# EFFECT OF EROSION CORROSION WITH DIFFERENT FLUIDS MECHANISM

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Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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JUNE 2012

# ABSTRACT

Erosion-corrosion is an important aspect of durability for materials used in the oil sands industry. The combination of a corrosive fluid and high volume of sand means that erosion, corrosion and their synergistic interactions all act to accelerate material damage. This paper presents the results of erosion corrosion on stainless steel with three different slurry which are 3.5% NaCl, seawater and water with the presence of sand. The studies of erosion corrosion with different fluids mechanism have been study by using electrochemical process. Stainless steel is used because of its higher strength and corrosion resistance. Surface roughness and corrosion rate of the specimen were determined in this experiment. By using electrochemical test, polarisation study was carried out to investigate the electrochemical corrosion behaviour of stainless steel in three different slurries. With the presence of 10% wt of sand, the solution was maintaned at constant temperature and constant velocity. A constant potential scan rate of 20 mV/s was used in all experiments. The corrosion rates of the specimen were determined from polarisation curve using Tafel extrapolation method. Surface roughness of the specimen was measured before and after the corrosion test has been done. At the end of the experiment, the erosion corrosion is acted more on specimen with seawater slurry followed by water and 3.5% NaCl. This result are influenced by high quantity of chloride ion contain in the seawater.

# ABSTRAK

Karatan melalui pergerakan cecair yang berkarat dan permukaan logam adalah satu aspek ketahanan yang penting untuk bahan-bahan yang digunakan dalam industry pasir minyak. Kombinasi karatan dan pergerakan cecair dan kandungan pasir yang berisipadu tinggi iaitu semua interaksi untuk menghasilkan kerosakan. Kertas kerja ini membentangkan keputusan Karatan melalui pergerakan cecair yang berkarat pada keluli tahan karat dengan tiga buburan berbeza iaitu 3.5% NaCl, air laut dan air dengan kehadiran pasir. Proses ini telah diuji dengan menggunakan proses elekrokimia. Keluli tahan karat digunakan kerana mempunyai kekuatan dan halangan pengaratan yang lebih tinggi. Kekasaran permukaan dan kadar pengaratan telah dikaji melalui proses kajian pembelauan. Dengan kehadiran 10% pasir, cecair itu adalah pada suhu dan halaju yang malar. Kadar imbasan potensi tetap 20mV / s telah digunakan dalam semua ekperimen. Kadar pengaratan sampel telah ditentukan dari lengkung pembelauan menggunakan kaedah ekstrapolasi Tafel. Kekasaran permukaan sampel telah diukur sebelum dan selepas ujian pengaratan dilakukan. Pada akhir eksperimen, Karatan melalui pergerakan cecair yang berkarat dan permukaan logam bertindak dengan lebih tinggi pada buburan air laut diikuti oleh air dan 3.5% NaCl. Hal ini adalah disebabkan oleh zarah-zarah klorida yang tinggi di dalam air laut.

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| | |
|---|---|
| $R_a$ | Surface Roughness |
| $Fe$ | Iron |
| $H_2O$ | Water |
| $O_2$ | Oxygen |
| $e^-$ | Electron |
| $Fe(OH)_2$ | Ferrous Nydroxide |
| $Ecorr$ | Potential Corrosion |
| $Icorr$ | Corrosion Current |
| $V$ | Voltage |
| $E(p)$ | Pitting Potential |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| NaCl | Sodium Chloride |
| SCE | Saturated Calomel Electrode |
| SS | Stainless Steel |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

This chapter will discuss about the project background, problem statements, project objectives and the scopes of the project.

## 1.2 PROJECT BACKGROUND

Erosion-corrosion is an important aspect of durability for materials used in the oil sands industry. The combination of a corrosive fluid and high volume of sand means that erosion, corrosion and their synergistic interactions all act to accelerate material damage.

The study of erosion and wear of materials in corrosive environments. Erosion–corrosion tests were carried out by immersing the materials in the different aqueous solution and presence of sand particles. In each case, pure corrosion and combined erosion–corrosion effects were studied by partially protecting the materials from the impact of solid particles during the tests. Erosion–corrosion mechanisms were determined from microstructural studies, wear analysis and surface roughness measurement.

