# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# INVESTIGATION ON MICROSTRUCTURE BEHAVIOR AND HAZ HARDNESS OF STAINLEES STEEL AISI304 AT DIFFERENT FILLER WIRE DIAMETER AND VOLATGE USING MIG WELDING

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Bachelor of Manufacturing Engineering (Manufacturing Process) with Honors

By

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# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA**

TAJUK: **Investigation On Microstructure Behavior and HAZ Hardness of Stainless steel AISI 304 At Different Filler Wire Diameter and Voltage Using MIG Welding.**

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I hereby, declared this report entitled "Investigation on Microstructure Behavior and HAZ Hardness of Stainless Steel AISI304 at Different Filler Wire Diameter and Voltage Using MIG Welding" is the results of my own research except as cited in references.

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# APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honors. The members of the supervisory committee are as follow:

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# ABSTRACT

The research work conducted in this dissertation aims to investigate the microstructure behavior and analyze Heat Affected Zone (HAZ) of austenitic stainless steel AISI 304 weldments. Here, the welding is conduct base on three different sizes of filler wire (ER308L). The sizes are 0.8mm, 1.0mm, and 1.2mm respectively. The arc voltage use is 20V, 25V and 30V. The current flow for metal inert gas (MIG) welding is set to constant value 100A. Meanwhile the plate size for base material is 5mm. The experiment starts with preparing the specimen by welding process using MIG welding equipment. Then the specimens are dividing into two groups to undergo HAZ hardness and microstructure observation. The behavior of AISI 304 microstructure is studying using Optical Microscope. Hardness of HAZ area is evaluated by Rockwell hardness test. The result is to finding the relation of different filler diameter size wire with the austenitic stainless steel microstructure behavior. A change in microstructural contains and its properties are studying.

# ABSTRAK

Kajian ini dijalankan bertujuan untuk mengkaji perubahan bentuk mikrostruktur serta mengkaji kawasan pengaruhan haba (HAZ) pada kimpalan '*austenitic stainless steel*'AISI 304. Proses pengimpalan dijalankan berdasarkan tiga saiz yang berza-beza diameter logam penambah '*filler wire*' jenis ER308L. Saiz logam penambah yang digunakan adalah 0.8mm, 1.0mm dan 1.2mm serta voltan yang digunakan pula adalah 20V, 25V, dan 30V. Arus yang digunakan pula adalah kekal pada 100A. Tebal plat '*stainless steel*' yang digunakan adalah 5mm. Eksperimen dimulakan dengan memotong kepingan plat '*stainless steel*' dan mengimpalnya menggunakan mesin kimpalan MIG. Selepas itu, penyambungan plat tersebut dipotong untuk dianalisa kekerasan HAZ dan perubahan bentuk mikrostruktur. Perubahan bentuk mikrostruktur dikaji dan dilihat dengan menggunakan '*Optical Microscope*' manakala tahap kekerasa HAZ diuji menggunakan mesin '*Rockwell hardness test*'. Ujian ini dilakukan adalah untuk mengkaji hubungan antara saiz diameter '*filler wire*' dan voltan terhadap perubahan mikrostruktur AISI 304 serta tahap kekerasan HAZ. Perubahan rupa bentuk atau mikrostruktur dan kandungannya juga di kaji dalam eksperimen ini.

# DEDICATION

*Dedicated to my beloved father, En. Ahmad bin Selamat and my lovely mother, Pn. Allpiah bte Hj. Kasbi who are very concern, patient and supporting. Last but not least, to all my brothers, sisters and friends. The work and success will never be achieved without all of you.*

