THE EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL WELDED JOINT WITH ER70S FILLER METAL

NUR ALIYA ALINA BT AB RADZAK
B091810078

BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS

2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical and Manufacturing Engineering Technology

THE EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL WELDED JOINT WITH ER70S FILLER METAL

Nur Aliya Alina Binti Ab Radzak

Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

2022

THE EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL WELDED JOINT WITH ER70S FILLER METAL

NUR ALIYA ALINA BINTI AB RADZAK

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

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

Signature :

Name : Nur Aliya Alina Binti Ab Radzak

Date : 16 January 2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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 Manufacturing Engineering Technology (Process and Technology) with Honours.

Signature : ....

NUR AIMAN HANIS BINTI HASIM
Pensyarah
Jabatan Teknologi Kejuruteraan Pembuatan
Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan
Universiti Teknikal Malaysia Melaka

Supervisor Name : Puan Nur Aiman Hanis Binti Hasim

Date : 18 January 2022

Signature : ....

Co Supervisor Name : Dr Mohd Fauzi Bin Mamat

DR. MOHD FAUZI BIN MAMAT
Pensyarah kanan
Jabatan Teknologi Industri
Fakulti Teknologi Kejuruteraan Mekanikal Dan Pembuatan (FTKMP)
Universiti Teknikal Malaysia Melaka

