EFFECT OF SOIL RESISTIVITY IN PEKAN CAMPUS TO THE
CORROSION BEHAVIOR OF STEEL PIPE SYSTEM

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We certify that the project entitled *"Effect of Soil Resistivity in Pekan Campus to the Corrosson Behavior of Steel Pipe System" is* written by *Mohd Firdaus Bin Ahmad Sani*. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Examiner   Signature

EFFECT OF SOIL RESISTIVITY IN PEKAN CAMPUS TO THE CORROSION
BEHAVIOR OF STEEL PIPE SYSTEM

MOHD FIRDAUS BIN AHMAD SANI

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

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

SUPERVISOR'S DECLARATION

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature   :
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DEDICATION

To my beloved parents, Mr. Ahmad Sani Bin Othman and Mrs. Noor Asiah Bte. Hussin, family and friends, without whom and his/her lifetime efforts, my pursuit of higher education would not have been possible and I would not have had the chance to study for a mechanical course. Also to my supervisor, Mrs. Dayangku Noorfazidah Bte. Awang Shri and Faculty of Mechanical Staff, without whose wise suggestions, helpful guidance and direct assistance, it could have neither got off the ground nor ever been completed. Thanks a lot to my university and my friends in their support and advice towards this project. Thanks to all for your enduring patience and continuous encouragement.

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ABSTRACT

Underground pipe system will place at different place and will pass through the different soil structure. This different soil condition has different soil resistivity that will give the different result of the corrosion rate at same pipeline system. In this experiment, soil resistivities of different type of soils were measured by using Earth Resistance Tester. It is found that the soil resistivity of sand is the lowest at 5.03 kΩ·cm and followed by clay and loam with 94.25 kΩ·cm and 628.32 kΩ·cm respectively. The effect of soil resistivity on corrosion behavior of coated and uncoated specimen were examined by buried the specimen in three different type of soil for 50 days. The surface morphology were examined by using SEM while corrosion rate was calculated using weight loss. Surface morphology examinations indicate the type of corrosion occurred on the steel pipe was uniform corrosion, erosion corrosion and pitting corrosion. It is found the corrosion rate is highest in sand followed by clay, loam and atmosphere. It is also found that coating has decreased the corrosion rate of the specimen with highest at sand which 6.76 mpy followed by clay, loam and atmosphere with 6.36, 5.88 and 1.52 mpy respectively.In conclusion, with the lower soil resistivity, the corrosivity of the steel pipe will be higher. It is also found that coating specimen proves that it can reduce the corrosion rate of the pipeline system.

ABSTRAK

Sistem paip bawah tanah yang diletakkan di tempat yang berbeza dan akan melewati struktur tanah yang berbeza. Keadaan tanah ini mempunyai rintangan tanah yang berbeza mengikut jenis tanah yang akan memberikan keputusan kadar kakisan yang berbeza pada sistem paip yang sama. Dalam kajian ini, rintangan tanah diukur dengan menggunakan "Earth Resistance Tester" bagi menentukan kadar rintangan yang terjadi pada pelbagai jenis tanah. Rintangan tanah yang di hitung menunjukkan tanah pasir mempunyai rintangan lebih rendah dengan 5.03 kΩ·cm diikuti dengan tanah liat dan tanah lempung dengan masing- masing 94.25 kΩ·cm dan 628.32 kΩ·cm. Kesan rintangan tanah terhadap perilaku kakisan untuk besi yang dilapisi cat dengan tidak dilapisi dilakukan dengan menanam besi kajian di tiga jenis tanah yang berlainan selama 50 hari. P emeriksaan permukaan morfologi dilakukan dengan menggunakan SEM sementara kadar kakisan dikira dengan menggunakan kaedah berat badan besi. Permukaan pemeriksaan morfologi menunjukkan jenis kakisan berlaku pada paip baja korosi seragam, korosi berombak dan korosi berlubang. Kadar kakisan tertinggi ditemui terjadi pada besi yang di tanam di tanah pasir diikuti oleh tanah liat, lempung dan atmosfera. Didapati juga besi yang dilapisi dapat menurunkan kadar kakisan dengan besi yang tertinggi di tanam pada tanah pasir dengan 6.76 mpy yang diikuti oleh tanah liat, lempung dan atmosfera dengan masing-masing 6.36, 5.88 dan 1.52 mpy. Sebagai kesimpulan, rintangan tanah yang lebih rendah akan meningkatkan kadar kakisan pada spesimen besi ujikaji. Dari projek ini juga, dapat dibuktikan bahawa kadar kakisan dapat dikurangkan dengan menggunakan spesimen besi yang dilapisi cat untuk paip sistem.

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LIST OF SYMBOLS

cm	Centimeter
°C	Degree Celsius
g /cm³	Density
g	gram
I	Impressed current
m	Meter
mm	Milimeter
mpy	mils per year
Ω	Ohm
%	Percentage
V	Potential Energy or Voltage
Ω/cm	Soil Resistivity

LIST OF ABBREVIATIONS

e^-	Electron
A	Surface Area
AC	Alternating current
ASTM	American Standard Testing Method
CL	Chloride
D	Density
DC	Direct current
Fe	Ferrous
H	Hydrogen
HCL	Hydrochloric Acid
SEM	Scanning Electron Microscope
T	Time
W	Weight Loss in grams

CHAPTER 1

INTRODUCTION

1.1　Introduction

Corrosion is defined in different ways, but the usual interpretation of the term is "an attack on a metallic material by reaction with its environment". Corrosion is natural and inevitable, but it can be minimized and delayed. This concept of corrosion can be used in a broader sense, where this includes attack on nonmetallic materials. For example, the response of steel to soil corrosion depends primarily on the nature of the soil and certain other environmental factors, such as the availability to moisture and oxygen. These factors can lead to extreme variations in the rate of the attack. So this project is to effect of Soil Resistivity to the corrosion behavior of steel pipe system. By following the useable concept of the corrosion mechanism, it is easier to understand various conditions to be that which cause active corrosion on steel pipe in soil.

1.2　Background of study

The resistivity of a soil is probably the most commonly used criterion of corrosivity because it is easy to measure. The resistivity of a soil depends on its chemical content, moisture content and temperature. Low-resistivity soils for instance generally contain high concentrations of soluble salts. The presence of anions in the salt degrades protective oxide films on steel accelerating the rate of the electrochemical reactions at the metal surface.

Since macrocells are responsible for many of the instances of severe corrosion of underground structures, the expectation a correlation to exist between soil moisture content and underground corrosion. Such correlations are found in the literature. For

example, researcher found that only resistivity and redox potential were better predictors of corrosiveness than moisture content. Data showing the effect of salt content which is chlorides and sulfates on the resistivity of single salt solutions are also found. The data show a systematic trend of decreasing resistivity with an increasing concentration profile for sulfate and chloride solutions.

A wide variety of soluble salts are typically found in soils. In fact two soils having the same resistivity may have significantly different corrosion characteristics, depending on the specific ions available. The major factors that accelerate corrosion are chlorides, sulfates, and the soil acidity (pH). In many areas soils encountered along a pipeline route will be approximately neutral with 7 pH value. Mild steel is widely used in pipes buried in soil. The corrosion of such metallic materials leads to numerous problems concerning for example water supply systems and soil pollution by ferric ions.

Laboratory investigations are highly important but require knowledge of the physical and chemical properties of the soil which can be affected by many factors particularly by changes in the nature of soil.

Actually, steel in deareated, dry soil should not corrode at all but must soils are not dry. Soil resistivities are an indication that moisture and dissolved salts are present and the corrosivity of soil is almost proportional to the decrease in resistivity. (S. Arzola, 2003)

1.3   Problem statement

Pipelines play an extremely important role throughout the world as means of transporting gases and liquids over long distances from their sources to the ultimate consumers. Pipelines suffer from corrosion, cracking and other problems. External corrosion has been recognized for many years as one of the main deterioration mechanisms that may reduce the structural properties of buried transmission pipelines (M. A. Alodan, 2007). The resistivity of soil also can corrode the steel pipe. But by monitoring the corrosive soil environment it will help to prevent catastrophic failure.

Nowadays there are many probe and soil corrosion rate monitor. With a low cost investment it will represent significant savings of the high cost of pipeline failure.

Underground pipelines will pass through the different soil structure and different soil conditions have different resistivity that will affect the corrosion rate of the same pipe at different place. Other structures are often the result of differential corrosion cells of which a variety of different types exist. These include differential aeration cells where different parts of a pipe are exposed to different oxygen concentrations in the soil and cells created by differences in the nature of the pipe surface or the soil chemistry. Galvanic corrosion is a form of differential cell corrosion in which two different metals are electrically coupled and exposed in a corrosive environment. These all are the corrosion behavior that usually happen at pipe in soil. (M. A. Alodan, 2007)

1.4   Project objectives

The goal of this study was to evaluate the effect of Soil Resistivity in Pekan Campus to the corrosion behavior of steel pipe system. This project enhances a student ability to work individually. The objectives of this project are:

i.   To investigate the effect of soil resistivity to the corrosion behavior of steel pipe system.

ii. To analyze the corrosion type occurs to the steel pipe system.

iii. To determine the corrosion rate of pipe system by using weight loss method.

iv. To determine the changes of surface of steel pipe using Scanning Electron Microscope (SEM).

v.   To evaluate the effect of coating on different soil resistivity.

1.5   Project scopes

This project is aim to evaluate the effect of soil resistivity on corrosion behavior on steel pipe. The scopes of the project are:-

i.   Steel pipe dimension is 80 mm length, 22 mm inner diameter and 26 mm outer diameter.
ii.   Analysis the soil resistivity using Earth Resistance Tester.
iii.   Performing the exposure of mild steel pipe for 50 days.
iv.   Analysis of corrosion rate based on weight loss method.
v.   Surface morphology investigating using Scanning Electron Microscope (SEM).

CHAPTER 2

LITERATURE STUDY

2.1   Introduction

To view corrosion engineering in its proper perspective, it is necessary to remember that the choice of a material depends on many factors, including its corrosion behavior. Figure 2.1 shows some of the properties that determine the choice of a structural material. Although primarily concerned with the corrosion resistance of various materials the final choice frequently depends on factors other than corrosion resistance. The engineering aspects of corrosion resistance cannot be overemphasized. Complete corrosion resistance in almost all media can be achieved by the use of either platinum or glass but these materials are not practical in most cases. (Mars G. Fontana, 1986)
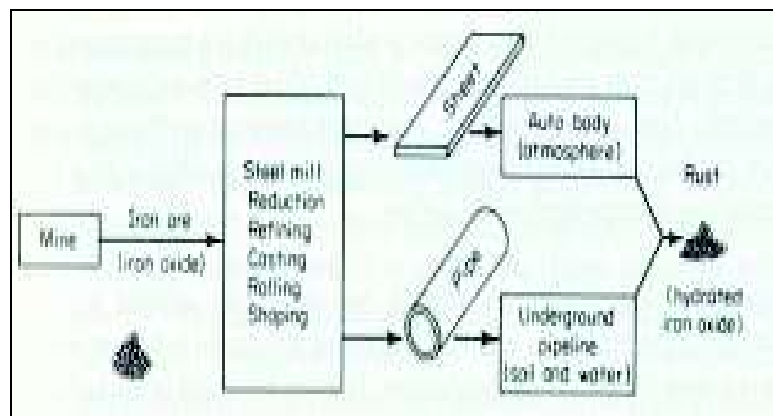
Figure 2.1: Metallurgy in reverse

Source: Mars G. Fontana 1986

2.2 Definition of corrosion

Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment. Some insist the definition should be restricted to metals but often the corrosion engineers must be consider both metals and nonmetals for solution of a given problem. Corrosion can be fast or slow. For example the sensitized 18-8 stainless steel is badly attacked in hours by polythionic acid and the railroad tracked usually show slight rusting not sufficient to affect their performance over many years.

Corrosion of metals could be considered as extractive metallurgy in reverse as illustrated by Figure 2.2. Extractive metallurgy is concerned primarily with the winning of the metal from the ore and refining or alloying the metal for use. Most iron ores contain oxides of iron and rusting of steel by water and oxygen results in a hydrated iron oxide. Rusting is a term reserved for steel and iron corrosion although many other metals form their oxides when corrosion occurs. (Mars G. Fontana, 1986)
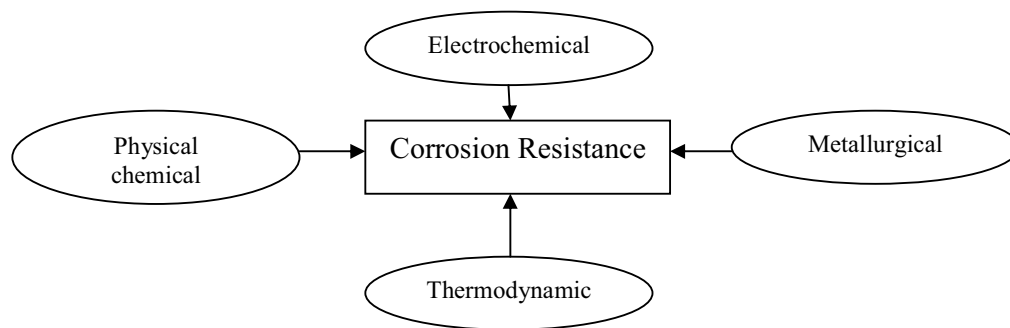
Figure 2.2: Factor affecting corrosion resistance of a metal

Source: Mars G. Fontana 1986

2.3 Factors influencing corrosion reactions

Mechanism of a chemical reaction it is advisable to separate the factors which determine the tendency or driving force of the reaction to proceed from those which influence the rate of the reaction made possible by the existence of this tendency. This tendency is an expression of the fact that the system is not in a state of equilibrium or

inherent stability. It is measured by the difference in energy between the initial and final state of the system for any particular case. In most cases the observed rate is determined not by the absolute magnitude of this tendency but by other factors which depend primarily upon the environment.

