INVESTIGATION OF MIG WELDING TO THE CORROSION BEHAVIOUR OF CARBON STEEL

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ABSTRACT

A welding process was performed on the low carbon steel based on different welding parameters in this experiment. The main objective of this study was to investigate the effect of welding voltages (19 V, 20 V, 21 V, and 22 V) and wire feed rates (90 ipm, 100 ipm, 110 ipm, and 120 ipm) to the corrosion behaviour of welded carbon steel in synthetic seawater environment (3.5 wt% NaCl). Besides that, the microstructure changes in the weldments of maximum and minimum voltages were analysed and compared with the as-received sample before welding process. On the other hand, the penetration level of the weldments was analysed due to the different welding parameter. The welding method in this experiment was metal inert gas (MIG) with filler metal (ER 70S-6 with 1.2 mm diameter). Based on the results obtained, the corrosion rate decreased when the welding voltage was increased from 19 V to 22 V or when the wire feed rate was increased from 90 ipm to 120 ipm until the full penetration level of weldment occurred. In conclusion, the lowest corrosion rate occurred at highest welding voltage and highest wire feed rate when full penetration of weldment occurred. The corrosion product that formed on the surface of the sample was iron oxides and pitting was found on the surface of the exposed area after the corrosion test.

ABSTRAK

Satu proses kimpalan telah dijalankan ke atas keluli karbon rendah berdasarkan beberapa parameter kimpalan yang berlainan dalam eksperimen ini. Objektif utama bagi kajian ini adalah untuk mengkaji kesan voltan kimpalan (19 V, 20 V, 21 V dan 22 V) dan kadar suapan wayar (90 ipm, 100 ipm, 110 ipm, and 120 ipm) kepada kelakuan kakisan kimpal dalam persekitaran air laut sintetik (3.5wt % NaCl). Selain itu, perubahan mikrostruktur dalam hasil kimpal voltan maksimum dan minimum telah dianalisis dan dibandingkan dengan sempel yang diterima sebelum proses kimpalan. Di samping itu, tahap penembusan daripada hasil kimpal yang disebabkan oleh parameter kimpalan berbeza dianalisis. Kaedah kimpalan dalam eksperimen ini adalah menggunakan mesin kimpalan MIG (metal inert gas) dengan logam pengisi (ER 70S-6 berdiameter 1.2 mm). Berdasarkan keputusan yang diperolehi, kadar kakisan akan menurun apabila voltan kimpalan meningkat dari 19 V ke 22 V dan kadar suapan wayar meningkat dari 90 ipm ke 120 ipm sehingga tahap penembusan penuh hasil kimpal terjadi. Kesimpulannya, kadar kakisan terendah berlaku pada voltan kimpalan dan kadar suapan wayar yang tertinggi ketika penembusan penuh kimpal berlaku. Hasil kakisan yang terbentuk di permukanan sampel adalah oksida besi dan bopeng telah dijumpai di permukaan kawasan yang terdedah selepas ujian kakisan.

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LIST OF SYMBOLS

A	Exposed area
d	Density
E_{corr}	Corrosion potential
E_{oc}	Open circuit potential
I	Welding current
I_{corr}	Corrosion current
K	Constant value
Q	Heat input
S	Welding speed
V	Welding voltage
%	Percentage

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
Ar	Argon
C	Carbon
CO_2	Carbon dioxide
Cr	Chromium
CR	Corrosion rate
Cu	Copper
e^-	Electron
EW	Equivalent weight
Fe	Iron
Fe^{2+}	Ferrous ions
Fe^{3+}	Ferric ions
$Fe_2O_3 \cdot nH_2O$	Iron (III) oxides
FeO(OH)	Iron (III) oxide-hydroxide
$Fe(OH)_3$	Iron (III) oxide-hydroxide
FHWA	Federal Highway Administration
GMAW	Gas Metal Arc Welding
HAZ	Heat affected zone
HCL	Acid hydrochloric
H_2O	Water
MIG	Metal inert gas
Mn	Manganese

Mo	Molybdenum
NACE	National Association of Corrosion Engineers
NaCl	Sodium chloride
Ni	Nickel
No	Number
O_2	Oxygen
OH^-	Hydroxide irons
P	Phosphorus
S	Sulphur
SAE	Society of Automotive Engineers
SCC	Stress corrosion cracking
SEM	Scanning electron microscopy
Si	Silicon
UMP	University Malaysia Pahang
V	Vanadium
Wt%	Weight percentage

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter explains about the background of study, problem statement, objectives, and scopes of this study. The purpose of this study can be identified by referring at the problem statement of this study. Besides that, the detail of the study and output can be obtained based on the objectives and scopes of this study.

