AN INVESTIGATION ON CORROSION OF LOW CARBON STEEL WELDED PLATE IN SODIUM CHLORIDE SOLUTION

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DECLARATION

I declare that this project entitled "An Investigation on Corrosion of Low Carbon Steel Welded Plate in Sodium Chloride Solution" is the result of my own work except as cited in the references.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Material & Structures).

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DEDICATION

Especially to my beloved

Mother and Father

Respectful Lecturers

And my faithful Friends

ABSTRACT

In recent years, corrosion of low carbon steel has become an important issue in safety, especially in the welded part of a structure. Additionally, corrosion can easily take place on any metal structures unpredictably and might cause catastrophic failures as long as the environment is appropriate, particularly when there is a continuous presence of moisture and oxygen. In this study, the experiment is aimed to investigate the corrosion product, surface hardness, weight loss and rate of corrosion of low carbon steel welded plate in 3.5% of sodium chloride solution. Hence, corrosion immersion test and Rockwell hardness test along with various characterization techniques such as Optical Microscope (OM), Confocal Microscope (CM), Scanning Electron Microscopy (SEM) and Electron Dispersive Spectroscopy (EDS) has been conducted in order to achieve the objectives. The data gained for welded specimens will be compared with non-welded specimens as its bench mark. It is found that the hardness, weight loss and corrosion rate of welded specimens is worse than non-welded specimens. This study is important in order to provide a quantitative understanding and explanation on corrosion attack of welded low carbon steel.

ABSTRAK

Marcapada menyaksikan, kakisan terhadap keluli berkarbon rendah telah menjadi antara perkara terpenting dalam isu keselamatan, terutamanya pada struktur yang berkimpal. Tambahan pula, pengaratan amat mudah terbentuk pada struktur besi tanpa boleh dijangka dan boleh menyebabkan kemalangan maut, selagi keadaan persekitraan sekeliling sesuai, lebih-lebih lagi dengan adanya kehadiran kelembapan dan oksigen. Tujuan kajian ini dijalankan adalah untuk mengkaji produk kakisan, kekerasan permukaan, penurunan berat bahan serta kadar kakisan pada spesimen keluli berkarbon rendah yang telah dikimpal di dalam larutan natrium klorida berkepekatan 3.5%. Maka, ujian rendaman kakisan, ujian kekerasan Rockwell serta pelbagai aplikasi teknik perincian seperti Mikroskop Cahaya (OP), Mikroskop Confocal (CM), Mikroskop Imbasan Elektron (SEM) dan Spektroskopi Serakan Elektron (EDS) telah dijalankan untuk mencapai tujuan kajian ini. Data yang telah dikumpul bagi spesimen berkimpal telah dibandingbezakan dengan spesimen yang tidak berkimpal sebagai penanda aras. Hasil kajian mendapati bahawa kekerasan permukaan, penurunan berat bahan serta kadar kakisan pada spesimen keluli berkarbon rendah yang telah dikimpal lebih teruk berbanding dengan spesimen tidak berkimpal. Kajian ini amat penting dalam usaha menyalurkan kefahaman secara kuantitatif dan penerangan tentang serangan kakisan terhadap keluli berkarbon rendah.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBEREVATIONS

MIG	Metal Inert Gas
ppm	Parts Per Million
HRB	Rockwell B-scale
TIG	Tungsten Inert Gas
OM	Optical Microscope
HAZ	Heat-Affected Zone
CM	Confocal Microscopy
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
SMAW	Shielded Metal Arc Welding
SEM	Scanning Electron Microscope
AISI	American Iron and Steel Institute
EDS	Electron Dispersive Spectroscopy
RSPA	U. S. Department of Transportation's Research
OPS	Special Programs Administration Office of Pipeline Safety