In considering the group of three typical reactions involved in corrosion, it shall denote as primary factors those which determine the tendency of the metal to corrode and thus influence its initial rate of solution and as secondary factors those which influence the rate of the subsequent reactions. This term in no wise implies that these secondary factors are of lesser importance. In fact, by influencing the nature and distribution of the final corrosion products, they usually determine the ultimate rate of corrosion and the useful life of the metal in each environment.

In the general case, some one or two of the many factors involved exert outstanding influence upon the ultimate rate of corrosion in term of controlling or dominant factors. In general, the primary factors have to do with the metal or alloy itself. The secondary factors more with the specific environment. It is convenient to divide them in this way, although no sharp distinction can be made. (Frank N. Speller, 1926).

2.4   Mechanism of corrosion

Corrosion of metals takes place through the action of electrochemical cells. Although this single mechanism is responsible, the corrosion can take many forms. Through an understanding of the electrochemical cell and how it can act to cause the various forms of corrosion, the natural tendency of metals to corrode can be overcome and equipment that is resistant to failure by corrosion can be designed. (NAVFAC, 1992)

2.4.1   The Electrochemical Cell

As in all chemical reactions, corrosion reactions occur through an exchange of electrons. In electrochemical reactions, the electrons are produced by a chemical reaction, the oxidation, in one area, the anode and travel through a metallic path and are

consumed through a different chemical reaction in another area, the cathode. In some cases, such as the common dry cell battery, electrochemical reactions can be used to supply useful amounts of electrical current. In marine corrosion, however, the most common result is the transformation of complex and expensive equipment to useless junk. In order for electrochemical reactions to occur, four components must be present and active. These components are the anode, cathode, electron path, and electrolyte. (NAVFAC, 1992)

(i)   Anode

In an electrochemical cell, the anode is the site where electrons are produced through the chemical activity of the metal. The anode is the area where metal loss occurs. The metal loses electrons and migrates from the metal surface through the environment. The electrons remain in the metal but are free to move about in response to voltage gradients. (NAVFAC, 1992)

(ii)   Cathode

The cathode in an electrochemical cell is the site where electrons are consumed. For each electron that is produced at an anodic site, an electron must be consumed at a cathodic site. No metal loss occurs at sites that are totally cathodic. (NAVFAC, 1992)

(iii)   Electron Path.

In order for electrons to flow from the anodic sites to cathodic sites, the electrons migrate through a metallic path. This migration occurs due to a voltage difference between the anodic and cathodic reactions. Electrons can move easily only through metals and some non-metals such as graphite. Electrons from electrochemical reactions cannot move through insulating materials such as most plastics nor can they directly enter water or air. In some cases, the electron path is the corroding metal itself, in other cases the electron path is through an external electrical path. (NAVFAC, 1992)

(iv)   Electrolyte

Electrolytes are solutions that can conduct electrical currents through the movement of charged chemical constituents called ions. Positive and negative ions are present in equal amounts. Positive ions tend to migrate away from anodic areas and toward cathodic areas. Negative ions tend to migrate away from cathodic areas and towards anodic areas. (NAVFAC, 1992)

2.4.2   Correlation between current flow and weight loss

For each specific anodic reaction a characteristic number of electrons are produced in the reaction of one metal ions. Thus, all other things being equal, the metal loss is proportional to the number of electrons that are produced. As the electrons produced migrate to cathodic areas through the electron path, the metal loss is proportional to the current flow. In cases where more positively charged ions are produced, more electrons flow for a given number of corroding metal atoms but the current flow remains proportional to the metal loss. (NAVFAC, 1992)

(i)   Anodic reactions

Metal loss at anodic sites in an electrochemical cell occurs when the metal atoms give up one or more electrons and move into the electrolyte as positively charged ions. The generic chemical formula for this metal loss at anodic sites is:

$$M \longrightarrow M^+ + e^- \qquad\qquad \text{(Eq. 2.1)}$$

where:

M   = uncharged metal atom at the metal surface

M^+ = positively charged metal ion in the electrolyte

e-   = electron that remains in the metal

This type of chemical reaction is called oxidation even though it does not directly involve oxygen but only results in an increase in positive charge on the atom

undergoing oxidation. More than one electron can be lost in the reaction as in the case for iron where the most common anodic reaction is:

$$Fe ---> Fe^+ + 2e^-$$ (Eq. 2.2)

where:

Fe = metallic iron

Fe^+ = ferrous ion that carries a double negative charge

(ii)   Cathodic reactions

The electrons that are produced at anodic sites are consumed at cathodic sites. The types of chemical reactions that consume electrons are called reduction and have the generic chemical formula:

$$R^+ + e- --> R$$ (Eq. 2.3)

where:

R^+ = a positive ion in solution

e- = an electron in the metal

Ro = the reduced chemical

In reduction, the chemical being reduced gains electrons and its charge is made more negative. In some cases, the where the ion in solution has a multiple positive charge, the total positive charge on the ion may not be neutralized. In other cases, the chemical which is reduced may not be a positive ion but is a neutral chemical which then becomes a negatively charged ion in solution in a reaction such as: (NAVFAC, 1992)

$$R + e- --> R^-$$ (Eq. 2.4)
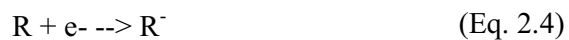
2.4.3 Forms of corrosion

Form of corrosion is generally well known from one of the most enduring books on corrosion engineering. The different forms of corrosion represent corrosion phenomena categorized according to their appearance. The basic forms of corrosion and divided into three groups based on their ease of identification. The three categories used are:

- Group 1   : Readily identifiable by ordinary visual examination.
- Group 2   : May require supplementary means of examination.
- Group 3   : Verification is usually required by microscopy.

The main forms of corrosion are shown in Figure 2.3 together with the respective group categories. In this figure, the number of forms has been expanded somewhat from Fontana's original grouping of eight basic forms. (Roberge Pierre R, 1999)
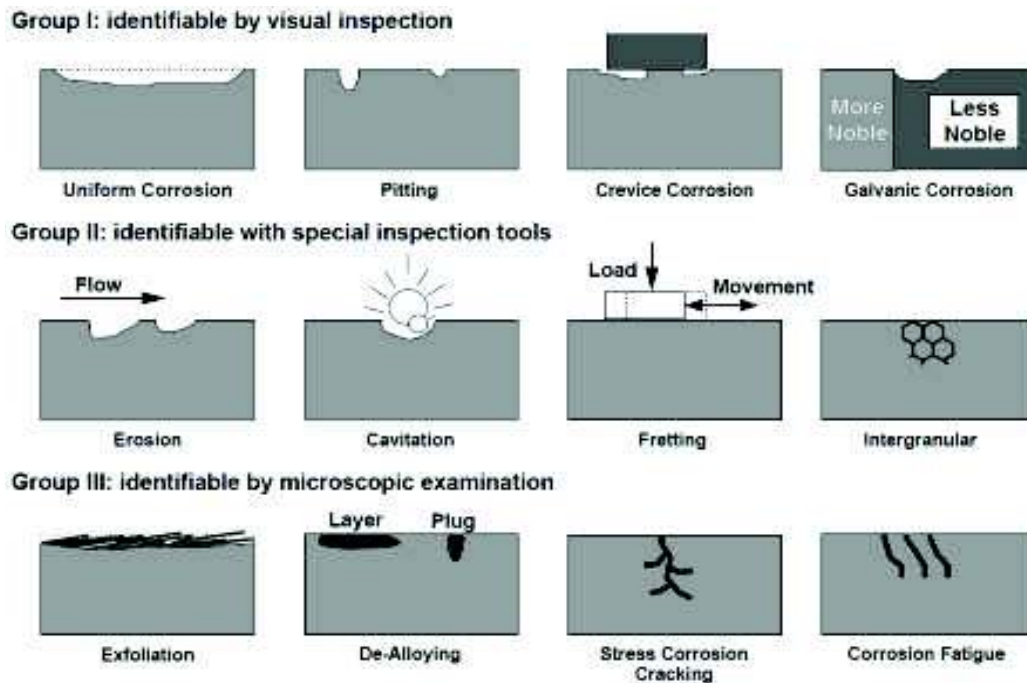
Figure 2.3: Main forms of corrosion regrouped by their ease of recognition.

Source: Roberge Pierre R 1999

(i)   Cavitation corrosion

Cavitation corrosion is corrosion that is enhanced through the formation and collapse of gas or vapor bubbles at or near the metal surface. Cavitation corrosion is similar to erosion corrosion and pitting is usually encountered. Cavitation can often be verified by a hydrodynamic analysis that can be used to locate and minimize bubble formation or move the area of bubble collapse to an area where the attack will have a minimal effect.

Under high velocity flow conditions, particularly when the flow is turbulent, areas of high and low pressure will be induced. In areas of low pressure, gas and vapor bubbles will be produced. When these bubbles move to an area of higher pressure, they collapse and their implosion creates a pressure wave that can remove protective films and cause increased corrosion.

The mechanism of cavitation corrosion the formation and collapse of gas or vapor bubbles in a liquid can cause localized damage to the films responsible for limiting corrosion. Once this localized corrosion is established, the local roughening can often serve as a new site for further turbulence and more cavitation attack. (NAVFAC, 1992)

(ii)   Crevices corrosion

Crevices are corrosion that is accelerated by differences in environment between separated areas on a single metal. These types of attack is usually associated with the small volumes of stagnant solution cause by holes, gasket surfaces, lap joint, surface deposits and crevices under bolt and rivet heads.

A difference in environment can be due to non-uniform deposits or fouling on the surface, or, more commonly, built in features which create significant difference in environment. It is often the most difficult form of corrosion to avoid in design and also is one of the most common causes of failure of marine equipment. Figure 2.4 shown the crevice corrosion on tubing.

Figure 2.4: Crevice on tubing

Source: NAVFAC, 1992

Any situation that creates a difference in environment between areas on a single metal can cause concentration cell attack. The basic mechanism is essentially the same as in galvanic corrosion but in the case of concentration cell corrosion the driving force is the difference in potential between a single metal exposed to different environments rather than the difference in potential between two different metals exposed to a single environment. The rates of attack experienced in concentration cell corrosion are affected by relative anode/cathode areas in the same manner as in galvanic corrosion. In crevice corrosion, the resistance of the electrolyte to the flow of ions can also be a significant factor in limiting attack in deep tight crevices. (NAVFAC, 1992)

(iii)   Dealloying

Dealloying is the selective corrosive attack of one or more constituent of a metallic alloy. In dealloying, the size and shape of the original component is often retained. The remaining constituent is often a different color than the original alloy and the depth and location of attack can be easily identified by this color change. Dealloying can either occurs over the entire surface (layering) or localized in pits (plug type).

Most of the commonly used metallic material is alloys formed from mixing two or more metals. Pure metals are usually too soft and weak to be used structurally. In this form of corrosion, dealloying, corrosion selectively attacks one or more constituent of the alloy mixture.

As can be seen from the galvanic series, constituents of many common alloys have widely separated positions on the galvanic series. In the case of brass, the main constituents are zinc and copper. In the case of cast iron, the main constituents are iron and graphite. When the surface of such alloys is exposed to an electrolyte, galvanic action proceeds with the more anodic material being selectively attacked. In many cases, the cathodic material remains behind and is bound into its original shape by a residue of remaining anodic material and corrosion products. The strength of the remaining material is, however, greatly reduced and will often fail during normal handling. Single phase material, where the alloy constituents are well mixed, are often less susceptible to this form of attack than alloys where phases of largely different composition are present. In many alloys, heat treatments have been developed specifically to make the alloy more homogeneous and less susceptible to dealloying. (NAVFAC, 1992)

(iv)   Hydrogen embrittlement

Hydrogen embrittlement is the severe loss of ductility of a metal when hydrogen has been introduced into the metal structure. Hydrogen can enter most metals. Due to the small size of the hydrogen atom, it can migrate through the metal structure and cause a loss of ductility similar to that experienced in stress corrosion cracking.

Hydrogen atoms can enter a metal either from hydrogen gas, usually at elevated temperatures, or from atomic hydrogen that is electrolytically formed on its surface. This hydrogen can either reduce the energy required for forming cracks under stress or can accumulate at areas of high stress, such as crack tips, and cause pressure, which directly assists crack propagation. High strength materials in general are the most susceptible to hydrogen embrittlement. Hydrogen can be formed electrolytically during electroplating, during welding when hydrogen is present in the electrode material, in the

electrode coating, in the shielding gas, or simply as moisture on the metal surface, or when excessive cathodic protection is applied potentials more negative than minus 1.2 volts are normally required for significant hydrogen formation by cathodic protection. (NAVFAC, 1992)

(v)   Immunity

Immunity is the lack of measurable attack on a metal when exposed to operational environments. A metal that is immune to corrosion in a given environment will not show any change due to corrosion after exposure.

The first form of corrosion described is the lack of attack, or immunity. This can result from the action of two basic mechanisms. Corrosion test measurements that are used to measure very low corrosion rates must be used to validate that corrosion activity is completely absent.

Immunity can result from two basic mechanisms. In the first case, the energy content of the metal is lower (more stable) than any of the corrosion products that could possibly form. Such metals are commonly found in nature as metals that indicates the stability of the metallic state for these elements. Corrosion of such metals where an increase of energy is required will not take place naturally just as a ball will not roll uphill unless pushed. In the second case, there is an energy tendency for the metal to corrode, but corrosion activity is prevented by the presence of a highly stable passive film. Not only must this film be stable in the environment, but it must be able to repair itself by reaction with the environment if it is damaged.