Date : 18 January 2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

This report is dedicated to my beloved family in perticular, for their endless love, support and encouragement. To my main supervisor Puan Nur Aiman Hanis Binti Hasim and my co supervisor, 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.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Welding process such as GMAW appears to be growing the fastest, with recent years showing the greatest growth. However, the process during welding, rapid heating and cooling takes place which produce severe thermal cycle near weld line region of any metal that gets submerged in the heating zone. Gas Metal Arc Welding (GMAW), sometimes known as metal inert gas (MIG) welding, is a type of welding method in which an electric arc is produced between a consumable wire electrode and the workpiece metal(s), heating, melting, and joining them. The main objective of this study were to study the welded joint of low carbon steel joint with filler metal ER70s. Next, to carry out the non-destructive test by using radiography testing and liquid penetrant inspection. Last but not least,to study the effect of heat treatment on the mechanical and microstructure properties by performing hardness and impact test. Radiography and liquid penetrant test were conducted to investigate the surface defects on the sample. After that, the sample were cut into 9 samples with the dimension of 55mm x 10mm x 12mm using abrasive water jet. The samples were prepared through two types of heat treatment process which is annealing with the temperature of 900˚C and tempering 450˚C. Next, the material characterization were confirmed through optical microscope and Scanning Electron Microscope (SEM/EDX). The macro hardness test were done by using Rockwell machine to evaluate the microhardness behaviour of treated and untreated samples. Meanwhile, for the impact test, the Charpy test were used to determine the relative toughness or impact toughness of the sample. The impact test results showed similar value of three samples with value 49.885J for untreated sample, 49.860J for tempered sample and 49.884J for annealed were tough and strong enough to break at the welded connection, however at the HAZ area, the annealed sample with value 49.884J is stronger than the tempered which have 48.860J and untreated samples with 47.885J. At annealed sample, the result of the graph showed that the line pattern of each area were in average compared to graph of untreated and tempered sample. Even though the line pattern of annealed sample were in average, but the annealed sample have the lowest value of hardness at HAZ and weld joint compared to tempered and untreated sample. Next, by performing SEM, it shown the presence of Iron (Fe) in the welded joint with 94.95% at untreated sample meanwhile after performing a heat treatment test, it showed that the structure has changed by showing the presence of manganese in the welded join area with 97.56% at tempered sample and 92.72% at annealed sample.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Proses kimpalan seperti GMAW nampaknya berkembang dengan pantas, dengan beberapa tahun kebelakangan ini menunjukkan pertumbuhan yang paling besar. Walau bagaimanapun, proses semasa mengimpal, pemanasan pantas dan penyejukan berlaku yang menghasilkan kitaran haba yang teruk berhampiran kawasan garisan kimpalan mana-mana logam yang terendam dalam zon pemanasan. Kimpalan Arka Logam Gas (GMAW), kadang-kadang dikenali sebagai kimpalan gas lengai logam (MIG), ialah sejenis kaedah kimpalan di mana arka elektrik dihasilkan antara elektrod wayar boleh guna dan logam bahan kerja, pemanasan, lebur, dan menyertai mereka. Objektif utama kajian ini adalah untuk mengkaji sambungan kimpalan sambungan keluli karbon rendah dengan pengisi ER70s. Seterusnya, untuk menjalankan ujian tanpa musnah dengan menggunakan ujian radiografi dan pemeriksaan penembus cecair. Akhir sekali, untuk mengkaji kesan rawatan haba ke atas sifat mekanikal dan struktur mikro dengan melakukan ujian kekerasan dan hentaman. Radiografi dan ujian penembusan cecair telah dijalankan untuk menyiasat kecacatan permukaan pada sampel. Selepas itu, sampel dipotong kepada 9 sampel berdimensi 55mm x 10mm x 12mm menggunakan pancutan air yang kasar. Sampel disediakan melalui dua jenis proses rawatan haba iaitu *annealing* dengan suhu 900˚C dan *tempering* 450˚C. Seterusnya, pencirian bahan disahkan melalui mikroskop optik dan Mikroskop Elektron Pengimbasan (SEM/EDX). Ujian kekerasan makro dilakukan dengan menggunakan mesin *Rockwell* untuk menilai tingkah laku kekerasan mikro bagi sampel yang dirawat dan tidak dirawat. Manakala bagi ujian impak, ujian *Charpy* digunakan untuk menentukan keliatan relatif atau keliatan impak sampel. Keputusan ujian impak menunjukkan nilai yang hampir sama bagi tiga sampel dengan nilai 49.885J untuk sampel yang tidak dirawat, 49.860J untuk sampel *tempered* dan 49.884J untuk *annealed* adalah lasak dan cukup kuat untuk pecah pada sambungan yang dikimpal, namun pada kawasan HAZ, sampel *annealed* dengan nilai 49.884J adalah lebih kuat daripada sampel *tempered* yang mempunyai nilai 48.860J dan sampel yang tidak dirawat dengan nilai 47.885J. Pada sampel *annealed*, keputusan graf menunjukkan bahawa corak garisan setiap kawasan adalah secara purata berbanding dengan graf sampel yang tidak dirawat dan *tempered*. Walaupun corak garisan sampel *annelaed* adalah secara purata, tetapi sampel *annealed* mempunyai nilai kekerasan yang paling rendah pada HAZ dan sambungan kimpalan berbanding sampel *tempered* dan tidak dirawat. Seterusnya, dengan melakukan SEM menunjukkan kehadiran *Iron* (Fe) dalam sambungan kimpalan dengan 94.95% pada sampel yang tidak dirawat manakala selepas melakukan ujian rawatan haba, ia menunjukkan bahawa struktur telah berubah dengan menunjukkan kehadiran *manganese* dalam cantuman yang dikimpal. kawasan dengan 97.56% pada sampel *tempered* dan 92.72% pada sampel *annealed.*

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform.

My utmost appreciation goes to my main supervisor, Puan Nur Aiman Hanis Binti Hasim and my co supervisor, Dr. Mohd Fauzi Bin Mamat for all their support, advice, and inspiration. Their constant patience for guiding and providing priceless insights will forever be remembered.

I would like to give a special thanks to my beloved mother, Hasmah Binti Yong for her endless support, love, and prayers. I dedicated this thesis for you. I would also like to thank my friends especially to my housemates, 807-K for the great supports and friendship. I also would like to thank seven beautiful individuals, BTS for always being there along ups and down in my life. Finally, thank you to all the individual(s) who had provided me the assistance, support, and inspiration to embark on my study.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF SYMBOLS AND ABBREVIATIONS