LIST OF SYMBOLS

Fe	=	Steel
H_2O	=	Water
I^-	=	Iodide
O_2	=	Oxygen
At^-	=	Astatide
Br^-	=	Bromide
F^-	=	Fluoride
nm	=	nanometre
mm	=	millimetre
Fe^{++}	=	Ferrous Ion
T	=	Time (hours)
Cl^-	=	Chloride Ion
ΔW	=	Weight Loss
OH^-	=	Hydroxyl Ion
°C	=	Degree Celsius
CO_2	=	Carbon Dioxide
NaCl	=	Sodium Chloride
H_2S	=	Hydrogen Sulfide
°F	=	Degree Fahrenheit
$CaCO_3$	=	Calcium Carbonate
%	=	Percent or Percentage
A	=	Total Area of Exposure

CHAPTER 1

INTRODUCTION

1.1 Background

Approximately about 85% of the global steel production in a year is carbon steel, making it the most frequently used material in engineering. Carbon steel plays a very significant role of applications in automotive, structural, buildings, marines, as well as oil and gas industry.

Low carbon steel is chosen due to beneficial characteristics such as its toughness, strength, ductility and weldability (Kiefner & Trench 2001). On top of that, it also offers a long-lasting, strong material to withstand the imposed service loads on pipelines and relatively cost effective. However, low carbon steel is still susceptible to corrosion while in service. It also might suffers degradation from discontinuities that formed during manufacturing or construction. Low carbon steel is also known to be strongly prone to corrosion attack from the presence of carbon dioxide (CO_2) and hydrogen sulfide (H_2S) gases that are dissolved in fluids or solutions (Nabhani, Jasim & Graham 2007).

Most of the time, pitting corrosion is considered as one of the most disastrous type of corrosion because its presence can be ultimately intricate to predict (Boucherit & Tebib 2005). In some cases, the most vital phase for the pitting corrosion to take place is during the initiation stage (initiation of pits). This initiation stage can be referred to as an event that resulted from aggregation of different phenomena which are related to a number of factors; mainly attributed to the properties of the metal and solutions in which the material get in contact with. The solutions for pitting corrosion likely to occur is commonly containing an aggressive anionic species such as chloride ions (Cl^-) (Frankel 1998).

On top of that, pitting corrosion is commonly occurred on the welded part of a structure due to many factors such as recrystallization and grain growth in the weld heat-affected zone (HAZ), as well as breaking of oxide film (Davis 2006). There are various studies of pitting corrosion, yet in-depth explanations and descriptions in this area is still lacking (Frankel 1998). Therefore, a quantitative understanding of the corrosion rate under certain conditions will be a crucial contribution in providing a precise and detailed risk assessment of the attack of corrosion on the welded low carbon steel.

1.2 Problem Statement

Pitting corrosion is detrimental to low carbon steel, especially on the welded zone. According to compile data on pipeline accidents and their causes established by U. S. Department of Transportation's Research (RSPA) and Special Programs Administration Office of Pipeline Safety (OPS); corrosion is the highest contributor of pipelines accidents, mostly on the welded zone (Gordon et al. 2004). It is because the welded zone is more susceptible to be exposed to carbon dioxide (CO_2), hydrogen sulfide (H_2S) gases, as well as chloride ions (Cl^-); particularly in an aqueous environment where the initiation of pits can easily take place.

1.3 Objective

The objectives of this project are as follows:

1. To run immersion corrosion test on welded and non-welded low carbon steel in an aqueous solution.
2. To conduct the hardness test of low carbon steel before and after immersion corrosion test.
3. To investigate the corrosion product on low carbon steel after immersion corrosion test.

1.4 Scope

The scopes of this project are as follows:

1. Execute Shielded Metal Arc Welding (SMAW) process to form butt joint welding on the specimens.
2. Check, compare and record the weight loss of specimens before and after immersion corrosion test, along with Rockwell hardness test.
3. Conduct a corrosion test by immersing the specimens at 3.5% concentration of sodium chloride (NaCl) solution for a period of time.
4. Use Optical Microscope (OM) and Confocal Microscope (CM) to check and record the microstructure of specimens after corrosion test.
5. Use Scanning Electron Microscope (SEM) and Electron Dispersive Spectroscopy (EDS) to investigate the specimens further in terms of specific elements and its chemical composition after corrosion test.