(vi)   Stress corrosion cracking

Stress corrosion cracking as shown in Figure 2.5 is the intergranular or transgranular cracking of a material due to the combined action of tensile stress and a specific environment. Stress corrosion cracking must be evaluated using microscopic examination of the cracked sections. The cracking is often branched. Stress corrosion

cracking can occur in the presence of other forms of corrosion attack or without the presence of other visible attack.

Metals are useful in engineering structures because of their strength, ductility, and durability. Ductility is extremely important as it allows the material to deform in response to loading thus redistributing the stresses. In some cases, however, chemical interactions with the environment can reduce the ductility of metals so that they behave more like brittle materials when subjected to stress.

Even after many years of intensive study, the exact mechanism of stress corrosion cracking remains a matter of extensive disagreement and study. It is commonly attributed to the rupture of protective films at the tips of pits or pre-existing cracks due to the applied stress. In many cases, the materials appear to be totally resistant to corrosion in a given environment until stresses are applied. They then crack catastrophically without any sign of other corrosion attack. (NAVFAC, 1992)
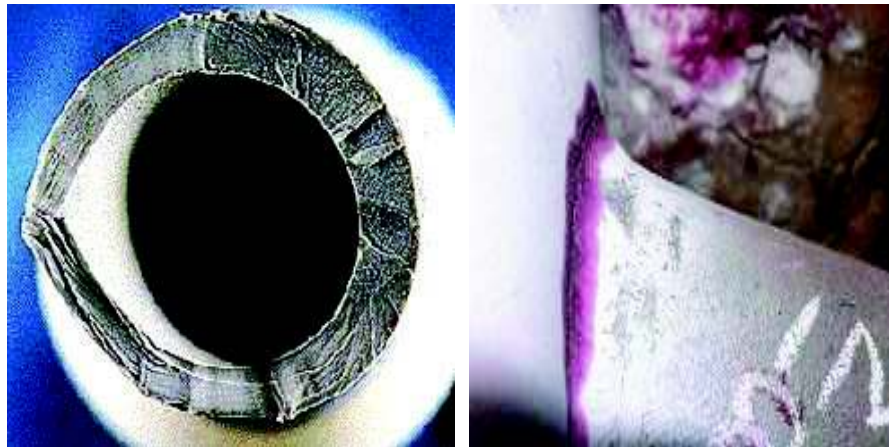
Figure 2.5: Stress corrosion cracking

Source: NAVFAC, 1992

(vii)   Atmospheric corrosion

The atmospheric environment varies drastically with regards to corrosivity depending on the geographical location. In atmospheric corrosion, the electrolyte is moisture from precipitation, fog or dew, sea spray, or other sources. The three factors that have the most influence on the corrosivity of the atmosphere at a given site are:

(1) The amount of time that exposed surfaces remain wet at the site

(2) The amount of chloride from the sea that reaches the surfaces

(3) The amount of industrial pollutants (mainly acids) that reach the surfaces.

In all atmospheric environments there is an excess of oxygen, thus the corrosion of most metals in atmospheric environments is not limited by the amount of oxygen present and can proceed rapidly when the electrolyte is present. The corrosivity of the atmosphere varies drastically. (NAVFAC, 1992)

The corrosion rate of steel, for example, can vary by a factor of 100. In general, the least corrosive atmospheres are found in dry inland (desert) sites and the most corrosive sites are industrial or industrial marine sites.

Moist tropical locations are very corrosive due both to the time of wetness and the high temperatures experienced. However, local conditions and features of design have an influence on corrosive attack that often exceeds the differences experienced due to geographical conditions.

Thus, generalizations regarding specific site corrosivity based on the corrosion of a single metal at a single location at a given site can be misleading. It is not prudent to ignore the possibility of corrosion at a dry inland site nor to consider corrosion inevitable at a marine industrial site. The rates of attack can vary at different sites, but the mechanisms of attack, features that cause accelerated attack and corrective measures for corrosion prevention and corrosion protection that can reduce the attack are similar. (NAVFAC, 1992)

(viii)   Erosion corrosion

Erosion corrosion is the acceleration or increase in rate of deterioration of attack on a metal because of relative movement between a corrosive fluid and metal surface. Failures because of erosion corrosion occur in a relatively short time and are expected largely because the evaluation corrosion tests were run under static conditions of because the erosion effects were not considered. (Mars G. Fontana, 1986)

Erosion corrosion is a combination of mechanical and corrosive attack. Abrasive particles in suspension, or high velocities, expose fresh metal surfaces which then suffer high rates corrosion. The figure of erosion corrosion was shown in Figure 2.6.
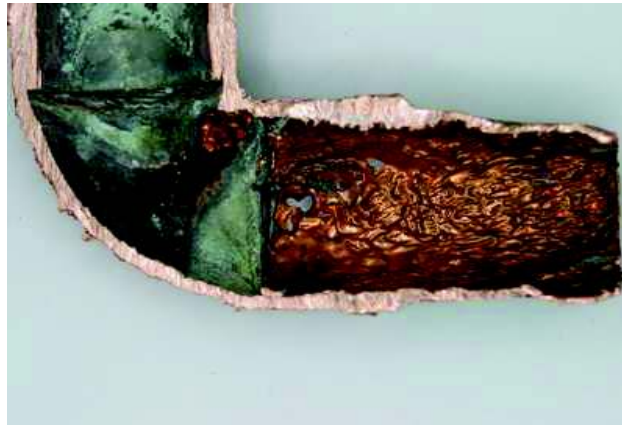
Figure 2.6: Erosion corrosion

Source: Mars G. Fontana 1986

Generally, relative movement between a corrosive fluid and metal surface is quite rapid and mechanical wear effects or abrasion is involved. Metal is removed from the surface as dissolved ions or it forms solid corrosion products that are mechanically swept from the metal surface. Sometimes movement of the environment decreases corrosion, particularly when localized attacked occurs under stagnant conditions but this is not erosion corrosion because deterioration is not increased. (NAVFAC, 1992)

(ix)   Fretting corrosion

Fretting corrosion is an attack that is accelerated by the relative motion of contacting surfaces. If inspected soon after the relative motion ceases, the surfaces will often be bright and have corrosion products attached to the surfaces.

When surfaces move in relation to each other, this relative motion can result in abrasion. This abrasion can increase the attack at these fraying surfaces. Fretting corrosion usually results in scuffed surfaces in joints or at other wear sites.

Fretting corrosion is usually a combination of corrosion and abrasive wear. The motion between the surfaces removes protective films and results in accelerated attack. Also, most corrosion products are abrasive and their presence increases the removal of protective films and in direct abrasion of the metal. (NAVFAC, 1992)

(x)   Intergranular corrosion

Intergranular corrosion is a selective attack of a metal at or adjacent to grain boundaries. Intergranular attack caused by high grain boundary energies or impurities at the grain boundaries results in attack with a grainy residue and rough surface. Under high magnification, the individual grains are often visible. Intergranular attack of aluminum alloys is associated with pitting or other localized attack. Sensitization in stainless steels has a similar grainy appearance. When caused by welding it is often localized in narrow bands adjacent to the weld and is sometimes called "knife line attack."

Just as most engineering metals are mixtures of one or more metals, they consist of large numbers of individual metal crystals called grains that are joined together at their surfaces or grain boundaries. As there can be differences in composition at or adjacent to these grain boundaries, selective corrosion can occur at these sites.

There are three mechanisms that have been identified as causing intergranular corrosion in various situations.

▪ The first mechanism is the selective attack of grain boundary material due to its high energy content. Metal crystals form in an ordered arrangement of atoms because this ordered arrangement has lower energy content than a disordered arrangement. Grain boundaries are highly disordered as they are at the boundaries of crystals which, although they are internally ordered, have random orientation with respect to each other. The disordered grain boundary is often 10 to 100 atoms wide and these atoms have a higher energy than the surrounding atoms. Higher energy material can be more chemically active than lower energy material and thus, the grain boundary material can be anodic with respect to the surrounding grains. When this occurs, the anodic area is small and the cathodic area is large, thus, rapid attack can occur. The result is that the individual grains are no longer joined with the strong grain boundary "glue" and disintegrate leaving a powdery residue and rough grainy surface.

▪ A second mechanism is selective attack of grain boundary material that has a different composition from the surrounding grains. When metals crystallize from the molten state, the crystals tend to be more pure than the molten material. This is because the pure metal crystals are more ordered and have lower energy content than if they contained large amounts of impurities. In some cases, most of the impurities are concentrated at the grain boundaries. When the composition of this impure material causes it to be more anodic than the surrounding grains, rapid attack can occur with results similar to those described above. When the composition of the impure grain boundary material causes it to be more cathodic than the surrounding grains, the favorable anode/cathode area ratio makes this situation relatively innocuous. Contamination of grain boundaries can sometimes also occur after manufacture. Mercury on aluminum can penetrate and contaminate the grain boundaries and cause subsequent intergranular attack. This is why mercury and mercury compounds are prohibited aboard aluminum ships or on aircraft.

▪ A third mechanism is selective attack adjacent to the grain boundaries due to the local depletion of an alloying element. This form of attack can occur in many stainless steels. It is called sensitization. Many stainless steels rely on a combination of nickel and chromium for their corrosion resistance. As both nickel and chromium

are expensive, they are added only in amounts necessary to obtain the necessary corrosion resistance. Another element, which is commonly present in ail steels, is carbon. In stainless steels, carbon atoms tend to concentrate at the grain boundaries as an impurity during solidification. Chromium carbides can form adjacent to the grain boundaries during welding and heat treatment. When these compounds form, the chromium is removed from the alloy adjacent to the grain boundaries and the resulting alloy does not have enough chromium content to remain passive. Again, there is a very unfavourable anode/cathode area ratio and rapid attack can occur. (NAVFAC, 1992)

(xi)   Uniform Corrosion

Uniform corrosion is the attack of a metal at essentially the same at all exposed areas of its surface. At no point is the penetration of the metal by corrosion twice as great as the average rate. In uniform corrosion, the metal loss occurs at essentially the same rate over the entire metal surface. Smooth surfaces are usually roughened during uniform corrosion. This form of corrosion is characterized by the lack of any significant non-uniform attack such as pitting or crevice corrosion, which will be described later. Corrosion products commonly remain on uniformly corroding surfaces but these can be removed by velocity, by mechanical action or by other mechanisms.

If a metal is not immune to attack and corrosion cannot be completely eliminated, uniform corrosion is considered the form of corrosion that can be tolerated in marine structures and equipment. It is also relatively easy to control uniform corrosion to acceptable levels through judicious selection of materials, the application of corrosion control measures, and to allow for any corrosion which does occur.

Uniform corrosion occurs when there are local anodic and cathodic sites on the surface of the metal. Due to polarization effects, these locations shift from time to time and a given area on a metal will be act as both an anode and as a cathode over any extended period of time. The averaging effect of these shifting local action cells results in a rather uniform attack and general loss of material and roughening of the surface. (NAVFAC, 1992)

2.5 Pipeline Corrosion

Pipeline was closely relates with soil. Generally, the pipeline system was exposure in soil. Soil is an aggregate of minerals, organic matter, water, and gases (mostly air). It is formed by the combined weathering action of wind and water, and also organic decay. The proportions of the basic constituents vary greatly in different soil types. For example, humus has very high organic matter content, whereas the organic content of beach sand is practically zero. The properties and characteristics of soil obviously vary as a function of depth. A vertical cross section taken through the soil is known as a *soil profile,* and the different layers of soil are known as *soil horizons.* The following soil horizons have been classified:

- Surface soil (usually dark in color due to organic matter)
- Organic horizon (decaying plant residues)
- Eluviation horizon (light color, leached)
- Accumulation horizon (rich in certain metal oxides)
- Parent material (largely non-weathered bedrock)

Corrosion in soils is a major concern, especially as much of the buried infrastructure is aging. Increasingly stringent environmental protection requirements are also placing a focus on corrosion issues. Topical examples of soil corrosion are related to oil, gas, and water pipelines; buried storage tanks (a vast number are used by gas stations); electrical communication cables and conduits; anchoring systems; and well and shaft casings. Such systems are expected to function reliably and continuously over several decades. Corrosion in soils is a complex phenomenon, with a multitude of variables involved. Chemical reactions involving almost each of the existing elements are known to take place in soils, and many of these are not yet fully understood. The relative importance of variables changes for different materials, making a universal guide to corrosion impossible. Variations in soil properties and characteristics across three dimensions can have a major impact on corrosion of buried structures. (Roberge Pierre R, 1999)

2.5.1   Soil classification systems

Soil texture refers to the size distribution of mineral particles in a soil. Sand (rated from coarse to very fine), silt, and clay refer to textures of decreasing particle coarseness. Table 2.1 shows the particle sizes in soil texture for sand, silt and clay.

Table 2.1: Particle Sizes in Soil Texture

Category	Diameter (mm)
Sand (very coarse)	1.00–2.00
Sand (coarse)	0.50–1.00
Sand (medium)	0.25–0.50
Sand (fine)	0.10–0.25
Sand (very fine)	0.05–0.10
Silt	0.002–0.05
Clay	<0.002

Source: Roberge Pierre R 1999

Soils with a high proportion of sand have very limited storage capacity for water, whereas clays are excellent in retaining water. One soil identification system has defined eleven soil types on the basis of their respective proportions of clay, silt, and sand. The eleven types are sand, loamy sand, sandy loam, sandy clay loam, clay loam, loam, silty loam, silt, silty clay loam, silt clay, and clay. A further identification scheme has utilized chemical composition, organic content, and history of formation to define types such as gravel, humus, marsh, and peat.

