# SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis 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 (Structure and Materials)"

Signature :..................................................

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Date :..................................................

A STUDY THE MATHEMATICAL MODELING OF CORROSION IN STAINLESS STEEL

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This Report Is Submitted In Partially Fulfillment of Requirement for the Bachelor Degree of Mechanical Engineering (Structure and Material)

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**DECLARATION**

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature :…………………………..
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Date :…………………………..

This thesis is dedicated to my parents who have never failed to give me moral support and also for my supervisor who teaching me that even the largest task can be accomplished if we can apply our logic thinking and also my friends give support and encouragement

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All praises and thanks be to Allah S.W.T, who has guided us to this, never could we have found guidance, were it not that Allah had guided us! (Quran 7:43). All praises again to the All Mighty Allah with His permission, I managed to carry out the study with His blessings of health, opportunity and knowledge.

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I hope this research will be guidance to researchers to make an improvement about mathematical modeling of corrosion in stainless steel in the future.

# ABSTRACT

This Projek Sarjana Muda (PSM) has been conducted to study the occurance of corrosion activity in stainless steel material. The research is focusing on principle of corrosion in stainless steel, theory of corrosion kinetics (Oxidation, Reduction, and Hydrolysis). General corrosion is much less occurring in stainless steel than in other metals. It only occurs when the stainless steel is at a pH value which is either very low (acid environments) or very high (alkaline environments) at high temperature. This project studies how corrosion activities in stainless steel occur with the use of COMSOL Multiphysics as tool. The mathematical modeling of corrosion in stainles steel is constructed to simulate the corrosion activity by using COMSOL Multiphysics. The result and analysis will be discuses on next chapter.

# ABSTRAK

Projek Sarjana Muda (PSM) ini telah dijalankan untuk mengkaji bagaimana berlakunya aktiviti hakisan terhadap keluli tahan karat. Penyelidikan ini memeberi fokus kepada prinsip kakisan terhadap keluli tahan karat, teori kinetik kakisan (Pengoksidaan, Pengurangan, dan Hidrolisis). Kebiasaanya kakisan kurang berlaku terhadap keluli tahan karat berbanding dengan logam lain. Ianya berlaku apabila keluli tahan karat terdedah kepada nilai pH yang sangat rendah (persekitaran berasid) atau nilai pH yang sangat tinggi (persekitaran beralkali) pada suhu yang tinggi. Projek ini dijalankan untuk mengkaji bagaimana aktiviti kakisan terhadap keluli berlaku dengan menggunakan perisian COMSOL Multiphysics sebagai alat kajian. Kemudian, pemodelan matematik kakisan keluli tahan karat dihasilkan untuk disimulasikan aktiviti hakisan dengan perisian COMSOL Multiphysics. Hasilnya dibincangkan dan dianalisis pada bahagaian yang seterusnya.

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| | | |
|---|---|---|
| $E^0$ | = | Standard electrode potential, V |
| n | = | Number of electrons transferred |
| $C_{ion}$ | = | Molar activity (concentration) of ions |
| K | = | Kelvin |
| V | = | Volt |
| R | = | Gas constant |
| F | = | Faraday’s constant |
| D | = | Diffusion |
| k | = | kinetic constant |

# CHAPTER 1

# INTRODUCTION

## 1.0 BACKGROUND

Stainless steel represents one of the more recent groups of steel group (Figure 1). Although invented at the beginning of the 20th Century, it took several decades before their use became widespread in the world. It came from steel family consist of Carbon Steel, Alloy Steel & Stainless Steel (see Figure 1.1).

