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> INVESTIGATION THE EFFECTS OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL JOINT WITH ER70s FILLER METAL



# BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS



# Faculty of Mechanical and Manufacturing Engineering Technology



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# Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

2023

#### INVESTIGATION THE EFFECTS OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL JOINT WITH ER70s FILLER METAL

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2023

#### DECLARATION

I declare that this thesis entitled "Investigation the Effects of Heat Treatment on Mechanical Properties and Microstructure of Low Carbon Steel Joint with ER70s Filler Metal" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



#### APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.



#### **DEDICATION**

This report is dedicated to my beloved family in perticular, for their endless love, support and encouragement. To my supervisor Ts. Dr. Mohd Fauzi Bin Mamat who has guided me along the way to finish this project. Thank you for all your support, and give me strength untill this project is finished.



#### ABSTRACT

Welding processes like Gas Metal Arc Welding (GMAW) appear to be expanding at the fastest rate, with the most significant growth occurring in the most recent years. However, the process of welding involves rapid heating and cooling, which results in a severe thermal cycle in the vicinity of the weld line region of any metal that becomes submerged in the heating zone. The GMAW welded process which also referred to as Metal Inert Gas (MIG) that using ER70s filler metal was used to joint the low carbon steel. The aim of this study were to investigate the heat treated of low carbon steel in improved its material's physical and mechanical properties. For the purpose of this project, two distinct types of heat treatment processes, namely tempering and annealing, were utilised as parameters. The next step is to carry out the non-destructive test by making use of radiography testing and liquid penetrant inspection. Last but not least, to perform a hardness test and an impact test in order to investigate the effect that heat treatment has on the mechanical and microstructural properties of the material. A Non-Destructive Testing (NDT) method which is liquid or dye Penetrant Testing (PT) that uses capillary forces to detect surfacebreaking flaws and Radiographic Testing (RT) that use gamma rays to examine the internal structure of the specimen has been carried out. After that, the samples were divided into two different types of samples using a abrasive water jet method. For the heat treatment sample is 50 mm x 10 mm x 10 mm and the sample for impact test has dimensions of 55 mm x 10 mm x 10 mm according to ASTM E23. Annealing at a temperature of 950° C and tempering at 500° C were the two types of heat treatment processes that were utilised in the preparation of the samples. The material characterization was carry out using an optical microscope Scanning Electron Microscope (SEM) and Energy Dispersive X-ray spectroscopy (EDX). The Rockwell and Charpy was used to evaluate the properties of samples that had been treated and those that had not been treated. The Charpy test was used to determine the relative toughness or impact toughness of the sample before it was subjected to the impact test. The result shows after conduct an non-destructive test, there is some defect appear at the surface of the weld joint which is porosity and spatter by using liquid penetrant test but there is no internal structure defect occur after performing an radiography test. After performing heat treatment process, the annealing show the best result in microstructures better than tempering as the grain growth normally and it also prove in increasing in the hardness value through the Rockwell hardness test. Next, after performing an impact test it prove that heat-treated samples are better toughness than untreated samples. The value recorded for annealed was the highest among the other sample which 138.761 kJ/m<sup>2</sup> at centre of the weld joint and 75.597 kJ/m<sup>2</sup> at HAZ. However by performing SEM the structure shows that only at centre of the joint was in ductile condition while at the HAZ was in brittle fracture. Heat treatment is an important process in the oil and gas industry. Through changes in hardness, strength, toughness, ductility and elasticity of materials, it gives the ability to alter the metallurgical characteristics of piping and equipment to better suit their intended applications.

#### ABSTRAK

Proses kimpalan seperti Kimpalan Arka Logam Gas (GMAW) nampaknya berkembang pada kadar terpantas, dengan pertumbuhan paling ketara berlaku dalam beberapa tahun kebelakangan ini. Walau bagaimanapun, proses kimpalan melibatkan pemanasan dan penyejukan yang cepat, yang mengakibatkan kitaran haba yang teruk di sekitar kawasan garisan kimpalan mana-mana logam yang menjadi tenggelam dalam zon pemanasan. Proses kimpalan GMAW yang juga dirujuk sebagai Gas Lengai Logam (MIG) yang menggunakan logam pengisi ER70s digunakan untuk menyambung keluli karbon rendah. Matlamat kajian ini adalah untuk menyiasat perlakuan haba keluli karbon rendah dalam meningkatkan sifat fizikal dan mekanikal bahannya. Untuk tujuan projek ini, dua jenis proses rawatan haba yang berbeza, iaitu pembajaan dan penyepuhlindapan, telah digunakan sebagai parameter. Langkah seterusnya ialah menjalankan ujian tidak merosakkan dengan menggunakan ujian radiografi dan pemeriksaan penembus cecair. Akhir sekali, untuk melakukan ujian kekerasan dan ujian hentaman untuk menyiasat kesan rawatan haba terhadap sifat mekanikal dan mikrostruktur bahan. Kaedah Ujian Tidak Merosakkan (NDT) iaitu Ujian Penembusan (PT) cecair atau pewarna yang menggunakan daya kapilari untuk mengesan kecacatan pecah permukaan dan Ujian Radiografik (RT) yang menggunakan sinar gamma untuk memeriksa struktur dalaman spesimen telah dijalankan. keluar. Selepas itu, sampel dibahagikan kepada dua jenis sampel yang berbeza menggunakan kaedah pancutan air yang melelas. Bagi sampel rawatan haba ialah 50 mm x 10 mm x 10 mm dan sampel untuk ujian impak mempunyai dimensi 55 mm x 10 mm x 10 mm mengikut ASTM E23. Penyepuhlindapan pada suhu 950° C dan pembajaan pada 500° C adalah dua jenis proses rawatan haba yang digunakan dalam penyediaan sampel. Pencirian bahan dijalankan menggunakan mikroskop optik Mengimbas Mikroskop Elektron (SEM) dan Spektroskopi sinar-X Penyebaran Tenaga (EDX). Rockwell dan Charpy digunakan untuk menilai sifat sampel yang telah dirawat dan yang tidak dirawat. Ujian Charpy digunakan untuk menentukan keliatan relatif atau keliatan hentaman sampel sebelum ia tertakluk kepada ujian hentaman. Keputusan menunjukkan selepas menjalankan ujian tidak musnah, terdapat sedikit kecacatan pada permukaan sambungan kimpalan iaitu keliangan dan percikan dengan menggunakan ujian penembus cecair tetapi tiada kecacatan struktur dalaman berlaku selepas melakukan ujian radiografi. Selepas melakukan proses rawatan haba, penyepuhlindapan menunjukkan hasil terbaik dalam struktur mikro yang lebih baik daripada pembajaan sebagaimana pertumbuhan bijirin secara normal dan ia juga terbukti dalam peningkatan nilai kekerasan melalui ujian kekerasan Rockwell. Seterusnya, selepas melakukan ujian impak ia membuktikan bahawa sampel yang dirawat haba adalah keliatan yang lebih baik daripada sampel yang tidak dirawat. Nilai yang direkodkan untuk penyepuhlindapan adalah yang tertinggi antara sampel lain iaitu 138.761 kJ/m<sup>2</sup> di tengah sambungan kimpalan dan 75.597 kJ/m<sup>2</sup> di HAZ. Walau bagaimanapun dengan melakukan SEM, struktur menunjukkan bahawa hanya pada bahagian tengah sendi berada dalam keadaan mulur manakala pada HAZ berada dalam patah rapuh. Rawatan haba adalah proses penting dalam industri minyak dan gas. Melalui perubahan dalam kekerasan, kekuatan, keliatan, kemuluran dan keanjalan bahan, ia memberikan keupayaan untuk mengubah ciri-ciri metalurgi paip dan peralatan agar lebih sesuai dengan aplikasi yang dimaksudkan.

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#### LIST OF SYMBOLS AND ABBREVIATIONS

GMAW	-	Gas Metal Arc Welding
MIG	-	Metal Inert Gas
GTAW	-	Gas Tungsten Arc Welding
AWS	-	American Welding Society
HAZ	-	Heat Affected Zone
NDT	-	Non-Destructive Test
SEM	-	Scanning Electron Microscope
EDX	and a second	Energy Disperse X-Ray
LPT	TE	Liquid Penetrant Testing
RT	1000	Radiography Testing
FCC	5M	Face Centered Cubic
BCC	-	Body Centered Cubic
C0 <sup>2</sup>	UNIV	ERSITI TEKNIKAL MALAYSIA MELAKA Carbon Dioxide
HSLA	-	High- Strength, Low-Alloy Steel
PWHT	-	Post-Weld Heat Treatment
EBSD	-	Electron Backscatter Diffraction

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#### **CHAPTER 1**

#### **INTRODUCTION**

#### **1.1 Background of Study**

In oil and gas industry, the most commonly used type of steel is low carbon steel. This is because it is less expensive to manufacture than medium-carbon and high-carbon steel. Besides, low carbon steel has a carbon content of only 0.3%, making it extremely easy to weld compared to the others. However, Low carbon steel with low carbon content has low hardness and weak in strength, and preventive maintenance is required on a regular basis to ensure long-term and safe operation (Hajili, 2017).

Beside, welding is used to construct the majority of structures. Welding is a common metal-joining process that is both reliable and efficient. The process of fusing two or more pieces of material into a single entity is referred to as welding (Vural, 2014). However, many problems arise during the welding process as a result of the different amounts of heat input as well as the quality of the weldments. Gas metal arc welding (GMAW) is the most common method for fabricating long-distance pipelines due to its high productivity, flexibility, and ease of mechanisation and automation but the thermal cycle creates an heat-affected zones (HAZ) in the base metal, which are heterogeneous regions in the welded joint (BM). The microstructure and surface composition of welds and adjacent base metal are affected by the heating and cooling cycle that occurs during the welding process. Similarly, the microstructure and mechanical properties of welded joints

differ significantly from those of the base metal (BM) and heat affected zone (HAZ) due to welding thermal cycles (de Oliveira Moraes et al., 2022).

This research is to identify the changes in mechanical properties on the low carbon steel by heat treatment to change the grain size and modify the structure of the material. The media for the quenching which is rapid cooling of heated metal also will be observed to obtain desirable material properties. Because of the heat treatment process, the infrastructure and equipment used in the oil and gas industry have a greater likelihood of lasting for a significant number of years (Nayak et al.,2015). This is because the heat treatment process strengthens the structures, allowing them to withstand severe pressures, temperatures, weights, and other conditions. The term "heat treatment" refers to the process of bringing a piece of metal up to a certain temperature, keeping it at that temperature, and then allowing it to cool (Chandra Kandpal et al., 2020).

#### 1.2 Problem Statement

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During the welding process, rapid heating and cooling occur, which causes a severe thermal cycle along the weld line region of any metal that is submerged in the heating zone. This cycle can be detrimental to the integrity of the weld. Because of the thermal cycle, the material does not heat up and cool down in an even manner. This causes the material to have a heat affected zone (HAZ) that is more rigid, sustaining stress, and a preponderance of cold cracking in both the weld metal and the base metal. An extensive range of heating and cooling temperatures is caused and impacted by hazardous stressors that continue to be present regularly. The microstructure and surface composition of welds and adjacent base metal are influenced by the heating and cooling cycle that occurs during the welding process. These changes to the component's properties are normally undesirable, and they ultimately result in the component's weakest point. Microstructural changes, for instance, can lead to residual stresses, a reduction in material strength, an increase in brittleness, and a lower resistance to corrosion and/or cracking. Performing a heat treatment process, which will improve the material's mechanical and microstructural properties, is one method that can be used to solve this problem. The process of heating the metal can make it more brittle while simultaneously increasing its strength. This results in an increase in the productivity as well as the quality of the metal. An annealing process and a tempering process are both examples of the kind of heat treatment process that will be carried out as part of the process of this research.

#### **1.3** Objective of Study

ALAYS

The objective of the research is:

- i. To study the non-destructive test utilising liquid penetrant inspection and radiography testing. UNIVERSITI TEKNIKAL MALAYSIA MELAKA
- To perform the heat treatment process namely annealing and tempering on welded joint.
- iii. To investigate the effect of heat treatment and ER70s filler wire on the mechanical test and microstructural properties.

#### 1.4 Scope of Study

The scope of this research are as follows:

- This experiment use GMAW type of welding machine which uses ER70s filler wire. A steel plate will joint with base metal using ER70s filler wire.
- ii. To perform non-destructive testing uses liquid penetrant and radiography penetrant to identify internal and external welding flaws.
- iii. The welded sample were go through a cutting process using abrasive water jet to produce specimens for microstructure, hardness and impact test.
- iv. The specimen were go through a heat treatment process at different temperature and different type of cooling rate.
- v. The experiment were conduct to investigate the effect of heat treatment and ER70s filler wire on the mechanical and microstructural properties.
- vi. The microstructure test experiments and morphological characterization were carried out to investigate the properties by optical microscope and energy dispersive x-ray analysis (EDX).
- vii. The experiment were test the mechanical properties of the three joints through the Rockwell Hardness test and Charpy test. The relationship between the microstructure and the mechanical properties will clarified.
- viii. The microstructure test experiments were carried out to investigate the type of fracture by Scanning Electron Microscope (SEM).

#### 1.5 Significant of Study

Welding process is essential in industries such as the pipeline industry. Pipelines play an important role in this industry as it was the most effective means of transporting and transferring fuels and liquid substances over long distances and at high temperatures. Pipelines also require the welding process to be carried out. In addition, welding is used in the construction industry for both the creation of new projects and the resolution of maintenance issues in order to create structures that are durable and can withstand high levels of pressure. Nevertheless, corrosion in the welding field has been a significant problem affecting the industry as a whole, particularly welding industries, for a considerable amount of time now. Through the utilisation of heat treatment, this project will achieve improvements in its overall mechanical properties. This research aims to assist the oil and gas industry by assisting them in improving their future production through the application of appropriate heat treatment procedures. This will help the industry to ensure long-term of material and safe operation of people around by investigate the heat treatment to hardness the low carbon steel to change the grain size and modify the structure of the material such as at pipeline, platform, tank and etc related to low carbon steel.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

The skilled trade of welding is one of the most dynamic. Welding is an important component in most manufacturing fields because of the variety of possible applications and the fundamental utility of the process. Welding comes in a variety of forms. Because of their different practical applications, each of these welds uses different types of metal filler materials and processes. As reported by (Kumar et al., 2019), welding is the process of permanently joining two materials (typically metals) by means of a controlled fusion caused by the correct combination of temperature, weight, and metallurgical conditions. Moreover, he stated that a variety of welding shapes have been developed based on the combination of temperature and weight, ranging from high temperature with no weight to high weight with low temperature.

#### 2.2 Welding Process

The primary goal of welding is to create a secure connection between two separate components that have been joined together. The process of welding is a type of fabrication in which two or more parts are joined together using heat, pressure, or a combination of the two in order to create a joint after the parts have cooled. Some techniques involve applying heat to two pieces of metal in order to basically melt them together. During this process, a "filler metal" is frequently inserted into the joint in order to serve as a binding agent. Other techniques for joining metal pieces together rely on the application of pressure, while others combine the use of heat and pressure in the same process. Welding is a process that always results in the work pieces being altered, in contrast to soldering and brazing, which are processes that join metal pieces while leaving them unaltered (M. Mahan, 2019). Welding processes are classified into two categories as shown in Figure 2.1:

- Fusion welding: The surface of the base metals are fused to form coalescence during the welding process.
- ii. Solid state: There is no melting of the base material during the process. In order to create the weld, the base material is heated until it reaches its point of melting. The primary component is heated to a temperature that is just below their respective melting points.



Figure 2.1 Types of welding process (https://www.weldingandndt.com/, 2017)

#### 2.2.1 Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW), also known as Metal inert gas (MIG) welding, is a type of gas-shielded welding that is typically performed manually, but can be automated. Because the filler wire also serves as an electrode, coils of solid bare wire are used to deliver the filler. The coil is fed automatically into the joint, where it is melted in the arc and deposited in the weld groove, eliminating the need for manual feeding. Depending on the application, alloying elements arc in the wire, and the shielding inert gas can be any of the following: argon, helium, nitrogen, carbon dioxide, or a combination of any of these gases. As shown in Figure 2.2, there are four primary methods for transferring metal: globular, short-circuiting, spray, and pulsedspray. Each of these methods has its own distingt cherestriction henefits and limitations.