CHAPTER 2

LITERATURE REVIEW

2.1 Steel

According to (Séblin et al. 2004), the word '*steel*' is regularly used to represent or to refer to various types of iron-based alloys. These alloys can be distinguished by the techniques used to manufacture them or by the percentage of the alloying elements that are added into the iron. Basically, the common types of iron-based alloys are carbon steel, stainless steel and high alloyed steel. Among all these steels, carbon steel gets the highest demands throughout the world. For over 98% of the construction materials are carbon steels which making them the most important alloys used, especially in petroleum and chemical industries (Seidu & Kutelu 2013).

2.2 Carbon Steel

Carbon steel has many other common names. Sometimes, it is termed as plain carbon steel, ordinary steels and straight carbon steel (Carbon Steel Handbook 2007). Carbon steel is generally an iron-based alloy with less than 2% of carbon content, as well as its alloying elements. According to American Iron and Steel Institute (AISI), steel is contemplated to be a carbon steel when a few characteristics are fulfilled. Firstly, the steel must has no minimum content for chromium, cobalt, columbium (niobium), molybdenum, nickel, titanium, tungsten, vanadium or zirconium; or any other elements to be added to obtain a desired alloying effect. However, the content for copper, manganese and silicon must not exceeded 0.40%, 1.65% and 0.60% respectively.

Carbon steel can be further grouped according to several deoxidation practices such as rimmed steel, capped steel, semi-killed steel and killed steel. Yet, carbon steels are normally categorized based on their carbon content as shown below:

a) **Low Carbon Steel.**

b) **Medium Carbon Steel.**

c) **High carbon Steel.**

Carbon steels are generally sorted based on their carbon content as it has the greatest impact on the mechanical properties. Hardness and strength increases as carbon content increases and improves hardenability as well. However, carbon also decreases a material weldability and intensifies brittleness because of its tendency to form martensite (Capudean 2003). Table 2.1 as shown below are the other properties of carbon steel according to their carbon content.

Table 2.1: Properties of Carbon Steel with Different Carbon Content

Carbon Content (%)	Density (10^3 kgm^{-3})	Thermal Conductivity (Jm^{-1}K^{-1}s^{-1})	Thermal Expansion (10^{-6} K^{-1})	Young's Modulus (G Nm^{-2})	Tensile Strength (M Nm^{-2})	Elongation (%)
0.2	7.86	50	11.7	210	350	30
0.4	7.85	48	11.3	210	600	20
0.8	7.84	46	10.8	210	800	8

(Source: Material Science & Engineering, 4th Edition, V. Raghavan, pp. 396)

According to (Steel Buildings 2010), there are a few benefits that appoint carbon steel as the material of choice in most of engineering applications. The benefits are include:

a) **Low cost.**
b) **Strength.**
c) **Durability.**
d) **Design flexibility.**
e) **Adaptability.**

2.2.1 Low Carbon Steel

Low carbon steel is also known as mild steel. It is the most commonly used steel as compared to medium and high carbon steel. This is because low carbon steel is relatively low cost and available in broad range of forms and sizes (Towler & Sinnot 2013). Low carbon steel has alloying elements made up of a small weight percentage of carbon which ranges from 0.06% to 0.28% as shown in the red circle of Figure 2.1. For the alloying elements such as manganese, it varies from 0.25% to 1.00%. Meanwhile, for phosphorus and sulfur, the content is limited to 0.04% and 0.05% respectively (Isakov 2009). Besides that, low carbon steel is more ductile than medium and high carbon steel which makes low carbon steel easier to be fabricated into any desired and needed shapes. At the same time, low carbon steel still provides an adequate and a reliable strength to a structure or a component.