GMAW	-	Gas Metal Arc Welding
MIG	-	Metal Inert Gas
GTAW		Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
NDT	-	Non-Destructive Test
SEM	-	Scanning Electron Microscope
LPT	-	Liquid Penetrant Testing
EDX	-	Energy Dispersive X-Ray
FCC	-	Face Centered Cubic
BCC	-	Body Centered Cubic
CO_2	-	Carbon Dioxide
ASRC	-	Alloy Steels Research Committee
HSLA	-	High- Strength, Low-Alloy Steel
PWHT	-	Post-Weld Heat Treatment
EBSD	-	Electron Backscatter Diffraction

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPENDICES

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The arc welding segment of the industry appears to be growing the fastest, with recent years showing the greatest growth. Welding is the most common joining method, and most common steels are weldable. These days, it become the most important activity in any manufacturing process, and the quality of welding has a direct effect on the performance of the endproduct. Welding can be defined as the process of joining materials into a single piece (Vural, 2014). As widely known, GMAW is a popular welding technique, particularly in industrial sectors. Gas Metal Arc Welding (GMAW), sometimes known as metal inert gas (MIG) welding, is a type of welding method in which an electric arc is produced between a consumable wire electrode and the workpiece metal(s), heating, melting, and joining them (Hajili, 2017). GMAW produces welds with enhanced mechanical characteristics and is often used because it results in welds that are more attractive as well as of higher quality. This technology is increasingly being applied in the construction industry, as well as pipe joining in the oil and gas industry.

Although the oil and gas industries has an incredible safety record over many decades, failures occasionally occur. Corrosion failures, fatigue failures, and ductile and brittle metal failures are the most common reasons of these failures. Due to the heat treatment process, infrastructure and equipments used in the oil and gas industry tend to last for many years because of the properties in the structures and it became stronger, and can survive severe pressures, temperatures, weights, and conditions (Pourazizi et al., 2020). Heat treatment is the process of heating a metal to a specified temperature, keeping it there, and then cooling it down (Chandra Kandpal et al., 2020). Mechanical characteristics of the metal part will alter during the process. This is due to the fact that high temperatures affect the microstructure of the metal. To sum up, heat treatment is critical for obtaining the appropriate mechanical characteristics and microstructure for a variety of applications. The present study will investigate the mechanical properties and microstructure of low carbon steel joint with ER70s filler metal with different type of heat treatments.

1.2 Problem Statement

During the welding process, rapid heating and cooling occur, causing a severe thermal cycle along the weld line region of any metal submerged in the heating zone. Due to the thermal cycle, the material is not uniformly heated and cooled, resulting in a harder heat affected zone (HAZ), sustaining stress, and a preponderance of cold cracking in the weld metal and base metal. Hazardous stressors that persist regularly cause and impact a wide variety of heating and cooling temperatures. When steel is heated to a certain temperature, it welds well; moreover, the heat generated on it has an unique microstructure from that of the base metal, referred to as the heat affected zone (HAZ) (Pisarski & Pargeter, 1984). Why do weld usually fails in HAZ? It is because when the HAZ is exposed to enough heat for a long enough time, the layer develops microstructure and properties that are different from the parent metal. These property adjustments are normally undesirable, and they end up becoming the component's weakest point. Microstructural changes, for example, can result in residual stresses, decreased material strength, increased brittleness, and decreased corrosion and/or crack resistance (Nayak et al., 2015). As a result, there are several faults in the HAZ. A pre- and/or post-weld heat

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

treatment can help to reduce HAZ issues. Heat treatment, as is well known, modifies the mechanical and microstructural qualities of the material, making it suitable for the purpose for which it is intended. Nam et al., (1999) proposed that during annealing, the microstructure softens and sometimes recrystallizes and recovers. They also proposed that the morphology of carbides is bound to vary throughout time. Steel's machinability, ductility, hardness, tensile strength, and impact strength are all improved by heat treatment. In this project, two types of heat treatment process which is annealing and tempering will be used.