A newer soil classification system has evolved in the United States that can be utilized to classify soils globally, at any location. In this "universal" classification system, soils are considered as individual three-dimensional entities that can be grouped according to similar physical, chemical, and mineralogical properties. The system uses a hierarchical approach, with the amount of information about a soil increasing down the classification ladder. From top to bottom, the hierarchy is structured in the following

categories: order, suborder, great groups, subgroups, families, and series. Further details are provided in Table 2.2. (Roberge Pierre R, 1999)

Table 2.2: Soil Classification System using Hierarchical Approach

Category	Basis for classification	Comments
Order	Differences in measurable and visible characteristics of soil horizons	Nine orders for mineral soils and one order for all organic soils
Suborder	Differences in development characteristics	Grouping according to accumulation of soluble materials, presence or absence of B horizons, mineralogy and chemistry
Great group	Presence or absence of certain horizons	Relative thickness of horizons is important
Subgroup	Typical or dominant concept of the great group	Coded as either the great group name with the "typic" prefix or a combination of great group names
Family	Differences in textural classes, mineralogy, acidity, and temperature	Plants generally react in a similar manner to the same soil family
Series	Differences in texture	Usually named after the location where the soil was first described

Source: Roberge Pierre R 1999

2.5.2 Soil parameters affecting corrosivity

Several important variables have been identified that have an influence on corrosion rates in soil; these include water, degree of aeration, pH, redox potential, resistivity, soluble ionic species (salts), and microbiological activity. The complex nature of selected variables is presented graphically in Figure 2.6. (Roberge Pierre R, 1999)

(i)   Water

Water in liquid form represents the essential electrolyte required for electrochemical corrosion reactions. A distinction is made between saturated and unsaturated water flow in soils. The latter represents movement of water from wet areas toward dry soil areas. The groundwater level is important in this respect. It fluctuates from area to area, with water moving from the water table to higher soil, against the direction of gravity. Saturated water flow is dependent on pore size and distribution, texture, structure, and organic matter. Water in liquid form represents the essential electrolyte required for electrochemical corrosion reactions. A distinction is made between saturated and unsaturated water flow in soils. The latter represents movement of water from wet areas toward dry soil areas. The groundwater level is important in this respect. It fluctuates from area to area, with water moving from the water table to higher soil, against the direction of gravity. Saturated water flow is dependent on pore size and distribution, texture, structure, and organic matter. (Roberge Pierre R, 1999)
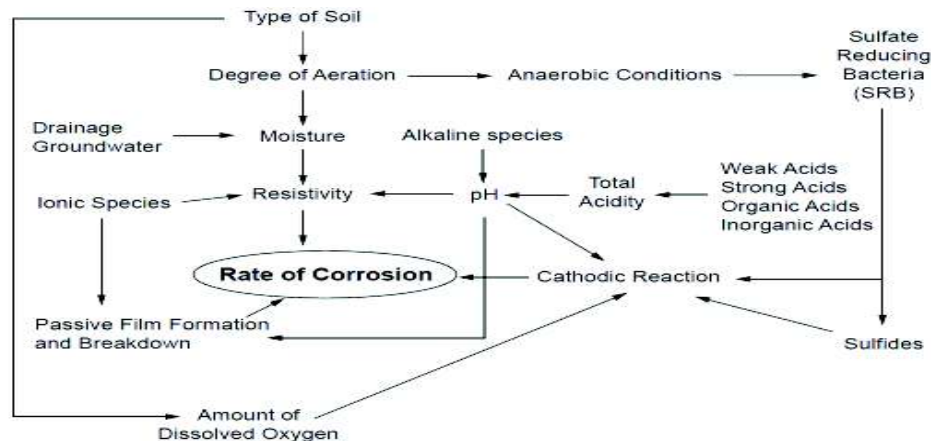
Figure 2.7: Relationship of variables affecting the rate of corrosion in soil.

Source: Roberge Pierre R 1999

Water movement in soil can occur by the following mechanisms: gravity, capillary action, osmotic pressure (from dissolved species), and electrostatic interaction

with soil particles. The water-holding capacity of a soil is strongly dependent on its texture. Coarse sands retain very little water, while fine clay soils store water to a high degree.

(ii)   Degree of aeration

The oxygen concentration decreases with increasing depth of soil. In neutral or alkaline soils, the oxygen concentration obviously has an important effect on corrosion rate as a result of its participation in the cathodic reaction. However, in the presence of certain microbes (such as sulfate-reducing bacteria), corrosion rates can be very high, even under anaerobic conditions. Oxygen transport is more rapid in coarse-textured, dry soils than in fine, waterlogged textures.

Excavation can obviously increase the degree of aeration in soil, compared with the undisturbed state. It is generally accepted that corrosion rates in disturbed soil with greater oxygen availability are significantly higher than in undisturbed soil. (Roberge Pierre R, 1999)

(iii)   Soil pH

Soils usually have a pH range of 5 to 8. In this range, pH is generally not considered to be the dominant variable affecting corrosion rates. More acidic soils obviously represent a serious corrosion risk to common construction materials such as steel, cast iron, and zinc coatings. Soil acidity is produced by mineral leaching, decomposition of acidic plants (for example, coniferous tree needles), industrial wastes, acid rain, and certain forms of microbiological activity. Alkaline soils tend to have high sodium, potassium, magnesium, and calcium contents. The latter two elements tend to form calcareous deposits on buried structures, and these have protective properties against corrosion. The pH level can affect the solubility of corrosion products and also the nature of microbiological activity. (Roberge Pierre R, 1999)

(iv)   Resistivity

Resistivity has historically often been used as a broad indicator of soil corrosivity. Since ionic current flow is associated with soil corrosion reactions, high soil resistivity will arguably slow down corrosion reactions. Soil resistivity generally decreases with increasing water content and the concentration of ionic species. Soil resistivity is by no means the only parameter affecting the risk of corrosion damage. A high soil resistivity alone will not guarantee absence of serious corrosion. Variations in soil resistivity along the length of a pipeline are highly undesirable, as this will lead to the formation of macro corrosion cells. Therefore, for structures such as pipelines, the merit of a corrosion risk classification based on an absolute value of soil resistivity is limited.

Soil resistivity can be measured by Earth Resistance Tester or more recently by electromagnetic measurements. The latter allows measurements in a convenient manner and at different soil depths. Another option for soil resistivity measurements is the soil box method, whereby a sample is taken during excavation. Preferably sampling will be in the immediate vicinity of a buried structure for example a pipe trench. (Roberge Pierre R, 1999)

(v)   Redox potential

The redox potential is essentially a measure of the degree of aeration in a soil. A high redox potential indicates a high oxygen level. Low redox values may provide an indication that conditions are conducive to anaerobic microbiological activity. Sampling of soil will obviously lead to oxygen exposure, and unstable redox potentials are thus likely to be measured in disturbed soil. (Roberge Pierre R, 1999)

(vi)   Chlorides

Chloride ions are generally harmful, as they participate directly in anodic dissolution reactions of metals. Furthermore, their presence tends to decrease the soil resistivity. They may be found naturally in soils as a result of brackish groundwater and

historical geological seabeds (some waters encountered in drilling mine shafts have chloride ion levels comparable to those of seawater) or come from external sources such as deicing salts applied to roadways. The chloride ion concentration in the corrosive aqueous soil electrolyte will vary as soil conditions alternate between wet and dry. (Roberge Pierre R, 1999)

(vii)   Sulfates

Compared to the corrosive effect of chloride ions, sulfates are generally considered to be more benign in their corrosive action toward metallic materials. However, concrete may be attacked as a result of high sulfate levels. The presence of sulfates does pose a major risk for metallic materials in the sense that sulfates can be converted to highly corrosive sulfides by anaerobic sulfate-reducing bacteria. (Roberge Pierre R, 1999)

(viii)   Microbiologically influenced corrosion

Microbiologically influenced corrosion (MIC) refers to corrosion that is influenced by the presence and activities of microorganisms and/or their metabolites (the products produced through their metabolism). Bacteria, fungi, and other microorganisms can play a major part in soil corrosion. Spectacularly rapid corrosion failures have been observed in soil as a result of microbial action, and it is becoming increasingly apparent that most metallic alloys are susceptible to some form of MIC. The mechanisms potentially involved in MIC have been summarized as follows:

- Cathodic depolarization, whereby the cathodic rate-limiting step is accelerated by microbiological action.
- Formation of occluded surface cells, whereby microorganisms form "patchy" surface colonies. Sticky polymers attract and aggregate biological and nonbiological species to produce crevices and concentration cells, the basis for accelerated attack.

- Fixing of anodic reaction sites, whereby microbiological surface colonies lead to the formation of corrosion pits, driven by microbial activity and associated with the location of these colonies.

- Underdeposit acid attack, whereby corrosive attack is accelerated by acidic final products of the MIC "community metabolism," principally short-chain fatty acids.

Certain microorganisms thrive under aerobic conditions, whereas others thrive in anaerobic conditions. Anaerobic conditions may be created in the microenvironmental regime even if the bulk conditions are aerobic. The pH conditions and availability of nutrients also play a role in determining what types of microorganisms can thrive in a soil environment. In general, microbial activity is highest in the surface O and A horizons, because of the availability of both organic carbon nutrients and oxygen. Microorganisms associated with corrosion damage in soils include the following:

- Anaerobic bacteria, which produce highly corrosive species as part of their metabolism.

- Aerobic bacteria, which produce corrosive mineral acids.

- Fungi, which may produce corrosive by-products in their metabolism, such as organic acids. Apart from metals and alloys, they can degrade organic coatings and wood.

- Slime formers, which may produce concentration corrosion cells on surfaces.

A summary of the characteristics of bacteria commonly associated with soil corrosion (mostly for iron-based alloys) is provided in Table 2.3. (Roberge Pierre R, 1999)

2.6   Soil resistivity

Soil resistivity is one of the most important factors in selecting a groundbed location. Soil resistivity expressed in ohmcentimeters (abbreviated ohm-cm), is one basic variable affecting resistance to earth of an electrode system. The actual value of

earth resistivity need not be measured to check the electrode earth resistance. Consider other fields where the value of resistivity is measured, also some of the factors affecting it that are of interest in earth testing.

Soil resistivity measurements can be used conveniently for geophysical prospecting to locate ore bodies, clays, and water-bearing gravel beneath the earth surface. The measurement can also be used to determine depth to bed rock and thickness of glacial drift. Measurements of earth resistivity are useful also for finding the best location and depth for low resistance electrodes. Such studies are made for example when a new electrical unit is being constructed, a generating station, substation, transmission tower, or telephone central office.

Soil resistivity also can be used to indicate the degree of corrosion to be expected in underground pipelines for water, oil, gas, gasoline, etc. In general, spots where the resistivity values are low tend to increase corrosion. This same kind of information is a good guide for installing cathodic protection.

2.6.1 Soil resistivity Concept

The deep groundbed designer call upon experience gained from other cathodic protection installations in the area. Earlier survey records often provide area resistivity. Many times the designer may obtain an estimate of average soil resistivity from knowledge of rectifier output from the groundbed that is to be replaced.

Soil resistivity generally relate to the salinity or purity of the water or moisture, which historically has permeated the soil and remains there to one degree or another. Table 2.3 show the broad guidelines relate areas and soil type conditions with its resistivity. (Pierre R. Roberge, 1999)

Table 2.3: Resistivity range based on soil types

Area and/or Soil Type	Resistivity Range (Ωcm)
Poor or slow drainage	150 - 1200
Low elevation	600 - 1500
Satisfactory to good drainage	1200 - 5000
Farm and range lands	3500 - 10000
Desert plains and mountains	5000 - 25000
Excellent drainage, dry and arid	10000 - 25000

Source: Pierre R. Roberge (1999)

Since ionic current flow is associated with soil corrosion reactions, high soil resistivity will arguable slow down corrosion reactions. Soil resistivity generally decreases with increasing water content and the concentration of ionic species. Sandy soils are high up on the resistivity scale and therefore considered the least corrosive. Clay soils, especially those contaminated with saline water are on the opposite end of the spectrum. (Pierre R. Roberge, 1999)

Table 2.4: Corrosivity ratings based on soil resistivity

Soil resistivity (Ωcm)	Corrosivity Rating
>20000	Essentially non-corrosive
10000 to 20000	Mildly corrosive
5000 to10000	Moderately corrosive
3000 to 5000	Corrosive
1000 to 3000	Highly corrosive
<1000	Extremely corrosive

Source: Pierre R. Roberge (1999)

Field soil resistivity measurements are most often conducted using the soil resistance meter. The Earth Resistance Tester requires the use of two metal probes or electrodes, driven into the ground along a straight line, equidistant from each other, as shown in the following Figure. Soil resistivity is a simple function derived from the voltage drop between the center pair of pins, with current flowing between the two outside pins. (Pierre R. Roberge, 1999)

An alternating current from the soil resistance meter causes current to flow through the soil, between the electrodes. The voltage or potential is then measured and then the meter registers a resistance reading. Figure 2.8 show the current flowing on the ground electrode.
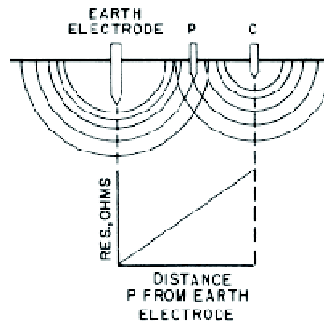
Figure 2.8: Current flowing on the ground electrode

Source: Megger 2006

2.6.2   Earth Resistance Tester

Earth resistance tester was use for testing power distribution lines, in-house wiring system and electrical appliances. It also has an earth voltage range for earth voltage measurement.