Figure 2.2 Gas Metal Arc Welding (GMAW) (https://www.sparkerweld.com/en, 2018)

For the purpose of joining large sections of metal, gas metal arc welding (GMAW) is an arc welding process that sees a lot of use because of its distinctive characteristics. These benefits include an increased process efficiency, a better wire electrode deposition rate, regulated high thermal energy dissipation, and no oxidation as a result of the use of shielding gas (Wahab, 2014). In addition to this, the gas metal arc welding (GMAW) method produces welds that are both more aesthetically pleasing and of higher quality than those produced by the shielded metal arc welding (SMAW) process. This is one of the primary reasons why GMAW is the more popular of the two methods (Abioye et al., 2019). This method is seeing a rise in popularity not only in the oil and gas industry but also in the construction industry, where it is utilised for the ALAYS joining of pipes. In gas metal arc welding (GMAW), argon is typically utilised as the shielding gas. Because the single-atom gas has a limited thermal conductivity and ionising potential, the result is a low transfer of heat to the surface of the arc. This is the reason for the phenomenon. As a consequence of this, argon results in a profound but اويبور سيني تيڪنيڪل ملد .restricted weld penetration

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The typical parameters for welding mild and low alloys using GMAW are presented in Table 2.1. When welding mild and low alloy steels, these two methods of metal transfer are typically used as parameters in the welding process.

Process	Diameter Of Wire		Voltage	Amperage	Shielding Gas
	inch	mm	(V)	(A)	
	0.035	0.9	28 - 32	165 - 200	98% Argon + 2%
Spray transfer	0.045	1.14	30 - 34	180 - 220	Oxygen or 75% Argon + 25% CO <sub>2</sub>
	1/16	1.6	30 - 34	230 - 260	
Short circuiting	0.035	0.9	22 - 25	100 - 140	100% CO <sub>2</sub>
transfer	0.045	1.14	23 - 26	120 - 150	75% Argon + 25% CO <sub>2</sub>

Table 2.1 Typical parameters for mild and low alloy welding using GMAW (https://www.haynesintl.com/, 2017)

#### 2.2.2 Process of Gas Metal Arc Welding (GMAW)

Metal inert gas (MIG) welding and metal active gas (MAG) welding are two other names for gas metal arc welding. The coalescence of metals is accomplished through the use of an electric arc, which heats the metals to their melting points. Figure 2.3 depicts a comprehensive diagrammatic representation of the GMAW operation in detail.

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A nozzle-shaped welding gun is used in this process to continuously feed the consumable filler wire into the weld puddle, resulting in the coalescence of two base materials. An effective inert atmosphere, referred to as shielding, is created around the weld area in order to protect the weld puddle from contaminant contamination. The weld area is shielded with gases such as carbon dioxide, helium, argon, or various other gas mixtures, among other things. Figure 2.3 depicts an enlarged image of the welding area in greater detail.



Figure 2.3 Mechanism of GMAW (Dinbandhu et al., 2021)

#### 2.2.3 Types of metal transferral in gas metal arc welding

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Metal transferral in gas metal arc welding can take place in a variety of ways. The methods of transferring filler metal around the welding arc are dependent on a number of variables, including weld arc voltage, weld arc current, the nature of the shielding gas, the diameter of the filler wire, and the rate at which the wire is fed. The most common and traditional modes of metal transfer in GMAW are short-circuit transfer, globular transfer, and spray arc transfer. Short-circuit transfer is the most common and traditional mode of metal transfer in GMAW.

#### 2.2.3.1 Short-circuit transfer

It is possible that the filler wire will actually touch (short-circuit) the molten weld pool (base metal) between 20 and 200 times per second, as indicated by the term "short-

circuit transfer." It makes use of a power source with a constant voltage. During this process, the electrode wire diameter (0.6-1.1 mm) and welding current are kept to the bare minimum in the presence of 100 percent carbon dioxide  $(CO^2)$ , or a mixture of 75 percent -80 percent argon + 25 percent -20 percent carbon dioxide  $(CO^2)$  shielding gas. During this process, Wire feeding speeds outpace burnup rates of the filler wire electrodes when current and voltage are low enough (low current, low voltage). Short-circuiting occurs when the filler wire dips into the weld puddle, causing the arc to go out and the short-circuiting to occur. The current in the wire electrode increases as a result of this short circuit, and the tip of the electrode becomes molten as a result. There is a magnetic effect that occurs, which results in the necking of the wire electrode and the formation of a molten droplet that falls into the weld puddle, as depicted in the illustration. This is followed by another adjustment of the arc, and the entire process is repeated.

#### 2.2.3.2 Globular Transfer

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In this case, it is a reference to the difference in metal transfer between shortcircuiting and spray arc transfer. globular transfer can occur when the values of welding parameters (wire feed speed, voltage, and amperage) are greater than the standards for shortcircuiting transfer, as in the case of arc welding. It occurs with carbon dioxide  $(CO^2)$  and helium-opulent shielding gas at a relatively low current and high arc voltage, indicating that it is a rare event. The effects of magnetic separation forces and current density are inconsequential during the course of the process. The gravitational pull of the welding arc causes liquefied filler wire balls to fall all over the welding arc, spreading all over the place. The transfer rate of droplets is relatively slow, with only a few drops per

second being transferred. As illustrated in Figure, the droplets are quite large in size, typically three times the diameter of the filler wire.

#### 2.3 ER70s Filler Metal

Filler metals are able to liquify and melt at higher temperatures, which allows for the formation of a brazed or soldered connection between two parts that fit together very closely. When joints are prepared correctly, the capillary attraction distribution process can take place. This requires a filler metal that has adequate melting and flow characteristics. Joints formed by filler metals meet service requirements for a variety of characteristics, including strength and resistance to corrosion, amongst others. When choosing a filler metal, there are seven factors that need to be taken into consideration: the base material that will be welded, the welding position, the regulatory specifications and codes, the design requirements, the shielding gas, the post-weld heat treatment, and the welding equipment. The welder is able to select the appropriate filler metal by referring to the letter-number designations, which are presented in Figure 2.4. These designations are created specifically for each variety of filler metal.



Figure 2.4 Filler metal number designation (The letter-number designations

The classification of the electrode is what determines the amount of silicon that is present in carbon steel electrodes; the most common types are ER70S-3 and ER70S-6. Pipe applications that require open-root work are sometimes done with ER70S-2, ER70S-4, and ER70S-7 because these grades contain less silicon than the others. A lower silicon content produces a puddle that is firmer and gives the designer more control over the back bead design (Primo, 2014). An S-6 type electrode can be used in an open-root weld with a lower inductance than an S-2 type electrode. This is due to the fact that the S-6 type has a higher silicon content and the puddle is more fluid (Primo, 2014). When performing a short-circuit transfer, it is absolutely necessary to keep the contact tip-to-work distance at a constant level in order to guarantee a smooth transfer. The shielding gas and short-circuit transfer mode consisting of 75% argon and 25% carbon dioxide is the most frequently used combination for carbon steel electrodes.

#### 2.4 Welding Metallurgy

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The study of the reasons behind why metals behave in the ways that they do is known as metallurgy. This provides an explanation of the properties, behaviour, and internal structure of the metal. In addition, the term "metallurgy" can refer to the treatments and processes that are used to modify the properties of a metal so that it can be used for a particular purpose. The ability of gas metal arc welding to weld two metals that are mechanically identical or mechanically dissimilar, specifically ferrous and non-ferrous metals, is the topic of the metallurgy that is discussed in this case study. According to Rahman et al., (2016) in his research, numerous studies are currently being conducted in the field of metallurgical engineering to investigate the ways in which heat treatment may be utilised to improve the physical and mechanical characteristics of low carbon steel. It is

common knowledge that the atomic structure of a material can have an effect on the properties of the material. For instance, face-centered cubic (FCC) metals and alloys are known for their exceptional ductility. When two grains come into contact with one another, the result is a grain boundary because there is a mismatch in the ordered atoms of the two grains. Each crystal has an ordered array of atoms. A wide range of the material's properties can be altered as a direct result of imperfections in the crystal structure, such as dislocations and point defects (which include solute atoms and vacancies, respectively) (Krauss, 2017).

To ensure that the weldment parameters are satisfied, the crystal structure of the metal is used to select the type of welding that is most appropriate. Low carbon steels have body-centered cubic (BCC) microstructures, which can change during the formation and joining of the weld pool. As a result, the welded surface will have a heterogeneous microstructure. As a result of the fact that heat is utilised in the welding process in order to join the metals, the necessary melting ranges, which can range from solid to liquid and are compatible with welding, are generally referred to as phase diagrams in order to ensure the most effective implementation of the steel welding process. When a sufficient amount of heat is applied to a particular surface, the face-centred cubic (FCC) structure of austenite begins to replace the ferrite BCC structure that was previously present. Welding, on the other hand, can be an advantageous method of joining; however, the temperature changes that are caused by welding can potentially degrade the characteristics under certain conditions (Magudeeswaran et al., 2018).

#### 2.5 Area at fusion weld – Heat Affected Zone (HAZ)

The area of a metal or thermoplastic material that is directly exposed to the environment is referred to as the heat affected zone (HAZ). Even though HAZ does not melt, processes that involve a significant amount of heat have the potential to alter the material's properties as well as its microstructure. Welding and high-heat cutting are two processes that frequently result in modifications to a material's mechanical properties. The HAZ refers to the space that exists between the base metal and the surface that has been cut or welded. These areas can range in size and severity depending on the characteristics of the material, the level of intensity and concentration of the heat, as well as the method that was used. When the HAZ is heated to a high enough temperature for an extended period of time, it goes through a series of structural and physical changes that set it apart from the parent metal (Jeong et al., 2021). The majority of the time, these shifts in property are undesirable and serve as a vulnerability in the material. Microstructural changes, for example, can lead to residual stresses, a reduction in material strength, an increase in brittleness, and a lower resistance to corrosion and cracking. As a direct consequence of this, the HAZ has a very high rate of operational failure. The zones and their boundaries in the heat affected zone are depicted in Figure 2.5, which can be found below.



Figure 2.5 Zones and boundaries in the heat affected zone (https://whatispiping.com/, 2021)

#### 2.6 Welding Parameter

The quality of the welding joint, as well as its productivity and cost, are all affected by the parameters of the GMAW welding process. If all of the parameters for welding are adjusted correctly, it is possible to create the ideal arc (Krauss, 2017). The following are major determinants:

i) Voltage

ii) Current

iii) Speed

- iv) Diameter of the wire
- v) Shielding gas flow rate
- vi) Orientation of the electrode
- vii) Distance between the nozzle and plate

According to (Owolabi et al., 2016), the welding current is the most important variable in the arc welding process. Not only is it the most important variable, but it also has a significant effect on the melting rate, the deposition rate, the penetration depth, and the amount of base metal that is melted. According to the findings of his research, increasing the welding current can increase the hardness of the weld up to 115A and 116A for mild steel and low carbon steel, respectively, but after that point, the hardness of the weld begins to decrease. When the welding current is increased, the ultimate tensile strength of the steel decreases. However, the ultimate tensile strength of mild steel increases when the welding current is increased to 200A and 115A, respectively. When the welding current is increased, there is a corresponding decrease in both the samples' yield strength and impact strength.

#### 2.7 Defects after Welding

Errors are possible during the welding process, just as they are during every other manufacturing process. During the process, there is a possibility that the shape and dimensions of the metallic structure will undergo some minor alterations. It is possible that it was brought about by the use of an incorrect welding procedure or technique. In spite of the fact that it is physically impossible to produce a weld joint that is completely free of defects, these flaws can be reduced to a certain extent by taking the appropriate safety measures. External defects and internal defects are the two categories that fall under the umbrella term "welding defects." Defects that are visible from the outside can be found on the top surface of the welded material, while defects that are visible from the inside can be found at a certain depth in the welded material. The classification of some of the weld defects that can occur in GMAW is shown in Figure 2.6.



Figure 2.6 Classification of welding defects (Welding Defects – Welding & NDT, n.d.)

#### 2.7.1 Type of Defects

Cracks, spatter, porosity, and incomplete fusion are some of the most common welding flaws that can be found in the welding field (Teichmann, Muller, & Dilger, 2018). Other common welding flaws include porosity. These are the types of defects that are typically visible after a weld has been completed, whether it was done in a single pass or in its entirety, depending on the nature of the defect. The majority of it is very simple to identify.

#### i) Weld Crack

These are the most dangerous kinds of flaws that can occur in welding. According to virtually all production standards, you are not permitted to do so. It may manifest itself on the surface, within the welded metal, or in a region that has been subjected to intense heat. During the welding process, different kinds of cracks can appear depending on the temperature of the metal being welded.

#### i. Hot Cracks

UNIVERSITITEKNIKAL MALAYSIA MELAKA It is possible for hot cracks to appear either during the welding process itself or during the crystallisation stage of the weld joint. At this point, temperatures can soar above 10,000 degrees Celsius.

als

#### ii. Cold Cracks

These cracks appear after the weld has been created and the temperature of the metal has dropped significantly. They are also able to be manufactured hours or days after steel has been welded. The majority of instances of this take place whenever there is a deformation made in the steel structure.
# iii. Crater Cracks

These cracks manifest themselves at the very end of the welding process, just before the operator finishes the weld joint. They are typically produced in the latter stages of the process. In order to prevent the metal from becoming too thin after the weld pool has cooled and frozen, the volume of the weld must be sufficient. In the absence of this, a crater will begin to crack.

Because of this, cracks are considered to be the most potentially hazardous of all defects, particularly surface cracks, and virtually all specifications prohibit the acceptance of any crack that is detectable by normal methods of examination. Surface cracks are especially dangerous. It's possible for cracks to show up in a variety of places and ways. The illustration of a crack that frequently occurs in welded joints can be seen in Figure 2.7. The following are examples of factors that can contribute to the formation of crack.

i. Incorporating hydrogen into the process of welding ferrous metals.
ii. Using a low welding current while maintaining a high welding speed.
iii. Failure to perform preheating prior to beginning welding.
iv. The solidification of residual stress caused by shrinkage.

v. Incorrect filling of th crater during the welding process.



Figure 2.7 Welding crack (Aluminum Welding Procedure: Best Practices to Prevent Defects - Aquasol Welding, n.d.)

### ii) Incomplete Penetration and Fusion

Weld discontinuities are referred to as incomplete fusions when there is a lack of fusion between the weld metal and the fusion faces or between adjoining weld beads. This lack of fusion can happen in any location within the weld joint, including fillet welds and/or groove welds, and it can be present in either type of weld. During the welding process, if the base material or previously deposited weld metal cannot be heated to its melting temperature, an incomplete fusion may occur as a result. This could be due to a number of factors. It is usually found on one leg of a fillet weld and is the result of an incorrect welding angle, which permits an imbalance of heat between the two sides of the joint. Failure to remove oxides or other foreign material from the surface of the base material, to which the deposited weld metal must fuse, is another factor that can contribute to this issue. Incomplete joint penetration is a joint root condition in a groove weld that occurs when the weld metal does not extend through the joint thickness. This type of joint root condition is known as "incomplete joint penetration." It refers to the situation in which the base metal or filler metal does not completely fill the root of the weld. The design of the groove weld or the way it was set up may not have been suitable for the welding conditions in some cases, which can lead to incomplete joint penetration. These issues manifest themselves in circumstances in which the root face dimensions are excessively large, the root opening is insufficient, or the included angle of a v-groove weld is insufficiently wide. All of these characteristics of the joint's design work together to make it more difficult for the weld to penetrate all the way through the joint's thickness. Figure 2.8 shows an example illustration of incomplete penetration and fusion defect.



Figure 2.8 Lack of fusion and incomplete penetration defect (The Most Common Welding Defects: Causes and Remedies - Technoweld, n.d.)

### iii) Porosity

During the process of solidification, gases can become trapped in molten metal, resulting in the formation of cavities or pores known as porosity. To put it another way, porosity can be thought of as gas bubbles that have become trapped in the weld metal. There is a wide range of possible forms and dimensions for the porosity, including distributed, wormhole, surface breaking pores, and crater pipes, among others. An illustration of porosity that is uniformly distributed can be seen in figure 2.9.



Figure 2.9 Uniformly distributed porosity (10 Welding Defects and Discontinuities Causes & Remedies, n.d.)

