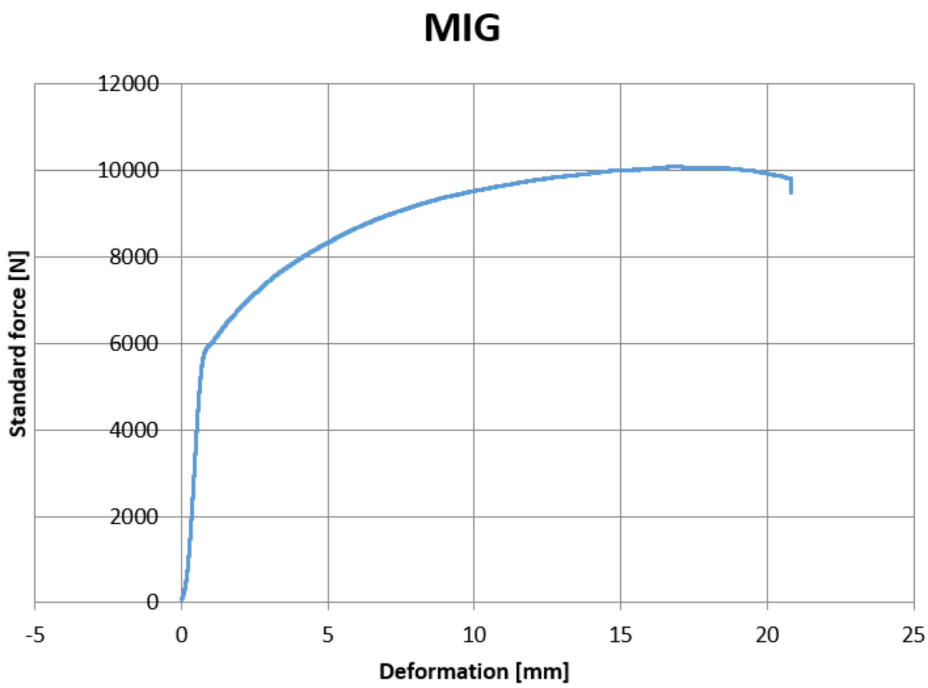


Figure 5.12. Bending test curve of MIG welded samples.

Figure 5.13. MIG sample after the bending test.

The MIG welding process is a smoother process with fewer defects because the continuous nature of MIG reduces the chance of a defect because you don't have to worry about starting and stopping repeatedly during the welding process.

- From Table 5.2 above, we find the following:
  a. Maximum Flexure Angle: The greatest flexure angle of the welded connections produced by MIG and TIG welding processes was 90°. This suggests that during the bending test, the specimens experienced considerable deformation and bent at a straight angle.
  b. Maximum Load (Fmax):
- The maximum load (Fmax) of the MIG-welded joints was marginally greater than that of the TIG-welded joints (Fmax = 10007.87 N). This shows that, in the context of this bending test, MIG welding could offer little benefit in terms of load-bearing capability.
- Deflection at Fmax (dL at Fmax):
- TIG-welded joints showed a somewhat less deflection of 13.41593 mm at the maximum load (dL at Fmax) than MIG-welded joints, which had a deflection of 16.87928 mm. This suggests that TIG-welded joints may have an advantage in terms of stiffness or flexibility depending on the needs of the particular application since they deform less at the location of maximum stress.
- Conclusion: The findings of the bending test show subtle distinctions between TIG and MIG welding processes. TIG welding showed less deflection at the highest load point, but MIG welding showed a larger maximum load. When choosing between MIG and TIG welding for a particular application, one should consider many criteria, including the need for load bearing, the required level of flexibility, and the overall structural performance of the welded connections. The best welding process for a specific job should also take into account other criteria, including cost, efficiency, and simplicity of application.

PART 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

- The purpose of this study was to experimentally investigate the mechanical properties of welding joints for low carbon steel alloy with a thickness of 8mm, specifically Type A285 gr.C. Two types of welding methods, TIG and MIG, were employed, and the welded samples were subjected to comprehensive characterisation for their mechanical properties. The study found that the MIG welding method exhibited superior properties compared to the TIG welding method, mainly due to the automated feeding speed in MIG welding. Hardness tests revealed that the base metal (BM) exhibited the highest hardness value, followed by the heat-affected zone (HAZ), while the fusion zone exhibited the lowest hardness. Tensile tests demonstrated that MIG welding resulted in higher values compared to TIG welding. The ultimate tensile strength was recorded as 492.4 MPa for MIG welding and 489.6 MPa for TIG welding. Furthermore, in the bending test, MIG welding exhibited greater resistance than TIG welding, with the resistance of the metal welded by the MIG method measured at 10,086.77 N and the resistance in the TIG welding method measured at 10,007.87 N

6.2. RECOMMENDATIONS FOR FUTURE WORK

- Find out what the thermal residual stresses are in the fusion zone.
- Determine which welding parameters contribute to the occurrence of welding faults.
- Learn how different preheat temperatures affect the microstructure and mechanical characteristics.

- We can use heat treatment to examine how the results alter in other studies in the future.
- Investigating how various welding joints, including those made of carbon steel, react to impact testing.
- Research how microhardness influences the fusion zone.

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RESUME

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