**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

## BORANG PENGESAHAN STATUS TESIS*

JUDUL: CORROSION BEHAVIOUR OF STEEL FOR SIMULATED CONCRETE IN CHLORIDE AQUEOUS SOLUTION

SESI PENGAJIAN : 2007-2008

Saya CHANG WENG SOON

mengaku membenarkan tesis (PSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka .
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

Alamat Tetap:
-3, RELAKANG PASAR, 35500 BIDOR, PERAK

Cop Rasmi:
MOHD. ASYADI 'AZAM BIN MOHD. ABID
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

Tarikh: 30-4-2008

Tarikh: 23.4.2008

* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

# DECLARATION

I hereby, declare this thesis entitled "Corrosion Behaviour of Steel for Simulated Concrete in Chloride Aqueous Solution" is the result of my own research except as cited in the references.

Signature : ...........................................................................
Author's Name : CHANG UENG SOON
Date : 30-4-2008

# APPROVAL

This PSM submitted to the senate of UTeM and has been as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Materials Engineering). The members of the supervisory committee are as follow:

....................................

(Main Supervisor: Mohd. Asyadi 'Azam bin Mohd. Abid)

(Official Stamp & Date)

**MOHD. ASYADI 'AZAM BIN MOHD. ABID**
*Pensyarah*
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

....................................

Co-Supervisor

(Official Stamp & Date)

**MOHAMAD HAIDIR BIN MASLAN**
*Tutor*
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

# ABSTRACT

Steel reinforced concrete is probably the most extensively used construction material in the world. However, many cases of structural failure have occurred during recent years especially for those structures that are exposed to marine environment such as harbour structures and bridge structures. Structural failures are mainly due to the steel reinforcement corrosion. The objective of this study has been conducted to look into the effect of different concentration of chloride content on corrosion rate in steel reinforced concrete. The second objective is to compare and study the morphology of reinforced steel before and after corrosion based on difference concentration of chloride in concrete. The reinforced steel bar used in this study was based on commercially available which obtained from Ann Joo Steel Berhad. Four steel reinforced concrete specimens were manufactured with cement/sand/water ratio of 1:3:0.5 by weight. Then, each of the specimens was subjected to concentrations of sodium chloride solution with the percentage of 1%, 3%, 5%, and 7% by weight for reveal the relationship between chloride ion and corrosion rate. The morphology of reinforced steels is compared and analysis. The study is shown that the corrosion rate of reinforced steel bar is directly proportional to the chloride concentration. The corrosion products on reinforced steel bar also increase with the chloride concentration .Some pits are found on the reinforced steel .Finally, the potential of cost saving and life saving is high via understanding the corrosion behaviour and problem of steel reinforced concrete before tragedy occurred.

# ABSTRAK

Konkrit jenis besi tetulang merupakan bahan binaan yang paling banyak digunakan dalam dunia. Akan tetapi, terdapat banyak kes kegagalan struktur berlaku kebelakangan ini terutama pada struktur dibina di persekitaran laut seperti struktur di labuan dan jambatan. Kegagalan struktur ini adalah disebabkan pengaratan besi tetulang dalam konkrit. Objektif bagi kajian ini adalah menentukan kesan perbezaan kepekatan klorin ke atas kadar pengaratan pada konkrit jenis tetulang. Objektif kedua adalah mempelajari and membanding microstruktur untuk tetulang besi sebelum dan selepas pengaratan pada kepekatan berlainan dalam konkrit. Besi tetulang yang digunakan adalah diperolehi dari Ann Joo Steel Berhad. Empat konkrit besi tetulang disediakan pada nisbah simen/pasir/air 1:3:0.5 mengikut berat. Kemudian, empat sample ini direndamkan dalam cecair natrium klorin.dalam peratusan 1%, 3%, 5% dan 7% mengikut berat supaya hubungan di antara pengaratan dan kepekatan ion kloride dapat dikaji. Microstruktur untuk besi tetulang adalah dibanding dan dianalisis.keputusan kajian ini menunjukkan kadar pengaratan tetulang besi adalah berkadar langsung dengan kepekatan ion kloride. Bahan pengaratan pada tetulang besi juga bertambah dengan kepekatan ion kloride yang lebih tinggi. Lubang-lubang dapat deperhatikan pada tetulang besi. Akhirnya, berpotensi tinggi untuk menjimatkan jumlah wang dan nyawa jika masalah dan amalan pengaratan diketahui sebelum tragedi berlaku.

# DEDICATION

*TO MY BELOVED FATHER, MOTHER AND SISTER*

ADKNOWLEDGEMENT

First, I would like to express my sincere and appreciation to my supervisors,Mohd Asyadi Azam Bin Mohd Abid who always have been providing guidelines and related information for the completion of the thesis. He has shown great faith in me and has been very supportive throughout the research. In addition, not forgetting to extend my gratitude to University Tun Hussein Onn (UTHM) and their technicians where I carried on my research. To staffs of Ann Joo Steel Berhad who is willing to send me some raw material for the research. Furthermore, I would like to express my appreciation to technicians in polymer lab and material lab who willing to share their knowledge to me during the research. Also, not forgetting to express my sincere to all lecturers of Manufacturing Engineering Faculty (FKP),UTeM for their nurturing.