(i)   Principle of measurement

The earth resistance measurement with fall-of-potential method which is a method to obtain earth resistance value Rx by applying AC constant current I between

the measurement object E (earth electrode) and C (current electrode), and finding out the potential difference V between E and P (potential electrode) as shown in Figure 2.9.
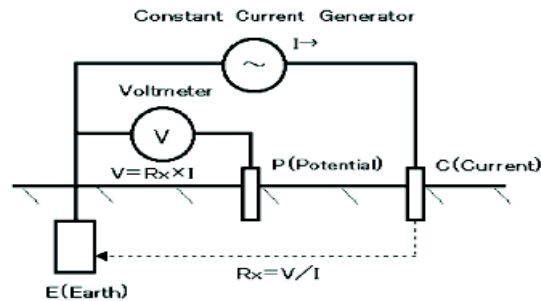
Figure 2.9: Circuit diagram for earth resistance tester

Source: A.W. Sperry 1998

(ii)   Precise measurement

The auxiliary earth spikes P and C stick deeply into the ground. It is should be aligned at an interval of 5-10m from the earthed equipment under test. Green lead wire were connect to the earthed equipment under test, the yellow wire to the auxiliary earth spike P and the red wire to the auxiliary earth spike C from terminals E, P and C of the instrument. The all wire connection was shown in Figure 2.10.
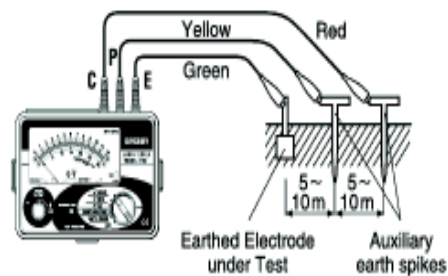
Figure 2.10: Wire connection of earth tester

Source: A.W. Sperry 1998

The range switch was set to x100Ω position and presses the test button. LED will remains illuminated during the testing. Turn the range switch to x10Ω and x1Ω when the earth resistance is low. This indicated value is the earth resistance of the earthed equipment under test. Figure 2.11 show the scale of the earth tester.

Range	Measuring Range	Scale		Scale Factor
Earth Voltage	0-30V	A	30	x 1
Earth Resistance	0-12Ω	B	12	x 1
	0-120Ω	B	12	x 10
	0-1200Ω	B	12	x 100
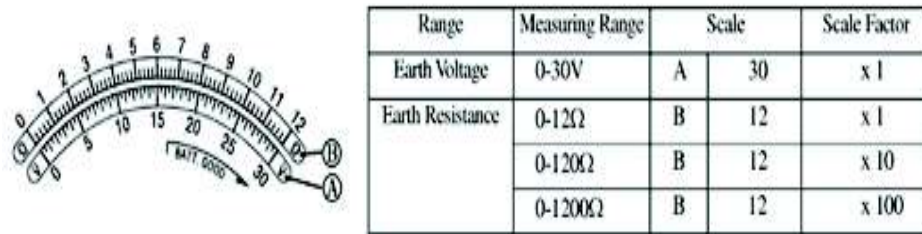
Figure 2.11: The scale reading of earth tester

Source: A.W. Sperry 1998

2.6.3 Variables affecting resistance of soil

There are four variables that affect the ground resistance of a ground system:
(i)   Length/depth of the ground electrode
(ii)   Diameter of the ground electrode
(iii)   Number of ground electrodes
(iv)   Ground system design

(i)   Length/depth of the ground electrode

One very effective way of lowering ground resistance is to drive ground electrodes deeper. Soil is not consistent in its resistivity and can be highly unpredictable. It is critical when installing the ground electrode that it is below the frost line. This is done so that the resistance to ground will not be greatly influenced by the freezing of the surrounding soil. Generally, by doubling the length of the ground electrode you can reduce the resistance level by an additional 40 %. There are occasions where it is physically impossible to drive ground rods deeper areas that are composed of

rock, granite, etc. In these instances, alternative methods including grounding cement are viable.

(ii)   Diameter of the ground electrode

Increasing the diameter of the ground electrode has very little effect in lowering the resistance. For example, you could double the diameter of a ground electrode and your resistance would only decrease by 10 %.

(iii)   Number of ground electrodes

Another way to lower ground resistance is to use multiple ground electrodes. In this design, more than one electrode is driven into the ground and connected in parallel to lower the resistance. For additional electrodes to be effective, the spacing of additional rods needs to be at least equal to the depth of the driven rod. Without proper spacing of the ground electrodes, their spheres of influence will intersect and the resistance will not be lowered. The spheres of influence were shown in Figure 2.12.
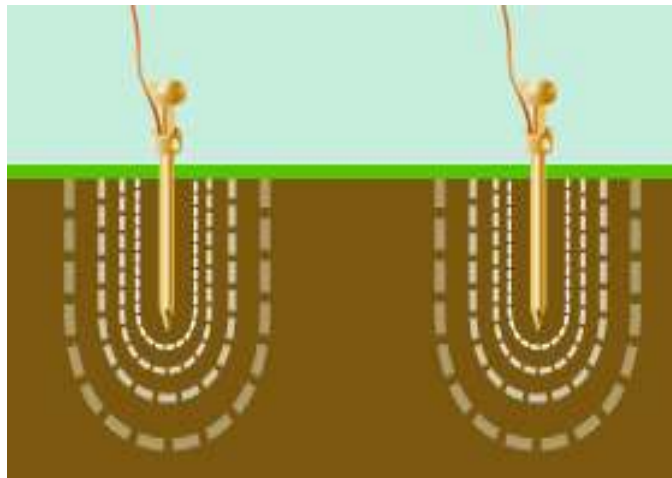
Figure 2.12: Each ground electrode has its own 'sphere of influence'

Source: Fluke Corporation

(iv)   Ground system design

Simple grounding systems consist of a single ground electrode driven into the ground. The use of a single ground electrode is the most common form of grounding and can be found outside your home or place of business. Complex grounding systems consist of multiple ground rods, connected, mesh or grid networks, ground plates, and ground loops. These systems are typically installed at power generating substations, central offices, and cell tower sites. Complex networks dramatically increase the amount of contact with the surrounding earth and lower ground resistances. Figure 2.13 until Figure 2.16 shown the various system design that driven into ground.

Figure 2.13: Single ground electrode
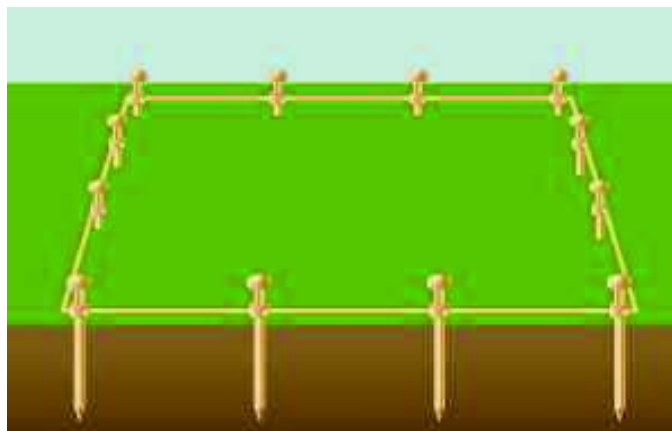
Figure 2.14: Multiple ground electrodes connected
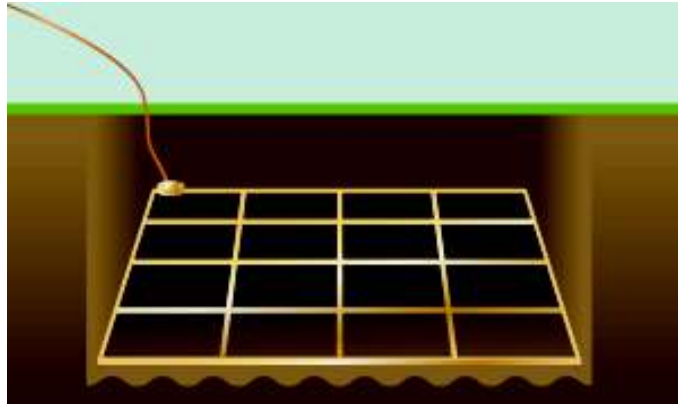
Figure 2.15: Mesh network
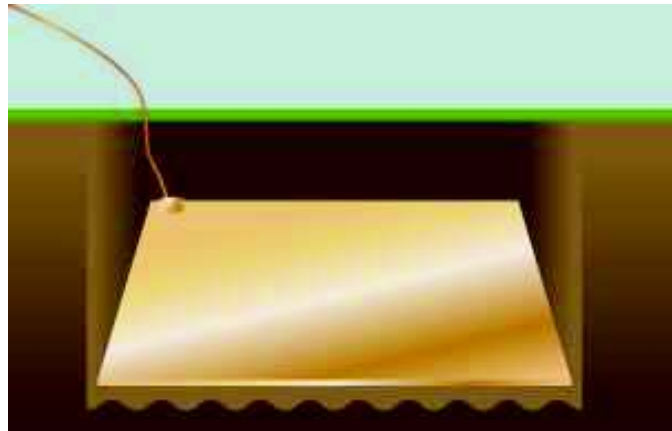
Figure 2.16: Ground plate

Source: Fluke Corporation

2.6.4 Resistivity Decreases with Moisture and Dissolved Salts

In soil, conduction of current is largely electrolytic. Therefore, the amount of moisture and salt content of soil radically affects its resistivity. The amount of water in the soil varies, of course, with the weather, time of year, nature of sub-soil, and depth of the permanent water table. Table 2.5 shows typical effects of water in soil; note that when dry, the two types of soil are good insulators with resistivities greater than 1000×10^6 ohm-cm. With a moisture content of 15 percent, however, note the

dramatic decrease in resistivity by a factor of 100,000. Actually, pure water has an infinitely high resistivity. Naturally occurring salts in the earth, dissolved in water, lower the resistivity. Only a small amount of salt can reduce soil resistivity quite a bit.

Table 2.5: Effect of Moisture Content on Earth Resistivity

Moisture Content, Percent by Weight	Resistivity (Ohm-cm)	
	Top soil	Sandy Loam
0.0	1000×10^{6}	1000×10^{6}
2.5	250,000	150,000
5.0	165,000	43,000
10.0	53,000	22,000
15.0	21,000	13,000
20.0	12,000	10,000
30.0	10,000	8,000

Source: Fluke Corporation

Since ionic current flow is associated with soil corrosion reactions, high soil resistivity will arguably slow down corrosion reactions. Soil resistivity generally decreases with increasing water content and the concentration of ionic species. Soil resistivity is by no means the only parameter affecting the risk of corrosion damage. A high soil resistivity alone will not guarantee the absence of serious corrosion. Soil resistivity is a measure of the ability of a soil to conduct a current. The lower the resistivity of a soil, the better is the soil's electrolytic properties and the higher is the rate at which the corrosion can proceed. The Figure 2.17 shows the effect of resistivity on the soil corrosivity range.
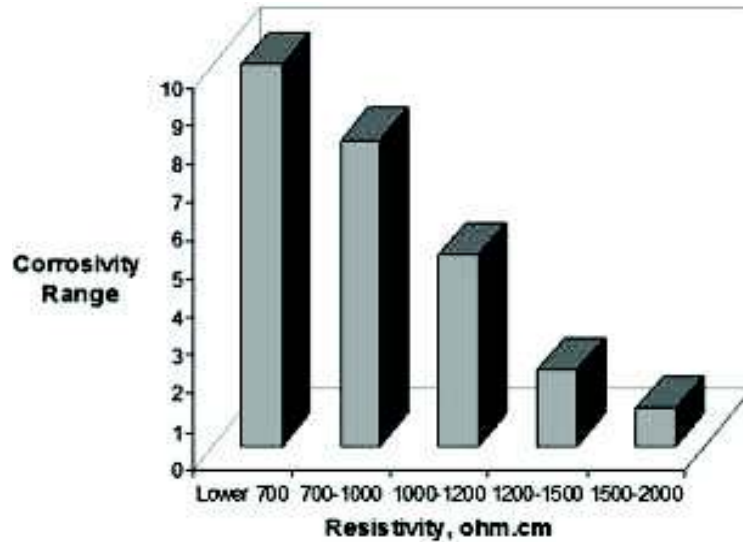
Figure 2.17: Effect of resistivity on the soil corrosivity range

Source: A.I.M. Ismail, 2008

Soil investigation previous results showed that soil resistivity values decrease according to the increase in moisture and temperature to support ionic exchange between buried pipe surface and corrosive soil environment. The resistivity of the soil is determined by the moisture content and the concentrations of the different ions and their mobilities. Soil solutions of different concentrations are produced by the action of subsurface water on minerals. The soil solution is relatively dilute in temperate climates with moderate rainfall. In areas with heavy rainfall the salt concentrations are increased in the deeper regions as a consequence of marked leaching out. High levels of salt concentrations also occur in areas which have previously been sea beds, or where large quantities of fertilizer, de-icing salt, etc. have been used. (A.I.M. Ismail, 2008)

CHAPTER 3

METHODOLOGY

3.1   Introduction

Project methodology is a body of practices, procedures and rules used by those who work in a discipline or engage in an inquiry and a set of working methods. This chapter will be discussed about methodology study that include specimen preparations, exposure in soil, weighing the specimen, surface morphology, cleaning experiment and corrosion rate analysis. The specimen for this project is steel pipe. The test that will be carrying out for this project is analysis of soil resistivity to the corrosion behavior of steel pipe system. The method of this project was referred from the American National Standard (ASTM) depends on the suitability. All the methods that will be explained in this chapter are very important procedure to ensure it follow the entire project schedule so that it will be move smoothly. Effective methods will give clear view on how to do this project.