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| | | |
|---|---|---|
| GMA | - | Gas Metal Arc |
| GMAW | - | Gas Metal Arc Welding |
| GTA | - | Gas Tungsten Arc |
| GTAW | - | Gas Tungsten Arc Welding |
| HAZ | - | Heat Affected Zone |
| MIG | - | Metal Inert Gas |
| AISI | - | American Iron Standard Institute |
| SEM | - | Scanning Electron Microscopy |
| TIG | - | Tungsten Inert Gas |
| AWS | - | American Welding Society |
| ASTM | - | American Society for Testing and Materials |
| HRD | - | Thin steel and medium case hardened steel and pearlitic malleable iron |
| DOE | - | Design of experiment |
| C | - | Carbon |
| Cu | - | Copper |
| Si | - | Silicon |
| S | - | Sulfur |
| P | - | Phosphorus |
| Fe | - | Ferrous |
| Mg | - | Magnesium |
| Mn | - | Manganese |
| Wt. % | - | Weight of percentages |
| Zn | - | Zinc |
| CC | - | Constant Current |
| CV | - | Constant Voltage |
| DC | - | Direct Current |
| °C | - | Celsius |
| V | - | Voltage |
| A | - | Amperage |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction to Welding

Manufacturing operations require joining process in a way that is considered as an important process to be applied in almost every operation or process that involves fabricating or products. While there are many methods for joining metals, welding is one of the most convenient and rapid methods available. The term welding refers to the process of joining metals by heating them to their melting temperature and causing the molten metal to flow together. LeMouse (2008) stated in welding the aim is to use a form of blow torch to weld together two or more pieces of metal. This works by melting down these points of the metal to a point where they become soft enough to be pushed together. This means that the actual fabric of the metal itself has been joined at these parts, rather than using an intermediary substance to glue them together, and as such the bond is far more powerful and reliable – which is obviously paramount for cars, planes, bridges and anything else required to bear heavy weights and strong forces without breaking.

According Klobcar et al., (2004) welding is a complex process in terms of control of temperature fields, strains, residual stresses, formation of cracks and their propagation, especially when considering welding of hard tooling. Extreme temperature transients in the welded material often cause significant residual stress. Welding has become a prevalent mechanical joining methodology in various industries because of its advantages over other joining methods including design flexibility, cost savings, overall weight reduction and structural performance enhancement (Song, 2003). Mainly, in order to gain an acceptable weldments outcome, Song et al., (2003) recommended approaches such like welding type selection, controlling welding process parameters and modifying the structural configuration.

Meanwhile, Jeffus (2004) stated filler material is added when needed to form a completed weld in the joint. It is also important to note that the word material is used because today welds can be made from a growing list of material such as plastic, glass, and ceramics. In general, welding includes any process that causes material join through the attractive action of inter-atomic or inter-molecular forces as opposed to purely macroscopic or even microscopic mechanical interlocking forces (Messler, 2004).

### 1.1.1 Fusion Welding

The arc-welding processes are undoubtedly the most important fusion welding processes. Heat is used to melt metal to form a bridge between the parts to be joined so that on removal of the heat source and solidification, the parts are united. The heat to melt metal in the joint can be provided by a variety of heat sources such as an oxy-fuel gas flame, gas shielded arcs, flux-shielded arcs, electron or laser beams. Here, part of the joint in the work piece is metal which has been melted or fused (Houldcroft and John, 1989).

Fusion welding is a joining process that uses fusion of the base metal to make weld. Three major types of fusion welding processes are as follows (Kou, 2003):

a) Gas welding.
b) Arc welding.
c) High-energy beam welding.

### 1.1.2 Gas Metal Arc Welding (GMAW)

Gas Metal Arc Welding (GMAW), by definition, is an arc welding process which produces the coalescence of metals by heating them with an arc between a continuously fed filler metal electrode and the work. The process uses shielding from an externally supplied gas to protect the molten weld pool. The application of GMAW generally requires DC+ (reverse) polarity to the electrode. In non-standard terminology, GMAW is commonly known as MIG (Metal Inert Gas) welding and it is less commonly known as MAG (Metal Active Gas) welding. In either case, the GMAW process lends itself to weld a wide range of both solid carbon steel and tubular metal-cored electrodes.