Finally, to my family and friend for their care and encouragement that has inspired me to complete this research. This research could not have been completed without their unconditional support. I would like to end by saying that people mentioned above will forever hold dear in my heart and will never be forgotten. Thank you all.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREBIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

| | |
|---|---|
| % | -Percentage |
| £ | -Pound |
| A | -Area |
| $A/cm^2$ | -Ampere per centimeter square |
| ASTM | - American Standard Testing Method |
| B | - Stern-Greary Constant. |
| $b_a$ | - Slope of the anodic Tafel reaction |
| $b_c$ | - Slope of the cathodic Tafel reaction |
| BS | -British Standards |
| BSI | -British Standards Institution |
| C | -Carbon |
| $Cl^-$ | -Chloride Ion |
| CR | - Corrosion Rate |
| $C_s$ | - Surface Chloride Content |
| CTL | - Chloride Threshold Level |
| $C_x$ | - Total Chloride Content (% by mass of cement or concrete) |
| $D_{app}$ | - Apparent Diffusion Coefficient for Chloride ($m^2/s$) |
| $E_{pit}/E_b$ | - Pitting Potential/breakdown potential |
| $E_{corr}$ | -Corrosion potential |
| erfc | - Error Function |
| EW | - Equivalent Weight |
| Fe | -Ferrite |
| $Fe(OH)_2$ | -Ferum(II)Hydroxide |
| $Fe(OH)_3$ | - Ferum(III)Hydroxide |

| | |
|---|---|
| $Fe^{2+}$ | -Ferrite (II) Ion |
| $Fe^{3+}$ | -Ferrite (III) Ion |
| $Fe_3O_4$ | -Ferum(iV)Oxide(III) |
| g | -Gram |
| $H^+$ | -Hydrogen Ion |
| $H_2O$ | -Water |
| HCl | -Hydrochloric Acid |
| $I_{cor}$ | -Rate of the overall process of corrosion |
| $I_a$ | - Anodic current |
| $I_c$ | -Cathodic Current |
| $I_{con}$ | -Current that circulates inside the concrete from the anodic area to the cathodic area |
| $I_{corr}$ | - Corrosion Current Density |
| $i_{corr}$ | - Intensity of the corrosion current |
| $I_m$ | -Current that flow inside the steel from the cathodic area to the anodic |
| Kg | -Kilogram |
| l | -Little |
| LPR | - Linear Polarization Resistance |
| $m^3$ | -Meter Cubic |
| $mA/m^2$ | -Miliampere per meter square |
| ml | -Mililiter |
| mm | -Millimeter |
| mm/y | -Millimeter per year |
| MPa | -Mega Pascal |
| $MPam^{1/2}$ | -MegaPascal Root Meter Square |
| MS | - Malaysia Standard |
| $Na^+$ | -Sodium Ion |

| | |
|---|---|
| NaCl | - Sodium Chloride |
| $O_2$ | -Oxygen |
| $OH^-$ | -Hydroxide Ion |
| OM | -Optical Microscope |
| PSM I | - Project Sarjana Muda I |
| PSM II | - Project Sarjana Muda II |
| R.H | -Relative Atmospheric Humidity |
| $R_p$ | - Polarization Resistance |
| S | -Second |
| SCE | -Saturated Calomel Electrode |
| SEM | - Scanning Electron Microscope |
| t | -Time |
| TP | - Tafel Plot Technique |
| US | -United State |
| USA | -United State American |
| V | -Volt |
| w/c | -Water over Cement |
| XRD | - X-ray Diffraction |
| $\mu A/cm^2$ | -Micrometer per centimeter square |
| $\mu m$ | -Micrometer |
| | - Density |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Corrosion problem occurred on earth for more than a century. It occupied many fields that have application of metal such as electronic sector, agricultural sector, manufacturing sector and chemical plant. However, corrosion happen in construction field is the most critically because it involves large amount of human that live under these structures.

Corrosion of reinforcing steel in concrete is the most deterioration process influence steel reinforced concrete structures or construction field. Steel reinforced concrete structures form an important part of our infrastructure. Buildings, slabs, beam, bridge decks and piles, all these structures can be executioned with steel reinforced concrete. Concrete can provides physical and chemical protection to the reinforcing steel. The main aim of physical protection is hindered the ingress of aggressive species such as oxygen, moisture and chloride ion to the steel concrete interface. The chemical protection is involved via high basicity of pore solution such as sodium, calcium and potassium oxides. Concrete provides the ideal environment for protecting embedded steel because of its alkalinity. A layer of passive protection film is formed on the reinforcing steel surface under high alkalinity. Therefore, the reinforcing steel is not subject to corrosion and possesses almost unlimited durability.