3.2   Project flow chart

In evaluating the effect of soil resistivity on corrosion behavior steel pipe system, the planning of the overall progress is done to assure the project will finish on schedule.

For the diagram as shown Figure 3.1, the project starts with study and gathers some information about the literature review and research related to the title. This consist a review of the concept of corrosion that happen nowadays. These tasks have been done through research on the internet, books and others sources.

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                    ┌─────────┐
                    │  Start  │
                    └─────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │    Specimen and surface preparation       │
   │              ▪ Cutting                     │
   │              ▪ Cleaning                    │
   │              ▪ Painting                    │
   └──────────────────────────────────────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │        Soil resistivity measurement        │
   └──────────────────────────────────────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │           Weighing specimen                │
   └──────────────────────────────────────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │             Exposure in soil               │
   └──────────────────────────────────────────┘
                         │
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   ┌──────────────────────────────────────────┐
   │     Cleaning and weighing the specimen     │
   └──────────────────────────────────────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │   Surface morphology by using Scanning     │
   │  Electron Microscopy (SEM) after exposure  │
   │                in soil                     │
   └──────────────────────────────────────────┘
                         │
                         ▼
   ┌──────────────────────────────────────────┐
   │          Corrosion rate analysis           │
   └──────────────────────────────────────────┘
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                         ▼
                    ┌─────────┐
                    │   End   │
                    └─────────┘
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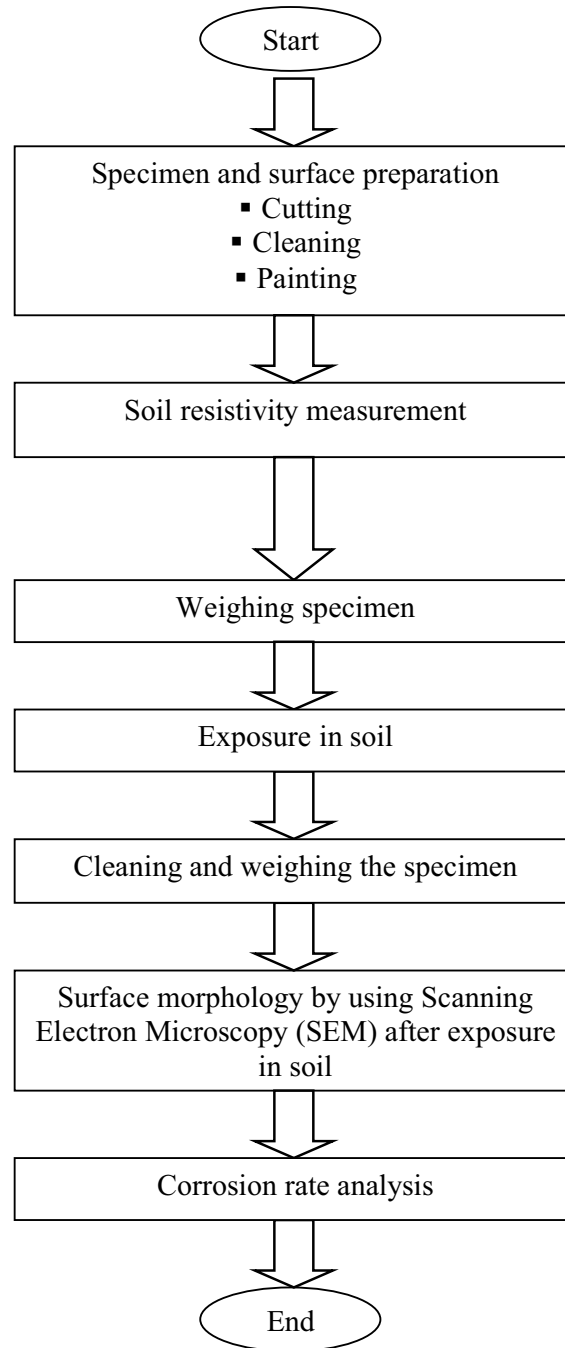
Figure 3.1: Experiment procedures

3.2.1 Specimen and surface preparation

The first step in corrosion testing concerns the specimens itself. The specimens used for this project is steel pipe. Generally size and shape of specimen vary and selection is often matter of convenience depends on scope experiment but for this project the specimen has same size and shape. There were eight pieces of steel pipe with 22mm inner diameter, 26mm outer diameter and was cut into 80mm length for each piece of steel pipe. Figure 3.2 shows that specimen dimension that was used in this project.


Outer diameter, OD = 26mm
Inner diameter, ID   = 22mm
Length, L   = 80mm
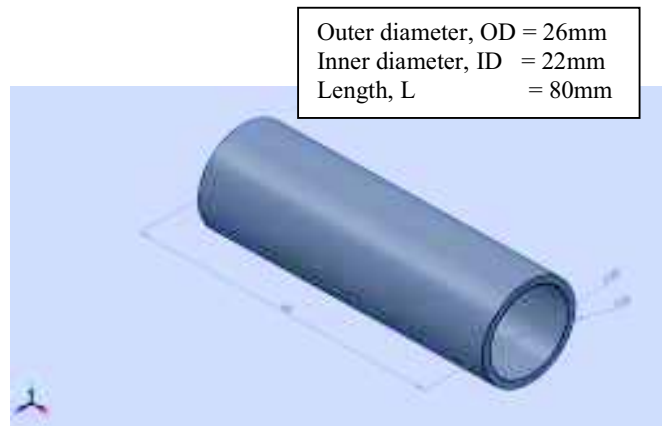
Figure 3.2: Dimension of steel pipe

The material used in this soil resistivity experiment is mild steel. The pipe has been to cut by using band saw machine into 80 mm length. Figure 3.3 show the machine used in cut and Figure 3.4 shows the mild steel pipe before and after cut.


Figure 3.3: Band saw machine that was use to cut the steel pipe
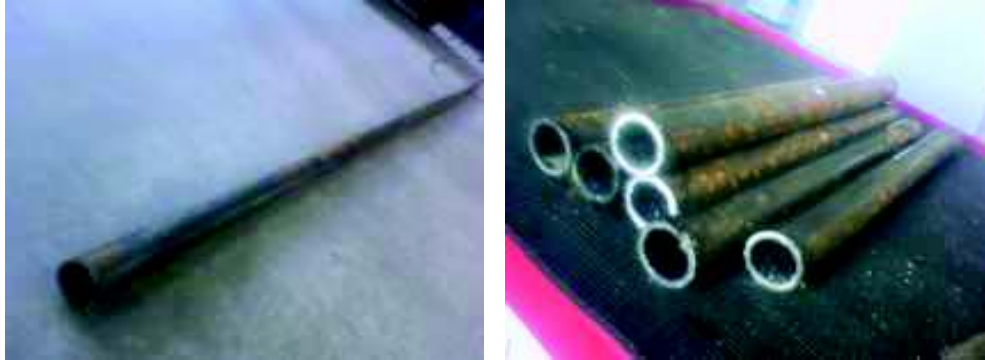
Figure 3.4: Mild steel pipe before and after cut

The surface of steel pipes was clean and the initial weight for each specimen was taken before exposure in soil. All eight specimens were divided into two major groups: exposure at atmosphere and exposure in soil. For exposure in soil the three type of soil was used which is sand, clay and loam. The soil samples for sand soil were getting from beach sand around Lagenda Beach. However the clay sample was collect from mosque at Tanjung Kuala Selangor and loam soil from inside the UMP Campus itself. This grouping of the experiment is explained in Figure 3.5. Figure 3.6 showed the 8 pieces of specimen that was uncoated and coated with several layer of paint. All the steel pipe must be fixed by rubber tape at both end of pipe before it exposure in soil to prevent soil and water enters the internal side of pipe such as Figure 3.7.
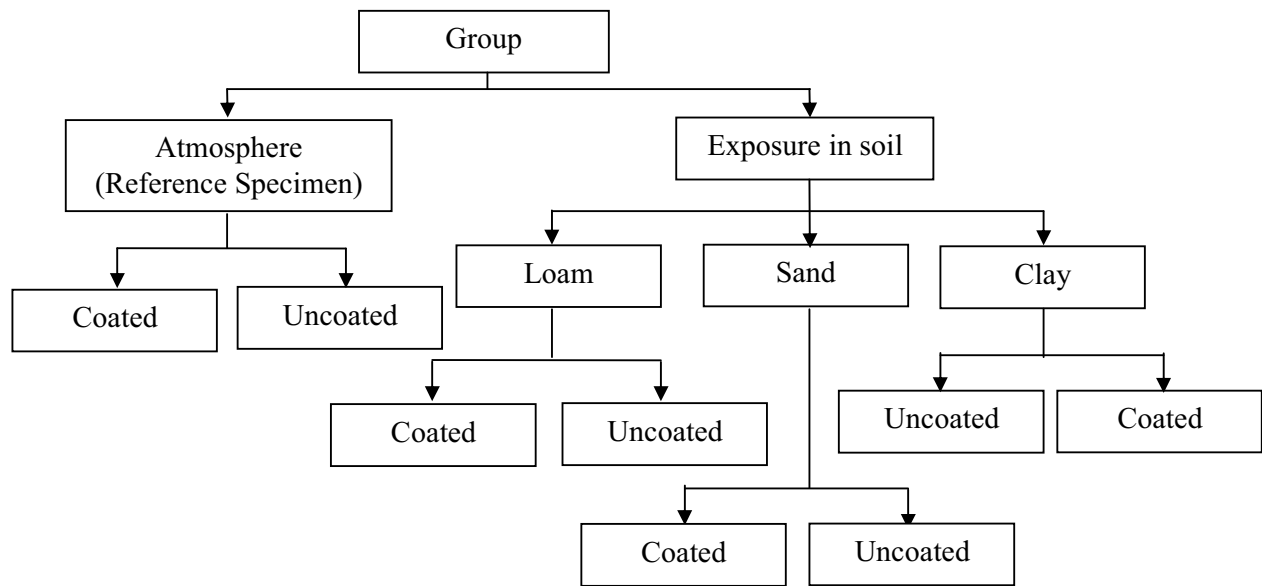
Figure 3.5: Configuration of soil resistivity testing

Figure 3.6: All specimen before exposure in soil

Figure 3.7: Both end of specimen were closed by rubber

3.2.2 Soil resistivity measurement

The soil resistivity measurement is most necessary procedure in order to evaluate the effect of soil resistivity on corrosion behavior of steel pipe. The measurement of the soil resistivity at different types of soil is done using Earth Resistance Tester Model 4102A Kyoritsu. Figure 3.8 shows the complete set of earth tester.

Figure 3.8: Complete set of earth Tester

The Earth Tester operation was based principle fall-of-potential method, which is a method to obtain earth resistance value Rx by applying AC constant current I between the measurement electrode to find out the potential difference voltage, V. A voltage is impressed between the outer electrodes causing current to flow and the voltage drop between the inner electrodes is measured using a sensitive voltmeter. Alternatively, the resistance can be measured directly. The resistivity, ρ is then:

$$\rho = 2\pi AR \qquad \text{(Eq. 3.1)}$$

Where, ρ   = soil resistivity (Ω.cm)

A   = electrode separation (cm)

R   = resistance (Ω)

The resistivity indicates the probable corrosivity of the soil. Its value depends on the soil water content on the layers and on types of soils. Using dimensional analysis, the correct unit for resistivity is ohm-centimeter. This procedure was referred from American National Standard (ASTM) G57-95a.

3.2.3 Sample Weighing before and after exposure

After surface preparation, the specimens dimension was carefully measured to calculate of the surface area. The original area is used to calculate the corrosion rate throughout the test. If the dimension of the specimen change appreciably during the test, the error introduced is not important because the material is probably corroding at too fast a rate. The initial weights of specimens were weighed using electronic balance as shown in Figure 3.9.

Figure 3.9: Electronic balance

After measuring, the specimen was degreased by washing in a suitable solvent cleaning such as hydrochloric acid. The specimens were immersed in hydrochloric acid for 1 to 25 minutes with concentration is within range 30% until 40%. This cleaning procedure was referred to American National Standard (ASTM) G1-03. The specimens should be exposed to the soil environment immediately. After specimens were exposed in soil the specimens were clean and the final weight was taken. The different weights before and after exposed are representing the corrosion rate analysis.

3.2.4 Exposure in soil

All six specimens were exposed in different soil. The exposure period was for 50 days. Figure 3.10 until Figure 3.12 shows the specimens exposure in different types

of soil. After exposure, the specimens were taken out from soil for cleaning process, weighing and surface analysis of steel pipe.

Figure 3.10: Specimen exposure in loam

Figure 3.11: Specimen exposure in clay

Figure 3.12: Specimen exposure in sand

3.2.5   Cleaning procedure of the specimens

The importance of examining the specimens prior to cleaning should be emphasized. One common cleaning procedure consists of rubber-stopper cleaning method that has been found satisfactory for most corrosion tests. If appreciable quantities of corrosion specimen this method does not determine the true corrosion rate because all of the corroded metal is not removed. If it is desirable to get down to bare or unaffected metal then more drastic cleaning methods must be used. The danger is that uncorroded metal may also be removed and these methods should not be used when the corrosion rate is very low.

Cleaning methods may be classified as mechanical, chemical and electrolytic. For mechanical such as scraping, brushing, scrubbing with abrasives, sandblasting and the rubber-stopper method described. The chemical method involve such as the use of chemicals and solvent. Electrolytic, which involves making the specimen the cathode under an impressed current in a variety of chemical reagent with or without inhibitors added. In this project, the chemical method will be used to clean the specimens to minimum the losses of base metal. The degreasing agents that will be use is thinner and kerosene.

