CORROSION ASSESSMENT ON

REINFORCED CONCRETE AND ITS SERVICE LIFE PREDICTION

By

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Best dedicated to my beloved family and friends…

ABSTRACT

Deterioration of structural concrete may be caused either by chemical or physical effects. Corrosion of embedded steel is a major cause of deterioration of concrete structures at the present time. This lead to structural weakening due to loss of steel cross-section, surface staining, cracking or spalling and delamination of concrete and then gradually reduces the service life of the reinforced concrete structures. The most biggest problem is concerned with the structural integrity and safety of reinforced concrete structures by reducing the load carrying capacity.

This project was to assess the degree of corrosion on reinforced concrete structure and estimating the residual service life. It was conducted based on electrochemical methods. These methods include galvanostatic pulse method and linear polarization method. A Non-Destructive Test techniques called GalvaPulse was used in this study. These equipments allow us to determine the degree of corrosion, rate of corrosion and interpret the result in corrosion mapping.

From the results, assessment on the validation of corrosion in short and long terms by using predictive models are discussed.

ABSTRAK

Kemerosotan struktur konkrit bertetulang adalah berkemungkinan berpunca daripada tindakbalas kimia dan keadaan semulajadi konkrit. Pengaratan tetulang besi di dalam konkrit merupakan punca utama kemerosotan struktur konkrit bertetulang pada masa ini. Ini akan membawa kepada kelemahan struktur akibat kehilangan luas keratan tetulang besi, kekotoran pada permukaan konkrit, keretakan, pecah dan jatuh dalam bentuk serpihan. Ini akan mengurangkan tempoh khidmat struktur konkrit bertetulang dan memberi kesan terhadap integriti dan keselamatan struktur konkrit bertetulang dengan mengurangkan kapasiti menanggung beban.

Projek ini adalah untuk menilai tahap pengaratan struktur konkrit bertetulang dan menganggarkan tempoh khidmat struktur. Ini dilaksanakan berdasarkan teknik "electrochemical". Ini termasuklah teknik "galvanostatic pulse" dan "linear polarization". Kedua-dua teknik ini menggunakan ujian tanpa musnah yang dikenali GalvaPulse. Peralatan ini akan membolehkan kita untuk mengenalpasti darjah pengaratan, kadar pengaratan dan juga menafsirkan keputusan melalui pemetaan pengaratan.

Daripada keputusan yang dicapai, penilaian terhadap pengaratan dalam masa yang singkat dan masa yang panjang akan dapat dikenalpasti dengan menggunakan model-model ramalan tempoh perkhidmatan struktur.

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APPROVAL

This project report attached herewith, entitled "Corrosion Assessment On Reinforced Concrete and Its Service Life Prediction" submitted by Syed Burhanuddin Hilmi Bin Syed Mohamad in partial fulfillment of the requirement for the degree of Master of Science (Structural Engineering and Construction) is hereby accepted.

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DECLARATION

I hereby declare that the project report is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for other any other degree at UPM or other institutions.

Syed Burhanuddin Hilmi Bin Syed Mohamad

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A	=	area of the reinforcement
B	=	empirical constant for corroding steel
Cd1	=	capacity of double layer
F	=	Faraday constant (96500 C)
K	=	correction factor for corrosion uniformity
R(t)	=	corrosion rate at time t
R_A	=	anode reaction electrical resistance
R_c	=	cathode reaction electrical resistance
R_E	=	concrete electrical resistance
R_p	=	polarisation resistance
R_Ω	=	ohmic resistance
T	=	time
V	=	valence
W_m	=	molecular mass
d(0)	=	initial diameter of the reinforcement
d(t)	=	reinforcement diameter at time (t) after the beginning of propagation period.
i	=	electrical current
icorr	=	corrosion intensity
ΔU	=	voltage in the macrocell element
ΔD	=	loss of diameter with time
ΔE	=	potential response
Δi	=	applied current
β_a	=	anodic Taffel constant
β_c	=	cathodic Taffel constant

CHAPTER I

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete, when used in reinforced concrete structures, should perform two basic functions. It must show adequate mechanical and bond strength with the reinforcement and must be sufficiently fire resistant. As far as concrete durability is concerned, concrete should be resistant to weather conditions and aggressive environmental effects and should provide sufficient protection against reinforcement corrosion.

Portland cement concrete is an ideal environment for steel because it provides both a physical barrier to the access of aggressive species and chemical protection because in the highly alkaline pore solution of the cement paste, steel is readily passivated (I. L. H. Hansaon & C. M. Hansson, 1993).

Steel reinforcement embedded in concrete will not normally corrode due to the deformation of a protective iron oxide film which passivates the steel in the strongly alkaline conditions of the concrete pore fluid. This passivity can be destroyed by chlorides penetrating through the concrete and due to carbonation. Corrosion is then initiated. Steel corrosion is an electrochemical process involving establishment of corroding and passive sites on the metal surface.