Porosity is produced when nitrogen, oxygen, and hydrogen are absorbed in the molten weld pool and then later released and trapped in the solidified weld metal. This process results in the creation of the porosity. The most common cause of nitrogen and oxygen being taken up by the weld pool is inadequate gas shielding. If there is more than 1.5 percent air entrainment in the shielding gas, then gross surface breaking pores will be produced. Distributed porosity can be created with as little as 1 percent air entrainment in the shielding gas. Aside from that, porosity is typically brought on by gas line leaks, high

gas flow rates, draughts, and an excessive amount of weld pool turbulence. All of these factors contribute to a turbulent environment in the weld pool. Condensation of moisture that originates from wet electrodes, fluxes, or the surface of the workpiece can result in the production of hydrogen.

There are a few different approaches that can be taken to conquer it. To begin, the pretreatment of material surfaces prior to welding can be just as important to producing a clean weld as the actual welding process itself. In the absence of appropriate cleaning, the aftereffects of manufacturing may result in porosity and contamination of the surface. Next, make a mental note of the direction that the gas is moving coming from the shield. The more powerful the flow of gas, the more the surrounding air is thrown off balance. It is possible that this will cause impurities to combine with the weld puddle, which will then result in an impure weld. Despite the fact that flow rates might be different for different applications, it is extremely important to pick the right flow rate for each application. Checking the equipment is the final step, but it should never be skipped. Over time, there is a possibility that hoses will develop leaks and that wires will become exposed or damaged. Before you start an arc, you should verify that all of the connections are secure to ensure an accurate flow from the gas shield. Check the cleanliness of the tip of the weld gun. Sometimes the tip can become clogged, which can result in contaminants being introduced into the weld.

# iv) Slag Inclusion

During the welding process, solid foreign matter can become entrapped, creating what is known as an inclusion as shown in figure 2.10 above. It could be an inclusion of tungsten, copper, or some other metal. Alternatively, it could be an inclusion of slag, which could either be linear, isolated, or grouped. In addition, it is possible that the inclusion is a non-metallic substance, such as sulphide or oxide, which is the result of chemical reactions, physical effects, or contamination that takes place during the welding process. Internal and volumetric in nature are typical characteristics of inclusion defects. Incorrect welding parameters, incorrect manipulation of the electrode by the operator, incorrect cleaning of the electrode between runs, or improper storage of consumables are the most common causes of these issues.



Figure 2.10 Diagram of slag inclusion (Troubleshooting Your Weld - The 12 Most Common Problems & How to Fix Them | UNIMIG Welding Guides & Tutorials, n.d.)

### 2.8 Carbon Steel as Base Material

Steel is a type of metal alloy that is typically constructed out of iron and carbon, in addition to various trace metals. The fact that it has a high tensile strength while still being relatively inexpensive to produce makes it a popular metal choice among manufacturers. Steel, on the other hand, can be produced in a wide variety of forms, each of which has its own particular set of characteristics. For example, carbon steel is frequently chosen over other types of steel in a variety of applications. The Alloy Steels Research Committee (ASRC) defines carbon steels as "steels that include less than 0.5 percent manganese and 0.5 percent silicon; all other steels are classified as alloy steels. Carbon steels are distinguished from alloy steels by the low levels of these two elements (Metals. & International., 1997). According to (Metals. & Internasional., 1997), the primary alloying elements that are used in steel are manganese, lead, nickel, chromium, molybdenum, vanadium, niobium, and cobalt. Other alloying elements include silicon and cobalt (Frihat, 2015). On the basis of the amount of carbon that they contain, carbon steels can be divided into one of three categories: low carbon steel, medium carbon steel, and high carbon steel. NIKAL MAL AYSIA MEL In the following table 2.2 show the comparison of the carbon content, microstructure, and characteristics of these different materials.

Table 2.2 The analysis of the differences in the microstructure, amount of carbon, and properties (Carbon Steel: Properties, Examples and Applications - Matmatch, n.d.)

Type of	Carbon	Microstructure	Properties	Examples
Carbon	Content			
	(Wt.%)			
Low carbon -	< 0.25	Ferrite, pearlite	• Low hardness and	AISI 304,
steel			<ul><li>cost.</li><li>High ductility.</li></ul>	ASTM
			toughness,	A815, AISI
			machinability and weldability.	316L
Medium -	0.25 - 0.60	Martensite	• Low hardenability,	AISI 409,
carbon steel			medium strength, ductility and	ASTM A29,
			toughness.	SCM 435
High carbon -	0.60 - 1.25	Pearlite	• High hardness,	AISI 440C,
steel	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0	strength, low	EN 10088-3
		2	ductility.	
2		7		

# 2.8.1 Low Carbon Steel

The type of carbon steel that sees the most usage is known as low-carbon steel. The

carbon content of these steels is typically lower than 0.25 weight percent on average. Because they are unable to be hardened by heat treatment (which forms martensite), this is typically accomplished through cold working. Carbon steels are typically characterised by low strength and relative pliability. On the other hand, they have a high ductility, which makes them great for machining and welding, in addition to being inexpensive. Although high-strength, low-alloy steels (HSLA) are frequently categorised as low-carbon steels, these steels also contain other elements, such as copper, nickel, vanadium, and molybdenum. The term "low-alloy" refers to the amount of carbon in the steel. Together, these can account for up to ten weight percent of the steel's total composition. The increased tensile and tensile yield strengths of high-strength, low-alloy steels are achieved through heat treatment, as the name suggests. They also maintain ductility, which allows them to be easily formed and machined into different shapes. HSLA are superior to plain low-carbon steels in terms of their resistance to corrosion.

Ferrite, a solid solution phase of carbon dissolved in alpha-iron that crystallises as a body-centered cubic (BCC) crystal, makes up the majority of its structure (Evans, 2012). Ferrite is the most ductile phase of steel, and its presence is a significant contributor to low carbon steel's superior machinability in comparison to other carbon and alloyed steels. When the amount of carbon in steel is increased, a proportionally greater amount of pearlite is produced in the microstructure of the metal. The microscopic structure of pearlite is composed of alternating layers of ferrite and iron carbide (cementite). Pipes, structural forms (including I-beams, channel, and angle iron), components for buildings and bridges, food cans, and vehicle body components are all common applications for low carbon steels, which are widely used in these industries.

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### 2.8.2 Medium Carbon Steel

The range of carbon content in medium-carbon steel is 0.25 to 0.60 weight percent, and the range of manganese content in medium-carbon steel is 0.60 to 1.65 weight percent. The autenitizing, quenching, and tempering steps of this steel's heat treatment give it a martensitic microstructure, which improves the steel's mechanical properties and gives it a more durable appearance. However, additional alloying elements such as chromium, molybdenum, and nickel can be added to improve the steel's ability to be heat treated and, consequently, hardened. Heat treatment can only be performed on very thin sections. The increased strength of hardened medium-carbon steels in comparison to low-carbon steels comes at the expense of the material's ductility and toughness. The majority of the time, these steels are put to use in the production of forgings, shafts, axles, gears, crankshafts, and couplings. Steels with between 0.40 and 0.60 percent carbon are used to manufacture rails, railway wheels, and rail axles (Singh, 2020).

### 2.8.3 High Carbon Steel

The range of carbon content in high-carbon steel is between 0.60 and 1.25 weight percent, and the range of manganese content is between 0.30 and 0.90 weight percent. In comparison to the other carbon steels, it possesses the highest hardness and toughness but the lowest ductility. Because they are typically hardened and tempered before being used, high-carbon steels have a high wear resistance that makes them ideal for a variety of applications. High-carbon steels like tool steels and die steels contain additional alloying elements in addition to carbon, such as chromium, vanadium, molybdenum, and tungsten. These steels are classified as high-carbon steels. The incorporation of these elements results in the production of a steel that is exceptionally resistant to wear and tear, and this property is due to the formation of carbide compounds such as tungsten carbide (WC).

### 2.8.4 Application of Carbon Steel in Oil and Gas Industry

Carbon steel is a metal that is known for its high strength and excellent resistance to wear and tear. It is the type of steel that is utilised the most frequently in the oil and gas industries. Pipelines, structural components, platforms, and a variety of other types of objects can all be built with it. Carbon steel is an iron alloy that contains up to two percent carbon, which increases the material's strength and offers corrosion resistance. Carbon steel is extremely important in the oil and gas industries because of these characteristics (Wahab, 2014). In addition to that, the steel has minute amounts of other metals like nickel and chromium incorporated into it. In addition, carbon steel has sufficient structural and thermal strength, it is cost-effective, and the surfaces of carbon steel can be protected against corrosion by using well-known corrosion inhibitors. The structure of a typical oil and gas pipeline is depicted in figure 2.11 and 2.12.



Figure 2.11 Carbon steel in industry pipeline (Carbon Steel Seamless Pipes, n.d.



Figure 2.12 Carbon steel in offshore platform (Offshore Structure Design, Construction & Maintenance Online Training | PetroKnowledge, n.d.)

# 2.9 Heat Treament Process

The term "heat treating" refers to a group of industrial, thermal, and metalworking processes that are used to change the physical and sometimes chemical properties of a material by subjecting it to a heating and cooling process. Heat treating can also be referred to simply as "heat treatment".

The proper application of heat treatment will change the material's physical and mechanical properties, and it will also be of assistance in the production of other essential components. The release of stresses that can occur as a result of applying a heat treatment process in the correct manner can make the steel simpler to machine or weld. The temperature and length of time that the heat treatment is applied for are two of the primary factors that determine the phase transformations that take place. In order to manufacture high-quality parts and components with the desired characteristics, it is necessary to exercise stringent control over both temperature and time. The rate at which an object cools down after undergoing a heat treatment at a high temperature is another very important process parameter. As was previously mentioned in relation to steels, a slow cooling rate will result in the formation of ductile and tough pearlitic microstructures. Steels with a combination of high-strength and high-toughness martensitic microstructure can be produced by tempering steels that have been quenched to produce these microstructures. Quenching produces martensitic microstructures with high strength but low toughness. The production of high-quality alloy components is dependent on both an understanding of and control over the temperatures and times of heat treatments, as well as the cooling rates from heat treat temperatures.

 Table 2.3 The contrasting findings of the heat treatment applied to the welded joint from the earlier study

Author	Material	Process	Finding
Kučerová	Low carbon low	Annealing	The retained austenite carbon content
et al.,	alloyed steel.		decreased in proportion to the declining
(2019)	UNIVERSITI 1	<b>FEKNIKAL</b>	volume fraction of retained austenite. The
			volume fraction of retained austenite
			ranged anywhere from 11 to 18 percent
			regardless of the treatment it was subjected
			to. Coarser microstructures, longer retained
			austenite laths, lower retained austenite
			carbon concentrations, and a more
			prominent retained austenite lath bainite
			morphology were all produced by slower
			cooling.

Table 2.3 Continue

Reyes et al., (2017)	Low carbon steel	Annealing Tempering Hardening Normalizing	The investigation into how the heat treatment affected the sample of steel reveals that there is always a compromise to be made between two of the material's properties. The steel's toughness and tensile strength are both decreased after tempering, while its level of hardness is slightly increased. The untreated control phases have a microstructure that is composed of ferrite and pearlite, whereas the micrograph of the hardened phase is predominately composed of coarse martensite. The sample's microstructure reveals that tempering resulted in the formation of martensite, along with recrystallization of ferrite.
Chandra Kandpal et al., (2020)	Alloy steel (EN 31, EN 24 and EN 8)	Annealing Normalizing Hardening	Based on the findings, it is possible to draw the conclusion that the various heat treatment processes and cooling rates have a significant impact on the mechanical qualities of the material. It is going to produce results that are satisfactory in terms of high ductility and low toughness. After the manufacturing process, this treatment is denoted as being final. In comparison to the other heat-treated samples, the hardened sample exhibited the highest levels of tensile strength and hardness, but it exhibited the lowest levels of ductility and impact strength.
Prabakaran & Kannan, (2021)	Austenitic stainless steel (AISI316) and low carbon steel (AISI1018)	Annealing	The effects of PWHT on a wide range of metal complexes were studied in great detail. Both the tensile strength and the elongation of the joint were significantly improved through the application of PWHT at 960 degrees Celsius. After being subjected to PWHT at 960 degrees Celsius, the chromium carbide was successfully dissolved, and it did not precipitate once more in the grain or on the grain boundaries of the weld zone.

Table	2.3	Continue

ValdesTabernero	Hot-rolled	Annealing	The incremental increase in maximum
et al.,	6 mm		temperature is beneficial to the production
(2020)	thick low		of austenite. As a direct consequence of
	carbon		these activities, the volume fraction of
	steel		ferrite will decrease, while the volume
	sheets		fraction of intercritical austenite will
			increase.
			Nonrecrystallized ferrite has a higher
			dislocation density than recrystallized
			ferrite, which contributes to the material's
			increased tenacity.

#### 2.9.1 Stages of Heat Treatment

The metal or alloy is heated to a particular temperature, which can go as high as 1300 degrees Celsius in some cases, kept at that temperature for a predetermined amount of time, and then allowed to cool. This process is repeated until the desired result is achieved. Heating a metal causes changes to occur in the physical structure of the metal, which is sometimes referred to as the microstructure of the metal. These changes cause the metal's physical properties to change as well. The time it takes to heat the metal up to the desired temperature is referred to as the "soak time. A metal that has been soaked for an extended period of time will exhibit distinct microstructure changes in comparison to a metal that has been soaked for a brief period of time.

The length of the soak time has an effect on the properties of a metal, as metal that has been soaked for an extended period of time will exhibit these changes (Mesquita et al., 2017). The outcome of the metal will be affected by the cooling procedure after the soak time has passed. For the purpose of achieving the desired result, metals can be cooled either precipitously, through a method known as quenching, or gradually, within the furnace itself. The temperature during soaking, the amount of time spent soaking, the temperature during cooling, and the amount of time spent cooling all contribute to the desirable qualities of a metal or alloy. The properties of a metal can be altered during the manufacturing process by subjecting the metal to heat treatment multiple times; some metals may even be subjected to treatment on multiple occasions.

According to figure 2.13, the process of heat treatment consists of three stages: gradually heating the metal to provide uniform temperature distribution; soaking the metal at a certain temperature for a specified period of time; and finally, cooling the metal to room temperature in order to achieve the desired characteristics. The three stages that comprise the process of heat treatment are the heating phase, the soaking phase, and the cooling phase.



Figure 2.13 Temperature time cycle and its reaction to the TTT diagram (Metallurgy – Indian Iron & Steel Sector Skill Council,

n.d.) 35

### i. Heating

The first step in the process of heat treatment is heating the material. When heated to a certain temperature, it is possible to change the structure of alloys through this process. At room temperature, the alloy can be described as being formed either by a solid solution, a mechanical mixture, or a combination of the two processes. When forming a solid solution, two or more metals are used on each other to form a solution that does not show the elements of either of the metals, not even when examined under a microscope. During the time that the elements and compounds are in the mechanical mixture, they are easily observable and are compacted by a matrix of base metal.

ii. Soaking

The stage known as "soaking" is the point at which the entire portion of the heated metal undergoes a complete structural transformation. The length of time that the metal is allowed to soak is directly proportional to its mass. To put it another way, soaking is when a portion of metal gradually turns red as a result of it having been heated for an extended period of time.

## iii. Cooling

The final phase of the heating process is the cooling off period. It also alters the structure of the metal after it has been soaked because the metal is cooled in a different way depending on whether it is quenched or cooled in still air. This results in a different chemical composition. There is no way to skip any of the three stages of the heat treating process. The heating stage helps change the structure of the metal from the room temperature until it completely reaches the soaking stage, which is when the metal evenly

becomes red. During this stage, the metal is heated until it completely reaches the soaking temperature. The metal undergoes a complete transformation into its new properties during the cooling stage of the process, which is the stage at which it is referred to as "cooling."

### 2.9.2 Types of Heat Treatment

The optimal characteristics of a metal can only be achieved through the use of heat treatment, which can either soften or condition the metal (as in normalising and annealing) or harden the metal (as in hardening, quenching, and tempering). Heat treatment is essential for achieving this goal. These treatments lead to the formation of three distinct microstructures, which are referred to as pearlite, bainite, and martensite respectively. The manufacturing of steel frequently makes use of the following four primary kinds of heat treatment processes: annealing, tempering, hardening, and normalising. Annealing is the most common of these. In the manufacturing process, the precise heat treatment that must be applied will be decided based on the chemistry of the metal, the size of the component, and the characteristics that must be achieved.