The alloy material range for GMAW includes: carbon steel, stainless steel, aluminum, magnesium, copper, nickel, silicon bronze and tubular metal-cored surfacing alloys. The GMAW process lends itself to semiautomatic, robotic automation and hard automation welding applications. Table below shows that Gas Metal Arc Welding (GMAW) welding process is applicable for all materials of all thickness ranges while on the other hand Gas Tungsten Arc Welding (GTAW) or welding process is suitable mostly on thinner work pieces.

**Table1. 1**: Overview of welding processes (Kou, 2003)

| Material | Thickness[b] | SMAW | SAW | GMAW | FCAW | GTAW | PAW | ESW | OFW | EBW | LBW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon steels | S | × | × | × | | × | | | × | × | × |
| | I | × | × | × | × | × | | | × | × | × |
| | M | × | × | × | × | | | | × | × | × |
| | T | × | × | × | × | | | × | × | × | |
| Low-alloy steels | S | × | × | × | | × | | | × | × | × |
| | I | × | × | × | × | × | | | | × | × |
| | M | × | × | × | × | | | | | × | × |
| | T | × | × | × | × | | | × | | × | |
| Stainless steels | S | × | × | × | | × | × | | × | × | × |
| | I | × | × | × | × | × | × | | | × | × |
| | M | × | × | × | × | | × | | | × | × |
| | T | × | × | × | × | | | × | | × | |
| Cast iron | I | × | | | | | | | × | | |
| | M | × | × | × | × | | | | × | | |
| | T | × | × | × | × | | | | × | | |
| Nickel and alloys | S | × | | × | | × | × | | × | × | × |
| | I | × | × | × | | × | × | | | × | × |
| | M | × | × | × | | | × | | | × | × |
| | T | × | | × | | | | × | | × | |
| Aluminum and alloys | S | | | × | | × | × | | × | × | × |
| | I | | | × | | × | | | | × | × |
| | M | | | × | | × | | | | × | |
| | T | | | × | | | | | | × | |

According Table 1.1, the process code are as follows: SMAW (Shielded Metal Arc Welding), SAW (Submerge Arc Welding), GMAW (Gas Metal Arc Welding), FCAW (Flux Cored Arc Welding), GTAW (Gas Tungsten Arc Welding), PAW (Plasma Arc Welding), ESW (Electro Slag Welding), OFW (Oxy Fuel-Gas Welding), EBW (Electro Beam Welding), LBW (Laser Beam Welding). While the abbreviations: S,sheet up to 3mm; I, intermediate, 3-6mm; M, medium, 6-19mm; T, thick, 19mm and above;X, recommended respectively.

### 1.1.3 Stainless Steel Weldments

Stainless steel is extensively used in variety of application where corrosion resistance is required in combination with good strength and toughness. From the various classes of stainless steel, austenitic, martensitic, ferrictic, precipitation-hardenable and duplex stainless steel, austenitic is the most easily welded. It contains 16-25% Cr, 7-20% Ni, and less than 0.08% C (Shankar, 2006). Jeffus (2004) stated that keeping the carbon content low in stainless steel will help reduce carbide precipitation. Carbide precipitation occurs when alloys containing both chromium and carbon are heated. The chromium and carbon combine to form chromium carbide (Cr3 C2). The amount of chromium carbide formed is dependent on the percentage of carbon, the time that the metal is in the critical range, and the presence of stabilizing elements.

Wang (2008) mentioned that the mechanical and chemical properties of the stainless steel weldments are very important for the structure to exhibit their strength and anti-corrosion character. Hsaio (2008) added that welded structure made of stainless steel are commonly used in the power generation, oil and gas, marine transportation, petrochemical industries due to their higher mechanical strength and better corrosion resistance. Stainless steels are defined as iron base alloys which contain at least 10.5% chromium. The thin but dense chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance and prevents further oxidation. There are five types of stainless steels depending on the other alloying additions present, and they range from fully austenitic to fully ferritic types (Nadzam, 2006).