In addition to evaluation of different types of sensors new developed portable equipment using galvanostatic pulse technique was tested under laboratory conditions. The objective of laboratory tests is testing suitability of portable monitoring equipment for non-destructive and unambiguous determination of reinforcement corrosion. Comparing achieved results regarding their accordance to real conditions shall provide background information for on site situations.

The main investigation of corrosion is detection, degree of corrosion, measuring rate of corrosion, resistivity and determination of the remaining service life of the reinforced concrete structures using available prediction model. This project presents the study of corrosion, test technique and laboratory test by GalvaPulse equipment, analysis data from tests results and determination of remaining or residual service life.

1.2 Problems of Statement

The deterioration of concrete structures is a major problem in many countries throughout the world. There is no sufficient data on the corrosion rate of reinforcement exposed by methods of detection to different environments, such as acidic environment, chloride environment and marine environment. Thus, the real behaviour of reinforcements is not fully understood.

Corrosion always related to the deterioration of the service life. This has proceeded the search for methods of predicting the service life of both existing and new structures. The remaining service life of corroded reinforcement cannot be accurately estimated without reliable technical data on degree and corrosion rate

Prediction of the remaining service life of a corroding reinforced concrete structure is done with the help of empirical models and experimental methods. The problems is that, which one of the predictive models that available is reliable for predicting the service life towards the time taken to build up critical concentration at the reinforcement bar level to cause corrosion in certain conditions. The estimation of this initiation period is important in the estimation of the service life of the structure.

However, this project is trying to collect more data on degree and corrosion rate of reinforcement, which is needed in estimating the remaining service life using the validated predictive models. This will be carry out by using the new method known as Galvanostatic pulse method.

1.3 Project Objectives

The aim of this project is to study the corrosion detection and service life predictive model which are available and validated for reinforced concrete structures. Thus, the objectives of this project are as follows:

a) To carry out laboratory test to determine the corrosion potential, corrosion rate and resistance.

b) Compare the corrosion rate by GalvaPulse and weight loss measurement to determine the reliability of GalvaPulse.

c) To assess the validation of short term accelerated test data and observation on long term corrosion.

1.4 Scope of Project

The scope of this project is focused on measurement of corrosion potential, corrosion rate and corrosion resistance of reinforcement using available NDT techniques (GalvaPulse).

Laboratory testing on exposed reinforcement of five different environments were prepared to determine corrosion detection. Corrosion mapping was carried out on laboratory specimens. Result is analyzed to determine the reliability of GalvaPulse with respect to degree and corrosion rate.

The result collected from the probes will be use to determine the variables of corrosion and rate of corrosion.

Lastly, a study on service life of reinforced concrete structures will be carry out by using available predictive models and assess the validation of short term accelerated test data and observation on long term corrosion.

CHAPTER II

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete has been created to be one of the most resistant materials against high chemical, physical and mechanical loading and its maintenance costs are low. For many years, concrete have shown that this material has a very long services life. Concrete always exposed to natural elements such as air moisture, sunlight heat and rainwater (Hendriks, 1998).

The durability of a structure is the property which shows whether or not the structure will remain useful for its full design life even though it may not be subjected to loads sufficient to destroy it. The long term durability of reinforced depends on the ability of the near surface concrete to protect the reinforcing steel from detrimental substances found in its environment. Given a temperate climate and moderate exposure conditions durable concrete can be achieved by giving due consideration to the constituents, compaction, cover and curing "the four C's" (Nolan,1995).

Once initiated, reinforcement corrosion can quickly propagate, impairing a structure's utility and ultimately leading to collapse. Corrosion of embedded steel is probably the major cause of deterioration of concrete structures at the present time. This may lead to structural weakening due to loss of steel cross-section, surface staining and cracking or spalling. In some instances, internal delamination may occur.

The main cause of reinforcement corrosion is low cover to the reinforcement and also to a lesser extent of poor quality concrete. The presence of chlorides, whether added as calcium chloride or ingresses as de-icing salt, whilst of significance is less common than corrosion caused by low cover. however when chloride corrosion does occur, its effects may be wide ranging.