Forging and post-weld heat treatment, also known as preheat, are two common applications of heat treatment (Singh, 2020). To better understand the different phases that can be found in steel and cast iron, many people refer to the iron-carbon phase diagram figure 2.14. Steel and cast iron are both, as is common knowledge, composed of iron and carbon. There is a comparison of each of the heat treatment processes in the table that can be found in table 2.4.



Figure 2.14 The Iron Carbon Phase Diagram (The Iron Carbon Phase Diagram, n.d.)



Table 2.4 Comparison of different types of heat treatment process

	UNIVERSIT	TEKNIKAL M	<b>ALAYSIA</b>	<b>IELAKA</b>	
Type of	Definition	Process	Temperature	Purpose	Application
Heat			-	-	
Treatment					
Annealing	To soften metal in order to obtain the desired chemical and physical properties.	Involves heating a metal to a temperature at or near its critical point, followed by gradually bringing it down to room	260°C- 950°C	To make the materials softer.	Applicable to metals and metal alloys.

Table 2.4 Continue

Hardening	Is a process used to increase a metal's hardness.	The metal is heated until it enters the austenitic crystal phase, and it is then cooled off very quickly afterward.	Between 800°C- 900°C	The process of making a metal harder.	Used for high carbon and alloy content metal alloys.
Tempering	Is the process of removing excess hardness, and consequently brittleness, that has been caused by hardening.	By heating it to form austenite and then cooling it to form martensite.	As high as 950 °C for up to 20 hours	To reduce the brittleness of metals.	Primarily used for steel.
Normalizing	Is a process that is used to release the internal tensions that have been created by other processes such as casting, welding, or quenching.	Heating the steel to about 40° Celsius above its upper critical temperature limit, holding it there for a period of time, and then cooling it in air.	Between 750°C- 980°C	To increase toughness and ductility while maintaining high strength levels. MELAKA	Used mainly for material that require impact strength or have to withstand huge external stresses.

# i. Annealing

In order to obtain the desired chemical and physical properties of metals, annealing is both a chemical and a physical process that softens the metals. The process of annealing involves first heating the metal to a temperature above its upper critical temperature and then gradually bringing it down to room temperature. It enhances the metal's capacity to be shaped and worked with in cold environments. In addition to this, it enhances the metal's ability to be machined, as well as its ductility and toughness. The annealing process is one that is frequently utilised in the production of ferrous alloys. To produce pearlite or ferrite, the metal must first be heated to a temperature higher than its upper critical temperature, and then it must be cooled slowly. Pure metals and a variety of alloys that cannot be heat treated are annealed in order to make them more workable (Reyes et al., 2017). When the metal is heated to a high enough temperature, recrystallization occurs, which fixes any imperfections brought on by plastic deformation. (Phoumiphon et al., 2016). In general, the rate at which these metals cool has very little impact on the characteristics of the metals themselves. The majority of heat treatable nonferrous alloys are annealed as well to reduce the hardness of cold working. Annealing can be done either by heating or cooling the material. It is possible to fully crystallise these by gradually chilling them, which will result in the formation of a fine microstructure.

Ferrous alloys are often referred to as being "completely annealed" or "process annealed." Both of these terms refer to the same thing. In order to produce coarse pearlite, full annealing must be performed at extremely slow cooling rates. During process annealing, the rate of cooling can be increased all the way up to normalising before the process is complete. The production of a microstructure that is consistent is the primary purpose of process annealing as it was originally conceived. It is common practise to anneal nonferrous alloys using a variety of processes, such as "recrystallization annealing," "partial annealing," "complete annealing," and "final annealing," among others. The grain structure of various metals is depicted in figure 2.15. As shown in figure 2.15, the second step, which entails the elimination of dislocations and rearrangement of dislocations, is initiated by a slight increase in the annealing temperature. At the temperature at which rearrangement occurs, the opposing dislocations that are caused by diffusion are reduced, which results in a reduction in the total internal stresses of the material. After the elimination of dislocations with the opposite sign, the ones that are still present begin to grow in size in an effort to reduce the negative effects of the stresses that are generated from within. Polygonization is the name given to the process of rearranging the remaining dislocations.

During this process, edge dislocations combine to form tilt boundaries, and screw dislocations combine to form twist boundaries. Both of these boundary types are referred to as dislocations. The activation energy rises and the high-angle grain boundary begins to move as the temperature at which steel is annealed is raised to higher levels. Below the temperature at which recrystallization occurs, the only entities in the material that can move and thus reduce the internal stresses are dislocations and point defects. After going through the process of recrystallization, newly formed grains will start to grow in size. Large grains tend to grow at the expense of crystallised fine grains as the population of large grains increases. The aggressiveness of the growing process will increase in proportion to the temperature at which the steel is annealed. There is a connection between grain boundaries and this force. When grain size and grain border area are both increased, the result is a reduction in the amount of total energy that can be contained within an area



Figure 2.15 Grain growth in annealing process (What Is Annealing? Heat Treatment Process For Annealing - Win Win Solution, n.d.)

### ii. Tempering

The toughness of hardened steel can be improved through a process called "tempering," which involves heating the steel to produce austenite and then rapidly cooling it to produce martensite. Untempered martensite is a material that is strong, difficult, and brittle. The more fragile it is, the more robust and difficult to break it is. The elastic strain that occurs within martensite is what gives it its strength and hardness. This strain is brought on by the presence of an excessive number of carbon atoms in the spaces between the iron atoms that make up martensite. When there is a greater amount of carbon in a steel, martensite exhibits an increase in both its strength and its hardness (up to roughly 0.8w percent carbon).

During the process of tempering, the carbon atoms in martensite migrate out of the spaces between the iron atoms to form particles of iron carbide (Singh, 2020). When the carbon atoms in martensite separate from the iron atoms, the strain that was held in the material is released. As a consequence of this, the tensile strength of steel decreases while its toughness increases. The quantity of tempering that must be done is determined by the final application of the steel. Because a high level of toughness is not always required, it is sometimes appropriate to temper an object at a low temperature for only a short amount of time. It is possible to use a high carbon steel that has been tempered at a high temperature in situations where an extremely strong and tough steel is required. The colour chart for tempering steel, which was used in the heat treatment process, can be found in figure 2.16.



Figure 2.16 Tempering steel color chart (Tempering Steel Process - Microstructures and Color Chart, n.d.)

### iii. Normalizing

The internal stresses in a piece of metal that have been caused by welding, casting, or quenching can be alleviated through a process called normalizing, which is a form of heat treatment. Normalizing produces not only pearlite but also martensite and, under certain conditions, bainite, which results in a steel that is harder, stronger, and has less ductility than complete annealing of the same composition would produce. During the normalization process, the steel is heated to a temperature that is approximately 40 degrees Celsius higher than its upper critical temperature limit. It is then maintained at that temperature for an extended period of time before being cooled in air. Steels that have been normalised have been strengthened while also becoming more difficult to work with (Rahman et al., 2016). When it is in its normalised state, steel has a strength that is unmatched by any other material. As a result of this, components that need to be resistant

to impact or have the capacity to withstand extremely high external pressures are frequently normalised. The difference that occurs in the distance between the cementite plates in pearlite as a result of annealing and normalising is depicted in the following figure 2.17. Cementite has an extremely brittle structure, in contrast to the extremely malleable ferrite. They tend to harden the ferrite by bringing the cementite plates in normalised medium pearlite closer together. This prevents the ferrite from yielding as easily, which leads to an increase in the material's overall hardness.



Figure 2.17 Difference on pearlitic structure due to annealing and normalizing (Practical Maintenance » Blog Archive » Heat Treatment of Steel, n.d.)

### iv. Hardening

Hardening is the most common heat treatment procedure for increasing a metal's hardness. A metal (usually steel or cast iron) must be heated above its upper critical temperature and then rapidly cooled to harden it by quenching. Depending on the alloy and other factors (such as the exchange between maximum hardness and fracture and distortion), cooling can be done with forced air or other gases (such as nitrogen). Because of their increased heat resistance, liquids such as oil, water, a polymer diluted in water, or

brine may be used (Rahman et al., 2016). A portion of austenite transforms into martensite, a hard, brittle crystalline structure, when it is rapidly cooled (depending on the alloy composition). A metal's quenched hardness is determined by its chemical composition and quenching process. Figure 2.18 depicts the steel being rapidly cooled using water after it has been heated.



Figure 2.18 Oil quenching in hardening process (What is oil Quenching? Basics of oil Quenching and Quenching oil Types | Valvoline, n.d.)

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# 2.9.3 Heat Treatment on Welded Joint

In the oil and gas (upstream, midstream, and downstream) industries, as well as the chemical processing industries, welding is a critical component in operating and maintaining assets. While welding has many applications, it can unintentionally damage equipment by transferring residual stresses into the material, causing material properties to deteriorate. PWHT (Post Weld Heat Treatment) is a process that is commonly used to ensure that a component's material strength is maintained after welding.

PWHT can help improve material strength by reducing residual stresses, controlling hardness, and reducing residual stresses (Moore & Booth, 2015). Following welding, heat treatment may be used for one or more of the following reasons:

- i. To achieve dimensional stability so that tolerances are maintained during machining operations or service shake-down.
- ii. To design and fabricate novel metallurgical structures with the required mechanical properties.
- iii. By reducing residual stress in the welded component, the possibility of inservice problems such as stress corrosion or brittle fracture is reduced.

Residual stresses can combine with load stresses to exceed a material's design limitations if PWHT is done incorrectly or not at all. This can lead to weld failures, increased cracking potential, and increased brittle fracture sensitivity. In general, the higher a material's carbon content, the more likely it is to require PWHT after welding procedures. Likewise, the higher the alloy content and cross sectional thickness of a material, the more likely it is to require PWHT.

# 2.10 Summary of Literature Review

Gas Metal Arc Welding (GMAW), also known as metal inert gas (MIG) welding, is a type of welding in which an electric arc is formed between a wire electrode and the metal workpiece being welded. This type of welding is abbreviated as "GMAW." The welds produced by GMAW are of a higher quality and more aesthetically pleasing than those produced by shielded metal arc welding (SMAW). The welding current is the most important variable to consider when carrying out an arc welding procedure. Carbon steels are classified as alloy steels by the Alloy Steels Research Committee (ASRC), which defines carbon steels as "steels containing less than 0.5 percent manganese and 0.5 percent silicon." All other types of steel are considered to be carbon steels. On the basis of the amount of carbon it contains, carbon steel can be divided into one of three categories: low carbon, medium carbon, and high carbon steel.

Carbon steel is an iron alloy that contains up to 2 percent carbon, which indirectly increases the material's strength. Because of this, carbon steel is an essential component in the oil and gas industries. In the production of steel, as well as in welding and joining, heat treatment is frequently utilised, with post-weld heat treatment concentrating on the weld bead and joining metal. A metal that has been soaked for a long period of time will exhibit different microstructure changes in comparison to a metal that has been soaked for a short amount of time. This is because the characteristics of a metal are influenced by the length of the soak time. Heat treatment is essential for achieving the best characteristics and can be used to either soften or condition a metal (as in the case of normalising and annealing) or to harden a metal (as in the case of hardening, quenching, and tempering). Heat treatment is essential for achieving the best characteristics.

#### **CHAPTER 3**

### METHODOLOGY

### 3.1 Introduction

This chapter 3 provide a detailed description of the processes that were carried out in order to determine the effect that heat treatment has on the mechanical properties and microstructure of low carbon steel joints that have been filled with ER70s filler metals. Previous researchers have also looked into this study, tested their hypotheses, and investigated the effect that heat treatment has on low carbon steels. This information has been presented in order to demonstrate a perspective on how this work is carried out through studies and processes for the potential application of particular fields and areas that are included in this subject.

Figure 3.1 presents a flow chart that illustrates the general internal process that was carried out for the purpose of this study. In the first stage of this research project, the preparation of specimens involves making a butt joint between two plates of low carbon steel using the GMAW welding process to create V-shaped welding grooves. After that, a series of nondestructive tests were performed on the specimen in order to identify any defects it might have. After that, the sample was fragmented into smaller pieces with dimensions of 50 mm x 10 mm and x 12 mm thickness for hardness and microstructure tests. Samples for impact are measured as 55 mm x 10 mm and x 10 mm thickness. Annealing and tempering are two types of heat treatment processes that were used on these samples. After the samples had completed the heat treatment process, they were put

through a series of tests to evaluate their mechanical properties, including a test to determine their level of hardness and an impact test. Analytical scanning techniques, such as an optical microscope which is scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDX) were utilised in order to study the microstructure elements of the welded low carbon steel. This was done in order to identify the material characterization. Following that, all of the data was analysed in order to reach a conclusion about the study.







# **3.2 Preparation of workpiece**

Among the items required for the preparation of this workpiece is a low carbon steel plate with single V groove weld preparation on the surface that will be joined. This faying surface shaped also known as edge preparation before welding has the potential to increase the weld's strength. A butt weld is the type of joint that is most suitable for this type of fabrication and the most common type of joint that is used for this type of fabrication. This is because these two pieces of metal are placed together in the same plane and duet o the the faying surface (v-groove) that has been done. The dimension of the workpiece is as mention in the Figure 3.2 and 3.3.



Figure 3.2 Dimension of workpiece 1



Figure 3.3 Dimension of workpiece 2

# 3.2.1 Process of Gas Metal Arc Welding (GMAW)

Butt joints which are a well-known form of joint were applied in this study in accordance with the standard established by the American Welding Society (AWS). These joints were the types that were used in this study. The concept behind the butt joint is quite comparable to that which is utilised in the welding sector. Shielded metal arc welding was both the technique that had to be used in order to keep the quality of the welding work that was being done and the type of welding that was used for the purposes of this study (GMAW). The Gas Metal Arc Welder (GMAW) was selected because it is compatible with a wide range of industries, it is easy to operate, and it does not require any additional safety measures. However, precautions need to be taken in order to ensure both good safety and quality welding. The following is the procedure that was followed when performing GMAW welding:

i. The design of the weld joint can take a number of different forms. However, for the purposes of this study, the butt joint was selected.

- ii. Butt welds can be created in a number of different ways, and each of these methods serves a distinct function. The layering, as well as the width of the gap and the shape of the groove, are all variable factors. The v-groove shape was chosen as it is one of the most suitable for the this type of weld joint used and offers an advantage in increasing the weld strength.
- iii. The ER70s filler metal electrode was utilised in the process of welding the butt joint.
- iv. Both the current setup and the amp were adjusted appropriately.

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v. The travel speed of the welding in order to ensure that the welded joint receives sufficient penetration.

This parameter needs careful monitoring in order to prevent and get rid of internal flaws and cracks that are caused by insufficient welding techniques. When the current was abnormally weak, the appropriate speed ought to have been decreased as well. To eliminate the potential for corrosion and to ensure the integrity of the welded joint, the groove needs to be completely filled in.

# 3.3 Non-Destructive Test (NDT)

The non-destructive testing (NDT) approach was a way to examine the qualities of a material, component, structure, or system for one-of-a-kind variations, as well as welding faults and discontinuities, without causing any harm to the original item being tested. This kind of examination was carried out before the heat treatment test on the sample set could

be carried out in order to check the quality of the sample. Liquid penetrant testing and radiography were utilised in order to guarantee the quality of the sample, the welded connection, and the continuity of the sample that was utilised for this research project.

### 3.3.1 Liquid Penetrant Inspection

The sample underwent inspection using liquid penetrant testing, which looked for flaws in the weld sample that had not previously been spotted. To begin with, the representative was cleaned with a cleaner to remove any foreign substance that might have been on the surface of the sample. After that, a light spraying of the liquid penetrant was done onto the surface of the test plate that had previously been cleaned. The sample was allowed to dry for approximately seven to ten minutes, but this time frame varied depending on the temperature of the base metal. After that, the surface was thoroughly cleaned with the cleanser to remove any trace of the penetrant that had been left behind. Then, wait for an additional two to five minutes, until it has completely dried. The developer was applied to the surface by spraying a thin layer onto it, and then the process was left alone for approximately ten minutes before the indication appeared, as depicted in Figure 3.4 of the process. Figure 3.5 depicted the applicant that was used in the liquid penetrant testing, and Figure 3.6 demonstrated the indication that was used in the liquid penetrant inspection.



Use SKC-S (Cleaner) and spray on a cloth and wire brush to clean the surface of the weld test specimen from any impurities.