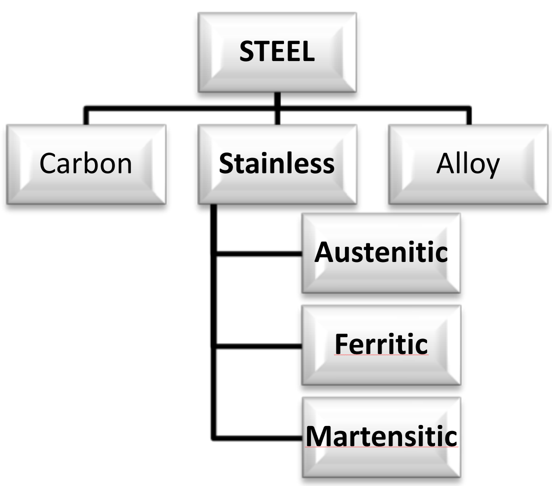



Figure 1.1 Group of Steel

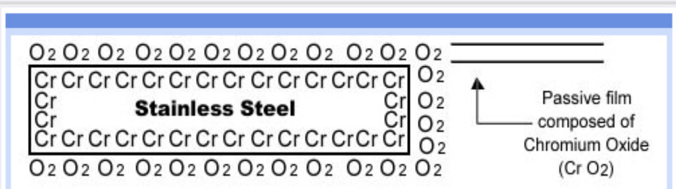
Stainless steels are generally very corrosion resistant and perform satisfactorily in most environments. The limit of corrosion resistance of a given stainless steel depends on its alloying elements which means that each grade has a slightly different response when exposed to a corrosive environment. Care is therefore needed to select the most accurate grade of stainless steel for a given application. Generally, the higher the level of corrosion resistance required, the higher the level of alloying elements and the greater the cost of the material.

All stainless steels are iron-based alloys that contain a minimum of around 10.5% Chromium. The chromium in the alloy forms a self-healing protective clear oxide layer (see Figure 1.2). This oxide layer gives stainless steels their corrosion resistance. The self healing nature of the oxide layer means the corrosion resistance remains intact regardless of fabrication methods. Even if the material surface is cut or damaged, it wills self heal and corrosion resistance will be maintained (see Table 2.1).

| **NORMAL CARBON STEEL** |
| --- |


| |
| --- |
| Fe + C + Mn = Carbon Steel |
| Carbon Steel + O2 = RUST |

| **STAINLESS STEEL** |
| --- |




| |
| --- |
| Fe + C + Mn + Cr = Stainless Steel |
| Stainless Steel + O2 = Material Protected with a CrOxide layer |

Table 1.1 Differences between normal carbon steel and stainless steel resistence to corrosion

Self-healing effect of stainless steel that chromium oxide is a thin and transparent passive layer of chromium oxide that allows the natural beauty of stainless steel to remain intact. It is also self-healing and forms readily in air.

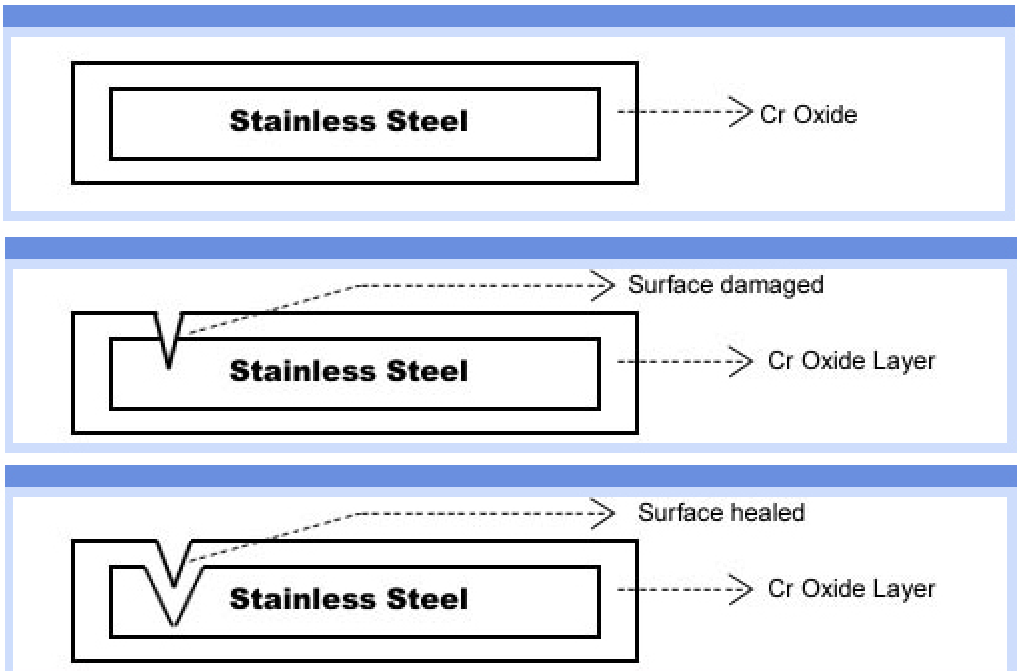



Figure 1.2 Self-healing effect of stainless steel

(Source: www.hoto.com)

The corrosion of different grades of stainless steel will differ with various environment situations. Suitable grades will depend upon the service environment. Grades high in Chromium, Molybdenum and Nickel are the most resistant to corrosion.