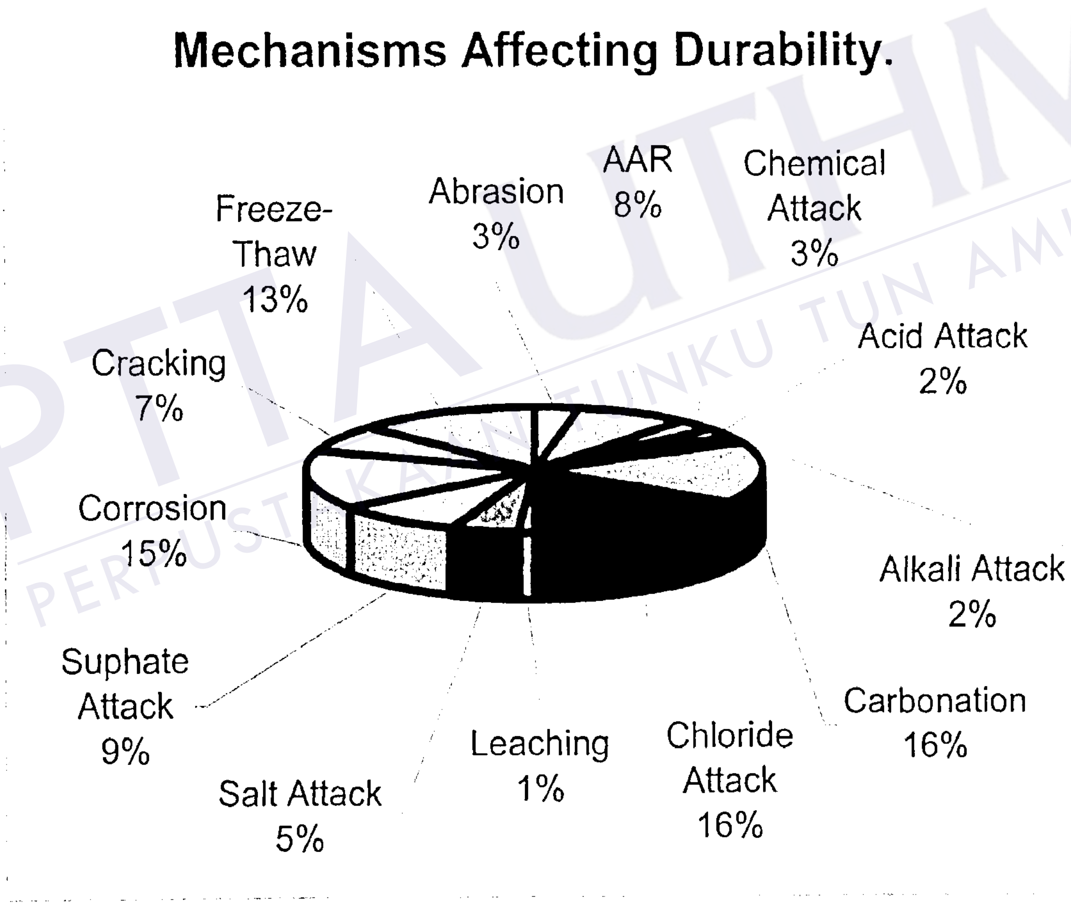

Figure 2.1: Contribution of Various Mechanisms Affecting Durability (Basheer, 1995)

2.2 Definition of Corrosion

Deterioration of structural concrete may be caused either by chemical and physical environmental effects upon the concrete itself or by damage resulting from the corrosion of embedded steel. Corrosion is an electrochemical phenomenon, in which the potential of the steel and the exchange of electrical current between steel and concrete pore solution plays an important roles (Rob B. Polder, 2002).

Concrete Society, 1984 defined reinforcement corrosion as an electrochemical process requiring the presence of moisture and oxygen and can only occur when the passifying influence of the alkaline pore fluids in the matrix surrounding the steel has been destroyed, most commonly by carbonation or chlorides.

2.3 Corrosion of Reinforcement In Concrete

The electrochemical reactions which lead to the corrosion of steel in concrete need the presence of water and oxygen near the steel. The rate at which corrosion occurs and the time to initiation is significantly influenced by the permeation properties. Chemical processes govern the rate of decomposition of concrete and its durability. Research has indicated that a concrete which is low in permeation properties lasts longer without exhibiting signs of distress and deterioration (Basheer 1991).

Permeation characteristics and fracture strength are the fundamental properties of concrete that influence the initiation and extent of damage and can form the basis by which deterioration can be predicted.

