EFFECT OF DIFFERENT SODIUM CHLORIDE (NaCl) CONCENTRATION ON CORROSION OF COATED STEEL

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Report submitted in partial fulfillment of requirements
for award of the Degree of
Bachelor of Mechanical Engineering

FACULTY OF MECHANICAL ENGINEERING
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I certify that the project entitled "*Effect of different Sodium Chloride (NaCl) concentration on corrosion of coated steel*" is written by Mohd Firdaus Bin Ibrahim. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor Mechanical Engineering.

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In the name of ALLAH, Most Gracious, Most Merciful

To my beloved my family also to all my friends

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Firstly, my highest gratitude goes to God because of His mercy and kindness my final year project has successfully finished within the time provided. Many things I have learned throughout a year especially in corrosion process that is how it can occur, how to prevent it and so on. These experiences gained will be very useful for my future career. I hope that all information gained from my final year project may benefit to others especially Universiti Malaysia Pahang (UMP) student and staff for reference and research.

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ABSTRACT

One of the ways to prevent the corrosion from occurs is coating or painting. Paint is used as protector to the materials such as mild steel that prevent the corrosion to occur. Besides that, the corrosion rate in different concentration of Sodium Chloride (NaCl) solution is different. This study is carried on the 5 sample of mild steel as specimen that immersed in different concentration of NaCl that is 0% of NaCl, 1.5% of NaCl, 2.5% of NaCl, 3.5% of NaCl and 4.5% of NaCl. This study is carried 6 days and the result is obtained by photo snapping at second day (2nd day), fourth day (4th day) and sixth day (6th day) continuously. The paint quality is analyzing from width of corrosion, peeling, wear off and changes in colour. After that, to obtain the corrosion rate, the mass loss experiment was carried out. The purpose of this study is to study the corrosion on coated steel in different concentration of NaCl solutions. Besides that, this study also to investigate the performance of protective coating on steel in different concentration of NaCl solutions. At the end of the experiment, we can conclude that the corrosion rate is increase when the concentration of NaCl solution is also increase. Other than that, the performance of the protective coating especially paint on steel is different when it immersed in the different concentration of NaCl that is the quality of paint in 4.5% of NaCl solution is most fast to decrease.

ABSTRAK

Salah satu cara untuk mengelakkan pengaratan adalah melalui pengecatan. Penggunaan cat ini adalah adalah sebagai pelindung kepada bahan tersebut contohnya keluli lembut daripada berlakunya kecacatan. Selain itu, kadar pangaratan adalah berbeza apabila berada di dalam larutan NaCl yang berbeza. Kajian ini dilakukan pada 5sampel keluli lembut atau specimen yang mana ia direndamkan di dalam larutan yang mempunyai kepekatan yang berbeza iaitu 0% NaCl, 1.5% NaCl, 2.5% NaCl, 3.5% NaCl dan 4.5% NaCl. Selepas itu, eksperimen dijalankan selama 6 hari dengan pengambilan foto pada hari ke-2, hari ke-4 dan hari ke-6 dilakukan dan berterusan. Kualiti cat dilihat berdasarkan nilai lebar pengaratan, pelepuhan, pengelupasan dan perubahan warna. Selepas itu, untuk mencari kadar hakisan, mass loss eksperimen dilalukan.Kajian ini adalah bertujuan untuk mempelajari tentang hakisan pada besi yang dilindung di dalam larutan NaCl yang berbeza. Selain itu, kajian ini adalah untuk menyelidik persembahan cat pada besi didalam larutan NaCl yang berbeza kepekatan. Pada akhir eksperimen ini, dapat disimpulkan bahawa pada larutan yang mempunyai kepekatan NaCl paling tinggi, kadar hakisan adalah lebih cepat berbanding dengan kepekatan NaCl yang lebih rendah. Selain itu, kualiti cat juga paling cepat menurun di dalam larutan NaCl yang paling tinggi kepekatannya iaitu 4.5% NaCl berbanding dengan larutan NaCl yang lebih rendah kepekatannya.

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LIST OF SYMBOLS

%	Percentage
°C	Degree Celsius
cm	Centimeter
g	Gram
µ	Micro
ipm	Inches per month
ipy	Inches per year
m	Meter
mm	Millimeter
mpy	Mils per year
mmpy	Milimeters per year
pmpy	Picometers per year
s	seconds

LIST OF ABBREVIATIONS

A	Area
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium Carbonate
Cl	Chlorine
Cr	Chromium
Cu	Copper
$CuSO_4$	Copper Sulphate
D	Density
e^-	Electron
$E_{eq,H}$	Hydrogen evolution
Fe	Ferum
$FeSO_4$	Ferrous Sulphate
H	Hydrogen
HCl	Hydrochloric Acid
H_2O	Hydrogen Oxide (Water)
H_2SO_4	Hydrogen Sulphate
K	Constant for corrosion rate
Mg	Magnesium
MgOH	Magnesium Hydroxide
Mn	Mangan
Na	Sodium
NaCl	Sodium Chloride
Ni	Nickel

O_2	Oxygen gas
OH^-	Hydroxyl
P	Phosphorus
S	Sulphur
Si	Silicon
T	Time of exposure
W	mass/ weight
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 STUDY BACKGROUND

Mild steel is the combination of some metal elements and the carbon contains less than 0.18%. Due to the low carbon contain in the steel, mild steel cannot through the hardening process. Mild steel is known as alloy metal because it contains the quantity of alloy elements. Besides carbon, there are other elements that contain in this steel such as Mangan (Mg), Silicon (Si), and Phosphorus (P) that added to changes of the mechanical and physical properties of materials. There are two types of alloy steel that is low alloy steel and high alloy steel. The low alloy steel contains less than 5% of total element of metal alloy and the high alloy steel contains higher than 5% of total element of metal alloy also not contain the Carbon (C) element. Alloying is a method that very effective and the composition is to increase the strength of material also repairing the physical properties and whole characteristic of that alloy materials.

Corrosion can be defined as the changes of material as a result of chemical attack that caused by the environment of material. Besides that, corrosion also can be defined as the degradation of material in their environment. This is because the changes in environment that influenced by some factor that is weather and humidity rate. The corrosion had affected to the industry loss that caused by the requirement to change the part that has been corroded. It indirectly makes the life span of components or parts because the corrosion process. Because of that, some research have carried out to study and finding the steps that needed to protect the corrosion or decrease the corrosion rate per year.

Electrochemical reaction is a one process of electron transferring and chemical changes of materials. This electrochemical reaction will go through the two processes that is oxidation process (anode reaction) and reduction process (cathode reaction). Oxidation process is a chemical reaction process that produces the electron where as the reduction process is a chemical reaction process that will use the electron. There are three components that will make the corrosion occur that is water, oxygen and steel. The reaction this three components will produce the corrosion process that will cause the life span of the material is shorten and damage the physical and mechanical properties of material also the performance of that material.

The research and study about corrosion is interesting and need to proceed and continuous because nowadays, mostly industries still using steel and it alloy as the main material in the critical parts such as structural parts for oil platforms and structural for bridge. This is important to decrease the corrosion rate and the life span of material will longer. Corrosion prevention can be carried with many ways depends on the application in the industry.

This study will include the aspect of electrochemical for corrosion and the effect of the different concentration of sodium chloride (NaCl) on corrosion of coated mild steel that is the specimen that is used in this study and the factor that affect to the paint that used to coated the steel.

1.2 PROBLEM STATEMENT

There are many researches about the corrosion, the effect of corrosion and how to prevent the corrosion. This is because the mild steel and its alloys is a main material in the industry today either as the structure of a construction or as the raw material for manufacturing process of a product. However, due to material degradation with the environment that is corrosion process, it causes the life span of the material decrease and gives the effect on the mechanical and physical properties of the materials.