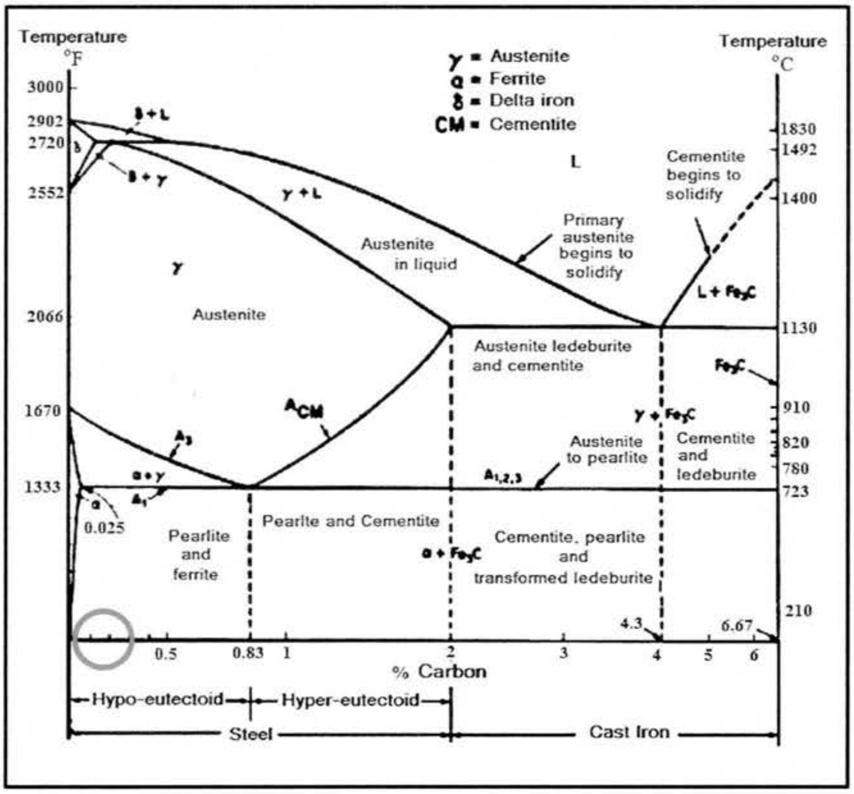

Figure 2.1: Ranges of Weight Percentage of Carbon Content

(Source: http://global.britannica.com)

Due to its moderate strength, good weldability and formability, low carbon steel is broadly used in applications such as chemical processing and gas storage tanks, as well as transportation pipelines, especially in oil and gas industries (Seidu & Kutelu 2013). Besides that, carbon steel is also used in enormous scales in marine applications, nuclear power and fossil fuel power plants, as well as automotive industries, construction and metal-processing equipment. As a comparison to iron-based materials such as wrought iron[1] and cast iron[2], they have lower strength and more brittle to operate appropriately as structural materials. On the other hand, stainless and high alloy steels are only crucial and beneficial for specific products such as high-temperature piping and high pressure vessels.

[1] Almost pure iron
[2] Normally relatively high carbon material

Plus, this type of steels cannot be economically made to fulfill the great demand of quantities for structures and construction industries due to their expensive cost of raw materials, as well as their manufacturing process. Therefore, stainless and high alloy steels are not apt to be used as structural materials. Merely, low carbon steel offers the appropriate ranges of desired properties that are required for structural applications.

Moreover, the beneficial effects of the toughness[3], strength, ductility and weldability of low carbon steel make it the best material to manufacture pipelines for transferring substances such as oil and gas (Kiefner & Trench 2001). Besides that, low carbon steel also offers a long-lasting and effective properties to withstand the imposed service loads on pipelines. Not only strong and tough, low carbon steel also resistant to defects. In ideal conditions, the properties of low carbon steel are durable and do not degrading with the passage of time. For instance, over the ranges of temperatures (−28.89°C to +121.11°C) in which they are commonly utilized, low carbon steel is still stable and steady as its properties are not changing with time (Kiefner & Trench 2001).

Even though low carbon steel is durable and reliable as a structural material, low carbon steel components are still disposed and susceptible to corrosion process, specifically while in service. This corrosion effect can clearly be seen especially when low carbon steel is used in chemical, salt and acid surroundings, as well as in sour crude oil environments. The corrosion that occurs mainly on the oil pipelines has caused a severe death accidents (Seidu & Kutelu 2013).

[3] Toughness is the ability to resist crack