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

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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.

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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.

Signature : ....

Supervisor Name : Ts. Dr. Mohd Fauzi Bin Mamat

Date : 09 January 2023

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 surface-breaking 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 $138.761\,\mathrm{kJ/m^2}$ at centre of the weld joint and $75.597\,\mathrm{kJ/m^2}$ 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 $138.761\ \mathrm{kJ/m^2}$ di tengah sambungan kimpalan dan $75.597\ \mathrm{kJ/m^2}$ 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	-	Energy Disperse X-Ray
LPT	-	Liquid Penetrant Testing
RT	-	Radiography Testing
FCC	-	Face Centered Cubic
BCC	-	Body Centered Cubic
CO^2	-	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

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

The objective of the research is:

i. To study the non-destructive test utilising liquid penetrant inspection and radiography testing.

ii. 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:

i. 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:

i. 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.

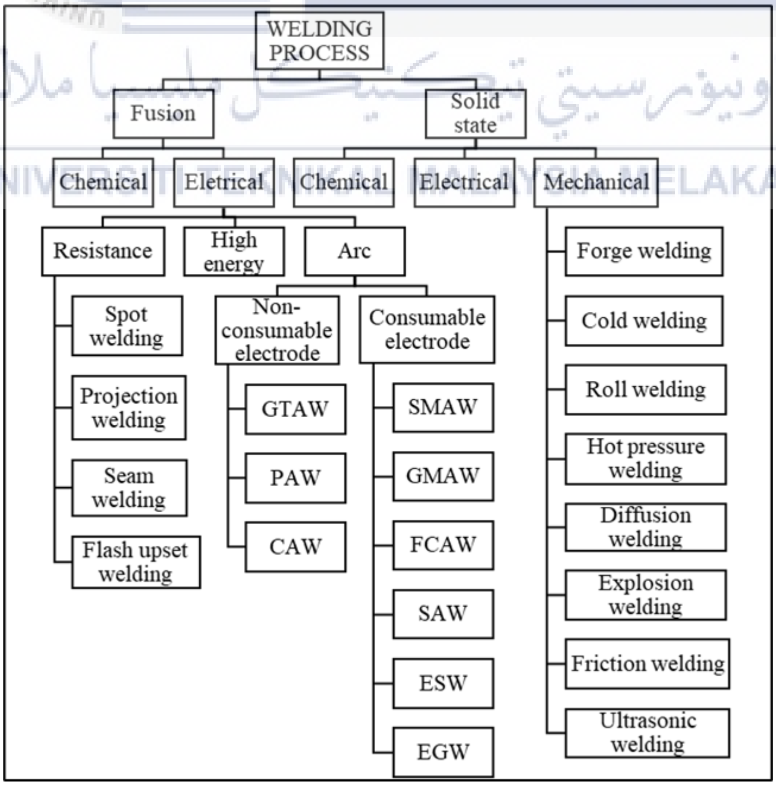

Figure 2.1 Types of welding process
(https://www.weldingandndt.com/, 2017)