## 1.3 PROBLEM STATEMENT

Erosion-corrosion can be refers as a corrosion process enhanced by the action of flowing fluids. The process can also be characterized by whether the fluid contains solid particles, is in the form of impinging droplets, or is undergoing cavitation. Cavitation is the formation and sudden collapse of vapor bubbles in a liquid.

Erosion-corrosion can result in general corrosion that occurs at a higher rate than would be expected under stagnant conditions. In this case the measure of erosion-corrosion would be the rate of surface waste or the rate of penetration. The more usual effect of erosion-corrosion, however, is localized attack, which can appear as grooves, gullies, waves, rounded holes, etc., and usually exhibits a directional pattern that correlates with the direction of flow.

## 1.4 PROJECT OBJECTIVE

The objectives of this study are:

i) To study the erosion wear of the material in the aqueous slurries.
ii) To study the behavior of erosion-corrosion on the material by using different fluid mechanism.

## 1.5 SCOPE OF THE PROJECT

The scopes of the project are limited to:

i. Comparison with NaCl slurry, seawater slurry and water slurry.
ii. Investigation of the surface roughness of the material.
iii. Microstructural study of the material.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In this chapter, it will discuss about the process of corrosion, erosion-corrosion and the fluid mechanism that have been used in this project.

## 2.2 THEORY OF CORROSION

Corrosion is a one of the chemical degradation brought about by a flow of electric current during the chemical reaction process. Processes and procedures that can be applied in order to prevent corrosion in engineering components was called corrosion engineering. Corrosion can be defined as the damage or destruction of a surface that is due to electrochemical reactions on the surface. The real metal gets thinner and acquires uneven surface contour. The process of the corrosion started with a crack at the surface of the material,if that material or metal has any residual stress or applied stress, and propagate it under prevalent tensile stress, leading to fracture.

Cavitation is the growth and collapse of cavities or bubbles inside a liquid cause by the sudden changes of internal pressure in the liquid. During the collapse of the bubbles, a large pulse of stress is generated and this is often occampanied by a high velocity jet of liquid that impinges the solid surface in contact with the liquid. The rapid repetition of the stress pulse would induce localised fatique failure and subsequent material removal. Cavitation erosion can be refers as damage that occur due to fatique processes occuring in the surface of the material itself. If cavitation attack causes accelerated removal of an existing passive film or corrosion product layer, and if the removal rate determining mechanism is the rate of replacement growth of the film or layer, then the resulting type of loss of material is referred to cavitation erosion-corrosion( Raman.A,2007).

## 2.3 MECHANISM OF CORROSION

Corrosion theorists are obliged to take into account considerations of the infinitely small and necessarily complex activities on the molecular and at the ionic, electronic and atomic levels. Three basic kind of corrosion can be listed as chemical, electrochemical and physical. For example, a common representation of the corrosion reaction maybe expressed with respect to iron, water and oxygen in this chemical reaction.

$$Fe + H_2O + \frac{1}{2}O_2 \rightarrow Fe(OH)_2 \quad (2.1)$$

This indicates that the initial reaction of iron with oxygen in pure water is to form ferrous hydroxide. Corrosion would not occur if one of these elements is absent entirely. Corrosion involves both an anodic and cathodic reactions. The anodic reaction involves metal dissolution (corrosion) (R. Roberge. 1999). For corroding metals, the anodic reaction invariably is of the form:

$$M \rightarrow M^{n+} + ne^- \text{ ( Loss of electrons)} \quad (2.2)$$

### 2.3.1 Corrosion of Steel

Corrosion of steel is an electrochemical reaction followed by a chemical reaction:Anodic reaction (Bayliss, D.A and Deacon, D.H.1985):

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad (2.3)$$

The corrosion reactions can be illustrated using chemical terminology as follow equation (2.3).This is simple way of describing the process where iron is removed as charged particle called ions ($Fe^{2+}$) electron(e-) carry current to balance the electric charge. Clearly a balancing reaction must occur at the cathode and under ordinary natural exposure conditions this can be represented as follows:

Cathodic reaction:

$$H_2O + \frac{1}{2} O_2 + 2e^{-} \rightarrow 2OH^{-} \qquad (2.4)$$

In short, hydroxyl ions are produced at the cathode .These two reactions can

combined in a chemical equation (2.5):

$$Fe + H_2O + \frac{1}{2} O_2 \rightarrow 2OH^{-} + Fe^{2+} \qquad (2.5)$$

The ferrous and hydroxyl ions react together to form ferrous hydroxide:

$$2OH^{-} + Fe^{2+} \rightarrow Fe(OH)_2 \qquad (2.6)$$

This is simple form of rust which unstable and is eventually oxidized (i.e. react with oxygen) to form the familiar reddish brown rust, chemically denoted FeOOH. This is the form of rust usually produced in air, natural water and soils. However,under acidic conditions hydrogen is produced at the cathode and the corrosion product may be Fe3O4 (magnetite).