This research is important to find the steps that needed to decrease the corrosion rate especially in the sea water because the NaCl is the salt that have their salinity and can be representing as the sea water. From this, we can increase the life span of the material that is mild steel that used in industry.

This research will focus about the concentration of NaCl that will effect on the corrosion of coated steel. Nowadays, the real world problem why this experiment or research ii carried is because the corrosion is always happen in the sea water and this will make the ship easy to corrode.

There are several main reasons what the advantages are and why we should study about corrosion that is economics, safety, and conservation. To reduce the economic effect of corrosion, corrosion engineers and with the support of corrosion scientist should be purpose to reduce the material losses as well as the additional economic losses, that result from the corrosion of piping, tanks, metal components of machines, ships, bridges, marine structures and so on.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To study the corrosion on coated steel in different concentration of NaCl solutions.
2. To investigate the performance of protective coating on steel in different concentration of NaCl solutions.

1.4 SCOPE OF STUDY

The scopes of this study are:

1. The materials that used in this experiment are coated mild steel.
2. The physical changes of coated steel after immersed in different NaCl solutions.
3. The analysis of the formation of rust on scratched coated steel in different solution of NaCl.
4. To calculate the corrosion rate, the mass loss experiment is carried.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Corrosion is the destructive attack of a metal by chemical and electrochemical reaction with its environment. Deterioration by physical causes is not called corrosion, but is described as erosion, galling, or wear. In some instance, chemical attack accompanies physical deterioration, as described by the following term that is corrosion-erosion, corrosive wear, and fretting corrosion. Non metal are not included in this definition of corrosion. Plastic may swell or crack, wood may split or decay, granite may erode, and Portland cement may leach away, but the term corrosion, in this book, is restricted to chemical attack of metals.

Rusting applies to the corrosion of iron or iron-base alloys with formation of corrosion products consisting largely of hydrous ferric oxides. Nonferrous metal, therefore, corrode, but not rust (Revie and Uhlig, 2008).

2.2 APPLYING PAINT COATINGS

The coating should be applied to the dry metal surface as soon as possible after the metal is cleaned in order to achieve a good bond. For the better one, the metal should first be given a phosphate coat, in which case the prime coat, if necessary, can be delayed for a short while. The advantages of a phosphate coat are it can give the better bond of paint to the metal and good resistance to undercutting of the paint film at scratches or other defects in the paint at which rust forms also progresses beneath the organic coating. For many years it has been standard practice to coat automobile bodies and electric appliances with phosphate first before painting (Hudson, 1961).

Only in unusual cases paint should be applied through damp or wet surface because poor bonding of paint to steel results under these conditions. A second coat can be applied after the first has dried, or a sequence of top coats can follow. A total of four coats with combined thickness of not less than about 0.13 mm are considered by some authorities to be the recommended minimum for steel that will be showing to corrosive atmospheres (Hudson, 1961).

One of the advantages of this process compared to spraying is that it results in a uniform, thin coating that is about 25 µm thick with coverage on both exterior and interior cavity surfaces. In addition, this process is controllable, automated, efficient, and environmentally acceptable (John, 1992).

2.3 EFFECT OF CHLORIDE ION CONCENTRATION ON CORROSION

Unlike pH, the chloride ion concentration can significantly be different between bodies of water and effects of chloride ion concentration on corrosion processes are of importance due to the abundance of salt present in the environment. The average salinity level of the sea is 3.5%. Although Sodium chloride (NaCl) is found in abundance, other salts are also present whereby the composition includes a variety of ions listed from highest to lowest concentrations: chloride (Cl), sodium (Na), sulphates (SO_4), magnesium (Mg), calcium (Ca), potassium (P), carbonate (CO_3) and bromide (Br). This study is researched by some people and has been written in their book respectively. They are Agency (2001) and then proceed again by Mobin and Malik, 2007.

The rate of corrosion is usually higher in salt versus fresh water as researched by Ardagh et. al., 1933. This can be explained by the presence of chloride ions, which is it known to substantially decrease the ability of the passive film to negative metal oxidation or dissolution. The small size and negative charge of the chloride ion penetrates through the passive layer to the positively charged metal cation destroying the protective function of the passive film (Ibrahim et. al., 2009). Metals heavily affected by the breakdown of the passive film that are stainless steels and aluminum. This already stated by Malik (1999) and then by Dexter (2006). With the breakdown of the passive film, pitting corrosion of stainless steels is commonly observed, particularly in seawater.

For items of metallic facts, which are retrieved from the water, the presence of chloride ions is expected to increase the rate of corrosion. This factor is important for forensic investigators to characterize (especially for crime laboratories located along ocean coastlines) in order to appropriately assess the rate of corrosion.

2.4 CORROSION OF STEEL MECHANISM IN SOLUTION

At the medium of steel or mild steel (specimen), the reaction of corrosion that occurs is:

$$Fe + H_2O \rightarrow Fe(H_2O)_{ads} \qquad (2.1)$$

$$Fe(H_2O)_{ads} \rightarrow Fe(OH^-)_{ads} + H^+ \qquad (2.2)$$

$$Fe(OH^-)_{ads} \rightarrow Fe(OH)_{ads} + e^- \qquad (2.3)$$

$$Fe(OH)_{ads} \rightarrow Fe(OH)^+ + e^- \qquad (2.4)$$

$$Fe(OH)^+ + H^+ \rightarrow Fe^{2+} + H_2O \qquad (2.5)$$

When steel is immersed in the water, H_2O the steel (Ferum) atom will lose their electrons and become the positive ion that will dissolve to the electrolyte while the cathode reaction will produce the reduction reaction at H^+ in the water solution until the hydrogen gas, H_2 will formed. The complete reaction for anode and cathode is as shown in equation 2.6 and 2.7.

$$\text{Anode: } Fe \rightarrow Fe^{2+}\ 2e^{-} \qquad (2.6)$$

$$\text{Cathode: } 2H^{+} + OH^{-} \rightarrow H_2 \qquad (2.7)$$

In the solution of water, there are hydroxyl ions (OH^{-}) that come from the dissociation reaction of water as shown in the equation 2.8.

$$H_2O \rightarrow H^{+} + OH^{-} \qquad (2.8)$$

The hydroxyl ions will react with the iron (Fe) ions and becomes like the equation 2.9 shown

$$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2 \qquad (2.9)$$

When there is excess of substance of oxygen in the solution, it will form hydroxide ion at the cathode as shown in the equation 2.10.

$$2H_2O + O_2 + 4e^{-} \rightarrow 4(OH^{-}) \qquad (2.10)$$

Then, this will make the corrosion process faster and produces rusting. This will be shown by equation 2.11 below.

$$Fe(OH)_2 + OH^{-} \rightarrow Fe(OH) + H_2O \qquad (2.11)$$

Then, the full reaction is written as the equation 2.12 that show the reaction of corrosion process in the presence of water.

$$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_2 \qquad (2.12)$$

Chloride ion is a negative charge ion (anion). From researched have been made by Brasher, he stated that the concentration of anion in the electrolyte is important to concerns the electrolyte behavior on protector (the layer of protector oxide that formed at the top of steel surface). Chloride anion in the electrolyte assumed as too aggressive towards that oxide layer. Therefore, chloride ion is too sensitive to metal that contain iron.

As we know, at the cathode, the reduction of oxygen will occur and it shown in the reaction 2.13.

$$2H_2O + O_2 + 4e^- \rightarrow e^- + 4OH^- \qquad (2.13)$$

Whereas, at the anode, the oxidation reaction will occur because the Fe ion will lose their electrons and the equation 2.14 can be produced.

$$Fe \rightarrow Fe^{2+} + 2e^- \qquad (2.14)$$

The increase of dissolved oxygen in the solution will make the reduction of oxygen increase to become the hydroxyl ion. This reaction use electrons that produced from oxidation reaction that happen at the steel. So, the increases the number of oxygen reduction will cause the electrons that needed is increase. That why when the oxygen dissolve in solution is more, it will make the corrosion on steel is increases also. All of this information has stated by Sponas (1998) from the research about the effect of industrial composition variation on the transformation behavior of ultralow carbon steel.