Figure 3.4 Procedure of liquid penetrant inspection



Figure 3.5 The applicant used for testing liquid penentrants; (a) SKC-S cleaner, (b) FLUXO P 125 red penetrant, (c) FLUXO 7



Removal of the penetrant and cleaning

Residual penetrant within the discontinuity

Figure 3.6 Illustration of liquid penetrant through weld surface (American Testing Services | Understanding Your Inspection – Liquid Penetrant -American Testing Services, n.d.)

#### **3.3.2 Radiographic Testing**

Radiographic testing (RT), also known as non-destructive testing (NDT), is a technique that analyses the internal structure of manufactured components in order to find flaws or defects. This technique can be seen in Figure 3.7. Radiographic testing is a non-destructive testing method. During the radiography testing, the sample was placed in the middle, with the radiation source on one side and a sensitive film or detector on the other. As soon as the x-ray or gamma-ray radiation was turned on, the density and thickness of the material that made up the test part would absorb some of the radiation. If the specimen were thicker and denser, then less radiation would be able to pass through it.

The amount of radiation (also known as a radiograph) that travelled through the test specimen and arrived at the film was captured on film (or by an electronic device) and displayed as a radiograph. Examining the radiograph's data is an easy way to locate any flaws that may be present. If the substance was whole and free of imperfections, then the rays passed through it in an equal and consistent manner. Rays travelling through the faults were absorbed to a minor level due to the changed density of the material when it came from a source that contained imperfections. As a result of the fact that the defects in the parent metal caused it to have a lower density, the defective metals were able to transmit radiation much more effectively than the sound metal. As a direct consequence of this, the radiograph film appeared to be darker in the area where the defects were exposed. The Figure 3.7 show the mechanism of how this radiography test works.



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## 3.4 Cutting of Sample for Testing

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In order to improve the data collection, the samples were sliced into the appropriate dimensions for the subsequent experimentation and sample analysis. Before beginning the welding process, the raw materials were chosen and then processed to remove any contaminants that might have been present. Following the butting of the plates together, a waterjet machine was used to cut the welded plate to the appropriate length and width. The drawing of the sample was created in AutoCAD before it went through the waterjet process, and the size of the sample was measured to be 50 mm x 10 mm x 10 mm for hardness and microstructure test sample and 55 mm x 10 mm x 10 mm for impact test sample.

#### 3.4.1 Abrasive Water Jet Cutting Process

As can be seen in Figure 3.8, the workpiece was divided into smaller samples with the assistance of the waterjet machine. This was accomplished by slicing a very thin line into the material being processed with an extremely high-pressure stream of water. The cutting power of the waterjet is increased by adding a granular abrasive to it in order to achieve the required level of precision in the cutting. The drawing used to cut the workpiece can be seen in Figure 3.9 and 3.10, it was created using Autocad software.



Figure 3.8 The procedures of waterjet cutting



Figure 3.9 Pieces of work 1 with top view dimension for abrasive water jet cutting



Figure 3.10 Pieces of work 2 with top view dimension for abrasive water jet cutting

## 3.5 Heat Treatment Process

The effects of heat treatment were the most significant for this investigation. This is because whether or not heat treatment had an effect on the performance of the sample had a significant impact on how the overall research turned out. For the purpose of this project, two distinct types of heat treatment processes, namely tempering and annealing, were utilised as parameters. Figure 3.11 displayed the steps required for the sample to go through the process of tempering, while Figure 3.12 displayed the steps required for the sample to go through the annealing process.



Figure 3.11 The steps involved in the annealing process



Figure 3.12 The steps involved in the tempering process

The temperatures that have been used during the annealing test process are  $950^{\circ}$  C and  $500^{\circ}$  C for tempering. Both samples were soak for about 2 hours. After completion of the heat treatment annealing method, the samples were cooled at room temperature. As for tempering, it is a little different where the cooling is using a quenching method that uses oil.

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## **3.6** Mechanical Test

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The properties of a material that require a response to an applied load are referred to as its mechanical properties. The mechanical properties of metals had an effect on the range of applications for the material and, as a result, the expected service life. The characteristics of strength, ductility, hardness, impact resistance, and fracture strength are the ones that are examined the most frequently. In response to changes in temperature, loading rate, and other factors, the material's mechanical properties do not remain constant over time. Rockwell hardness was used to test materials for their macro hardness as well as their resistance to impact, and Charpy testing was used to investigate how materials behaved when subjected to high rates of deformation.

## 3.6.1 Hardness Test (Rockwell Hardness)

A hardness tester, such as the one shown in Figure 3.13, was the method that was utilised the majority of the time in order to evaluate the macrohardness behaviour of treated and untreated materials. A ball indenter was used to make the impressions in the samples. The indentation was made on the surface of the three primary regions, which are the base metal, the weld material, and the heat-affected zone (HAZ). In addition to that, many different layers of indentation testing were carried out in order to verify and



Figure 3.13 Mitutoyo HR-400 Rockwell Hardness Tester



Figure 3.14 Process to obtain the hardness value of each layer of specimen

## 3.6.2 Impact Test

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Impact testing was utilised in order to determine the relative toughness of a material, as well as its impact toughness. Impact tests are useful because they can determine the amount of energy that a material absorbs when it fractures. This information can be used to improve products. This absorbed energy is an indicator for a material's toughness, and it would be used to investigate the temperature-dependent brittle-ductile transition if it were found to exist. The goal was to establish whether or not the material in question is ductile or brittle. For the purpose of this experiment, the impact test was carried out in accordance with the standards of ASTM E23 using the Charpy method. The purpose of this investigation is to determine whether or not the materials are ductile or brittle. In addition to that, the Charpy test and the standards established by ASTM E23 were utilised in the impact test.

#### **3.6.2.1** The Charpy Test

The Charpy impact tester performed was following the ASTM E23, which can also be referred to as the Charpy V-notch test and is depicted in figure 3.16, is a strain rate test that involved impacting a standard notched sample with a controlled weight pendulum as it swung from a height that was previously determined. The examples that are depicted in figure 3.17 were the ones that were utilised the most and were deemed acceptable by the majority of people. For the purpose of this investigation, a specimen of type A was used. These are the standard Charpy V-notch specimens, and their dimensions are 55 mm in length, 10 mm in square, and they have a notch that is 2 mm deep and is machined on one face. The notch's tip radius is 0.25 mm. The sample was held in place by an anvil at both ends, and the face of the anvil that was opposite the notch was where it was struck by the pendulum. The amount of energy that was taken in while the sample was being broken was measured, and this would give an approximation of the notch toughness of the material being tested. During the experiment, the pendulum will swing back and forth, and the height of the swing will indicate the total amount of energy that was used up in the process of breaking the sample.



Figure 3.15 Instron CEAST 9050 Pendulum Impact Tester



Figure 3.16 The Charpy test method (Charpy Impact Steel Testing: Part One :: Total Materia Article, n.d.)



Figure 3.17 Charpy (Simple-Beam) impact test specimens (ASTM E23, 2015)

#### 3.7 Microstructure Characterization

The microstructure of a material is defined as the structure of a material's prepared surface as seen through a microscope with a magnification of 25 or higher. The microstructure of a material is a structure that is on a very small scale. It is possible for the microstructure of a material (such as metals, polymers, ceramics, or composites) to have a significant impact on the material's physical properties, which may include its resistance to corrosion, high or low temperature behaviour, or wear resistance. The analysis of the microstructure was very important. In most cases, the microstructure was analysed with the help of an optical microscope, a suitable metallurgical preparation, scanning electron microscopy (SEM), and energy dispersive x-ray spectroscopy (EDS) (EDX). In order to achieve a surface that is reflective like a mirror, the sample is polished using sandpaper of varying grits and sizes, such as 1000 µm, 2000 µm, and

diamond polishing pieces. After that, the sample will be etched in Nital solution for ten seconds in order to give the microstructure machine a clear view of the sample's structure.

#### **3.7.1** Optical Microscope

An optical microscope, such as the one depicted in Figure 3.18, consisted of one or more lenses that magnified the image of a sample that was placed within the focal plane of the lens. It is essential that an optical microscope be correctly configured in order to obtain an image that is true to its subject matter. Some of the components that make up an optical microscope can be rather complicated. The fundamental concepts involved in the functioning of an optical microscope can be broken down into manageable chunks. The objective lens of an optical microscope, such as the one shown in figure 3.20, was analogous to the performance of a very powerful magnifying glass. Because it has a short focal length, the lens needs to be kept relatively close to the object being examined so that it can function properly.

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Because of this, the light coming from the specimen was focused at a distance of approximately 160 mm inside the tube of the microscope, producing an image that was magnified and flipped upside down. The objective lens was responsible for producing the actual image, while the ocular lens was responsible for magnifying it to a point where it could be observed by a person. The majority of optical microscopes use an eyepiece called a compound lens eyepiece, which has one lens at the front of the eyepiece tube and another lens at the back of the eyepiece tube. The formation of a couplet as a consequence of this causes the virtual image to focus between the lenses, which in turn enables the eye to concentrate on the target. After using an optical microscope, the stage was lowered in order to make it easier to remove the microscope slide.



Figure 3.18 Zeiss AxioLab A1 Upright Light Microscope with AxioCam Erc



Figure 3.19 ZEISS EC EPIPLAN objectives lens (Micro-Lenses, n.d.)

# 3.7.2 Scanning Electron Microscopy (SEM) & Energy Dispersive X-Ray Spectroscopy (EDX)

Scanning electron microscopy as shown in Figure 3.20, also known as SEM, is a method that allows for a very detailed examination of the cells that make up a sample. The preparation of samples is not particularly difficult, and the SEM procedure does not

necessitate the processing of ultra-thin sheets even when dealing with a wide variety of samples. This is as a result of the fact that SEM can be used to analyse and calculate evaluations on a scale that can range anywhere from millimetres to nanometers. When using a low magnification, the SEM is able to receive a large sample size all at once; when using a higher magnification, however, high-resolution images of particular regions can be obtained. Energy-dispersive X-ray spectroscopy, or EDS for short, is a function that can be performed by every single SEM.

When used in conjunction with conventional SEM analysis, energy dispersive Xray spectroscopy (EDX) can provide a more comprehensive view of a sample's local chemical composition. The equipment of EDX can be seen in Figure 3.21. When an atom is hit by an electron beam, it produces characteristic X-rays that are specific to its atomic number. Because of this, it is possible to analyse the elemental composition of a material, either at a single location or across a large region, using methods such as line scanning and elemental mapping. Analyses of a more qualitative nature can also be utilised in the process of determining the chemical make-up of a substance.



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Figure 3.20 Zeiss EVO Scanning Electron Microscope



Figure 3.21 JEOL JSM 6010 PLUS/LV Scanning Electron Microscope



#### **CHAPTER 4**

#### **RESULTS AND DISCUSSION**

### 4.1 Introduction

The findings of this study are analysed in order to make a prediction about the expected outcome or result of the upcoming test that was the subject of the research. However, once the real results of the analysis have been obtained, the findings can be open to discussion. The preliminary findings from the sample tests are also addressed, despite the fact that they are not the final data that will determine the direction that the research will go. This subject is utilised in the process of determining and investigating the initial data expectations.

## 4.2 Composition of Welded Joint

Chemical composition entails qualitative testing of numerous sample components in conjunction with structured analytical approaches, which may necessitate the synthesis and production of delicate chemical composites and chemical reactions. In addition to quantitative analysis of the correlation coefficients of substances in various chemical reagents, the discovered substance's molecular structure was detected and validated across multiple platforms (Boumerzoug et al., 2010). The chemical compositions of the ER70s filler metal material and the low carbon steel material were shown in Table 4.1.

Elements	Low carbon steel (% wt)	Filler metal ER70s (% wt)	
Iron (Fe)	98.4	98.1	
Carbon (C)	0.174	0.104	
Manganese (Mn)	0.620	0.521	
Phosporus (P)	0.0277	0.0229	
Sulphur (S)	0.0212	0.0108	
Silicon (Si)	0.176	0.238	
Titanium (Ti)	0.0126	0.00436	
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Table 4.1 Chemical composition of low carbon steel and ER70s filler metal

To summarise, steel is frequently classified based on its carbon content. Low-carbon steel has a carbon content of less than 0.30%. Table 4.1 demonstrates that the carbon percentage of low carbon steel is 0.174%, which is lower than 0.3%. The low carbon steel's carbon content which can be seen in table 4.1 has been proven to have a carbon content of 0.174% which is less than 0.30%.

#### 4.3 Welded Structure

Low carbon steel plates were joined as shown in Figure 4.1 by welding them together at speeds and voltages sufficient for the thickness and speed of the steel plates. The steel plate is not submerged in water after the weld is finished; rather, it is allowed to slowly cool to ambient temperature while being exposed to the air.



## 4.4 Non destructive test

The term "non-destructive testing" refers to a range of inspection procedures that enable inspectors to assess and gather data about a material, system, or component without permanently altering it. These methods fall under the category of "inspection methods". In this particular investigation, the sample, the welded joint, and the continuity of the sample are all subjected to several tests, including radiographic and liquid penetrant examinations.

#### 4.4.1 Liquid penetrant testing

A non destructive test was performed on the workpiece and after placing the developer (white contrast), the dye penetrant showed the presence of a porosity and spatter type of defect on the welded zone as shown in Figure 4.2. According to the earlier article by (Wang et al., 2022), as the welding speed increases, the porosity also increases dramatically, and large pores begin to appear. The weld speeds will determine the pore size distributions in the joints that are produced.

For the spatter defect, (Cheng et al., 2021) once says that the process parameters have obvious effects on the fluid flow characteristics in the melt pool and the dynamic behaviours of metal vapour in the keyhole, both of which affect the spatter behaviours. These behaviours are in turn affected by the process parameters. When the power and speed parameters are set to their lowest settings, the fluid flow in the melt pool becomes unstable.



Figure 4.2 Porosity and spatter defect

## 4.4.2 Radiographic testing

Radiographic Testing also have been done which uses gamma rays to examine any flaws or defects in the internal structure. As a result for this testing, there is no crack or any defect occur on the inside of the welded zone. This result can be seen in the figure 4.3 and 4.4.



Figure 4.3 Result radiography sample 2

#### 4.5 Heat treatment process

Tempering and annealing are two different kinds of heat treatment techniques, and they are the ones that were used as parameters in this study. The annealing test process has utilised temperatures of 950 degrees Celsius, while the tempering temperature was set at 500 degrees Celsius. After the heat treatment annealing procedure had been finished, the samples were allowed to cool down at room temperature. When it comes to tempering, things are done a little bit differently because the cooling is done through a quenching procedure that makes use of oil. As a result the appearance of each sample was different, as can be seen in Figure 4.5, which can be found below. It is possible to tell which sample group is which just by looking at them: the annealed sample has a dark grey coating on the outside of its surface, the tempered sample has a brownish colour, and the untreated sample has maintained its initial appearance.



Figure 4.5 Visual appearances after treated; (a) Untreated (b) Tempered (c) Annealed

## 4.6 Microstructure analysis

The microstructure technique was an alternate strategy that was utilised in order to detect and recognise the traits that were shared by all three group samples. According to

the technique, the purpose of these tests is to determine the size of the grain by using equipment that is supported by a microscope.

## 4.5.1 Optical microscope

According to the approach, this test is utilised to determine the grain size by utilising equipment that is supported by a microscope. Figure 4.6 was a representation of how the untreated sample's grain development looked. According to the figure that can be found below, the findings of the microstructural analysis showed that the starting grain size had a substantial influence on the phases that were generated in the intercritical HAZ. In addition, there is evidence of both pearlite and martensite being present.



Figure 4.6 Microstructure of each region on the untreated sample; (a) Weld zone (b) Fusion (c) Coarse Grained zone (CGHAZ) (d) Fine grained zone (FGHAZ) (e) Inter-critical zone (IGHAZ) (f) Base metal



After undergoing tempering at 500 degrees Celsius, the microstructure of the pearlite could be observed, as shown in figure 4.7 below. The creation of black patches signified the formation of pearlite or cementite, whereas white spots suggested the formation of ferrite. Pearlite is formed by a eutectoid reaction as austenite cools below 723 °C (1,333 °F) during slow cooling of an iron-carbon alloy (the eutectoid temperature) (Sankaran et al., 2003). In addition, there were no discernible microstructural differences between any of the areas. This is due to the fact that there were no fine needle-like structures present in the welded area.