1.3 Objective of Study

i. To study the welded joint of low carbon steel joint with filler ER70s.

ii. To carry out the non-destructive test by using radiography testing and liquid penetrant inspection.

iii. To study the effect of heat treatment on the mechanical and microstructure properties by performing hardness and impact test.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.4 Scope of Study

The scope of this study:

i. Gas metal arc welding (GMAW) are used as welding method on the low carbon steel joint.

ii. Performing non –destructive test (NDT) by using radiography testing and liquid penetrant inspection to detect internal and external defects in the welded joint.

iii. Using abrasive water jet to cut the welded metal to the dimension 55mm x 10mm x 12mm.

iv. Mechanical testing of microhardness is carried out on the sample to investigate the resistant of the sample to indentation or penetration.

v. Investigate the material characterization using optical microscope, scanning electron microscope (SEM) and energy dispersive x-ray analysis (EDX) to analyse microstructure and fracture mode on welded cross section.

vi. Visual observation and inspection of the experiments are used to evaluate and analyse them.

1.5 Significant of Study

The oil and gas industry plays a very important role in the global energy supply as well as the world economy. Many technologies are crucial to the existence and functioning of this multi-billion-dollar industry. The oil and gas industry utilizes various highly complex infrastructure such as rigs, pipelines, platforms, bridges, offshore and onshore structure and ships. The vast majority of these infrastructures are built using welding technologies. Welding is important in oil and gas operations, both for new project construction and for the maintenance of existing facilities. Regarding this project, heat treatment will help to increase the mechanical properties. The purpose of this research is to help the oil and gas industry so that they will improve the future production in term of using suitable heat treatment process and reduce the cost of processing, time and energy of the workers.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Welding is the most critical operation in any manufacturing process, and the quality of the welding directly affects the ultimate product's quality. According to Kumar et al., (2019), welding is a procedure that permanently binds two materials (typically metals) together through the use of a specific mixture formed by the proper combination of temperature, weight, and metallurgical conditions. Additionally, he claimed that a range of welding forms have been developed depending on the relationship between temperature and weight, ranging from high temperatures with no weight to large weights with a low temperature. Nowadays, numerous welding techniques are used. The most often used varieties in industrial sectors are Gas Metal Arc Welding (GMAW) or MIG, Gas Tungsten Arc Welding (GTAW) or TIG, Flux Core Arc Welding, and Stick Welding. Apart from that, welding can be done underwater; nevertheless, this demands highly skilled operators who are aware with the conditions and scenarios encountered while working in the water.Welding Process

Metal is melted to form a bridge between the components to be connected, and when the weld metal solidifies, the components become connected. Welding is frequently accomplished by the use of pressure, perhaps in combination with heat (Jenney & O'Brien, 1991). Welding processes are classified into two categories as shown in figure 2.1:

i) Fusion - The surfaces of two components to be connected are cleaned, pressed together, and heated, resulting in the formation of a pool of molten metal connecting the components.

ii) Solid state - The joining metals are not melted. Rather than that, they are heated by friction created by the components moving together under normal load. This process softens the metals and cleans the surface. After then, the sliding is halted, the normal load is raised, and the two surfaces are joined.