The cleaning procedure is done after exposure of the specimen. The specimens were brush to remove the excess soil that stick on the specimen. After that the specimen was immersed in hydrochloric acid as the instructed in ASTM G1-03 standard. The concentration of hydrochloric acid that used in this cleaning procedure is 37% with volume 300ml. The immersion takes 7 minutes to 10 minutes to remove all the corrosion product. Figure 3.13 shows the immersion process in hydrochloric acid while Figure 3.14 shows the specimen after the cleaning process.

The purpose for this cleaning process by immersion specimen is to remove corrosion product so that weight loss calculation for specimen can be measured.

Figure 3.13: Specimen immerse in hydrochloric acid

Figure 3.14: Specimens after the cleaning process

3.2.6   Surface morphology

Surface observation was carried out after the cleaning process. The objective of cleaning process is to enable the structure surface of steel pipe to be seen more clearly. The observation on the surface morphology and surface structure of steel pipe is done using Scanning Electron Microscope (SEM). It is importance in understanding corrosion behavior and corrosion reactions. Figure 3.15 show the SEM machine that have in UMP laboratory. The model for this SEM machine is Carl Zeiss Evo50.
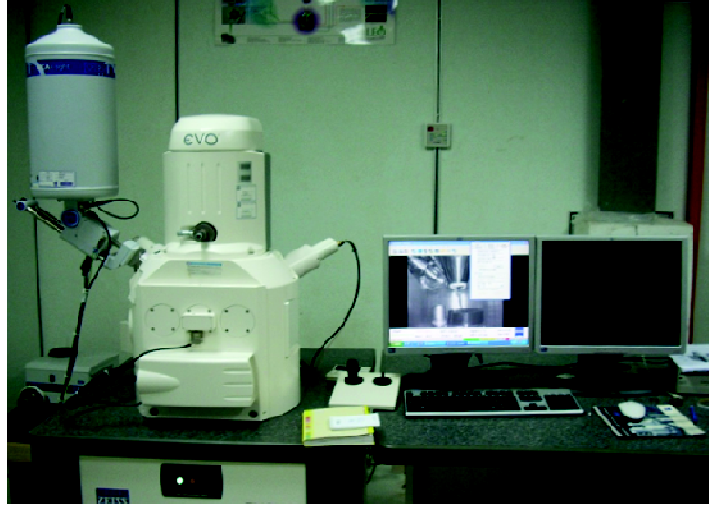
Figure 3.15: Carl Zeiss Evo50

(i)   Scanning Electron Microscope (SEM)

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. There are many advantages to using the SEM instead of a light microscope.

The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is relatively easy since most SEMs on require the sample to be conductive. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research areas today. (S. Chumbley, 2008)

(ii)   The Electron Source

The electron beam comes from a filament, made of various types of materials. The most common is the Tungsten hairpin gun. This filament is a loop of tungsten which functions as the cathode. A voltage is applied to the loop, causing it to heat up. The anode, which is positive with respect to the filament, forms powerful attractive

forces for electrons. This causes electrons to accelerate toward the anode. Some accelerate right by the anode and on down the column, to the sample. Other examples of filaments are Lanthanum Hexaboride filaments and field emission guns. The schematic diagram about the electron source was shown in Figure 3.16.
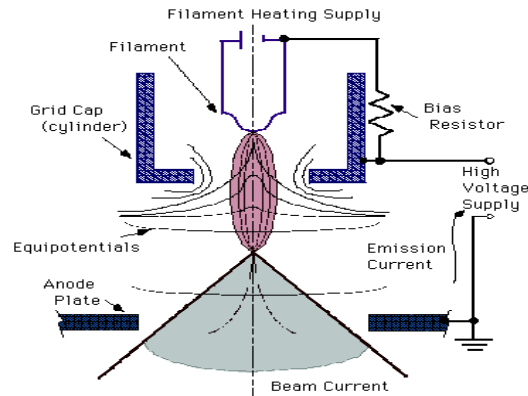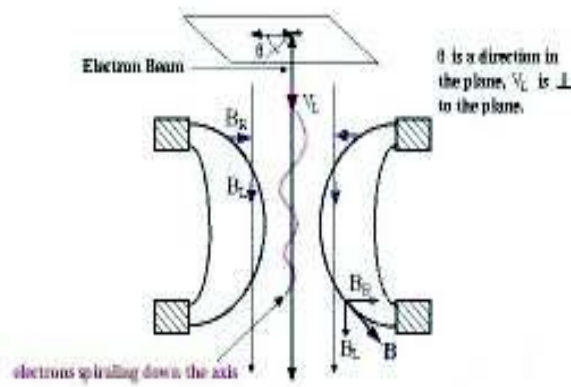

Figure 3.16: The electron source

Source: S. Chumbley 2008

(iii)   Forces in a Cylindrical Magnetic Lens

Nonaxial electron will experience a force both down the axis and one radial to it. Only electrons traveling down the axis feel radial forces from all sides of the lens. The unequal force felt by the off-axis electrons causes spiraling about the optic axis. Figure 3.17 has shown the forces acting in the cylindrical lens.

**Figure 3.17**: Forces in a Cylindrical Magnetic Lens

Two component to the B field:

$$B_L = longitudinal\ component\ (down\ to\ axis)$$
$$B_R = radial\ component\ (perpendicular\ to\ axis)$$

(iv)   Beam's Path through the Column

A beam of electrons is generated in the electron gun, located at the top of the column, which is pictured to the left. This beam is attracted through the anode, condensed by a condenser lens, and focused as a very fine point on the sample by the objective lens. The scan coils are energized (by varying the voltage produced by the scan generator) and create a magnetic field which deflects the beam back and forth in a controlled pattern. The varying voltage is also applied to the coils around the neck of the Cathode-ray tube (CRT) which produces a pattern of light deflected back and forth on the surface of the CRT. The pattern of deflection of the electron beam is the same as the pattern of deflection of the spot of light on the CRT. (S. Chumbley, 2008)
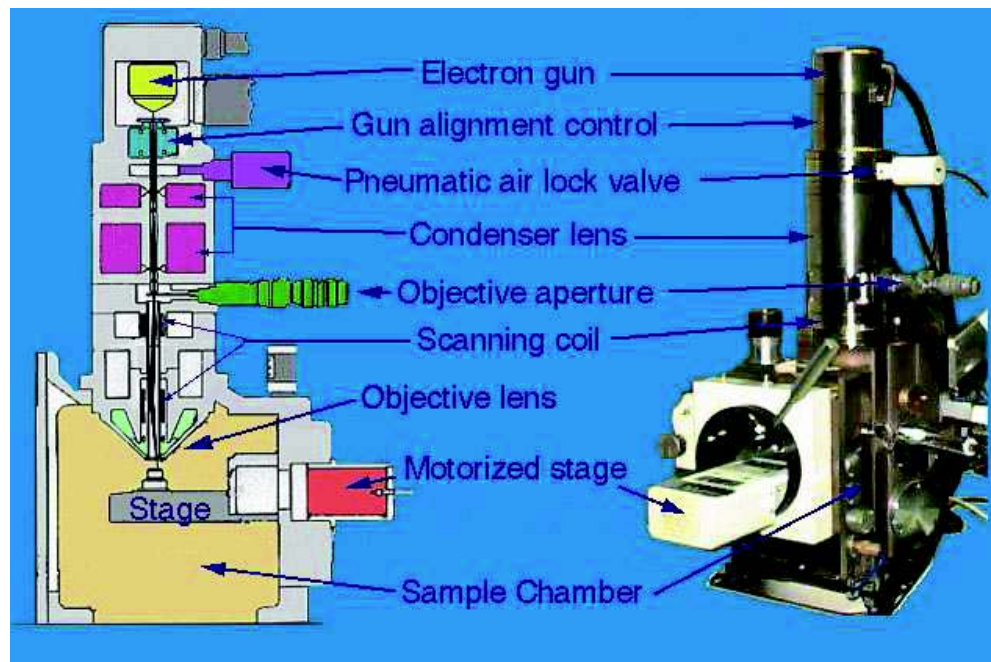

Figure 3.18: The electron beam

Source: S. Chumbley 2008

The electron beam hits the sample, producing secondary electrons from the sample. These electrons are collected by a secondary detector or a backscatter detector, converted to a voltage, and amplified. The amplified voltage is applied to the grid of the CRT and causes the intensity of the spot of light to change. The image consists of thousands of spots of varying intensity on the face of a CRT that correspond to the topography of the sample.

(v)   SEM Ray Diagrams

These schematics show the ray traces for two probe-forming lens focusing conditions: small working distance (left) and large working distance (right). Both conditions have the same condenser lens strength and aperture size. However, as the sample is moved further from the lens, the following occurs:

- the working distance S is increased
- the demagnification decreases
- the spot size increases
- the divergence angle *alpha* is decreased
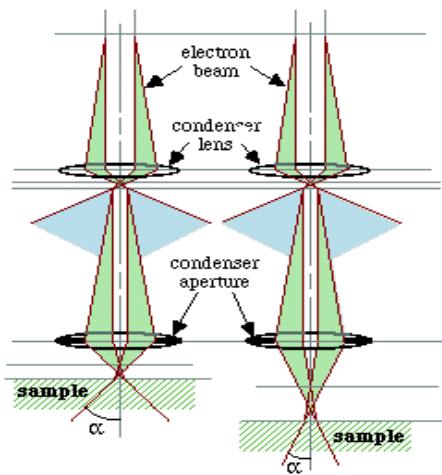

Figure 3.19: SEM Ray Diagrams

Source: S. Chumbley 2008

The decrease in demagnification is obtained when the lens current is decreased, which in turn increases the focal length f of the lens. The resolution of the specimen is decreased with an increased working distance, because the spot size is increased. Conversely, the depth of field is increased with an increased working distance, because the divergence angle is smaller. (S. Chumbley, 2008)

(vi)   SEM setup (Electron and specimen interaction)

When the electron beam strikes the sample, both photon and electron signals are emitted. While all these signals are present in the SEM, not all of them are detected and used for information. The signals most commonly used are the Secondary Electrons, the Backscattered Electrons and X-rays. (S. Chumbley, 2008)
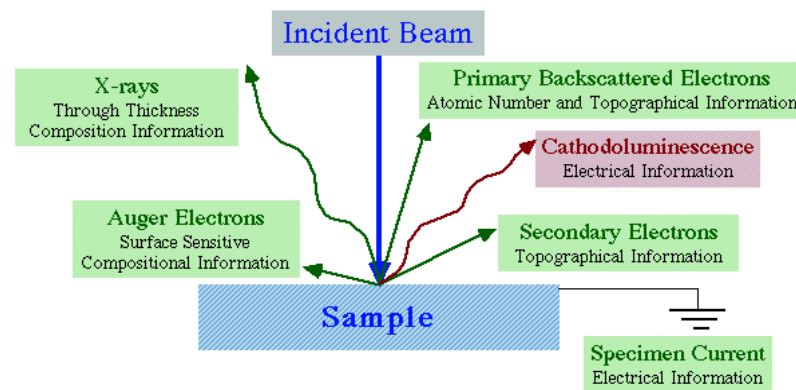
Figure 3.20: SEM setup

Source: S. Chumbley 2008

(vii)   Using a Vacuum

When a SEM is used, the column must always be at a vacuum. There are many reasons for this. If the sample is in a gas filled environment, an electron beam cannot be generated or maintained because of a high instability in the beam. Gases could react with the electron source, causing it to burn out, or cause electrons in the beam to ionize, which produces random discharges and leads to instability in the beam. The

transmission of the beam through the electron optic column would also be hindered by the presence of other molecules. Those other molecules, which could come from the sample or the microscope itself, could form compounds and condense on the sample. This would lower the contrast and obscure detail in the image.

A vacuum environment is also necessary in part of the sample preparation. One such example is the sputter coater. If the chamber is not at vacuum before the sample is coated, gas molecules would get in the way of the argon and gold. This could lead to uneven coating, or no coating at all. (S. Chumbley, 2008)

(viii)   Sample Chamber and Objective Lens

The sample chamber located at the base of the column and the lens and detectors located inside the sample chamber. Both components for this sample chamber were show in Figure 3.21 and Figure 3.22.