Figure 4.7 Microstructure of each region on the tempered sample; (a) Weld zone (b) Fusion (c) Coarse grained zone (CGHAZ) (d) Fine grained zone (FGHAZ) (e) Inter-critical zone (IGHAZ) (f) Base metal

The microstructure of each region of the annealed sample was illustrated in Figure 4.8. The transformation of austenite into soft pearlite, which was then mixed with ferrite or cementite, took place during the annealing process, which is characterised by a rapid cooling of oil-based quench. In comparison to the grain size of the untreated sample, the grain size of the microstructure was significantly smaller where the base metal was concerned. The decrease amount of pearlite in the steel results in soft but increase in ductility. It is undergoing a progressive transformation into fine needle-like (fragmented) martensite as it passes through the zone where it was welded. Martensite is a body-centered tetragonal (BCT) supersaturated solid solution of carbon in ferrite. Carbon is trapped in the crystal structure after fast cooling (Liu et al., 2023).



Figure 4.8 Microstructure of each region on the annealed sample; (a) Base metal (b) Inter-critical zone (IGHAZ) (c) Fine grained zone (d) Coarse grained zone (CGHAZ) (e) Fusion boundary zone (f) Weld zone



4.5.2 Line scanning by EDX

The capacity of an EDX machine to perform an analysis of the elements and compounds found in a sample while the instrument is operating in a low vacuum mode is one of its distinguishing characteristics. The findings of the analysis performed on the sample that was submitted have been displayed. In order to examine the surface of the low carbon steel sample, a line scanning test was carried out, as can be seen in Figure 4.9. The colour that corresponds to the amount of each element that can be found in the sample between the base and the welded sections. In accordance with Figure 4.9, it demonstrated

the presence of the following elements in the untreated sample: Carbon (C) and Iron (Fe). A graph with a red colour represents the element Carbon (C) and a graph with blue light represents the element Iron (Fe). It was discovered that the element carbon had the largest weight percentage of all treated sample but contain the lowest in iron.



Figure 4.9 Element and compound in untreated sample; (a) Electron image (b) EDX spectrum (c) Carbon (d) Iron

Referring to Figure 4.10, a line scanning test was carried out on the surface of the base metal and the welded joint area sample. The colour of the sample was meant to reflect the amount of the element that was present in the space that was created by the base metal and the welded junction. According to figure 4.10, it demonstrated the element content that

was discovered between the base metal and the welded joint area. The sample has been demonstrated to include a variety of different types of components based on its coloration. The element having Carbon (C) was demonstrated by the red graph, while the presence of Iron (Fe) was shown by the blue light graph. It was demonstrated that this tempered sample was in medium range between those two parameter in elements of iron and carbon contain.



Figure 4.10 Element and compound in tempered sample; (a) Electron image (b) EDX spectrum (c) Carbon (d) Iron

According to figure 4.11, it demonstrated the element content that was discovered between the base metal and the welded connection area. The sample has been demonstrated to include a variety of different types of components based on its coloration. The element having Carbon (C) was demonstrated by the red graph. The graph with the light blue colour contained the element Iron (Fe). It was demonstrated that this annealed heat treatment resulting in high contain of iron elements compared to the other parameter but lowest in carbon contain.



Figure 4.11 Element and compound in annealed sample; (a) Electron image (b) EDX spectrum (c) Carbon (d) Iron

# 4.7 Mechanical testing

The qualities of a substance that may be determined by how it reacts to a force that is exerted on it are referred to as its mechanical characteristics. The variety of applications that might be used with a particular material was influenced by the material's mechanical qualities, which in turn had an effect on the estimated service life of the material. The properties of a material that are examined the most commonly include its strength, ductility, hardness, impact resistance, and fracture strength. The material's mechanical characteristics do not stay the same over time as a result of changes in temperature, loading rate, and other factors. This is because the material is being worked over time. The Rockwell hardness test was used to determine a material's microhardness in addition to its resistance to impact, and the Charpy test was used to determine how a material reacted when subjected to high rates of deformation.

## 4.7.1 Hardness testing

The microhardness behaviour of treated and untreated materials was measured with a hardness tester. An indenter ball was used to make the marks in the samples. Three main areas, the base metal, the weld material, and the heat-affected zone (HAZ) as shown in figure 4.12 all had their surfaces indented. In addition, extensive indentation testing at various depths was performed to ensure the accuracy of the results.



Figure 4.12 Multiple layers of indention on the same surface 88

The measurements were carried out in a dispersed manner, and the area of the cross-sectional area that was given the most consideration was the area of the Heat Affected Zone (HAZ) and the weld joint. This is the region of the cross-sectional area in which the fusion reaction and the growing of microstructure variations are most active, as demonstrated in Table 4.2.

UNTREATED SAMPLE					
No	Area	Top (HRA)	Centre (HRA)	Bottom (HRA)	
1		44.9	43.8	41	
2	WALAYSIA	42.4	42.7	42.6	
3	Base metal	43.4	44.6	44.2	
4	TEK	45.2	45	44.4	
5	LIN .	44.4	-44.2	44.4	
6	*AINN	51.4	46.6	44.9	
7	ىل ملىسىكملاك	49	48.6	46.3	
8		46.9	52.4	49.5	
9	UNIVERSITIER	61.3	60.9	60.1	
10	Welded joint	60.9	61.4	60.9	
11		62.3	62.1	59.5	
12		61	58.1	50.2	
13		46.2	46.2	46.1	
14	HAZ	46.9	46.3	45.5	
15		48.9	46.1	45.5	

Table 4.2 Result from the hardness test of untreated sample

16		46.1	45	44.9
17		45	45.1	44.6
18	Base metal	44.4	44.1	44
19		43.6	43.6	43.5
20		41.9	43.9	42.2

Table 4.2 Continue

A line graph representing an untreated sample was presented in Figure 4.13. The line pattern does not fall inside the typical range. As is evident in the region of the welded joint, it was higher than both the HAZ and the base metal. This is due to the fact that the structure at the weld joint was very simple in comparison to that of other regions.



Figure 4.13 Hardness graph of untreated sample

TEMPERED SAMPLE				
No	Area	Top (HRA)	Centre (HRA)	Bottom (HRA)
1		43.3	42.8	42.3
2		42.9	43.7	43.6
3	Base metal	43.7	44.5	44.6
4		44.4	44.6	44.9
5		45.1	45.8	45.7
6		46.9	47.4	47.5
7	HAZ	49.4	50.2	49.8
8		51.6	52.2	51.5
9	WALAYSIA 44	56.8	57.8	59.1
10	Welded joint	56.3	58.1	59
11		56.5	57.9	59.4
12	L.S.	57.3	58.3	55.9
13	Ann -	48.6	47.6	48
14	ل مليسية HAZ	47.2	ىيۇىر47.1يتى ت	48.1
15	UNIVERSITI TEK	47.4	47.3	47.3
16		45.5	44.7	45.1
17		44.3	44.5	44.2
18	Base metal	44.2	44.4	44
19		43.9	43.8	43.6
20		42.7	43.6	42.9

Table 4.3 Result from the hardness test of tempered sample

Figure 4.14 shows that the tempered specimen has a lower hardness than the annealed specimen. This is consistent with (Tkalcec et al, 2004) finding that the decrease in hardness value was caused by the microstructural change that occurs during tempering,
which includes the loss of the acicular martensite pattern and the precipitation of tiny carbide particles. Tempered martensite is the name given to this microstructure. Tempering, according to (Edmonds et al., 2006) causes a rapid decrease in retained austenite content due to transformations of retained austenite to martensite constituent. The martensite hardness decreases continuously as carbon precipitates, indicating that it is primarily influenced by carbon in solid solution. Furthermore, (Suchanek et al., 2009) discussed other factors that cause a drop in hardness of tempered specimens, such as tempering relieving internal stress and causing carbon to diffuse from martensite carbide. This method enables microstructure transformation, which reduces hardness to the desired level while increasing ductility.



Figure 4.14 Hardness graph of tempered sample

ANNEALED SAMPLE											
No	Area	AreaTop (HRA)Centre (HRA)									
1		49.8	50.5	49.8							
2		50.3	50.3	49.1							
3	Base metal	50.6	50	49.9							
4		50.5	50.7	49.5							
5		50.9	49.7	49.8							
6		49.9	49.7	49.5							
7	HAZ	50.2	49.5	49.5							
8		50.6	49.5	49.4							
9	A MALAYSIA MA	49.2	50.5	49.6							
10	Welded joint	62.8	52.8	49.1							
11		62.8	63.5	61.4							
12	L'attac	63	63.4	41.5							
13	de la	48.5	49	49.6							
14	ل مليسياHAZ	50	ىيوىر 49.2 يى د	9 49.9							
15	UNIVERSITI TEK	NIKAL MAL		49.5							
16		49.7	49.7	49.5							
17		49.4	49.3	49.5							
18	Base metal	49.6	49.5	49.8							
19		49.8	49.6	50							
20		49.5	49.7	50							

Table 4.4 Result from the hardness test of annealed sample

The results of measuring the hardness of the annealed sample were displayed in Figure 4.15. When compared to an untreated sample graph, the line patterns in each location were about the same on average. The higher hardness of quenched specimen might be attributed to the formation of fine martensite resulting from fast cooling rate (S M Mahbobur, 2016). Even though the line pattern is fairly typical, the annealed sample has a much lower value of hardness at the HAZ and weld junction when compared to the tempered and untreated samples.



Figure 4.15 Hardness graph of annealed sample

# 4.6.2 Impact testing

Impact testing was utilised in order to establish the relative toughness of a material, in addition to its impact toughness, and this was accomplished by subjecting the material to force. Impact tests are helpful because they can quantify the amount of energy that a material absorbs when it fractures. This information may be used to design more effective safety measures. Utilizing this information may result in improved product quality. This absorbed energy is an indicator for a material's toughness, and it would be used to explore the temperature-dependent brittle-ductile transition if it were found to exist if it were discovered that it does exist (Srivastava et al., 2021). Finding out whether or not the material in question is ductile or brittle was the objective of the investigation. The impact test was carried out for the purpose of this experiment utilising the Charpy method in compliance with the requirements established by ASTM E23. This examination is being carried out with the goal of determining whether or not the materials are ductile or brittle. In addition to that, the ASTM E23 standards as well as the Charpy test were utilised in the impact test. The results of the impact test are displayed in the Table 4.5 that can be found below. Meanwhile, Figures 4.16 and 4.17 exhibit the bar graph of the impact test.



Figure 4.16 Condition of specimen before impact; (a) Untreated (b) Annealed (c) Tempered



Figure 4.17 Condition of specimen after impact; (a) Untreated (b) Annealed (c) Tempered

Type of sample	Part	Impact value (kJ/m <sup>2</sup> )	Energy consumed (J)	Type of Fracture
Untreated	Centre NIVERSI	129.381 FI TEKNIKAL N	217.5	AKA Ductile
	HAZ	23.496	42.5	Brittle
Annealed	Centre	138.761	233.75	Ductile
	HAZ	75.597	128.75	Brittle
Tempered	centre	99.208	166.25	Ductile
	HAZ	65.898	101.25	Brittle

Table 4.5 Charpy test result

Figure 4.18 bar graph illustrated that the toughness of the heat-treated samples and the untreated sample did not have significantly different result values. This was

demonstrated by the comparison of the two sets of samples. This is due to the fact that the area surrounding the welded joint is robust, and since the structure does not change, this explains why the result does not indicate a substantial difference. The material is more ductile and more impact-resistant at high temperatures (Barbosa et al., 2021).



Figure 4.18 Impact test bar graph for welded joint (Centre)

On the other side of impact area as can be shown in figure 4.19, each sample exhibited a significantly higher value in the HAZ region. The annealed sample slightly lower in value when compared to the annealed value at the welded connection but still the highest compare to the other two sample of HAZ. This is due to the fact that each surface of the annealed sample has a structure that is nearly identical to one another. At the HAZ area, the structure of the surface area was more subtle, which is why the toughness of the tempered sample decreased there. Low temperatures make a material more brittle and reduce its impact toughness.



4.6.3 Fracture Study by SEM

Scanning electron microscopy, which is commonly referred to as SEM was a method used to enables an extremely in-depth analysis of the cells that comprise a sample. The scanning was done for all the 3 parameters samples and 2 different spot each which is at the middle of the sample (weld zone) and Heat Affected Zone (HAZ) that already completed hit by impact test (charpy test). The result obtain was to show whether the sample was brittle or ductile. Based on the Figure 4.20 below shows that tempered and annealed was in a ductile condition as displaying a dimpled ductile fracture which is

thought to be connected with. This prove that microscope result that shows the changes of grain size effect the toughness of the sample (Valdes-Tabernero et al., 2020). Meanwhile, overall brittle failure with mostly cleavage fractures shows for the untreated sample as no heat applied.



Figure 4.20 SEM micrographs of Heat Affected Zone (Centre); (a) untreated (b) tempered (c) annealed

Next is the observation for the result at the Heat Affected Zone (HAZ) spot that can be seen in Figure 4.21 below. It can be said that all are in a brittle form where no elongation occurs and the flat surface on the surface of the three sample parameters shows that the sample was easily to break.



Figure 4.21 SEM micrographs of welded joint (HAZ) ); (a) untreated (b) tempered (c) annealed

# 4.6.4 Fracture Analysis by EDX MALAYSIA MELAKA

EDX analysis is one of the methods that can be utilised while doing element analysis or the chemical characterisation of samples. After the sample has been subjected to heat treatment, this is to demonstrate that there are still additional chemical elements present. According to figure 4.22, the element content can be seen in the graph. The element contained is 1.89% for Carbon (C) and contain 1.72% of Oxygen (O)



Figure 4.22 Elemental mapping analysis for untreated sample; (a) Electron image (b) EDX

In Figure 4.23, as the sample got heated, the elements Carbon (C) which have a red colour, make up 1.92% of the welded zone and contain 1.85% oxygen. While Iron (Fe) elements make up 96.23% of the tempered sample.



Figure 4.23 Elemental mapping analysis for tempered sample; (a) Electron image (b) EDX spectrum (c) Carbon (d) Oxygen (e) Iron

According to figure 4.24, the blue-colored elements that contain oxygen (O) have the highest content percentage of any other parameter sample, which comes out to 2.41%. As this annealed parameter was quench with oil, so that it resulted in comparison to the elements of carbon (C). The carbon content of quenching media increases depending on the nature of the fluid that can cool the specimen. Because of the rapid rate of cooling, atoms may not escape from the specimen, trapping carbon atoms inside (Dodo et al., 2020). The red graph showed an element carbon (C), which had a content of 2.27% in the sample. Iron (Fe) had a content of 95.32%, which was only slightly lowest than the sample of untreated and tempered sample.



Figure 4.24 Elemental mapping analysis for annealed sample; (a) Electron image (b) EDX spectrum (c) Carbon (d) Oxygen (e) Iron

### **CHAPTER 5**

## **CONCLUSIONS AND RECOMMENDATION**

### 5.1 Conclusion

- 1. We were able to study the welded joint of low carbon steel joint with filler ER70s and the effect of heat treatment on the mechanical and microstructural properties by performing hardness and impact test during this process. Specifically, we were able to study the welded joint of low carbon steel joint with filler ER70s. In addition, we were able to conduct the non-destructive test by making use of radiography inspection and liquid penetrant testing. The purpose of this study was to investigate the effects that heat treatment can have on the mechanical properties and microstructure in the HAZ and welded joint areas.
- 2. The non-destructive test known as NDT is always performed on non-porous materials, and it consists of two distinct processes that are used to identify surface flaws in the material. These tests are particularly efficient because the specimens are examined using techniques that do not compromise the dependability or functioning of the material that is being assessed. The specimen indicated that there was not a surface defect against the welded joint after being subjected to a dye penetrant test and radiography testing to determine whether or not there was a surface defect against the welded joint.