1.2 BACKGROUND OF STUDY

Corrosion can be defined as degradation of quality and properties in a material due to the chemical reaction between the components of the material and the surrounding. In other words, corrosion can be described as deterioration of essential properties such as mechanical properties and physical properties in a material (Seifedine, 2008). Corrosion can cause a variety of problems in our daily life, depending on the application of the metals. The first common problem is the leakage of the metal such as tanks and pipes, which allows leakage of fluids or gases out of the tanks or pipes. Metals are widely used in the piping system either in underground or seawater condition which corrosion is easily occurred. Besides that, the next effect of corrosion is the degradation of quality and properties in a material. The strength of the metal where the cross section of structural members is reduced due to the effect of the corrosion, leading to a loss of strength of the structure and subsequent failure of the structures.

Millions of dollars are lost each year due to the effect of corrosion. Much of this loss is due to the corrosion of iron and steel since the price of iron and steel is much more expensive and both metals are widely used in the industry compared to other type of metals (Osarolube et al., 2008). Based on the study entitled “Corrosion Costs and Preventive Strategies in the United States”, the total annual estimated direct cost of corrosion in the United State is a staggering $276 billion. Besides that, the indirect corrosion costs are lost time, and thus lost productivity because of outages, delays, failures, and litigation. The shipping industry cost of corrosion is $2.7 billion, broken down into new ship construction ($1.1 billion), maintenance and repairs ($0.8 billion), and corrosion-related downtime ($0.8 billion) (Koch et al., 2002).

Carbon steel is the most widely used engineering material despite its relatively limited corrosion resistance. Carbon steel is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction and metal-processing equipment. Carbon steel has been the most widely used structural material which is abundantly available, inexpensive and has adequate mechanical properties but has a high general corrosion rate (Kadhim, 2011).

Welding is a reliable and efficient metal-joining process which is widely used in the industry. With the growing emphasis on the use of automated and robotic system Metal Inert Gas (MIG) welding, with its all-position capabilities, Gas Metal Arc Welding (GMAW) has been employed increasingly in mechanized surfacing in the industry (Murugan and Parmar, 1994). However, during the welding process, due to the different quantity of heat input as well as the quality of the weldments, many problems arise from the process especially in corrosion (Funderburk, 1999). The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of welds and adjacent base metal. Metallurgical factor is one of the primary concerns to the corrosion of welded carbon steel (Davis, 2006). Thus, the joint is always considered as the weakest part of a component.

1.3 PROBLEM STATEMENT

Carbon steel is the most widely used engineering material in the overall of steel production worldwide. Although carbon steel is highly related to the limited corrosion resistance compared to other common types of steels such as stainless steel, carbon steel is still used in large tonnages in applications which are highly related to the high corrosion resistance requirement. Since carbon steels represent the largest single class of alloys in use, both in terms of tonnage and total cost, it is easy to understand that the corrosion of carbon steels is a problem of enormous practical importance. This is the reason for the existence of entire industries devoted to providing protective systems for irons and steel.

Carbon steels are commonly used in seawater for structural applications such as ship hulls, offshore platforms, sheet piles and coastal facilities as well as sea water piping systems. Millions of dollars are lost each year due to the effect of corrosion, thus the corrosion behaviour of carbon steel is utmost important to be studied. Previously, study of corrosion of welded carbon steels in seawater is always related to the type of material used. However, welding parameters such as welding voltages applied and wire feed rate play a big role in influencing the corrosion rate of the steel. Welding parameters have a high influence on the quality of the welding which directly affects the corrosion resistance of the material. Besides that, welding parameters have high influence on the heat input to the material which directly alter the microstructure of the weldments and indirectly affects the corrosion rate of the material. Although there are many researches and studies about the corrosion of welded carbon steel carried out in the past few decades in seawater environment, there is still no research came out which accurately describes the trend of corrosion rate to welding parameters. Thus, in this study, the effect of welding parameters on the corrosion rate of welded carbon steel in seawater environment is investigated.