2.5 EFFECT OF DISSOLVED SALTS ON CORROSION

The effect of sodium chloride concentration on corrosion of iron in air saturated water at room temperature is shown in Figure 2.1. The corrosion rate increases first with salt concentration and then decreases, with the value falling below that for distilled water when saturation is reached (26% NaCl).

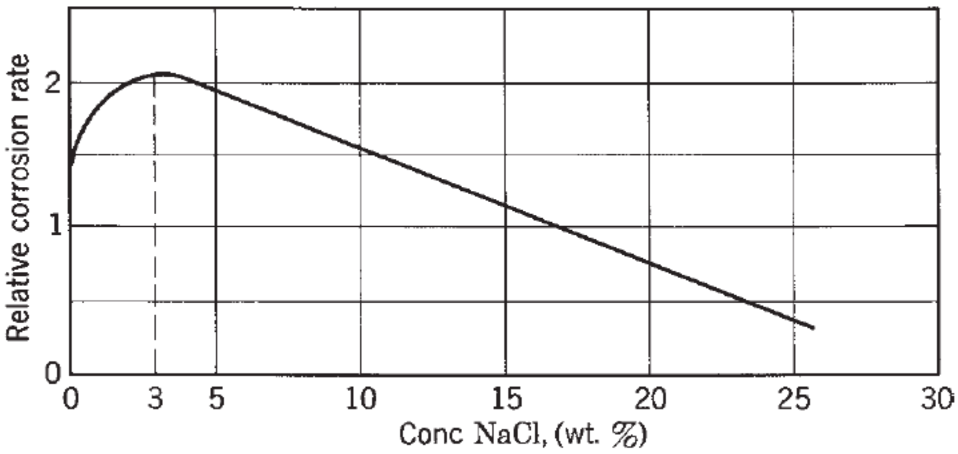


Figure 2.1: Effect of sodium chloride concentration on corrosion of iron in aerated solutions, room temperature (composite data of several investigations). (Borgmann, 1937)

Since oxygen depolarization controls the rate throughout the sodium chloride concentration range, it is important to understand why the rate first increases, reaching a maximum at about 3% NaCl (seawater concentration), and then decreases. Oxygen solubility in water decreases continuously with sodium chloride concentration, explaining the lower corrosion rates at the higher sodium chloride concentrations. The initial rise appears to be related to a change in the protective nature of the diffusion - barrier rust film that forms on corroding iron. In distilled water having low conductivity, anodes and cathodes must be located relatively near each other (Borgmann, 1937).

In sodium chloride solutions, on the other hand, the conductivity is greater; hence, additional anodes and cathodes can operate much further removed one from the other. At such cathodes, NaOH does not react immediately with $FeCl_2$ formed at anodes; instead, these substances diffuse into the solution and react to form $Fe(OH)_2$ away from the metal surface. Any $Fe(OH)_2$ so formed does not provide a protective barrier layer on the metal surface. Hence, iron corrodes more rapidly in dilute sodium chloride solution because more dissolved oxygen can reach cathodic areas. Above 3% NaCl, the continuing decreased solubility of oxygen becomes more important than any change in the diffusion that is barrier layer. Hence, the corrosion rate decreases (Borgmann, 1937).

2.6 FORMS OF CORROSION

There are many types or forms of corrosion that occur in the structure. From Figure 2.2, it has shown the forms of corrosion that occur to the metal structure. The several type or forms of corrosion are pitting, exfoliation, erosion and more (Jones, 1982).

i. General corrosion: General corrosion or rusting is the most familiar form of steel corrosion. It can be considered a uniform corrosion process in which numerous micro corrosion cells are activated at the corroded area. The cells could be minute grains where the boundary tends to be the anode, for example in atmospheric exposures, oxygen in the air is the usual oxidizing agent, and the water necessary for the reaction is readily available in the form of rain, condensation (dew, for example), or humidity (water vapor in the air). In the rusting of ordinary steel, the corrosion product (rust) does not form an effective barrier to further corrosion, but permits reactants to penetrate to the steel surface beneath and continue the rusting cycle.

ii. Pitting corrosion: A no uniform, highly localized form of corrosion that occurs at distinct spots where deep pits form. (A pit is a small electrochemical-corrosion cell, with the bottom of the pit acting as the anode.) Chloride-induced corrosion is of this type and can be seen frequently in structures exposed in coastal areas.

iii. Galvanic corrosion: When two metals of different electrochemical potential are joined or coupled electrically in the presence of moisture or an aqueous solution, one will act as the anode and corrode; the corrosion of steel when it is in contact with copper is a familiar example. This principle is used to advantage when steel is protected by galvanic methods (for example, galvanized steel or the use of other sacrificial anodes).

iv. Stress-corrosion: Under stress, corrosion processes proceed much faster and can lead to brittle failure as corrosion tends to be localized. Corrosion of this kind can occur in prestressing tendons in concrete.

v. Crevice corrosion: This form occurs when moisture and contaminants retained in crevices accelerate corrosion.

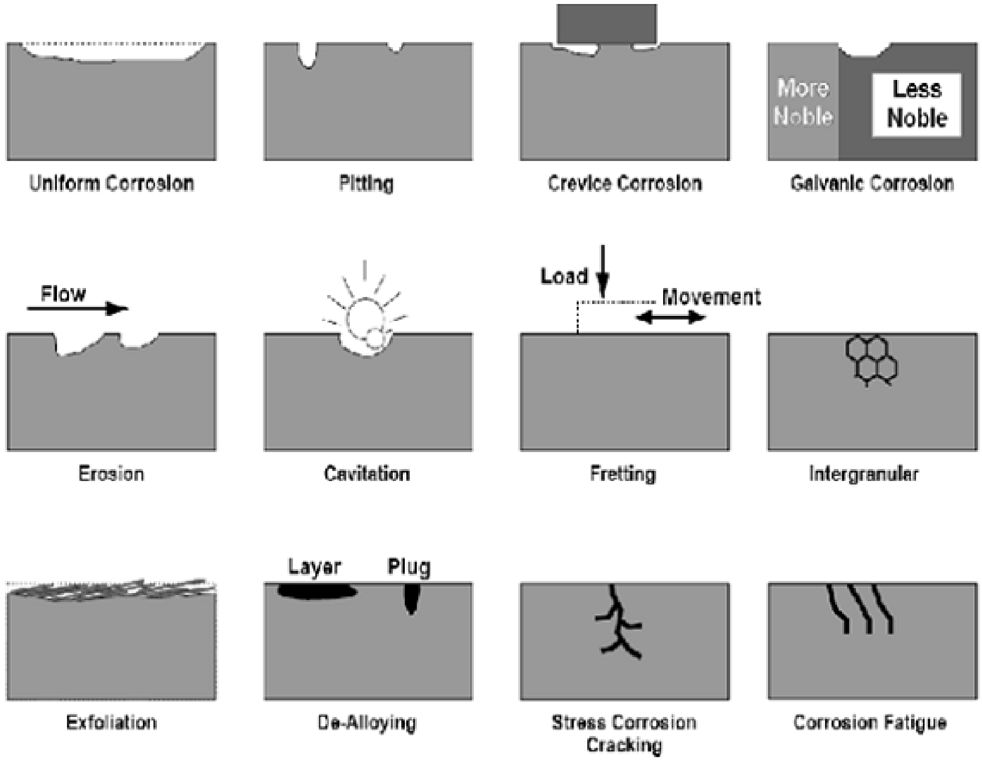


Figure 2.2: Forms of corrosions. (Jones et. al., 1982).