- 3. The specimen is then put through the processes of tempering and annealing after it has been sliced with an abrasive water jet. This research looks at three different types of samples: untreated, tempered, and annealed materials. The samples intended for tempering were left in the furnace at 500 degrees Celsius for approximately two hours, while the samples intended for annealing were left in the furnace for half an hour at 950 degrees Celsius. The samples were cooled to room temperature using an oil-based quenching method, however there was a minor variation between the untreated and treated samples. The results of the method of heat treatment are that the appearances of each sample group are distinguishable to the naked eye. For example, the annealed sample has a crispy dark grey coating outside its surface, the tempered sample has a brownish colour, and the untreated sample has maintained its initial appearance.
- 4. Following the completion of the heat treatment, it is necessary to carry out a mechanical test. The tests for impact and hardness that were carried out were for the purpose of conducting mechanical testing. The findings of the impact test revealed that the annealed sample is superior to the tempered and untreated samples in terms of its level of strength. However, in the HAZ zone, three of the samples were hardy and robust enough to crack at the welded connection. The results of hardness testing demonstrated that heat treatment can reinforce the structure, which ultimately results in a sample that is both more ductile and stronger.
- 5. An optical microscope, a Scanning Electron Microscopy (SEM) machine, and an Energy Dispersive X-Ray Spectroscopy (EDX) instrument were all utilised in the process of material characterization. Before starting the microscope and EDX, the 104

sample needs to be polished to the point where it looks like a mirror using sandpaper and a diamond polisher sheet. The sample must then undergo an etching process with Nital for ten seconds. Nital is utilised in order to improve visibility of the structure when viewed through a variety of lens diameters while utilising an optical microscope. The results of the microstructure test revealed that the annealed sample possessed a delicate structure, particularly in the area of the welded joint. For the SEM, the process was done after doing an impact test (charphy test) to observe whether the sample ductile or brittle in-depth analysis of the cells that comprise a sample.

6. Based on the outcomes of several forms of heat treatment, annealing offered the greatest results. The annealing process heats materials to extremely high temperatures, improving workability, increasing toughness, decreasing hardness, and increasing ductility and machinability. Beside quenching is a most better rate cooling method to be used in hardened steel by inducing a martensite transformation, where the steel rapidly cooled through its eutectoid point, the temperature at which austenite becomes unstable. The metal was cooled quickly by submerging it into oil which gave it extra hardness. It has given a "freeze" effect on the material's microstructure. The austenite-induced state is rapidly cooled until it transforms into its martensite form, which is a brittle configuration. To sum up, the main purpose of annealing is to make metal alloys less hard and more flexible. After being quenched, low-carbon steel tends to get brittle, which makes it more likely to break. By balancing the properties of metal alloys, annealing makes them stronger and more durable for a wide range of uses. For example, annealing can be used to lessen the effects of drawing, grinding, roll forming, or bending, so that the

metal can be worked on further. It is also used to get rid of stresses caused by welding.

# 5.2 Recommendation for future

- 1. During the course of the term, a number of challenges and constraints related to this study were faced. During process cut of the workpiece, the waterjet cutting machine suffered damage and there is no other suitable cutting machine option because most of the existing cutting machines will affect the pre heat sample and the cutting diameter is too large except for edm wire cut but it takes a long time to cut.
- 2. Next for the process of polishing, which is done to prepare the sample for microstructure and etching, the polished surface must not be touched or swept with a dry cloth. This is because making contact with a foreign surface can compromise the integrity of the polished surface, which could lead to a scratch. In addition to the procedure that takes place before the microstructure studies, the time spent immersing the sample in the liquid that makes up the Nital solution during the etching should not be longer than ten seconds. This is done to prevent the surface sample from being over-etched. In the event that there is excessive etching, the method for polishing must be started over from the very beginning. Besides that, the sample should be stored in a sealed place because it will make the sample rusty and affect the result in the process involving microstructure. The gap between the processes needs to be done more closely.

# 5.3 **Project Potential**

- Heat treatment is an important process in the oil and gas industry. Through changes in hardness, strength, toughness, ductility and elasticity of materials, it gives the ability to alter the metallurgical characteristics of piping and equipment to better suit their intended applications. There are many mechanical integrity aspects of heat treatment that ensure the desired outcome is not only achieved, but that it is achieved safely and without negatively affecting the asset. When done properly heat treating adds beneficial properties, most often essential characteristics to the component.
- 2. Although high carbon steel is stronger, but it is not used widely for all oil and gas applications, because it is more expensive to produce than carbon steel. Low-carbon steel contains a lower percentage of carbon content, making it cheaper to produce but also weaker than its counterpart. By not changing the material and increasing the cost of the material, because of that it is necessary to make a heat treatment over to improve their characteristics.

### REFERENCES

Kumar, H., Kumar, N., & Engineering, R. N. C. (2019). A Survey on Gas Metal Arc Welding (GMAW) -Review. 7(01), 595–600.

Singh, R. (2020). 6 - Classification of steels. In R. Singh (Ed.), *Applied Welding Engineering (Third Edition)* (Third Edit, pp. 53–60). Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-12-821348-3.00014-8

Primo, J. (2014). Gas Metal Arc Welding – GMAW Best Practices. *ME Mechanical*, 514. Zones (Hazs) In Steels Used In Constructing Offshore Platforms. In *Welding in EnergyRelated Projects* (pp. 415–428). Pergamon.

https://doi.org/https://doi.org/10.1016/B978-0-08-025412-8.50044-9

Wahab, M. A. (2014). 6.03 - Manual Metal Arc Welding and Gas Metal Arc Welding. In S. Hashmi, G. F. Batalha, C. J. Van Tyne, & B. Yilbas (Eds.), *Comprehensive Materials Processing* (pp. 49–76). Elsevier.

https://doi.org/https://doi.org/10.1016/B978-0-08-096532-1.00610-5

Owolabi, O. B., Aduloju, S. C., Metu, C. S., Chukwunyelu, C. E., & Okwuego, E. C. (2016). Evaluation of the Effects of Welding Current on Mechanical Properties of Welded Joints Between Mild Steel and Low Carbon Steel. *American Journal of Materials Science and Application*, *4*(1), 1–4.

Boumerzoug, Z., Derfouf, C., & Baudin, T. (2010). Effect of Welding on Microstructure and Mechanical Properties of an Industrial Low Carbon Steel. *Engineering*, *02*(07), 502–506. https://doi.org/10.4236/eng.2010.27066

Metals., A. S. for, & International., A. S. M. (1997). *Metals handbook. Volume 1, Volume 1,*. ASM International.

Jenney, C. L., & O'Brien, A. (1991). Welding Handbook\_Volume 1\_Welding Science And Technology. *American Welding Society*, *1*, 982.

WALAYSIA

Vural, M. (2014). 6.02 - Welding Processes and Technologies. In S. Hashmi, G. F.
Batalha, C. J. Van Tyne, & B. Yilbas (Eds.), *Comprehensive Materials Processing* (pp. 3–48). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-08-096532-1.00603-8

ونبؤم سيتي تنكنيكا مليسيا ملاك

Abioye, T. E., Ariwoola, O. E., Ogedengbe, T. I., Farayibi, P. K., & Gbadeyan, O. O.(2019). Effects of welding speed on the microstructure and corrosion behavior ofdissimilar gas metal arc weld joints of AISI 304 stainless steel and low carbon steel.MaterialsToday:Proceedings,17,871–877.https://doi.org/10.1016/j.matpr.2019.06.383

Moore, P., & Booth, G. (2015). 13 - Improving the fracture performance and fatigue life of welded joints. In P. Moore & G. Booth (Eds.), *The Welding Engineer's Guide to Fracture and Fatigue* (pp. 185–195). Woodhead Publishing. https://doi.org/https://doi.org/10.1533/9781782423911.2.185

Mesquita, R. A., Barbosa, C. A., & Machado, A. R. (2017). 2.9 Heat Treatment of Tool Steels. In M. S. J. Hashmi (Ed.), *Comprehensive Materials Finishing* (pp. 214–245). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-803581-8.09191-8

Phoumiphon, N., Othman, R., & Ismail, A. B. (2016). Improvement in Mechanical Properties

ALAYSIA

Plain Low Carbon Steel Via Cold Rolling and Intercritical Annealing. *Procedia Chemistry*, 19, 822–827. https://doi.org/https://doi.org/10.1016/j.proche.2016.03.108

Pisarski, H. G., & Pargeter, R. J. (1984). Fracture Toughness of Weld Heat Affected UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Nayak, S. S., Biro, E., & Zhou, Y. (2015). 5 - Laser welding of advanced high-strength steels (AHSS). In M. Shome & M. Tumuluru (Eds.), *Welding and Joining of Advanced High Strength Steels (AHSS)* (pp. 71–92). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-85709-436-0.00005-9

Adedayo, A. V, Ibitoye, S. A., & Oyetoyan, O. A. (2010). Annealing Heat Treatment Effects on Steel Welds. 9(6), 547–557.

Chandra Kandpal, B., Gupta, D. K., Kumar, A., Kumar Jaisal, A., Kumar Ranjan, A., Srivastava, A., & Chaudhary, P. (2020). Effect of heat treatment on properties and microstructure of steels. *Materials Today: Proceedings*, *44*, 199–205. https://doi.org/10.1016/j.matpr.2020.08.556

Evans, R. (2012). 2 - Selection and testing of metalworking fluids. In V. P. Astakhov & S. Joksch (Eds.), *Metalworking Fluids (MWFs) for Cutting and Grinding* (pp. 23–78). Woodhead Publishing. https://doi.org/https://doi.org/10.1533/9780857095305.23

Deepak, J. R., Bupesh Raja, V. K., Srikanth, D., Surendran, H., & Nickolas, M. M. (2020). Non-destructive testing (NDT) techniques for low carbon steel welded joints: A review and experimental study. *Materials Today: Proceedings*, *44*, 3732–3737. https://doi.org/10.1016/j.matpr.2020.11.578

ASTM. (2015). E23-07a - Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. *ASTM International*, *14*(C), 28. https://doi.org/10.1520/E002307AE01.2

Rahman, S. M. M., Karim, K. E., & Simanto, M. H. S. (2016). Effect of Heat Treatment on Low Carbon Steel: An Experimental Investigation. *Applied Mechanics and Materials*, 860, 7–12. https://doi.org/10.4028/www.scientific.net/amm.860.7 Reyes, A., Bedolla, E., Perez, R., & Contreras, A. (2017). Effect of heat treatment on the mechanical and microstructural characterization of Mg-AZ91E/TiC composites. *Composite Interfaces*, 24(6), 593–609. https://doi.org/10.1080/09276440.2017.1248201

Prabakaran, M. P., & Kannan, G. R. (2021). Effects of post-weld heat treatment on dissimilar laser welded joints of austenitic stainless steel to low carbon steel. *International Journal of Pressure Vessels and Piping*, *191*(January), 104322. https://doi.org/10.1016/j.ijpvp.2021.104322

Frihat, M. H. (2015). Effect of Heat Treatment Parameters on the Mechanical and Microstructure Properties of Low-Alloy Steel. *Journal of Surface Engineered Materials and Advanced Technology*, 05(04), 214–227. https://doi.org/10.4236/jsemat.2015.54023

Valdes-Tabernero, M. A., Kumar, A., Petrov, R. H., Monclus, M. A., Molina-Aldareguia, J. M., & Sabirov, I. (2020). The sensitivity of the microstructure and properties to the peak temperature in an ultrafast heat treated low carbon-steel. *Materials Science and Engineering A*, 776(January), 138999. https://doi.org/10.1016/j.msea.2020.138999

Jeong, S., Lee, Y., Park, G., Kim, B., Moon, J., Park, S.-J., & Lee, C. (2021). Phase transformation and the mechanical characteristics of heat-affected zones in austenitic Fe– Mn–Al–Cr–C lightweight steel during post-weld heat treatment. *Materials Characterization*, *177*, 111150.

https://doi.org/https://doi.org/10.1016/j.matchar.2021.111150

Krauss, G. (2017). 4 - Physical metallurgy of steels: An overview In R. Rana & S. B.
Singh (Eds.), *Automotive Steels* (pp. 95–111). Woodhead Publishing.
https://doi.org/https://doi.org/10.1016/B978-0-08-100638-2.00004-3

Kučerová, L., Jandová, A., & Rubešová, K. (2019). Microstructure analysis and mechanical properties of low alloyed steel with retained austenite obtained by heat treatment. *Manufacturing Technology*, *19*(2), 243–247.

https://doi.org/10.21062/ujep/277.2019/a/1213-2489/mt/19/2/243

ALAYSIA

Hajili, S. (2017). School Of Industrial And Information Welding processes for joining dissimilar metals and plastics.

https://www.researchgate.net/publication/323254307\_Advanced\_Manufacturing\_Weldi ng \_processes\_for\_joining\_dissimilar\_metals\_and\_plastics/references Hnizdil, M., & Chabicovsky, M. (2018). Experimental study of in-line heat treatment of 1.0577 structural steel. *Procedia Manufacturing*, *15*, 1596–1603. https://doi.org/https://doi.org/10.1016/j.promfg.2018.07.305

Cheng, H., Zhou, L., Li, Q., Du, D., & Chang, B. (2021). Effect of welding parameters on spatter formation in full-penetration laser welding of titanium alloys. *Journal of Materials Research and Technology*, *15*, 5516–5525. https://doi.org/10.1016/J.JMRT.2021.11.006 de Oliveira Moraes, D., Júnior, P. Z., Moraes e Oliveira, V. H. P., de Oliveira, A. C., & Filho, J. da C. P. (2022). Effect of the girth welding interpass temperature on the toughness of the HAZ of a Ni-based superalloy 625 clad API 5L X65 pipe welded joint. *Journal of Materials Research and Technology*. https://doi.org/10.1016/J.JMRT.2022.05.141

Ding, X., Ma, H., Zhang, Q., Yang, J., Li, D., & Fan, S. (2022). Effect of annealing heat treatment on microstructure and corrosion behavior of Ti6Al4V alloy fabricated by multi-laser beam wire-feed additive manufacturing in vacuum environment. *Journal of Alloys* and *Compounds*, 914, 165363. https://doi.org/10.1016/J.JALLCOM.2022.165363

Wang, Q., Wang, X., Chen, X., Huan, P., Dong, Q., Zhang, Q., & Nagaumi, H. (2022). Interactive effects of porosity and microstructure on strength of 6063 aluminum alloy CMT MIX + Synchropulse welded joint. *Transactions of Nonferrous Metals Society of China*, 32(3), 801–811. https://doi.org/10.1016/S1003-6326(22)65834-5

### **APPPENDICES**

### APPENDIX A ASTM E23

Designation: E23 – 12c

# Standard Test Methods for Notched Bar Impact Testing of Metallic Materials<sup>1</sup>

This standard is issued under the fixed designation E23; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

#### 1. Scope

1.1 These test methods describe notched-bar impact testing of metallic materials by the Charpy (simple-beam) test and the Izod (cantilever-beam) test. They give the requirements for: test specimens, test procedures, test reports, test machines (see Annex A1) verifying Charpy impact machines (see Annex A2), optional test specimen configurations (see Annex A3), designation of test specimen orientation (see Terminology E1823), and determining the percent of shear fracture on the surface of broken impact specimens (see Annex A4). In addition, information is provided on the significance of notched-bar impact testing (see Appendix X1), and methods of measuring the center of strike (see Appendix X2).

1.2 These test methods do not address the problems associated with impact testing at temperatures below -196 °C (77 K).

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3.1 *Exception*—Section 8 and Annex A4 provide inchpound units for information only.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 5.

#### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

B925 Practices for Production and Preparation of Powder Metallurgy (PM) Test Specimens E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E604 Test Method for Dynamic Tear Testing of Metallic Materials

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1823 Terminology Relating to Fatigue and Fracture Testing E2298 Test Method for Instrumented Impact Testing of Metallic Materials

#### 3. Summary of Test Method

3.1 The essential features of an impact test are: a suitable specimen (specimens of several different types are recognized), a set of anvils, and specimen supports on which the test specimen is placed to receive the blow of the moving mass, a moving mass that has sufficient energy to break the specimen placed in its path, and a device for measuring the energy absorbed by the broken specimen.

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### 4. Significance and Use

4.1 These test methods of impact testing relate specifically to the behavior of metal when subjected to a single application of a force resulting in multi-axial stresses associated with a notch, coupled with high rates of loading and in some cases with high or low temperatures. For some materials and temperatures the results of impact tests on notched specimens, when correlated with service experience, have been found to predict the likelihood of brittle fracture accurately. Further information on significance appears in Appendix X1.

#### 5. Precautions in Operation of Machine

5.1 Safety precautions should be taken to protect personnel from the swinging pendulum, flying broken specimens, and hazards associated with specimen warming and cooling media.

#### 6. Apparatus

6.1 General Requirements:6.1.1 The testing machine shall be a pendulum type of rigid construction.

6.1.2 The testing machine shall be designed and built to conform with the requirements given in Annex A1.

6.2 Inspection and Verification

1

An American National Standard

<sup>&</sup>lt;sup>1</sup> These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.07 on Impact Testing. Current edition approved Nov. 15, 2012. Published January 2013. Originally

Current edition approved Nov. 15, 2012, Published January 2013, Originally approved in 1933. Last previous edition approved 2012 as E23 – 12b. DOI: 10.1520/E0023-12C.