## 2.4 TYPES OF CORROSION

Many different corrosion mechanisms exist. The most common types are generally well understood. For each, the process is complex, incorporates many factors, and varies according to metal and specific operating conditions. Yet all still remain difficult to control, and represent a very serious threat to most piping systems. Once established, most corrosion problems will produce future years of operating difficulty and expense at varying levels of severity.

### 2.4.1 General Surface Corrosion

General surface corrosion (also referred to as Uniform Etch or Uniform Attack Corrosion) is the most common form of corrosion and results from a direct chemical attack on a metal surface and involves only the metal surface. (See figure 2.1.) General surface corrosion usually occurs over a wide area and is more or less equal in dispersion. On a polished surface, this type of corrosion is first seen as a general dulling of the surface, and if allowed to continue, the surface becomes rough and possibly frosted in appearance.

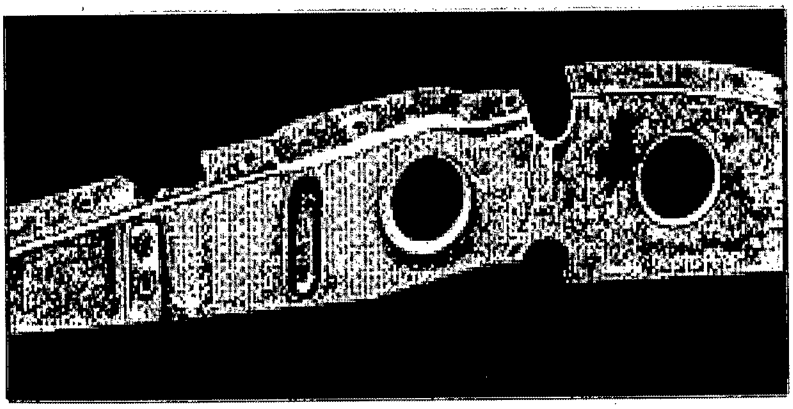
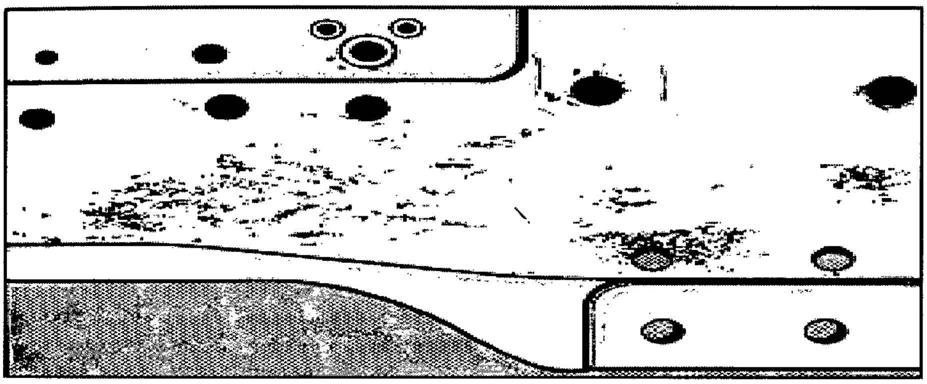