Stainless steels are available in a wide range of product forms, such as plate, sheet, strip, precision strip, billet, engineering rounds, bar, rod, wire, pipe, tube, forgings, rings, castings, sections – hot rolled, extruded, drawn, cold formed, sintered products. The flat product forms can be obtained in a variety of surface finishes, and advice should be sought on the suitability of the different finishes for particular applications. Table1.2 below show example of stainless steel grade (British stainless steel, 2001).

**Table1. 2**: Stainless steel grade (British stainless steel, 2001)

| | | | | | |
|---|---|---|---|---|---|
| *FERRITIC* | | | | | |
| 1.4512 | 409S19 | 11% Cr + Ti | 380 | 220 | 25 |
| 1.4016 | 430S17 | 17% Cr | 430 | 260 | 20 |
| 1.4000 | 403S17 | 13% Cr + Al | 400 | 230 | 19 |
| *MARTENSITIC* | | | | | |
| 1.4006 | 410S21 | 13% Cr 0.1% C | Normally supplied softened | - | - |
| 1.4028 | 420S45 | 13% Cr 0.3% C | Normally supplied softened | - | - |
| *DUPLEX* | | | | | |
| 1.4362 | - | 23% Cr 4.5% Ni | 600 | 420 | 420 |
| 1.4462 | - | 22% Cr 5.5% Ni 3% Mo | 660 | 480 | 20 |
| *AUSTENITIC* | | | | | |
| 1.4301 | 304S31} 304S16} 304S15] | 18% Cr 8.5% Ni | 540 | 230 | 45 |
| 1.4307 | 304S11 | 18% Cr 9% Ni Low C | 520 | 220 | 45 |
| 1.4404 | 316S11 | 17% Cr 11% Ni 2% Mo | 530 | 240 | 40 |
| 1.4541 | 321S31 | 17% Cr 9% N + Ti | 520 | 220 | 40 |
| *SUPER AUSTENITIC* | | | | | |
| 1.4539 | | 20% Cr 25% Ni 4.5% Mo + Cu | 530 | 270 | 35 |
| 1.4547 | | 20%Cr 18% Ni 6% Mo + Cu | 650 | 320 | 35 |

## 1.2 Problem Statement

Based on the finding, there is only a few related with mechanical properties of the stainless steel weldments have been studied. There also hardly found the study on the microstructure of Heat Affected Zone (HAZ) and stainless steel weldment area. Beside that, only a few studied have been done to evaluate the effect of filler wire diameter on weldments of stainless steel.

## 1.3 Objectives

The objectives of the research are as follows:

a) To study the effect of different ER308L filler wire diameter (0.8mm, 1.0mm, 1.2mm) on stainless steel AISI 304 weldments.
b) To study the HAZ hardness area.
c) To evaluate the microstructure behavior and conducted using Optical Microscope.
d) To study the effect of different voltage setting (20V, 25V, 30V) on stainless steel weldment.

## 1.4 Scope of Study

The study of this paper will cover the behavior of material that will be weld in different size of ER308L filler wire diameter (0.8mm, 1.0mm, and 1.2mm). Stainless steel will be use as a base metal. The microstructure behavior is investigating and inspected using Optical Microscope. Type of joint the material is butt joint. Gas Metal Arc Welding (GMAW) or MIG welding is the equipment to joint the steel. The performance of each weldments specimen will be compared in term of behavior of microstructure and area of HAZ hardness by Rockwell Hardness test.

***ER stands for bare rod filler wire***

## 1.5 Important of Study

The purpose of the project is to investigate the influence of different electrode diameter on stainless steel microstructure. Since stainless steel has been used widely in manufacturing industry, the revolutionary of joining this part in industry has been developing. The good strength of weldment is needed. There fore the behavior of microstructure is investigating to find the mechanical properties of material and hardness of HAZ that occurred after joining process using MIG welding.