2.7 BLISTERING AND DELAMINATION PROCESSES ON COATED STEEL.

When a coating is exposed to an aggressive medium, such as that found in a marine environment, the associated failure mechanisms of blistering and delamination are amongst the most important to be considered. These two modes of failure are often treated separately, but have so many common features that it could be argued that the differences are a matter of degree rather than type. There is a general consensus over the integrity of a typical coating and it is fair to assume that one will find defects, due to porosity or damage in service. Therefore the following considers the situation of an organically coated steel structure containing a defect, which is subjected to aggressive, immersed conditions (Scantlebury, 2001).

Due to the presence of imperfections in the coating, the steel substrate is directly exposed to its surroundings. This initiates a corrosion process, with the anodic reaction occurring at the defect, this reaction follows that shown in equation 2.6.

$$Fe \rightarrow Fe^{2+} + 2e \qquad (2.6)$$

In order to maintain electroneutrality within the system, this reaction is balanced by a cathodic reaction. In most naturally occurring situations, this reaction will be oxygen reduction, as illustrated in equation 2.7. These two reactions initially take place adjacent to each other but separate as the process continues with the cathode moving under the coating.

$$O_2 + 2H_2O + 4e^- = 4OH^- \qquad (2.7)$$

The ferrous ions produced in equation above go into solution and react to produce electrically neutral compounds through combination with cations in the medium. This leaves us with a charge imbalance. The environment has a surfeit of positive charge, in the form of whatever cations are present and the environment at the cathode is producing hydroxyl ions, resulting in an excess of negative charge. In the case of uncoated steel, the route for the counter-cations is straightforward. However, when the steel is coated the situation becomes more complicated. The path from the exposure environment to the cathodic site is either restricted or blocked completely.

It was shown by Mayne (1949) that coatings were so permeable to water and oxygen that their rate of arrival at the cathodic region was greater than that required for corrosion to proceed. Figure 2.3 shows a schematic representation of the results of the corrosion reactions, along the lines proposed by Schwenk (1981). It can be seen that the cathodically produced hydroxyl is present at both the blistering and the delamination sites. The alkaline nature of this resultant solution at these sites is considered to be a major contributory factor in the failure of the coating.

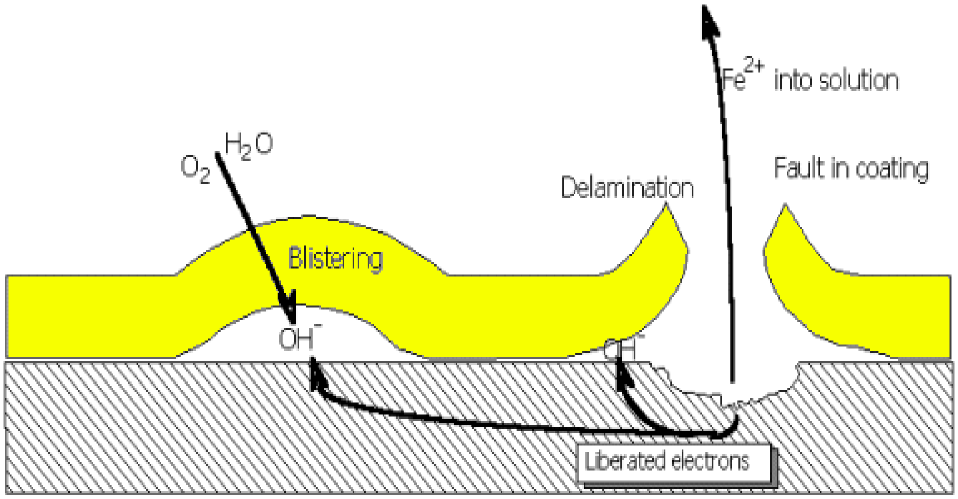


Figure 2.3: An illustration of the blistering and delamination processes after corrosion reactions. (Schwenk, 1981)

The reason this alkalinity causes such failure has been variously ascribed to saponification of the coating as the said by Castle and Watts, 1981, dissolution of the oxide layer at the interface and alteration of the ionic resistance of the film.

One particular feature that has been by a number of workers, is a delay time or initiation period between a coated substrate first being exposed to a corrosive environment and the start of the blistering or delamination process taking place. Leidheiser (1983) said this delay as due to the time required to set up a steady state diffusion in the film, whether this diffusion was of water, oxygen or ions was unclear. Nguyen et. al., 1991 on the other hand, suggests that the important route for diffusion is that of the cations along the paint or metal interface. Both interpretations provide explanations for the observed phenomena.

The work described here is related with blistering and delamination of an alkyd coating. Part of the essential quality of this research is to use, wherever possible, non-destructive test methods. To this end, some work has been carried out to determine the feasibility of incorporating pH indicators into the organic coating under investigation (Nguyen, T., et. al,. 1991)

The initial tests, described below, were carried out on an alkyd resin. The hypothesis of the tests was that cathodic areas under a clear resin coating may be identified by the high pH generated due to the presence of OH- produced by the oxygen reduction reaction; it should therefore be possible to track the delamination front as it proceeds along the interface as stated by Nguyen (1991).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

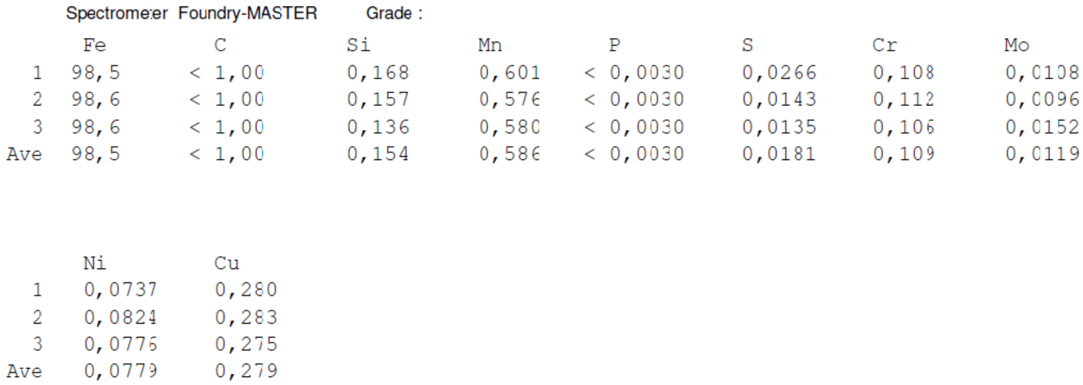
The methodology will be done right after the motivation and objectives of the project were identified. This methodology functioned as guidance in order to complete the project given. The completed structure of methodology illustrated and planned as guideline to achieve the objectives of the project.

In this study, the present work is aimed to investigate the effect of hydrogen production on steel coated during cathodic protection and study the failure behavior of coated steel in NaCl solution. The coated steel is scratch and put in the 35% of NaCl and sees the result. The electrode and the coated steel must be connecting to the electrical source. The coated steel and reference electrode are connecting to the negative pole of the electrical source and the other electrode which is will represent the oxidation connects to the positive pole.

3.2 MATERIALS COMPOSITIONS:

The materials that used in this experiment are the mild coated steel, distilled water, 1.5% of NaCl, 2.5% of NaCl, 3.5% of NaCl and 4.5% of NaCl solution, and beaker.

From the composition of material testing of mild steel, the result obtained is shown in Figure 3.1. From this composition, there are many element that combined in mild steel to make the it useful and strong.