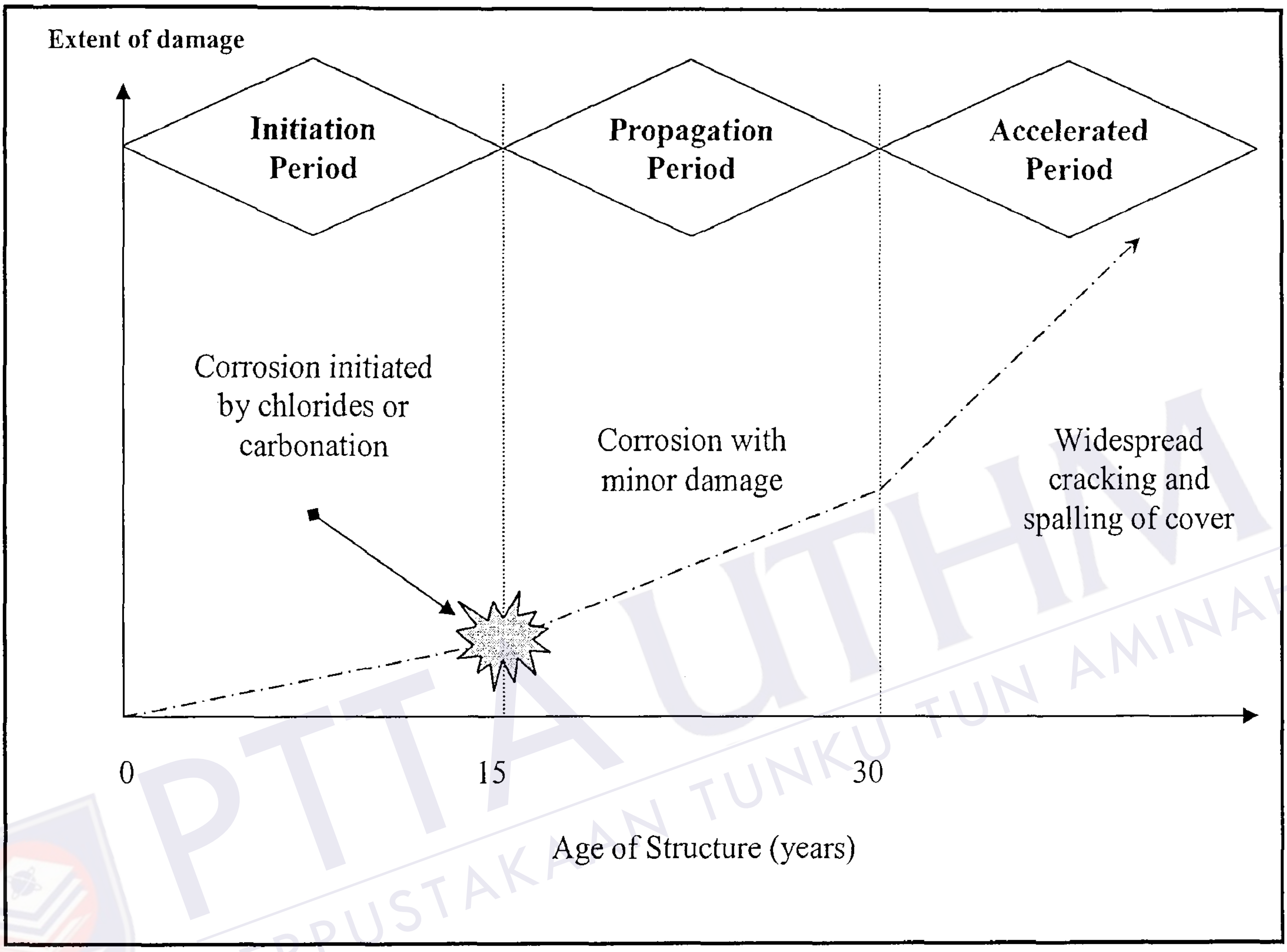

Figure 2.2: The Three Stages Model of Corrosion Damage

Corrosion of reinforcement bar on concrete can be divided into two stages as follows:-

(i) **Initial Stages**: Time required to disrupt the concrete cover and make reinforcement bar corrosion but no damage to surrounding concrete.

(ii) **Propagation Stage**: Time required for the corroding reinforcement bar to create sufficient expansion force to cause damage to the surrounding concrete after disruption

Cracking and spalling on the concrete surfaces are the visual signs of corrosion damages. The degree of corrosion of the reinforcement bar to cause the damage (propagation stage) is governed by parameters such as the concrete cover thickness, bar diameter and water to cement ratio (w/c).

2.4 Mechanism of Corrosion

Corrosion is an electrochemical process. A chemical process and a flow of electricity are necessary conditions for this phenomenon. The reinforcement in concrete may achieve this condition by having two areas in different concentrations of moisture, oxygen or dissolved substances.

The essential requirements for the electrochemical reactions which lead to corrosion of steel in concrete are the presence of water and oxygen near the steel. Concrete permeability therefore plays a significant role in the initiation and intensity of the corrosion reaction (Verbeck and Tutti ,1982).

The corrosion process that takes place in concrete is electrochemical in nature, very similar to a battery. Corrosion will result in the flow of electrons between anodic and cathodic sites on the reinforcement bar. For corrosion to occur four basic elements are required:

· Anode – site where corrosion occurs and current flows from.

· Cathode – site where no corrosion occurs and current flows to.

· Electrolyte – a medium capable of conducting electric current by ionic current flow (i.e. soil, water or concrete).

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