**Figure 2.1 :** General Surface Corrosion

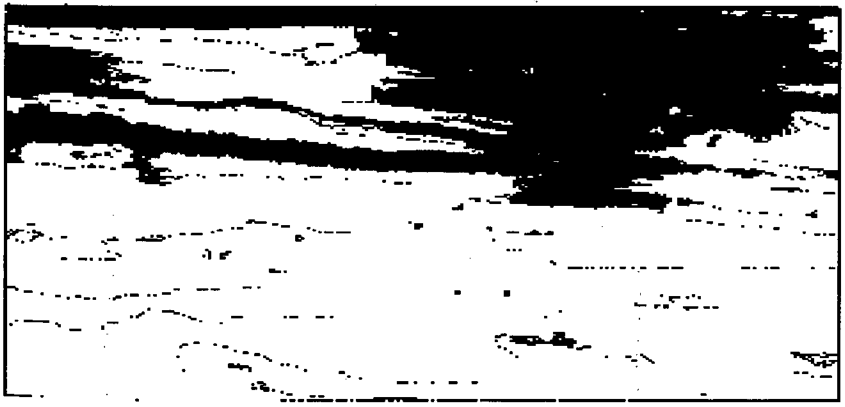
Source: Zaki Ahmad,2006

### 2.4.2 Pitting Corrosion

Pitting corrosion is one of the most destructive and intense forms of corrosion. It can occur in any metal but is most common on metals that form protective oxide films, such as aluminum and magnesium alloys. It is first noticeable as a white or gray powdery deposit, similar to dust, which blotches the surface. When the deposit is cleaned away, tiny holes or pits can be seen in the surface. (See figures 2.2 (a) and 2.2(b).) These small surface openings may penetrate deeply into structural members and cause damage completely out of proportion to its surface appearance (A Zaki,2006).



(a)



(b)

**Figure 2.2** :Pitting Corrosion (a) External View,(b) Magnified Cross Section.

Source: Zaki Ahmad, 2006

### 2.4.3 Concentration Cell Corrosion

Concentration cell corrosion, (also known as Crevice Corrosion) is corrosion of metals in a metal-to-metal joint, corrosion at the edge of a joint even though the joined metals are identical, or corrosion of a spot on the metal surface covered by a foreign material. Metal ion concentration cells and oxygen concentration cells are the two general types of concentration cell corrosion (A Zaki,2006). (See figure 2.3.)

#### a. Metal Ion Concentration Cells

The solution may consist of water and ions of the metal which is in contact with water. A high concentration of the metal ions will normally exist under faying surfaces where the solution is stagnant, and a low concentration of metal ions will exist adjacent to the crevice which is created by the faying surface. An electrical potential will exist between the two points; the area of the metal in contact with the low concentration of metal ions will be anodic and corrode, and the area in contact with the high metal ion concentration will be cathodic and not show signs of corrosion.

#### b. Oxygen Concentration Cells

The solution in contact with the metal surface will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse into the solution, thereby creating a difference in oxygen concentration between two points . Typical locations of oxygen concentration cells are under gaskets, wood, rubber, and other materials in contact with the metal surface. Corrosion will occur at the area of low oxygen concentration (anode). Alloys are particularly susceptible to this type of crevice corrosion(A Zaki,2006).

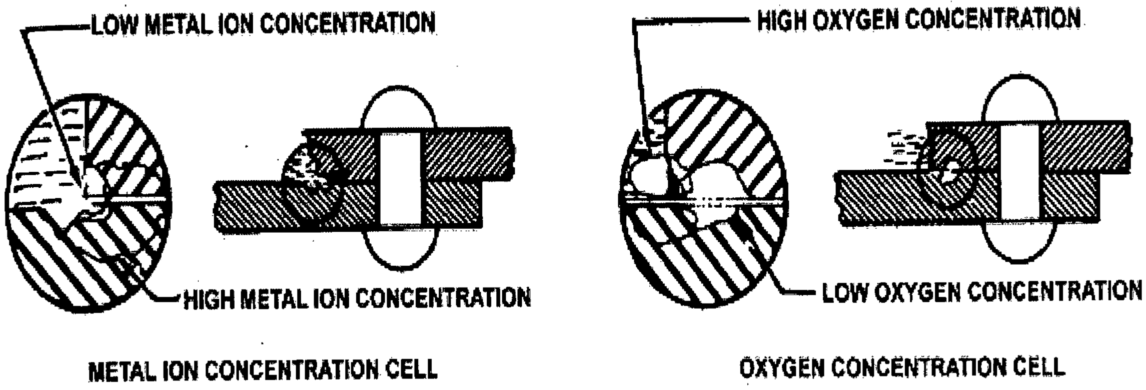


**Figure 2.3 :** Concentration Cell Corrosion

Source: Zaki Ahmad,2006

### 2.4.4 Erosion Corrosion

This is the gradual and selective deterioration of a metal surface due to mechanical wear and abrasion. It is attributed to entrained air bubbles, suspended matter and particulates under a flow rate of sufficient velocity. Erosion is similar to impingement attack, and is primarily found at elbows and tees, or in those area where the water sharply changes direction. Softer metals such as copper and brass are inherently more susceptible to erosion corrosion than steel.