## 1.1 PROBLEM STATEMENT

Stainless steels of various kinds are used in thousands of applications because its physical and mechanical properties. General corrosion is much less occurring in stainless steel than in other metals. It only occurs when the stainless steel is at a pH value which is either very low (acid environments) or very high (alkaline environments) at high temperature. The effects of corrosion in our daily lives are both direct, in that corrosion affects the useful service lives of our possessions, and indirect, in that producers and suppliers of goods and services incur corrosion costs, which they pass on to consumers. At home, corrosion is readily recognized on automobile body panels, charcoal grills, outdoor furniture, and metal tools. The problem is stainless also still have corrosion rate. Preventative maintenance such as painting protects such items from corrosion. This study on how the corrosion in the stainless steels is happening by using mathematical modeling software. The environment for this work studies in 3 different pH base, ph 6, pH 7 and pH 8. The concentration base is chloride concentration.

## 1.2 OBJECTIVES

- To study the occurrence of corrosion activity in stainless steel.
- To construct mathematical equation based on the kinetics of corrosion of stainless steel.

## 1.3 SCOPES

- Literature review on stainless steel and corrosion principles, its relation to Pourbaix diagram of iron.
- Theory of corrosion kinetics:
  - Oxidation (anedic)
  - Reduction (cathodic)
  - Hydrolysis
- Simulate the corrosion activities by using COMSOL Multiphysics.
- Result and analysis

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 TYPES OF STAINLESS STEEL

The most common alloys of stainless steel used in under three main groups;

1. Austenitic
2. Ferritic
3. Martensitic

Austenitic stainless steels contain chromium and nickel (7% or more) as major alloying elements. The crystallographic structure of the steels is austenitic with FCC crystal lattice (see Figure 2.1). The steels from this group have the highest corrosion resistance, weldability and ductility. Austenitic stainless steels retain their properties at elevated temperatures. At the temperatures 900-1400ºF (482-760ºC) chromium carbides form along the austenite grains. This causes depletion of chromium from the grains resulting in decreasing the corrosion protective passive film. This effect is called sensitization. It is particularly important in welding of austenitic stainless steels. Formation of chromium carbides is also avoided in stabilized austenitic stainless steels containing carbide forming elements like titanium, niobium, tantalum, and zirconium. Stabilization heat treatment of such steels results in preferred formation of carbides of the stabilizing elements instead of chromium carbides. These steel are not heat treatable and may be hardened only by cold work. Applications of austenitic stainless steels such as chemical equipment, food equipment, kitchen sinks, medical devices, heat exchangers, parts of furnaces and ovens.

Ferritic stainless steels contain chromium only as alloying element. The crystallographic structure of the steels is ferritic, BCC crystal lattice (see figure 2.1) at all temperatures. The steels from this group are low cost and have the best machinability. The steels are ferromagnetic. Ductility and formability of ferritic steels are low. Corrosion resistance and weldability are moderate. Resistance to the stress corrosion cracking is high. Ferritic steels are not heat treatable because of low carbon concentration and they are commonly used inannealed state. Applications of ferritic steels such as decorative and architectural parts, automotive trims and exhausting systems, computer floppy disc hubs, hot water tanks.

Martensitic stainless steels contain chromium as alloying element and increased (as compared to ferritic grade) amount of carbon. Due to increased concentration of carbon the steels from this group are heat treatable. The steels have austenitic structure (FCC) at high temperature, which transforms to martensitic structure (BCC) as a result of quenching. Martensitic steels have poor weldability and ductility. Corrosion resistance of these steels is moderate (slightly better than in ferritic steels). Applications of martensitic stainless steels: turbine blades, knife blades, surgical instruments, shafts, pins, springs.