1.4 OBJECTIVES

The main objective of this study is to investigate the effect of welding voltage and wire feed rate to the corrosion behaviour of weld carbon steel in synthetic seawater environment.

1.5 SCOPE

i) The material used is low carbon steel (AISI 1010).
ii) The welding method employed is MIG.
iii) Different welding voltages (19 V, 20 V, 21 V, and 22 V) and wire feed rates (90 ipm, 100 ipm, 110 ipm, and 120 ipm) are used to join the sample using butt joints.
iv) Microstructure analysis of welding specimens by using optical microscope/ scanning electron microscopy (SEM).
v) Electrochemical test by using potentiostat.
vi) Corrosion rate of welded carbon steel in synthetic seawater (3.5 wt% NaCl) environment.

1.6 THESIS OUTLINE

This thesis consists of 5 chapters which illustrate the flow of the project from introduction till the conclusion. Every chapter presents with different contents. After read the entire chapters in the thesis, the viewer may understand the detail of the project and obtains the output of the project.

Chapter 1 contains about the background of study, problem statement, objectives, and scopes of this study.

Chapter 2 contains all the literature review and some presentation of the earlier work. This chapter also presents about the information of the material that used in this study. Some concepts which relate to the corrosion also discusses in this chapter.

Chapter 3 contains the summary of the research methodology of this project. This chapter also explains about the flow of the project which includes the steps of project conducted.

Chapter 4 contains the results that obtained during this study. This chapter also explains the analysis and discussion of the result. The result obtained is discussed and compared to previous study in this chapter.

Chapter 5 explains the conclusion of the project. This chapter also includes the future recommendation of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents about the material that used in this study which includes type of material and some basic knowledge about the chosen material and the application of the material in seawater environment. On the other hand, some concepts which relate to the corrosion include the electrochemical reaction also discusses in this chapter. The formation of the corrosion product also explains in this chapter based on the chemical reaction. The corrosion determination method that used in this study which is polarization diagram and some formula which relate to the corrosion determination also include in this chapter. Different types of corrosion defects which relate to welding also discuss in this chapter such as stress corrosion cracking (SCC), pitting and galvanic corrosion. Besides that, this chapter also explains about the history background and presentation of the earlier work.

2.2 MATERIAL

2.2.1 Carbon Steel

Carbon steel is the most widely used engineering material in the overall of steel production worldwide (Morrow, 2010). Carbon steel can be defined as steel where the main interstitial alloying element is carbon. Carbon steel can be described as the structural material which is abundantly available, inexpensive, adequate formability and weldability, and has adequate mechanical properties but has a high general corrosion rate (Kadhim, 2011).

Although carbon steel is always related to the low corrosion resistance or high general corrosion rate, it is still the most widely used engineering material in this world. It is well known that carbon steel corrodes rapidly in seawater environment and requires adequate protection depending on the type of application. Though carbon steel is the most prone to corrosion, it is the least expensive of the most commonly perforated metals compared to other type of structural material. Carbon steel is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, pipelines, mining, and construction (Kadhim, 2011).

2.2.2 Types of Carbon Steel

Carbon steel can be divided into five groups based on its carbon content which are low carbon steel, mild steel, medium carbon steel, high carbon steel and ultra-high carbon steel. Typical groups of carbon steels are as tabulated in Table 2.1 and each group of carbon steel is provided with some examples which start with American Iron and Steel Institute (AISI). There are a total of five groups of carbon steel which shows different characteristics as discussed in Table 2.1. Different groups of carbon steel are applied in different application in worldwide and it depends on the characteristic of the carbon steel and the requirement of the application.