High pressure steam will often contribute to the erosion of carbon steel. Though typically not a problem at the water velocities encountered within most HVAC piping systems, high corrosion rates and the entrainment of high volumes iron oxide particulates can produce an erosion condition under certain conditions. Erosion at the base of elbows or after multiple sharp turns of the pipe has been documented to occur (A Zaki,2006).

### 2.4.5 Active-Passive Cells

Metals which depend on a tightly adhering passive film, usually an oxide, for corrosion protection are prone to rapid corrosive attack by active-passive cells. Active-passive cells are often referred to as a type of concentration cell corrosion. However, the active-passive cell is actually two forms of corrosion working in conjunction. The corrosive action usually starts as an oxygen concentration cell. As an example, salt deposits on the metal surface in the presence of water containing oxygen can create the oxygen cell. The passive film will be broken beneath the salt crystals. Once the passive film is broken, the active metal beneath the film will be exposed to corrosive attack. (See figure 2.4)

Rapid pitting of the active metal will result. This reaction can become locally intense due to several factors. First the reaction is augmented by the affected area, since the proportion of the exposed base metal is small compared to the surrounding nonreactive metal. This effectively concentrates the focal point of the reaction, often resulting in deep pits in a short time and a greater rate of corrosion (A Zaki,2006).

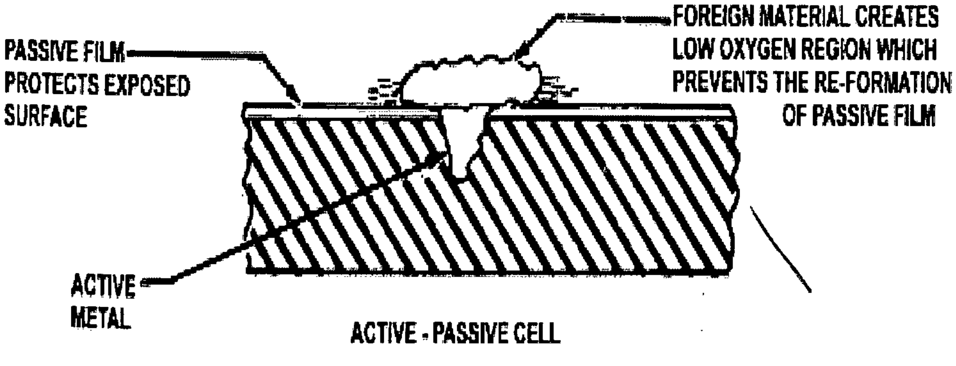


**Figure 2.4 :** Active-passive Cells Corrosion

Source: Zaki Ahmad,2006

### 2.4.6 Filiform Corrosion

Filiform corrosion is a special form of oxygen concentration cell which occurs on metal surfaces having an organic coating system. It is recognized by its characteristic worm-like trace of corrosion products beneath the paint film. (See figure 2.5) Polyurethane finishes are especially susceptible to filiform corrosion. Filiform occurs when the relative humidity of the air is between 78 and 90 percent and the surface is slightly acidic. This corrosion usually attacks steel and aluminum surfaces. The traces never cross on steel, but they will cross under one another on aluminum which makes the damage deeper and more severe for aluminum. If the corrosion is not removed, the area treated, and a protective finish applied, the corrosion can lead to intergranular corrosion, especially around fasteners and at seams.

Filiform corrosion can be removed using glass bead blastingmaterial with portable abrasive blasting equipment or sanding. Filiform corrosion can be prevented by storing aircraft in an environment with a relative humidity below 70 percent, using coating systems having a low rate of diffusion for oxygen and water vapors, and by washing the aircraft to remove acidic contaminants from the surface (A Zaki,2006).

**Figure 2.5 :** Filiform Corrosion

Source: Zaki Ahmad,2006

### 2.4.7 Galvanic Corrosion

Galvanic corrosion occurs when two dissimilar metals make contact in the presence of an electrolyte. (See figure 2.6) It is usually recognizable by the presence of a build-up of corrosion at the joint between the metals.