However, the presence of chloride ions introduced into concrete from contaminated aggregates or water and external environment in excess of a critical threshold level can damaged the passive protection film. After that, the durability of reinforced concrete structures may be drastically limited. This chloride induce corrosion of reinforced concrete structure may often mention on marine structure, both on shore and off shore. It becomes the major cause of the infrastructure deterioration in many parts of the world.

When the corrosion is initiated in reinforced concrete structures, the structures need to be repaired, renewed or replaced within a short period of years. This is extremely expensive, as can be noticed that the remediation of concrete bridges in the USA undertaken as a direct result of corrosion of the reinforcing steel cost the US state departments 5 billion in the year 2000; all forms of corrosion damage to concrete in UK in 1997 was £750million (BCA,2000).

## 1.2 Problem Statements

Concrete essentially take care of compressive stresses but weak in tension. Therefore, steel should embed in concrete to strength its tensile property. The concrete that after embed steel is called as reinforced concrete.

Usually the interaction between the material of the structure and the environment is called corrosion. Studying the history of steel reinforced concrete that very rare cases where a structure failed due to mechanical loadings which have not been considered at the design stage. The problem, instead, arises due to lack of sensitivity and knowledge of engineers when dealing with questions of corrosion. One of the main source of corrosion in reinforce concrete is caused by chloride. The high numbers of structures where corrosion and especially steel reinforcement corrosion has led to premature failures and costly restoration. As the saying state that "prevention is better than cure", it is necessary to understand, study, and prevent the corrosion problem before it occurred.

Corrosion of steel reinforcement in structures is now a feature which figures heavily in the maintenance of existing buildings, contributed to a number of structural collapses and involved large amount of human life. Concrete condition is simulated to investigate the influence of aggressive element such as ion chloride in corrosion of steel in concrete.

## 1.3 Objectives

The purposes of this project are:

i) To study the effect of different level of chloride content on corrosion rate in steel reinforced concrete.

ii) To compare and study the morphology reinforced steel before and after corrosion based on difference concentration of chloride in concrete.

## 1.4 Scope of Studies

Basically, the objective of this project is to study the influence of chloride which led to premature failures of construction. The research work will focus on study on the behaviour and microstructure of corroded steel in the laboratory scale. Among the methods that will be carried out to determine current trend of corrosion in Malaysia's buildings are included internet research, reference of previous and interview expert in this topic. It will involve several processing stage in corroding and checking the corrosion rate of samples by using electrochemical technique. This will followed by the observation stage in order to investigate microstructure and other. The finding will be analysis and the method of prevention corrosion in reinforce concrete will be suggested.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Electrochemical Theory of Corrosion

Corrosion can be defined in different ways but the common interpretation of the term is deterioration of a material especially metal by reaction with species in the environment to form chemical compound. The concept of corrosion can involved wider sense, where attack on non metallic materials. Corrosion of metallic material can be separated into three main groups. The first group is corrosion in other fluid like molten metal and fused salt. The second group is called wet corrosion, where the corrosive environment is water with dissolved species. The liquid is known as electrolyte and it is an electrochemical process at room temperature. The last group of corrosion is involved dry gas corrosive environment. Therefore, this group is known as dry corrosion. This group of corrosion is also often called chemical corrosion or high temperature corrosion.

This project concentrates just on wet corrosion. This corrosion process consists of an anodic reaction and a cathodic reaction. In the anodic reaction (oxidation), the metal dissolved at one site to form as positive ion ($M^{2+}$).The location where anodic reaction is called anode. The residual electrons released by the anodic reaction are conducted via the metal to the cathodic area or cathode where they are consumed in the cathodic reaction (reduction). It is seen that the process causes an electrical circuit without any accumulation of charges. Electrode is an electronic conductor which cathodic reaction and anodic reaction happens. Normally, the metal works as electronic conductor. Between the anode and cathode, ionic and must flow to avoid the build up of charge. Therefore, electrolyte is necessary for corrosion process. The electrolyte is usually an aqueous solution of ions such as $Na^+$, $Cl^-$, $OH^-$ and $Fe^{2+}$. The positive ions are called cations and the negative ions are known as anions. If there is no external source of electrons is applied, the consumption of electron in cathode must same rate to the generation of electron in anode. Based on the condition, this dissolution process is called wet corrosion and the mechanism is electrochemical. This electrochemical is occurred in steel reinforced concrete which regarding to this project.

## 2.2 Type of Concrete

Concrete (Figure 2.1) is a multiphase material construction material containing cement paste (unhydrated and hydrated compounds), water, aggregates (sand and gravel) and sometimes admixtures in required proportions. Concrete solidifies and hardens after mixing and placement due to a chemical process known as hydration. The overall mechanical and physical properties of concrete depend on the volume fraction and properties of the constituents and the mechanisms of interaction between the separate phases.

Strength grading of concrete is prevalent in many countries. It is useful to separate concrete into three general types based on compressive strength. These include low strength concrete(less than 20MPa), moderate strength concrete (20 to 40MPa) and high strength concrete (more than 40MPa) (Pedeferri et al., 2000). In Malaysia, the most common used concrete in structural work is moderate strength