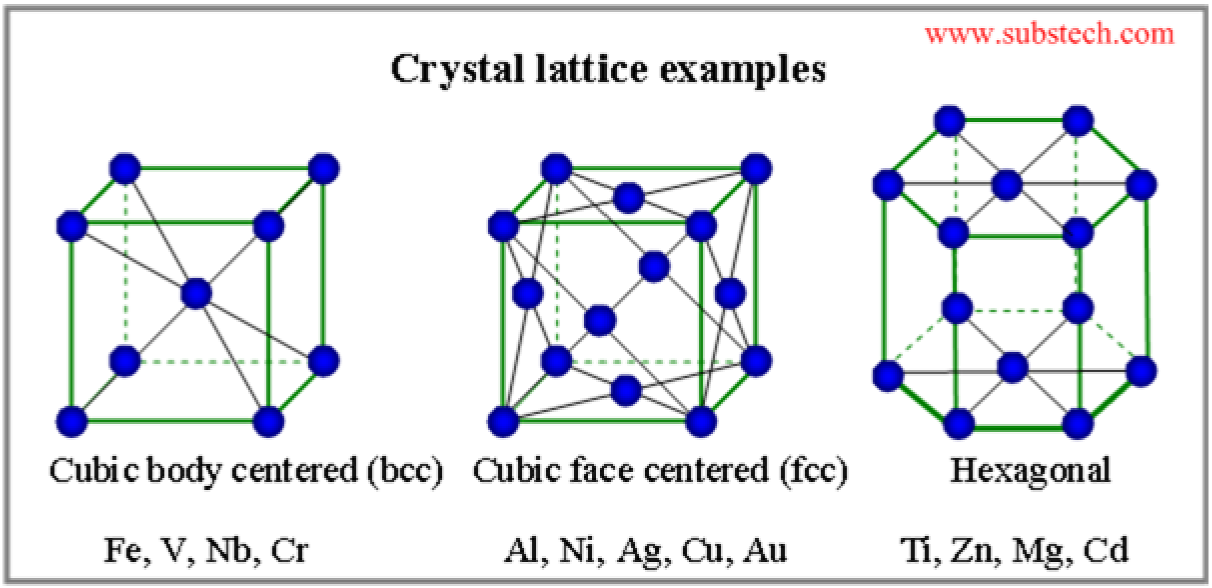



Figure 2.1 Examples of typical crystal lattice
(Source http://www.substech.com)

The types of corrosion in some environments and care must be taken to select a grade which will be suitable for the application. Corrosion can cause a variety of problems, depending on the applications:

- Perforation such as of tanks and pipes, which allows leakage of fluids or gases,
- Loss of strength where the cross section of structural members is reduced by corrosion, leading to a loss of strength of the structure and subsequent failure,
- Degradation of appearance, where corrosion products or pitting can detract from a decorative surface finish,
- Finally, corrosion can produce scale or rust which can contaminate the material being handled; this particularly applies in the case of food processing equipment.

## 2.2 CORROSION

Corrosion is the deterioration of a material due to interaction with its environment. Corrosion in an aqueous environment and in an atmospheric environment (which also involves thin aqueous layers) is an electrochemical process because corrosion involves the transfer of electrons between a metal surface and an aqueous electrolyte solution.

Many of nonmetallic, such as ceramics, consists of metal that have their chemical reactivity satisfied by the formation of bond with other reactive ions, such as oxides and silicates[1]. Metal corrode because of the electrovalent of ions is not stable. Corrosion has been classified in two different ways. One of the methods explains that corrosion can be dividing into low temperature and high temperature. But the most preferred classification of corrosion is wet corrosion and dry corrosion. Figure 2.3 is a general schematic for the corrosion mechanism. Concentration cells may also be formed where there are differences in metal ion concentration. A copper pipe in contact with copper ion solutions of different concentrations will corrode at the part in contact with the more dilute solution.