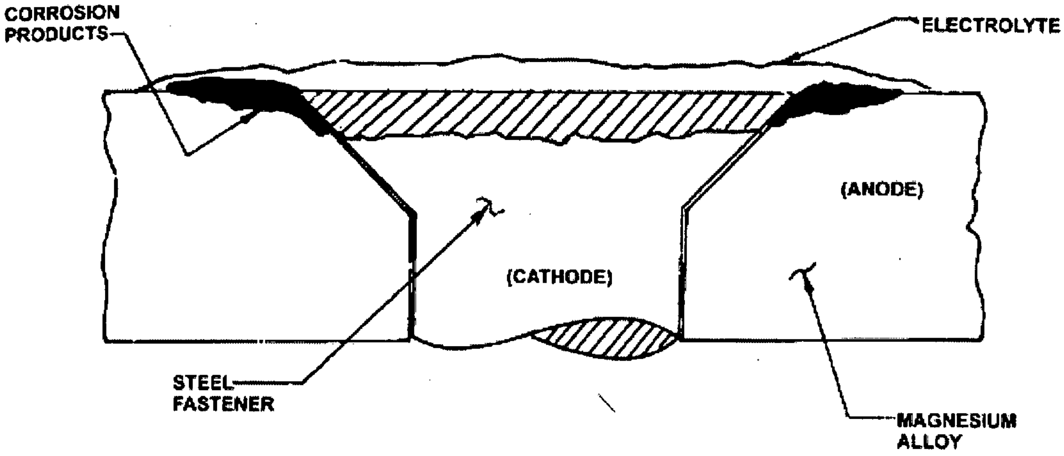


**Figure 2.6 :** Galvanic Corrosion

Source: Zaki Ahmad,2006

### 2.4.8 Stress Corrosion Cracking

This form of corrosion involves constant or cyclic stress, acting in conjunction with a damaging chemical environment. The stress may be caused by internal or external loading.

a. Internal stress may be trapped in a part of structure during manufacturing processes such as cold working or by unequal cooling from high temperatures. Most manufacturers follow up these processes with a stress relief operation. Even so, sometimes stress remains trapped. The stress may be externally introduced by riveting, welding, bolting, clamping, press fit, etc. If a slight mismatch occurs, or a fastener is over-torqued, internal stress will be present.

b. Internal stress is more important than design stress, because stress corrosion is difficult to recognize before it has overcome the design safety factor. The level of stress varies from point to point within the metal. Stresses near the yield strength are generally necessary to promote stress corrosion cracking. (See figure 2.7) However, failures may occur at lower stresses. Specific environments have been identified which cause stress corrosion cracking of certain alloys (A Zaki,2006).

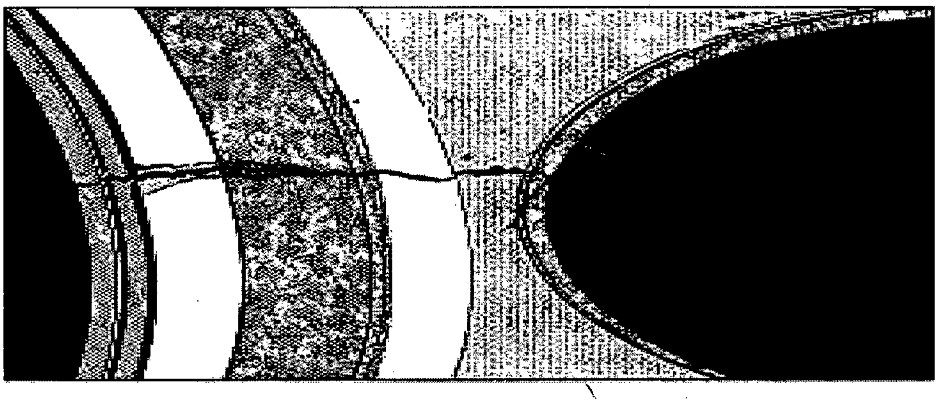


**Figure 2.7:** Stress Corrosion Cracking.

Source: Zaki Ahmad,2006

### 2.4.9 Fatigue Corrosion

Fatigue corrosion involves cyclic stress and a corrosive environment. Metals may withstand cyclic stress for an infinite number of cycles so long as the stress is below the endurance limit of the metal. Once the limit has been exceeded, the metal will eventually crack and fail from metal fatigue. However, when the part or structure undergoing cyclic stress is also exposed to a corrosive environment, the stress level for