<sup>&</sup>lt;sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

6.2.1 Inspection procedures to verify impact machines directly are provided in A2.2 and A2.3. The items listed in A2.2 must be inspected annually.

6.2.2 The procedures to verify Charpy V-notch machines indirectly, using verification specimens, are given in A2.4. Charpy impact machines must be verified directly and indirectly annually.

#### 7. Test Specimens

7.1 Configuration and Orientation:

7.1.1 Specimens shall be taken from the material as specified by the applicable specification.

7.1.2 The type of specimen chosen depends largely upon the characteristics of the material to be tested. A given specimen may not be equally satisfactory for soft nonferrous metals and hardened steels; therefore, many types of specimens are recognized. In general, sharper and deeper notches are required to distinguish differences in very ductile materials or when using low testing velocities.

7.1.3 The specimens shown in Figs. 1 and 2 are those most

widely used and most generally satisfactory. They are particularly suitable for ferrous metals, excepting cast iron.<sup>3</sup>

7.1.4 The specimens commonly found suitable for powder metallurgy materials are shown in Figs. 3 and 4. Powder metallurgy impact test specimens shall be produced following the procedure in Practice B925. The impact test results of these materials are affected by specimen orientation. Therefore, unless otherwise specified, the position of the specimen in the machine shall be such that the pendulum will strike a surface that is parallel to the compacting direction. For powder metallurgy materials the impact test results are reported as unnotched absorbed impact energy.

7.1.5 Sub-size and supplementary specimen recommendations are given in Annex A3.

7.2 Specimen Machining:

7.2.1 When heat-treated materials are being evaluated, the specimen shall be finish machined, including notching, after

<sup>3</sup> Report of Subcommittee XV on Impact Testing of Committee A-3 on Cast Iron, Proceedings, ASTM, Vol 33 Part 1, 1933.



FIG. 1 Charpy (Simple-Beam) Impact Test Specimens, Types A, B, and C



the final heat treatment, unless it can be demonstrated that the impact properties of specimens machined before heat treatment are identical to those machined after heat treatment.

7.2.2 Notches shall be smoothly machined but polishing has proven generally unnecessary. However, since variations in notch dimensions will seriously affect the results of the tests, adhering to the tolerances given in Fig. 1 is necessary (Appendix X1.2 illustrates the effects from varying notch dimensions on Type A specimens). In keyhole specimens, the round hole shall be carefully drilled with a slow feed rate. The slot may be cut by any feasible method, but care must be exercised in cutting the slot to ensure that the surface of the drilled hole opposite the slot is not damaged.

7.2.3 Identification marks shall only be placed in the following locations on specimens: either of the 10-mm square ends; the side of the specimen that faces up when the specimen is positioned in the anvils (see Note 1); or the side of the specimen opposite the notch. No markings, on any side of the specimen, shall be within 10 mm of the center line of the notch. Permanent markers, laser engraving, scribes, electrostatic pencils, and other reasonable marking methods may be used for identification purposes. However, some marking methods can result in damage to the specimens if not used correctly. For example, excessive heat from electrostatic pencils or deformation to the specimen from stamping can change the mechanical properties of the specimen. Therefore, care must always be taken to avoid damage to the specimen. Stamping and other

marking processes that result in deformation of the specimen should only be used on the ends of the specimens, prior to notching.

Note 1—Careful consideration should be given before placing identification marks on the side of the specimen to be placed up when positioned in the anvils. If the test operator is not careful, the specimen may be placed in the machine with the identification marking resting on the specimen supports (that is, facing down). Under these circumstances, the absorbed energy value obtained may be unreliable.

#### 8. Procedure

8.1 Preparation of the Apparatus:

8.1.1 Perform a routine procedure for checking impact machines at the beginning of each day, each shift, or just prior to testing on a machine used intermittently. It is recommended that the results of these routine checks be kept in a log book for the machine. After the testing machine has been ascertained to comply with Annex A1 and Annex A2, carry out the routine check as follows:

8.1.1.1 Visually examine the striker and anvils for obvious damage and wear.

8.1.1.2 Check the zero position of the machine by using the following procedure: raise the pendulum to the latched position, move the pointer to near the maximum capacity of the range being used, release the pendulum, and read the indicated value. The pointer should indicate zero on machines reading directly in energy. On machines reading in degrees, the reading should correspond to zero on the conversion chart furnished by the machine manufacturer.

Nore 2—On machines that do not compensate for windage and friction losses, the pointer will not indicate zero. In this case, the indicated values, when converted to energy, shall be corrected for frictional assumed to be proportional to the arc of swing.

8.1.1.3 The friction and windage loss shall not exceed 0.4 % of the scale range being tested and should not change by more than 10 % of the percent friction and windage loss measurements previously recorded on the machine. If the percent friction and windage loss does exceed 0.4 % or is significantly different from previous measurements, check the indicating mechanism, the latch height, and the bearings for wear and damage. However, if the machine has not been used recently, let the pendulum swing for 50 to 100 cycles, and repeat the percent friction and windage test before undertaking repairs to the machine. To ensure that friction and windage losses are within allowable tolerances, use one of the following evaluation procedures:

(1) For a machine equipped with an analog scale:

Raise the pendulum to the latched position; Move the pointer to the maximum scale value being used; Release the pendulum (without a specimen in the machine); Allow the pendulum to cycle five times (a forward and a backward swing together count as one cycle); Prior to the sixth forward swing set the pointer to between 5 and 10 % of the maximum scale value being used; After the sixth forward swing record the value indicated by the pointer (convert to energy if necessary); Divide the energy reading by 10; Divide by the maximum scale value being used, and Multiply by 100 to get the percent friction and windage loss.

(2) A machine equipped with a digital display: Determine the percent friction and windage loss per manufacturer's procedure. (3) For machine equipped with both an analog scale and digital display:

Determine the friction and windage loss using the same indicating device used to report absorbed energy (10.2.4 and A2.4).

Note 3—Prior to the 2012 version, the percent friction and windage was based on 11 (half) swings and the pointer was not engaged on the first swing. Now the pointer is engaged on the first swing. The difference is that the friction, windage, and pointer losses associated with the first swing are no longer assumed to be zero. On the 1st swing the pointer should go to 0.00, so any friction that will be recorded will only show up on the following 10 (half) swings.

8.2 Test Temperature Considerations:

8.2.1 The temperature of testing affects the impact properties of most materials. For materials with a body centered cubic structure, a transition in fracture mode occurs over a temperature range that depends on the chemical composition and microstructure of the material. Test temperatures may be chosen to characterize material behavior at fixed values, or over a range of temperatures to characterize the transition region, lower shelf, or upper shelf behavior, or all of these. The choice of test temperature is the responsibility of the user of this test method and will depend on the specific application. For tests performed at room temperature, a temperature of 20 °C ± 5°C is recommended.

8.2.2 The temperature of a specimen can change significantly during the interval it is removed from the temperature conditioning environment, transferred to the impact machine, and the fracture event is completed (see Note 6). When using a heating or cooling medium near its boiling point, use data from the references in Note 6 or calibration data with thermocouples to confirm that the specimen is within the stated temperature tolerances when the striker contacts the specimen. If excessive adiabatic heating is expected, monitor the specimen temperature near the notch during fracture.

8.2.3 Verify temperature-measuring equipment at least every six months. If liquid-in-glass thermometers are used, an initial verification shall be sufficient, however, the device shall be inspected for problems, such as the separation of liquid, at least twice annually.

8.2.4 Hold the specimen at the desired temperature within °C ( $\pm 2^{\circ}$ F) in the temperature conditioning environment. Any method of heating or cooling or transferring the specimen to the anvils may be used provided the temperature of the specimen immediately prior to fracture is essentially the same as the holding temperature (see Note 6). The maximum change in the temperature of the specimen allowed for the interval between the temperature conditioning treatment and impact is not specified here, because it is dependent on the material being tested and the application. The user of nontraditional or lesser used temperature conditioning and transfer methods (or specimen sizes) shall show that the temperature change for the specimen prior to impact is comparable to or less than the temperature change for a standard size specimen of the same material that has been thermally conditioned in a commonly used medium (oil, air, nitrogen, acetone, methanol), and transferred for impact within 5 seconds (see Note 6). Three temperature conditioning and transfer methods used in the past are: liquid bath thermal conditioning and transfer to the

specimen supports with centering tongs; furnace thermal conditioning and robotic transfer to the specimen supports; placement of the specimen on the supports followed by in situ heating and cooling.

8.2.4.1 For liquid bath cooling or heating use a suitable container, which has a grid or another type of specimen positioning fixture. Cover the specimens, when immersed, with at least 25 mm (1 in.) of the liquid, and position so that the notch area is not closer than 25 mm to the sides or bottom of the container, and no part of the specimen is in contact with the container. Place the device used to measure the temperature of the bath in the center of a group of the specimens. Agitate the bath and hold at the desired temperature within  $\pm 1^{\circ}C (\pm 2^{\circ}F)$ . Thermally condition the specimens for at least 5 min before testing, unless a shorter thermal conditioning time can be shown to be valid by measurements with thermocouples. Leave the device (tongs, for example) used to handle the specimens in the bath for at least 5 min before testing, and return the device to the bath between tests.

8.2.4.2 When using a gas medium, position the specimens so that the gas circulates around them and hold the gas at the desired temperature within  $\pm$  1°C ( $\pm$  2°F) for at least 30 min. Leave the device used to remove the specimen from the medium in the medium except when handling the specimens.

Nore 4—Temperatures up to +260°C may be obtained with certain oils, but "flash-point" temperatures must be carefully observed. Nore 5—For testing at temperatures down to -196°C (77 °K), standard

testing procedures have been found to be adequate for most metals. Note 6-A study has shown that a specime heated to 100 °C in water

Nore 6—A study has shown that a specime heated to 100 °C in water can cool 10 °C in the 5 s allowed for transfer to the specimen supports (1)<sup>4</sup>. Other studies, using cooling media that are above their boiling points at room temperature have also shown large changes in specimen temperature during the transfer of specimens to the machine anvils. In addition, some materials change temperature dramatically during impact testing at cryogenic temperatures due to adiabatic heating (2).

8.3 Charpy Test Procedure:

8.3.1 The Charpy test procedure may be summarized as follows: the test specimen is thermally conditioned and positioned on the specimen supports against the anvils; the pendulum is released without vibration, and the specimen is impacted by the striker. Information is obtained from the machine and from the broken specimen.

8.3.2 To position a test specimen in the machine, it is recommended that self-centering tongs similar to those shown in Fig. 5 be used (see A1.10.1). The tongs illustrated in Fig. 5 are for centering V-notch specimens. If keyhole specimens are used, modification of the tong design may be necessary. If an end-centering device is used, caution must be taken to ensure that low-energy high-strength specimens will not rebound off this device into the pendulum and cause erroneously high recorded values. Many such devices are permanent fixtures of machines, and if the clearance between the end of a specimen in the test position and the centering device is not approximately 13 mm, the broken specimens may rebound into the pendulum.

8.3.3 To conduct the test, prepare the machine by raising the pendulum to the latched position, set the energy indicator at the

maximum scale reading, or initialize the digital display, or both, position the specimen on the anvils, and release the pendulum. If a liquid bath or gas medium is being used for thermal conditioning, perform the following sequence in less than 5 s (for standard  $10 \times 10 \times 55$  mm ( $0.394 \times 0.394 \times 2.165$ in.) specimens, see 8.2.4). Remove the test specimen from its cooling (or heating) medium with centering tongs that have been temperature conditioned with the test specimen, place the specimen in the test position, and release the pendulum smoothly. If a test specimen has been removed from the temperature conditioning bath and it is questionable that the test can be conducted within the 5 s time frame, return the specimen to the bath for the time required in 8.2 before testing.

8.3.3.1 If a fractured impact specimen does not separate into two pieces, report it as unbroken (see 9.2.2 for separation instructions). Unbroken specimens with absorbed energies of less than 80 % of the machine capacity may be averaged with values from broken specimens. If the individual values are not listed, report the percent of unbroken specimens with the average. If the absorbed energy exceeds 80 % of the machine capacity and the specimen passes completely between the anvils, report the value as approximate (see 10.1) and do not average it with other values. If an unbroken specimen does not pass between the machine anvils, (for example, it stops the pendulum), the result shall be reported as exceeding the machine capacity. A specimen shall never be struck more than once.

8.3.3.2 If a specimen jams in the machine, disregard the results and check the machine thoroughly for damage or misalignment, which would affect its calibration.

8.3.3.3 To prevent recording an erroneous value, caused by jarring the indicator when locking the pendulum in its upright (ready) position, read the value for each test from the indicator prior to locking the pendulum for the next test.

8.4 Izod Test Procedure:

8.4.1 The Izod test procedure may be summarized as follows: the test specimen is positioned in the specimenholding fixture and the pendulum is released without vibration. Information is obtained from the machine and from the broken specimen. The details are described as follows:

8.4.2 Testing at temperatures other than room temperature is difficult because the specimen-holding fixture for Izod specimens is often part of the base of the machine and cannot be readily cooled (or heated). Consequently, Izod testing is not recommended at other than room temperature.

8.4.3 Clamp the specimen firmly in the support vise so that the centerline of the notch is in the plane of the top of the vise within 0.125 mm. Set the energy indicator at the maximum scale reading, and release the pendulum smoothly. Sections 8.3.3.1 - 8.3.3.3, also apply when testing Izod specimens.

#### 9. Information Obtainable from Impact Tests

9.1 *The absorbed energy* shall be taken as the difference between the energy in the striking member at the instant of impact with the specimen and the energy remaining after breaking the specimen. This value is determined by the machine's scale reading which has been corrected for windage and friction losses.

 $<sup>^{\</sup>rm 4}$  The boldface numbers given in parentheses refer to a list of references at the end of the text.

		WEEK (BDP 1)													
PROJECT ACTIVITIES	STATUS	MARCH					AF	PRIL		MAY				JUNE	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
MEETING WITH	PLAN														
SUPERVISOR & TITLE REVIEW	ACTUAL														
FINDING JOURNAL	PLAN	2													
RESEARCH	ACTUAL	P.													
<b>CHAPTER 1: INTRODUCTION</b>	PLAN	,A						1	1						
1	ACTUAL								2			1			
CHAPTER 2: LITERATURE	PLAN														
REVIEW	ACTUAL														
CHAPTER 3:	PLAN				/						5				
METHODOLOGY	ACTUAL														
NON-DESTRUCTIVE TEST	PLAN					1									
-Mal	ACTUAL		<		:4		D.			41					
DRAFT REPORT	PLAN	5						6		V	1	2			
	ACTUAL							- 10							
REVISE DRAFT REPORT	PLAN	EM	NI	K A	1 1	1.0	1. 1	ve	A.	ME	LA	V/			
ONIVER	ACTUAL	E.C	LINE.	n M		n A	L-M	2	5		L./*	ITV?			
SUBMISSION FINAL	PLAN														
REPORT, VIDEO & SLIDE	ACTUAL														
QUESTION & ANSWER	PLAN														
SESSION WITH PANEL	ACTUAL														

# APPENDIX B GANTT CHART BDP 1

		WEEK (BDP 1)													
PROJECT ACTIVITIES	STATUS	OCTOBER			NOVEMBER					DECEMBER				JANUARY	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
MEETING WITH	PLAN														
SUPERVISOR	ACTUAL														
RUN AN EXPERIMENT	PLAN														
~	ACTUAL														
DATA COLLECTION AND	PLAN														
ANALYSIS	ACTUAL	Sec.													
CHAPTER 4: RESULT AND	PLAN	2						1		1.					
DISCUSSION	ACTUAL											V.	1		
CHAPTER 5: CONCLUSION	PLAN											τ,			
AND RECOMMENDATION	ACTUAL														
SUBMISSION DRAFT	PLAN				1										
REPORT	ACTUAL														
REVISE DRAFT REPORT	PLAN		e .												
2 Mal	ACTUAL	$\langle \langle C \rangle \rangle$		5	• <		5		÷.			•			
PREPARING FINAL REPORT	PLAN	-					-	1	50		V	2	27		
	ACTUAL														
PROJECT PRESENTATION	PLAN	1.00											1.00		
UNIVER	ACTUAL	KP	IIK	AL	. N	A	_A	13	216		IE	_A	KA		

# APPENDIX C GANTT CHART BDP 2