Corrosion is considered to involve electrochemical processes; that is, chemical changes caused by electrical potential differences (voltage gradients). For corrosion to occur, in simple terms, three components must be present, as indicated schematically in Figure 2.2. These three components are:

- Anedic (oxidation) is an anode or electrode where there are excess electrons (negative potential) because of the release of positively charged ions into the electrolyte; i.e., corrosion occurs.
- Cathodic is a cathode (or counter electrode where electrons are consumed by the discharge of ions in the electrolyte).
- An electrolyte (or conductive medium that allows an ionic current to flow to maintain a charge balance).

[1] Jones, D.A. (1996) Principles and Prevention of Corrosion, 2nd Edition, London: Prentice Hall

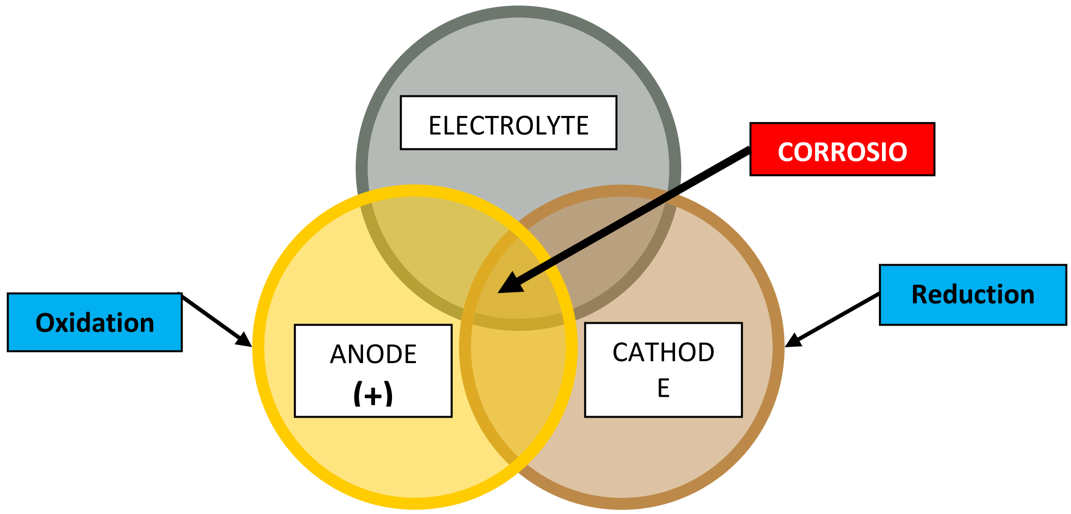



Figure 2.2 Three importants principle in corrosion

Like most other chemical reactions, corrosion rates increase as temperature increases. Temperature and pressure of the medium govern the solubilities of the corrosive species in the fluid, such as oxygen (O), carbon dioxide (CO), chlorides, and hydroxides.

### 2.2.1 Equation of corrosion reactions

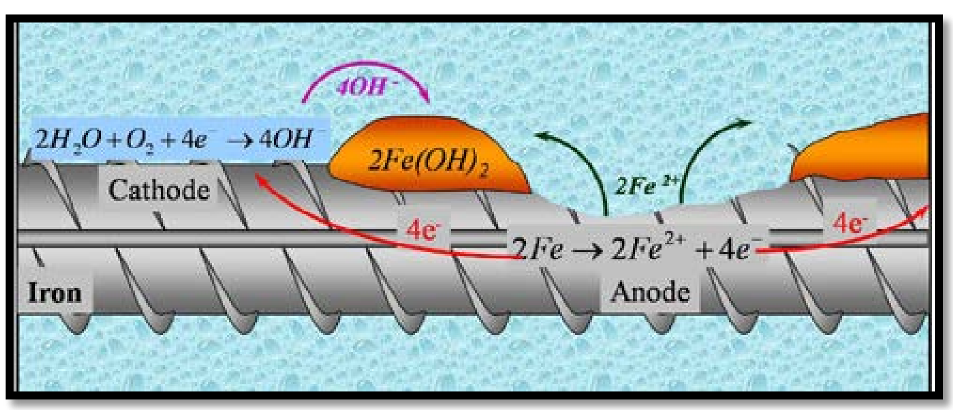



Figure 2.3 Schematic of corrosion mechanism of iron