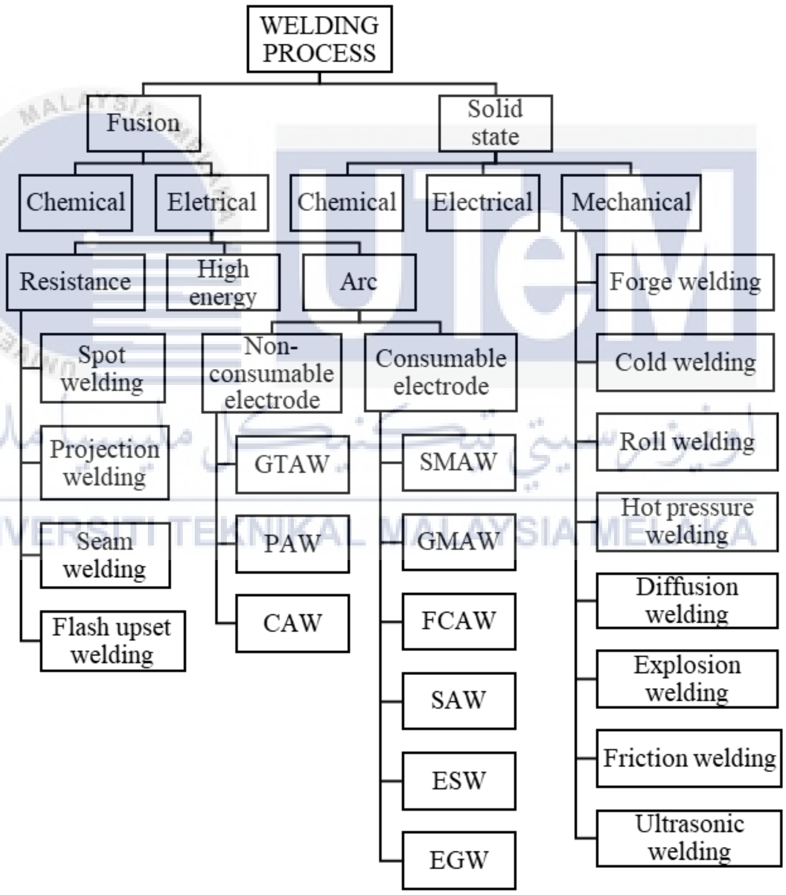

Figure 2.1: Types of welding process (https://www.weldingandndt.com/, 2017)

2.1.1 Welding Gas Metal Arc Welding (GMAW)

Gas Metal Arc Welding (GMAW), also known as metal inert gas (MIG) welding, is a process that involves the formation of an electric arc between a consumable wire electrode and the workpiece metal(s), heating and pressing them together to melt and join (Hajili, 2017). In addition to the wire electrode, a shielding gas is fed into the welding gun, effectively isolating the process from airborne pollutants. Techniques might be semi-automatic or totally automated. While GMAW is commonly driven by a constant voltage, direct current source, it can also be run on constant current or alternating current. External shielding gas protects molten metal from ambient oxides and nitrides during the welding process. There are four fundamental metal transfer processes in GMAW as in Figure 2.2 which were globular, short-circuiting, spray, and pulsed-spray, each having its own set of characteristics, advantages, and disadvantages.

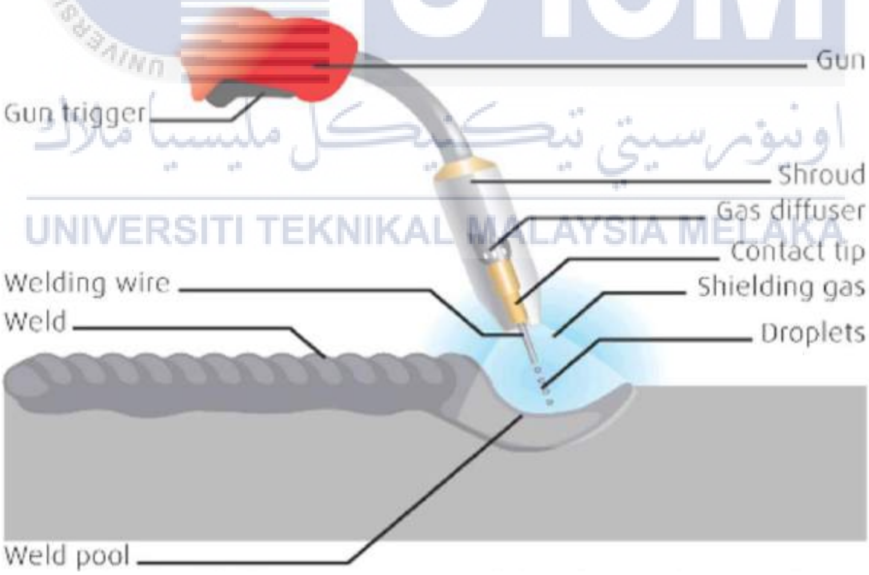

Figure 2.2: Gas Metal Arc Welding (GMAW) (https://www.sparkerweld.com/en, 2018)

Gas metal arc welding (GMAW) is a regularly utilised arc welding technology for joining large metal sections due to its unique properties. These advantages include an enhanced rate of wire electrode deposition, regulated high thermal energy dissipation, no