Table 2.1: Types of carbon steel

Carbon steel types	Example AISI No.	% of carbon	Explanation
Low carbon steel	1010, 1012	0.05-0.15	• It is neither ductile nor brittle. • It is normally used when huge quantities of steel and high surface finish are required. • It is used in the form of structural steel such as sheets, strips, rods and wires.
Mild steel	1018, 1020	0.16-0.29	• Its price is usually low and it provides the material properties which are acceptable under many circumstances. • It is characterized by a low tensile strength, but it is malleable, good machinability, and cheap • It is used to produce ship plates, welded turbines, boiler tubes and camshafts.
Medium carbon steel	1035, 1038	0.30-0.59	• It is stronger and possesses better hardness and tensile strength but less ductility than mild steel. • It has good machinability, deep hardening properties and fantastic wear resistance. • It is used in automotive components which required higher strength such as stronger nut, large forgings, and high tensile tubes.
High carbon steel	1055	0.6-0.99	• It is very strong, utilized in high-strength wires and springs. • Ductility and machinability of steel decreases with the increase in carbon content. • It is used in produce cold chisel, wrenches, jaws, hacksaw blades and railway service.
Ultra-high carbon steel		1-2	• It could be tempered for greater hardness. • It is utilized for special purposes such as non-industrial-purpose knives, punches or axles.

Source: Ashby and Johnson (2009)

2.2.3 Application of Carbon Steel in Seawater

Although carbon steel is highly related to the limited corrosion resistance compared to other common types of steels such as stainless steel, carbon steels are commonly used in seawater for structural applications such as ship hulls, offshore platforms, sheet piles and coastal facilities as well as seawater piping systems. All these applications required high corrosion resistance material since the medium environment of the applications is seawater which can increase the corrosion rate of the material (Kadhim, 2011). Basically, seawater in the ocean in the world has a salinity which is about 3.5 %. In other words, each litre by volume of seawater has approximately 35 grams of dissolved salts (predominantly sodium (Na^+) and chloride (Cl^-) ions).

Carbon steel is preferred in a seawater environment compared other types of material since carbon steel exhibit low initial cost compared with other materials, the ready availability of material and components and the existence of widely used and accepted welding procedures. However, the rate of corrosion of carbon steel is much higher and this becomes the main barrier of the usage of carbon steel in seawater environment. Basically, a system that produced or designed using carbon steel is much cheaper since carbon steel is inexpensive but the system is larger, heavier and shorter life compared to other structural material. Thus, the failures of the structure may occur earlier and it is within a few years and complete replacement is required compared to other better corrosion resistance structural material (Bennett, 2002).

However, in order to increase the corrosion resistance of carbon steel in seawater environment, method of coatings is largely applied. Coating is a famous and widely used method to protect the low corrosion resistance material such as plain carbon steel but it also increases the initial costs since more process is needed compared to plain carbon steel. Coating is applied on the both surfaces which are inner and outer surface in order to increase the corrosion resistance of the material. However, by applying a coating on the surface of the material, it introduces complications into the fabrication procedures, such as the need for a local removal prior to welding and re-application afterwards (Morrow, 2010). Besides that, heat treated carbon steel can be used compared to plain carbon steel in order to improve the corrosion resistance of the carbon steel. Heat treated carbon steel has better mechanical properties and corrosion resistance compared to the plain carbon steel since different microstructure existed in the material.

2.2.4 Welding Wire

In MIG welding, AWS ER70S-6 is a common wire types that used to join the common steel. AWS ER70S-6 is a mild steel welding wire that contains a higher percentage of manganese and silicon compared to other standard grades of MIG wire. This welding wire is chosen in order to produce high quality welds when used on dirty, oily, or rusty steel. The chemical composition of AWS ER70S-6 is shown in Table 2.2. High percentage of silicon content increases the fluidity of the weld pool which create a smoother bead appearance and resulting in minimal post-weld grinding. This wire is engineered to provide trouble-free performance from heavy duty, high speed, spray transfer applications all the way to light duty low speed, short-arc applications. ER70S-6 is designed for use with various gas mixtures such as 100 % CO_2, 75 %/25 % Ar/CO_2 or 98 %/2 % Ar/O_2 (Scholz, 1996).

Table 2.2: Chemical composition of AWS ER70S-6

Element	Weight, %
C	0.06 to 0.15
Si	0.8-1.15
Ni	0.15 (max)
Mo	0.15 (max)
Cu	0.5 (max)
S	0.035 (max)
Cr	0.15 (max)
Fe	Balance
Mn	1.40-1.85
V	0.025 (max)
P	0.03 (max)
Other	0.5 (max)

Source: Scholz (1996)