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        Spectrome:er  Foundry-MASTER        Grade :
         Fe          C          Si         Mn          P          S          Cr         Mo
   1    98,5      < 1,00      0,168      0,601    < 0,0030     0,0266     0,108      0,0108
   2    98,6      < 1,00      0,157      0,576    < 0,0030     0,0143     0,112      0,0096
   3    98,6      < 1,00      0,136      0,580    < 0,0030     0,0135     0,106      0,0152
 Ave    98,5      < 1,00      0,154      0,586    < 0,0030     0,0181     0,109      0,0119


         Ni          Cu
   1     0,0737      0,280
   2     0,0824      0,283
   3     0,0776      0,275
 Ave     0,0779      0,279
```

Figures 3.1: The composition of element for mild steel.

From initially, this experiment will use the mild steel because it has same properties with real carbon steel. Carbon steel is sometimes referred to as ‘mild steel’ or ‘plain carbon steel’. The American Iron and Steel Institute defines a carbon steel as having no more than 2% carbon and no other appreciable alloying element. Carbon steel makes up the largest part of steel production and is used in a vast range of applications. Welding carbon steels with carbon content greater than 0.3% requires that special precautions be taken. However, welding carbon steel presents far fewer problems than welding stainless steels in the flange making process.

Cost is a very important factor that is to be considered in the Manufacturing Industries. Mild steel is a cheap form of iron-carbon alloy, and hence is cheap and suitable to be used in the flange Manufacturing Industries. Mild steel is the most common high volume steel in production. It is often used when large amounts of steel is needed, for example as structural steel .Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications especially in the flange making industries. Mild steel is less hard than that of stainless steel as stainless steel reduces hydro-corrosion and increases the hardness of the steel. But this makes it less ductile.

Mild steel has a reasonable strength and hardness it is easier to weld than stainless, and it is cheaper. Even though mild steel has a relatively lower tensile strength, it is malleable and ductile, highly suitable for the manufacturing of flanges. Mild steel is any day more malleable than stainless steel, hence paving its way in to the manufacturing industries and its excessive use in flange making. It is subject to corrosion but is malleable and does not suffer from the brittleness issues of stainless steel thereby making stainless steel less effective to be used in flange making.

3.3 EXPERIMENTAL SETUP

1. The experiment is set up as Figure 3.2 that represent for one sample of the experiment setup.
2. There are 5 beaker in this experiment that contain the different concentration of NaCl that is 0% of NaCl, 1.5% of NaCl, 2.5% of NaCl, 3.5% of NaCl, and 4.5% of NaCl.
3. The 0% of NaCl means that the solution did not contain of NaCl. We just make 1 liter of distilled water as the solution.

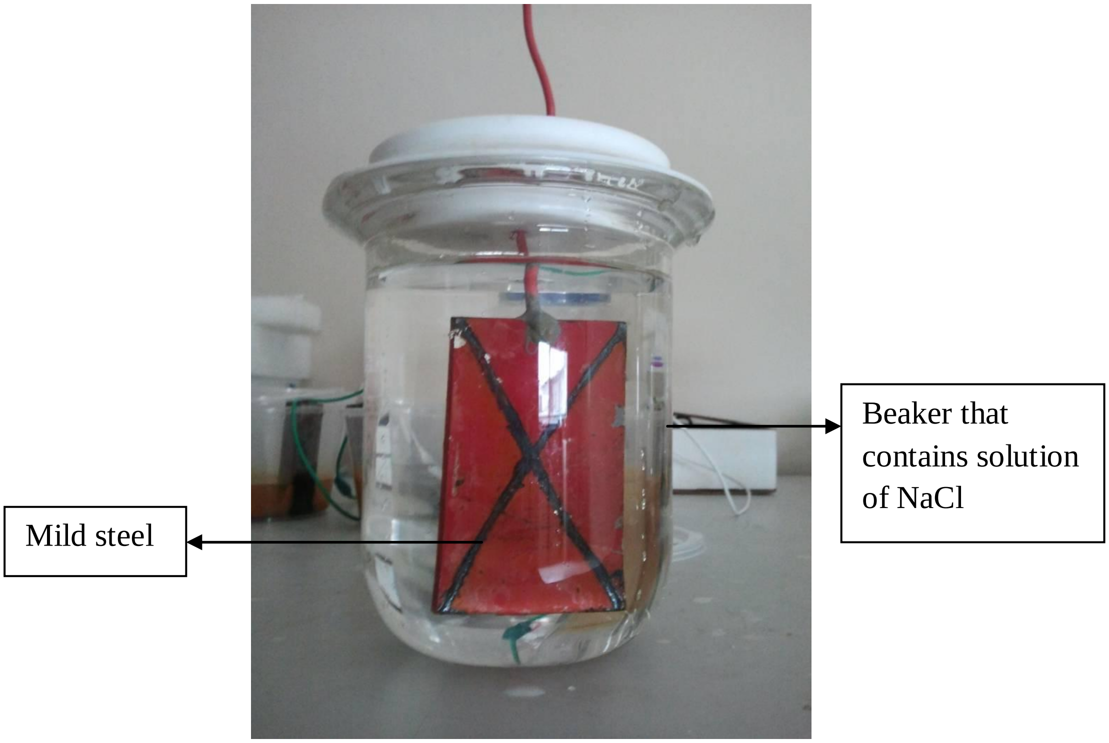


Figure 3.2: Experiment setup for one beaker.

4. The calculation to measure the concentration of NaCl in 1 liter solution of distilled water is shown as follow:

Concentration of 1.5% of NaCl = $(1.5 \div 100) \times 1000$
=15g of NaCl (for 1 liter of distilled water)

5. This 15g of NaCl we weighing and added in the distilled water. For the other concentration or percentage of NaCl, the amount of NaCl that used is shown ni Table 3.1.
6. For 0% of NaCl, it represent the solution of the experiment is only distilled water and no existence of NaCl in this solution.

Table 3.1: The concentration and mass of NaCl measured for 1 liter solution.

Concentration of NaCl (%)	Mass of NaCl (g)
0	0
1.5	15
2.5	25
3.5	35
4.5	45

7. Figure 3.3 show the step and how to measure the concentration of NaCl in 1 liter of distilled water. To measure the mass of NaCl, the scientific balance needs to set to 0 first to obtain the actual mass of NaCl.

Figure 3.3: Scientific balance used to measure the mass of NaCl

3.4 SPECIMENTS PREPARATION

1. The specimen in this experiment are mild steel because it properties almost same with the carbon steel.

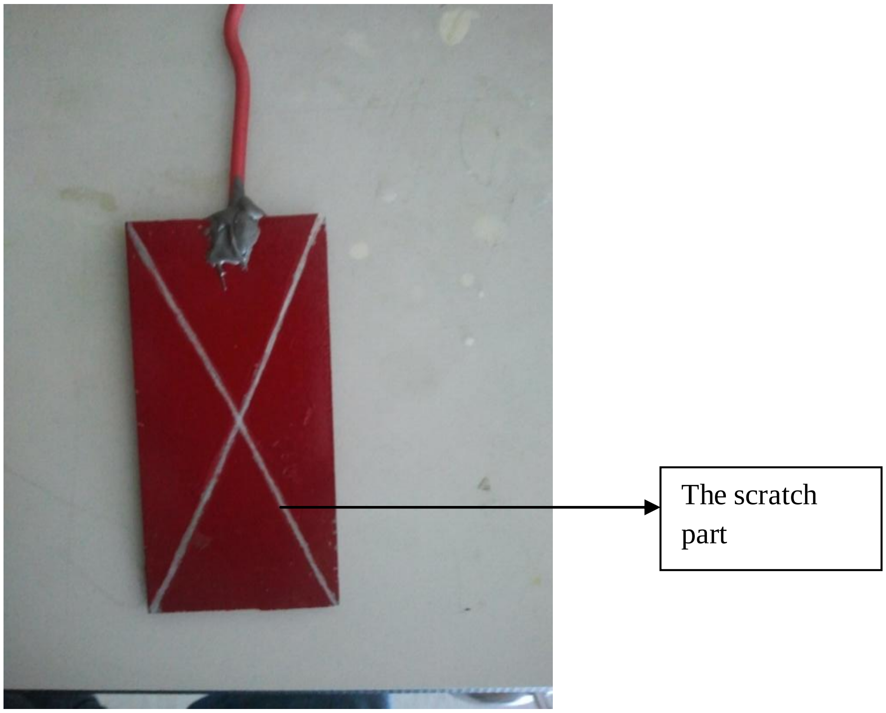
2. The mild steel cut with the suitable dimension that is 5cm×10cm×0.5cm. Actually the dimension of length and the thickness of the mild steel are not important because the surface area of the steel is important because from that we can see the changes of performance and we calculate the corrosion rate.
3. Figure 3.4 shows the specimen of this experiment that is mild steel before facing, cleaning and coating process.

Figure 3.4: Mild steel before facing, cleaning and coating process

4. This mild steel actually have some rust and not suitable to use in the experiment.
5. The ways how to remove the rusting or the layer that protect mild steel can be done by using the milling machine as shown in Figure 3.5.

Figure 3.5: Process to remove the layers that rust on the mild steel by using the milling machine.

6. This specimen then coated by using the paint and the thickness of the coated layer are 0.01mm.
7. After the specimen is coated, then it was connect with the wire to make sure the current flow through the steel during the experiment.
8. Then, the mild steel is scratch with the width 1mm to make use the corrosion can happen on the mild steel.
9. The specimen that is used in the experiment is shown in Figure 3.6.
10. For this experiment, there are 5 sample that is mild steel should be prepared.



The scratch part

Figure 3.6: The specimen that can be used in the experiment.

3.5 EXPERIMENT PROCEDURES

1. The mild steel with dimension 5cm × 10cm × 0.5cm are used in this experiment. This steel is scratched to accelerate the corrosion.
2. The coated steel is immersed in the different concentration of NaCl solution.
3. The coated steel are put in the 0% of NaCl (distilled water), 1.5% of NaCl, 2.5% of NaCl, 3.5% of NaCl and 4.5% of NaCl that acts as electrolyte.
4. After 2 days, snap the picture of the mild steel and analyze the differences that happen.
5. The experiment are continue and the observation is made every two days interval.(6 days)
6. Observation is made on the coated steel and recorded.
7. The density of this mild steel is 7.86 g/cm^3 or 7860 kg/m^3.

8. After this experiment, the mass loss experiment was carried to calculate the corrosion rate of the steel.
9. For the mass loss experiment, to determine the mass loss of the base metal when removing corrosion product, the specimen should be cleaned using Amine and HCl acid. By weighing the specimen before and after cleaning, the mass loss resulting from cleaning can be utilized to correct the corrosion mass loss.
10. The measurement of mild steel mass is repeating at least for several times to get the average mass of mild steel. After the average mass is obtained, the corrosion rate will be determined by using the formula.
11. The cleaning procedure should be repeated on specimens in several times. The mass loss should be determined after each cleaning procedure is preferred.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESULTS

From the experiment that conducted in duration of sixth day, the result that obtained is analyzed by the day of the experiment that is second day, fourth day and lastly sixth day.

4.1.1 The result for each two days immersion

a) 2nd day immersion

Figure 4.1 shows the performance of the specimen at the second day immersion. For the second day immersion, the corrosion is already happen on the scratch part of the mild steel in all NaCl concentration. The corrosion occurs faster in the solution that has high concentration of NaCl. The width of corrosion and the peeling of paint are not occurring yet in all solution. Besides that, in the solution of 0% of NaCl, the colour of solution is not change yet. But, for the solution of 1.5%, 2.5%, 3.5% and 4.5% of NaCl, the colour of the solution is already happen.

0% of NaCl	1.5% of NaCl	2.5% of NaCl	3.5% of NaCl	4.5% of NaCl
				

Figure 4.1: The performance of mild steel at the second day immersion.

b) 4th day immersion

Figure 4.2 shows the performance of the mild steel at the fourth day immersion for different concentration of NaCl. At the fourth day experiment, the changes of the result are more clearly compared with the second day experiment. From the result obtained, the corrosion on the scratch part of the specimen is more compared to the second day. The corrosion that happens in the plate of 4.5% of NaCl is more because the colour of plate is darken compared with the other concentration. For aspect of width of corrosion, the width of corrosion not happen yet in the solution 0% of NaCl but in the other solution that is 1.5%, 2.5%, 3.5% and 4.5% is already happen but still amount of little. Besides that, the colour of the solution in all solution is changes. The colour of the solution in all solution becomes more reddish because of the corrosion. For peeling of the paint aspect, it already happens but not much in all solution especially in high concentration. Other than that, in all solution, there are depositions of corrosion at the bottom of the beaker

0% of NaCl	1.5% of NaCl	2.5% of NaCl	3.5% of NaCl	4.5% of NaCl
				

Figure 4.2: The performance of mild steel at the fourth day immersion.

c) 6^{th} day immersion

Figure 4.3 shows the performance of the mild steel at the sixth day immersion for different concentration of NaCl. For the final day experiment or immersion of the steel, there are many changes that happen on the surface area of the steel and the colour of the solutions. For all solution in different concentration of NaCl, the corrosion already occurs at the scratch part. From the result viewed, the corrosion is more occur in the solutions that have high concentration of NaCl. The width of the corrosion at the scratch part of the specimen is increase compared to the fourth and second day immersion. For peeling of paint aspect, the peeling of paint already occur but little bit for 0% of NaCl and in the 4.5% of NaCl concentration, the paint is wear off more compared to others. The colour of the solutions is changes in all solution and it clearly can be seen. Lastly, on aspect of deposition, the solution 4.5% of NaCl is more compared to the other solution and it increases when the concentration of solution is increase.

0% of NaCl | **1.5% of NaCl** | **2.5% of NaCl** | **3.5% of NaCl** | **4.5% of NaCl**

Figure 4.3: The performance of mild steel at the sixth day immersion.

4.1.2 The Scoring techniques of failure behavior on corrosion of coated steel.

The scoring technique or rating technique will make the effect of different NaCl concentration on corrosion of coated steel easy to see. Let rating the corrosion failures behavior on coated steel as the follows. The results that come from this rating are inserted in the table to make easier to see as shown in Table 4.1.

Assume:

1 = the failures of steel is not happen.
2 = the failures of steel is low.
3 = the failures of steel is moderate.
4 = the failures of steel is high.
5 = the failures of steel is highest.

Table 4.1: The rating technique for the failure behavior at second, fourth and sixth days of experiment.

Day	1	2	3	4	5
2nd		✓			
4th			✓		
6th				✓	

The definition of failure that occurs at the steel or specimen can be measured by some aspect. The failure are seen when the corrosion are occur at the scratch part, the peeling of the paint is wear off from the steel and the paint is wear off from the steel. Besides that, the colour of the solution is changes also the deposition is formed at the bottom of the beaker. All of this aspect can be used to define the meaning of failures. The final step of scoring technique is by plotting a graph to see the effect of concentration on corrosion as shown in Figure 4.4.

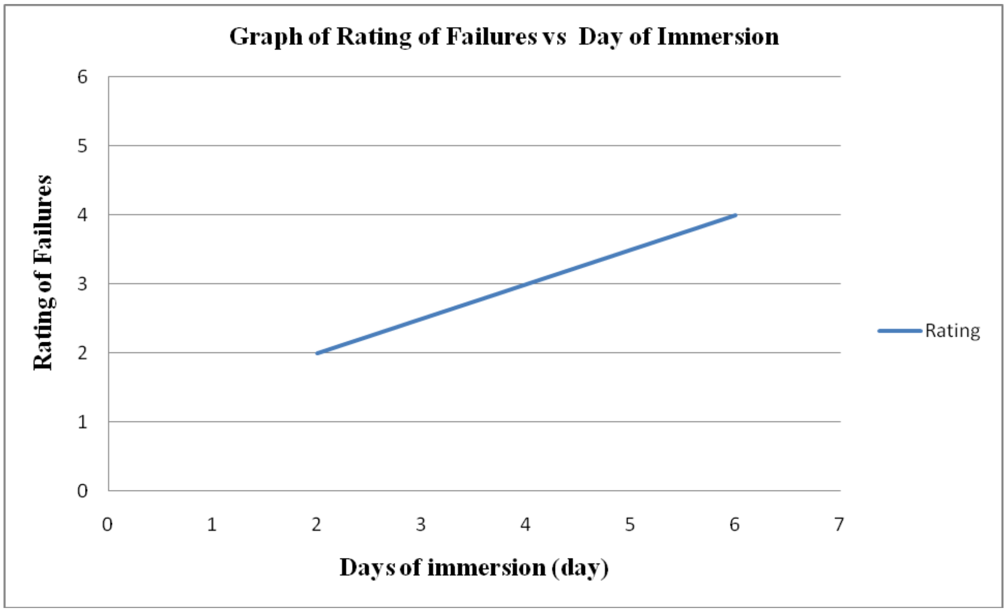


Figure 4.4: The graph of rating versus days of experiment.

4.2 THE MASS LOSS RESULT AND CALCULATION

To calculate the corrosion rate, the density and area of the specimen must be know first. Equation 4.1 shows the formula that used to calculate the corrosion rate of the specimen.

$$\text{Corrosion Rate} = (K \times W)\ (A \times T \times D) \qquad (4.1)$$

Where:

K = a constant (refer Table 2.1)

T = time of exposure in hours

A = area in cm^2

W = mass loss in grams

D = density in g/cm^3

From the corrosion rate equation, there are the constant that we need to use to calculate the corrosion rate. Table 4.2 shows the constant, K of corrosion rate equation.

Table 4.2: The constant may also be used to convert corrosion rate.

Corrosion Rate Units Desired	**Constant (K) in Corrosion Rate Equation**
Mils per year (mpy)	3.45×10^6
Inches per year (ipy)	3.45×10^3
Inches per month (ipm)	2.87×10^2
Millimeters per year(mm/y)	8.76×10^4
Micrometers per year (µm/y)	8.76×10^7
Picometers per second (pm/s)	2.78×10^6
Grams per square meter per hour ($g/m^2.h$)	$1.00 \times 10^4 \times D$
Milligrams per square meter per hour ($g/m^2.h$)	$2.40 \times 10^6 \times D$
Micrograms per square meter per second ($\mu g/m^2.s$)	$2.78 \times 10^6 \times D$

From the constant, K value above, the corrosion rate can be calculated using the equation 4.1. For the mass loss experiment, the data that need to know before calculate the corrosion rate is the initial mass of the steel (average mass), final mass of the steel (average mass), mass loss (g) that is the initial mass is minus with the final mass. Besides that, the area of the steel that corrode, the density of the steel and lastly the time of exposure that is the time of steel is immersed. For example, below is the calculation how to calculate the corrosion rate. Then, the Table 4.3 shows the corrosion rate for all the NaCl concentration obtained from the mass loss experiment.

Corrosion rate on 0% of NaCl

Initial mass of steel (average) = 193.8g

Final mass of steel (average) = 190.3g

Mass loss, W = 3.5g

Area of scratch part of steel, A = 4.9 cm^2

Density of specimen (mild steel), D =7.86 g/cm^3

Corrosion constant, K = 8.76×10^4

Time of exposure, T= 7days = 168hours

Corrosion rate $= (8.76 \times 10^4 \times 3.5)\ (4.9 \times 168 \times 7.86)$

$= 1.984 \times 10^9$ mmpy

Table 4.3: The corrosion rate obtained for mass loss experiment.

NaCl concentration (%)	Final mass (g)	Mass loss (g)	Corrosion rate (mmpy)
0	190.3	3.5	1.984×10^9
1.5	186.6	7.2	4.081×10^9
2.5	180.7	13.1	7.425×10^9
3.5	172.7	21.1	1.196×10^{10}
4.5	165.4	28.4	1.610×10^{10}

For the other concentration of NaCl, there are similarities in some parameters such as initial mass, area of scratch part of steel, corrosion constant, density of specimen and the time of exposure. The similarities are happen because we use the steel that same properties.

4.3 DISCUSSIONS

From the evaluation result of mild steel appearance, we can see that after one day of the experiment, the paint quality on the plate (mild steel) surface that immersed in the different solution (different concentration of NaCl) is still good. This indicates that the paint is still good ability to protect the surface of the mild steel plate. This shows that with the paint that covering the surface of the mild steel plate will delay the start of the corrosion process because the paint layer can slow the diffusion of water and oxygen to the metal surface is the cause of the corrosion reaction.

At the second day of the experiment, we can see the corrosion already occur on the scratch part of the plate. The corrosion that happens is different on the different plate because of the different solution. This corrosion is happen because in the presence of moisture, an oxidation reaction takes place on the energized area of the metal surface to elute metal as an ion (anode). A reduction takes place on low energy area (cathode). On the metal surface, oxidation on anode and reduction on cathode proceed in equal rates and metal corrosion takes place. Normally, corrosion of metal occurs on anode. On the second day experiment also, the changes of the solution already started on all solution of NaCl because the corrosion of the mild steel that also affect the electrolyte.

At the fourth day of experiment, the corrosion is more than compared with the second day. The changes of solution also happen from the previous day because the corrosion of the steel is increase. The deposition of corrosion is increases with the increases of the concentration of NaCl in the solution which is the concentration of 4.5% of NaCl is the clearly saw that the deposition is formed at the bottom of the beaker as shown in Figure 4.5. Besides that, if we observe the result on the fourth day, the width of the corrosion on the scratch part of plate also occurs. The main factor that causes the corrosion on steel in water is the existence of dissolved salt like sodium chloride (NaCl) that make the solution (distilled water) more active to rust.

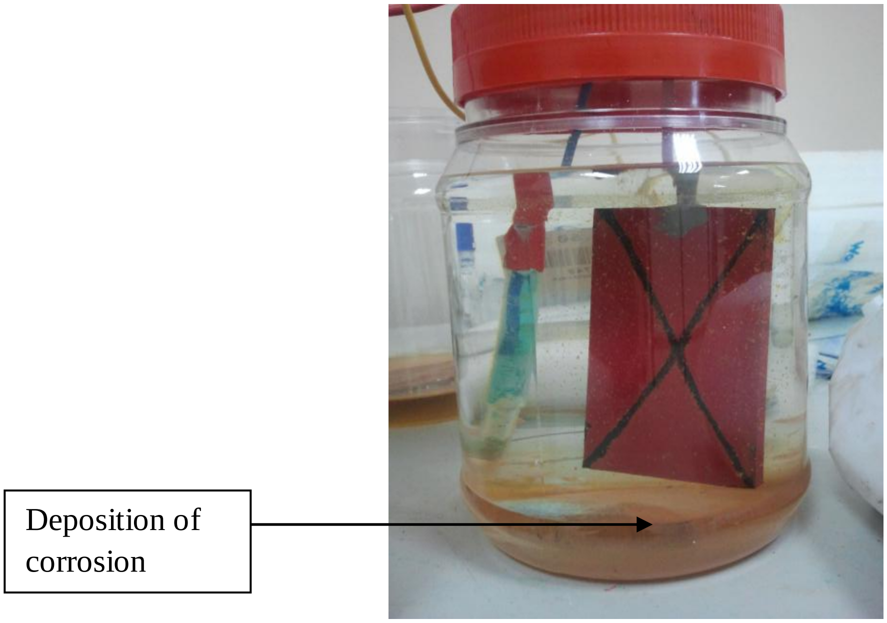


Figure 4.5: The deposition of corrosion that formed during experiment.

At the sixth day of the experiment, we can see the a little bit of change of the plate color that is the paint color. If compared with the result on second day, the color of the paint at the decrease. The factors that causes the hardness value of paint is decrease is because the width of corrosion at the scratch part of mild steel already started, and the peeling of the coating also already started.

Some researchers have explained that the damage occurred starting with peeling paint first layer. The peeling is the initial motivating factor in the occurrence of corrosion on the part that protected by paint. This peeling paint caused by the presence of water molecules that absorbed into the paint. In this case, the membrane acts as membrane semi permeable paint. When the concentration of the salt solution in the paint up, immediately osmotic pressure forcing water through a membrane in more aqueous solution. This will increases the water pressure in paint and peeling occurred at the same time. This phenomenon will cause the distance between paint layer and steel increased. Then, the layer of paint will peel until the corrosion occurs on the part that not protected anymore as shown in Figure 4.6.

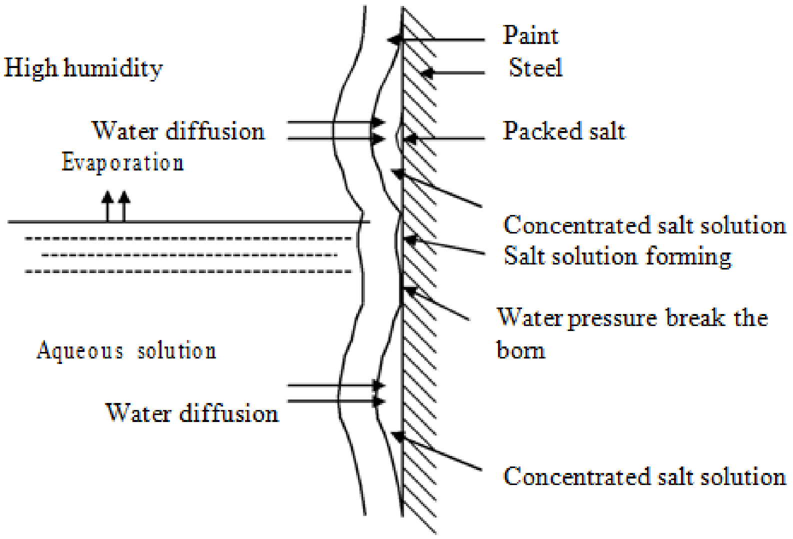


Figure 4.6: The development of peeling on the paint layer caused by osmotic pressure. (Sponas and Fonda, 1998).

The born between the paint layer and steel that protected (coated) must be strong and covered to whole surface to protect from damage caused by osmosis process. The common paint (no addition of epoxy), born between the paint and surface of steel not too strong compared to the paint that contain the epoxy that causes the water easy to diffuse to the paint. Then, this will affect to the paint that is it easy to exfoliation (peeling) and fade in color.

For mass loss experiment, the corrosion rate that obtained in different NaCl concentrations is different. From the table above, we can see when the concentration of NaCl is increased, the corrosion rate also increase. The corrosion rate that obtained is different because the mass loss from this experiment is not same. In solution 0% of NaCl, the corrosion rate is 1.984 × 10^9 mmpy and this is lower than 1.5% of NaCl that is 4.081 × 10^9 mmpy. In solution that contain of 4.5% of NaCl concentration, the corrosion is largest because it easy to occur because the effect of NaCl that make the corrosion easy to occur.

Figure 4.7 shows the graph of corrosion rate versus NaCl concentration. From this graph, we can see the when the concentration of NaCl increase, the corrosion rate of the metal will increase. The corrosion rate is the highest when the specimen that is coated mild steel is immersed in 4.5% of NaCl solution and the lowest corrosion rate is when the specimen is immersed in the distilled water (0% of NaCl).

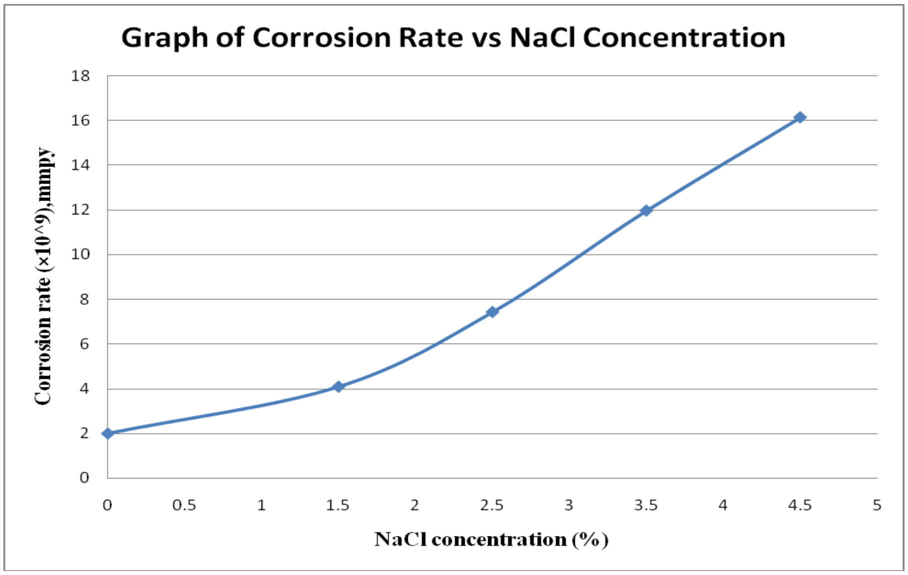


Figure 4.7: Graph of corrosion rate versus NaCl concentration.

The corrosion rate that obtained in the graph is different because the mass that loss when the final measurement that is at seventh day is not same. When the concentration in increased, the weight that loss is increase because the paint that cover the specimen (mild steel) is wear off in different quantity.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the experiment and the research, we can conclude that the salt water of will cause the corrosion is easier to occur. The increase of concentration of Sodium Chloride (NaCl) will make the corrosion easier to occur. The main factor why water salt is make corrosion is easier to happen because the existence of chloride ion (CI) and oxygen that dissolved in water. Then the sea water also can make the paint easy to wear off that will cause the corrosion easy to occur. At the plate with contain of NaCl concentration (sea water), the change of color at the unprotected plate (scratch part) with the paint will become the black color. This is maybe caused by element of magnesium and chlorine that exists in the sea water which is the dominant element and can be active reaction with the mild steel when the corrosion potential achieved.

Besides that, the time of protection will decreases the current flow that needed during cathodic protection. When the time of protection increase, the potential different will decrease during cathodic protection which is the mild steel plate will damage and the exfoliation will occur. During this experiment, the types of corrosion that occur are exfoliation corrosion. This is because the paint that is protecting mild steel will peel when we submerged it in the sea water solution.

Form the mass loss experiment, the result that obtained can be concluding that when the concentration of NaCl in increased, the corrosion rate is increase also. The highest corrosion rate that we obtained in this experiment is 1.610×10^{10} mmpy.

5.2 RECOMMENDATIONS

It is recommended to study another parameter that can know the other types of corrosion. In this experiment, the parameter that used is the concentration of NaCl. So, for the next study, the solution, and the specimen can be the parameter and then the time should be longer to obtain the better result.

It is also recommended that the process and method that will be use to coating for carbon steel so that the born between the paint and surface of carbon steel really strong until the protection that given by the paint is maximum. In this experiment, the mild steel is coated by painting. So, for the next study, the other method of coating should be tried such as dipping, electroplating, spraying, cementation, and diffusion.

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