Figure 3.21: Sample chamber located at the base of the column

Source: S. Chumbley 2008

The lens that focuses the beam of electrons towards the sample is in the center of the picture. The parts off to the right of the sample are different detectors. One is for

detecting the secondary electrons and the other is for detecting the backscattered electrons. The operator has the power to choose and switch detectors for use on each sample. Using the secondary electron detector produces a clear and focused topographical image of the sample. The backscatter electron detector produces an image that is useful when determining the make-up of the sample. Each element in the sample appears as a different shade, from almost white to black. (S. Chumbley, 2008)
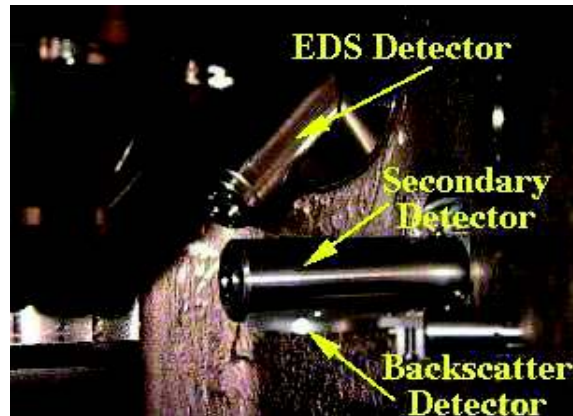
Figure 3.22: The lens and detectors located inside the sample chamber

Source: S. Chumbley 2008
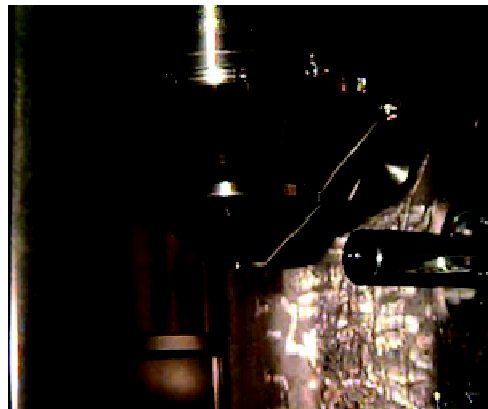
Figure 3.23: Lens that focuses the beam towards the sample

Source: S. Chumbley 2008

(ix)   Stage and specimen Preparation

A prepared sample is mounted on a specimen stub and placed on the stage. This stage was shows in Figure 3.24.
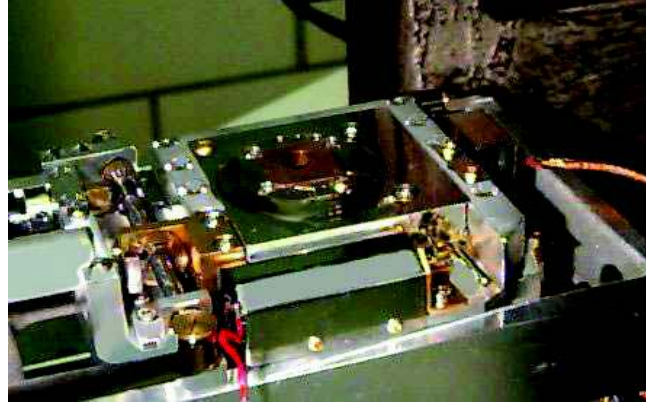
Figure 3.24: Specimen that place on stage

Source: S. Chumbley 2008

There are two basic types of SEM's. The regular SEM for specimen preparation requires a conductive sample. An environmental SEM can be used to examine a non-conductive sample without coating it with a conductive material. Three requirements for preparing samples for a regular SEM such as are:

1. Remove all water, solvents, or other materials that could vaporize while in the vacuum.
2. Firmly mount all the samples.
3. Non-metallic samples, such as bugs, plants, fingernails, and ceramics, should be coated so they are electrically conductive. Metallic samples can be placed directly into the SEM.

3.2.7   Corrosion rate analysis

Corrosion rate is expressed in percent of weight loss. The expression miles per year is the most desirable way of expressing corrosion rates and will be used. This expression is readily calculated from the weight loss of the metal specimen during the corrosion test by the formula given below:

$$corrosion\ rate = \frac{K \times W}{A \times T \times D}$$ (Eq. 3.2)

Where

K	$= 3.45 \times 10^6$ (constant value for corrosion rate in miles per year)
W	= weight loss in grams
D	= density of specimen in g/cm³
A	= area of specimen in cm²
T	= exposure time in hours

This corrosion rate calculation involves whole numbers which are easily handled. (Mars G. Fontana, 1986)

CHAPTER 4

RESULT AND DISCUSSION

4.1   Introduction

In this chapter, the effect of soil resistivities on the corrosion behavior of steel pipe will be examined and discussed. The resistance of soil was measured by Earth Resistance Tester as unit Ohms (Ω) was represent by R. The value of R will be measure in soil resistivity equation the get the exact value of resistivity. The surface morphology of specimens were examined by using Scanning Electron Microscope (SEM) to identify the corrosion behavior occurs at underground pipeline. All the specimens including reference specimen were weighing before and after in order to determine the weight loss of specimens in measurement purpose to know the corrosion rate.

4.2   Soil resistivity measurement

In pipeline system, steel pipe were placed through different soil. Each soil has resistivity that will affect corrosion of the steel pipe. In this experiment three different types of soils were choose to evaluate the effect of soil resistivity to the corrosion behavior on steel pipe. The soil resistivity values were calculated by using Equation 3.1 in Section 3.2.2. The results of soil resistivity measurement are shown in Table 4.1.

From Table 4.1, it clearly shown that the loam soil has highest resistivities with 628.32 kΩ·cm followed by the resistivities of clay soil that were measured at 94.25 kΩ·cm and the resistivities for sand soil which were measured at 5.03 kΩ·cm. Figure 4.1 show the value of resistivity for different soil.

Table 4.1: Soil resistivity measurements of different soil

Sample	Types of soil	Electrode separation (cm)	Resistance (Ω)	Soil resistivity (Ωcm)
A	Sand	500	1.6	5.03×10^3
B	Clay	500	30.0	94.25×10^3
C	Loam	500	200.0	628.32×10^3
D	Atmosphere	-	-	-
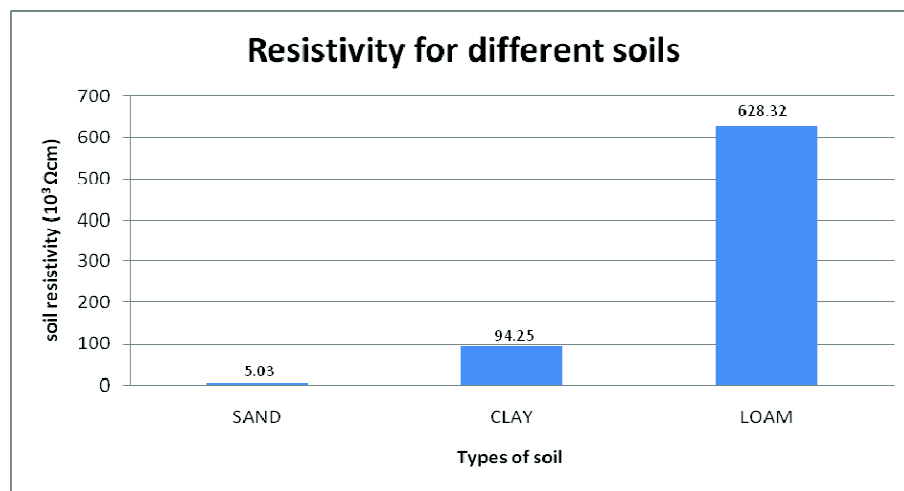
Figure 4.1: Resistivity for different soils

Based on the result from Table 4.1, it clearly shows that the different locations had slight differences in resistance of the soil. Figure 4.1 shows that the loams have higher resistivity compared to clay and sand. This is because the loam is a type of dry soil and it contains no soluble salts. The resistivity for sand is low because it is one of wet soil and have high amount of dissolved water. The location of sand soil is the closest with sea water. The moisture, minerals and dissolved water from the sea water affect the resistivity of sand soil thus explaining the low resistivity.

Soil structure which is the arrangement of soil particles and soil texture that refer to the composition of soil also affect the resistivity of soil. Soil has various shapes, sizes and degrees of development. Clay content has retention capacity for nutrients and water.

Clay soils resist wind and water erosion better than sandy soils because the particles are more tightly joined to each other. The electrical resistivity of soil can affect the rate of corrosion of metallic structures in contact with the soil. Higher moisture content or increased electrolyte concentration in sandy soil can lower the resistivity and thereby increase the rate of corrosion. The differences of soil resistivity measurements for different soil were proved by the previous result that was discussed in Section 2.6.1.

4.3   Specimens visual inspection

The pipes were exposures in soil for 50 days. After exposure, the specimens were observed to determine the corrosion product. The brown color observed on the pipe was identifid as corrosion product or rust. The surfaces of uncoated specimen were severely corroded as shown in Figure 4.2 until Figure 4.5.
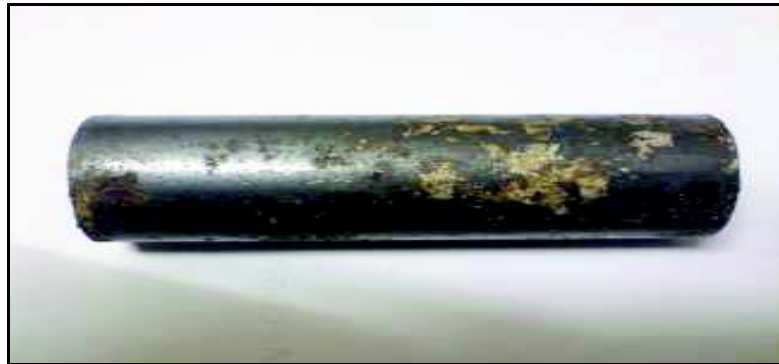
Figure 4.2: Specimen exposure in sand (A)

Figure 4.3: Specimen exposure in clay (B)

Figure 4.4: Specimen exposure in loam (C)

Figure 4.5: Specimen exposure at atmosphere (D)

The corrosion effect on the uncoated specimen is clearly observed by visual inspection compared to coated pipes. As shown in Figure 4.2, the corrosion on pipe buried in sand was more severe corroded compared to sand in Figure 4.3 and clay in Figure 4.4.

The low resistivity at the sand makes the electron in soil easier to move to form the corrosion behavior. This is because sand have the larger particle size with each other caused the electron easier to flow from anode to cathode compare with clay and loam size particle. The current flow will cause corrosion to occur. The corrosion current is formed with a flow of electrons from a high potential anode to a lower potential cathode

of the specimen. The specimen acts as a cathode at the point where the positive current enters and becomes the anode where it leaves the specimen. This is possible because specimen metals are conductive, so the electrons can flow through the metal from the anodic to the cathodic regions. Besides that, the presence of water is necessary in order to serve as a medium for the transport of ions transport ions to and from the specimen. Sand has high moisture compare with the clay and loam because of presence of sea water.

On the other hand, the specimens with coating shows that corrosion occur only at the scratched surface which is shown in Figure 4.6 until Figure 4.9.

Figure 4.6: Specimen exposure in sand (A)

Figure 4.7: Specimen exposure in clay (B)

Figure 4.8: Specimen exposure in loam (C)

Figure 4.9: Reference specimen (D)

From the visual observation for the 4 coating specimen, the corrosion product happen more extremely at specimen that exposure in sand as shown in Figure 4.6. For specimen that buried in clay and loam, respectively in Figure 4.7 and Figure 4.8, it only affects the paint of specimen. The corrosion products happen less than compare to specimen that buried in sand and only happen at the certain part. For the reference specimen, no corrosion product was observed.

From the observation for both uncoated and coated specimen, it shows that the corroded surface of uncoated steel pipe is more severe compared to coating steel pipes.

These because the protective coating the process to form general corrosion can be reduce. The corrosion process was blocked by layer of coating. From visual inspection, the corrosion behavior that might be happens on the surface of the specimen is general corrosion. This is because the thicknesses of surface specimen were reducing uniformly across the surface. It is relatively uniform reduction of thickness over the surface of a corroding material. General corrosion also can be controlled by selecting suitable materials, cathodic protection and corrosion inhibitors.

4.4   Scanning Electron Microscope examination

The surface morphology of the steel pipe was examined by using SEM with magnification of 30X and 200X. But before that the specimen were cut so that it fit with the stage at the SEM machine. Figure 4.10 show the specimen after cut into 30mm by using Bandsaw machine.

Figure 4.10: Specimen for SEM stage

Only uncoated specimens were examined using SEM machine as the coated specimen did not show much difference among each of the coating specimen. The surface morphology of uncoated steel pipe for 200X magnification at the surface of steel pipe was shown in Figure 4.11 until Figure 4.14.
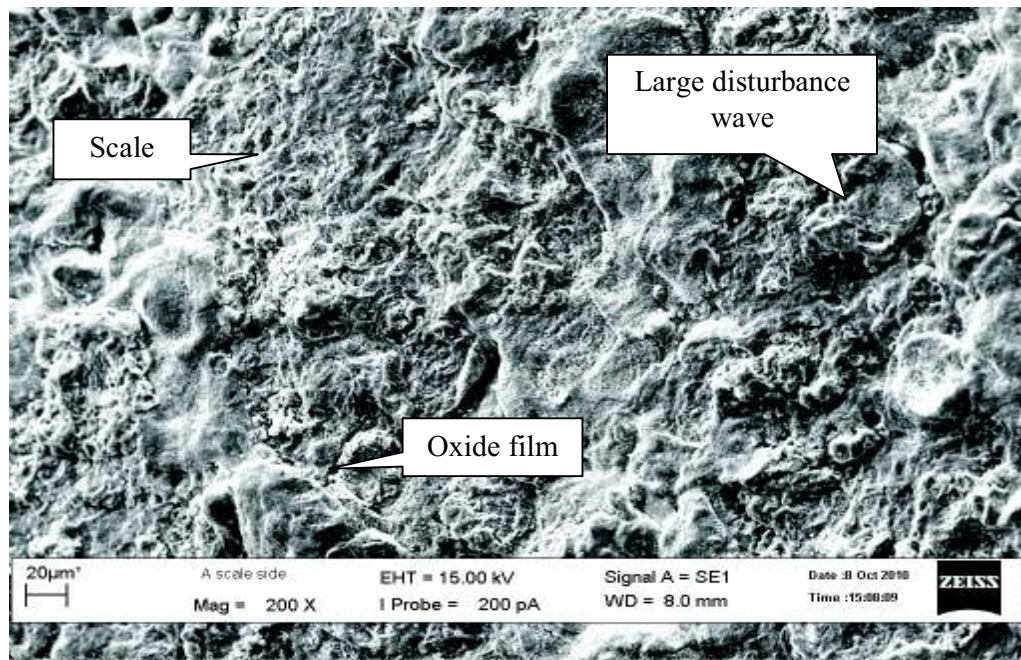
Figure 4.11: Surface Morphology of Uncoated Steel pipe exposure in sand
Magnification 200X
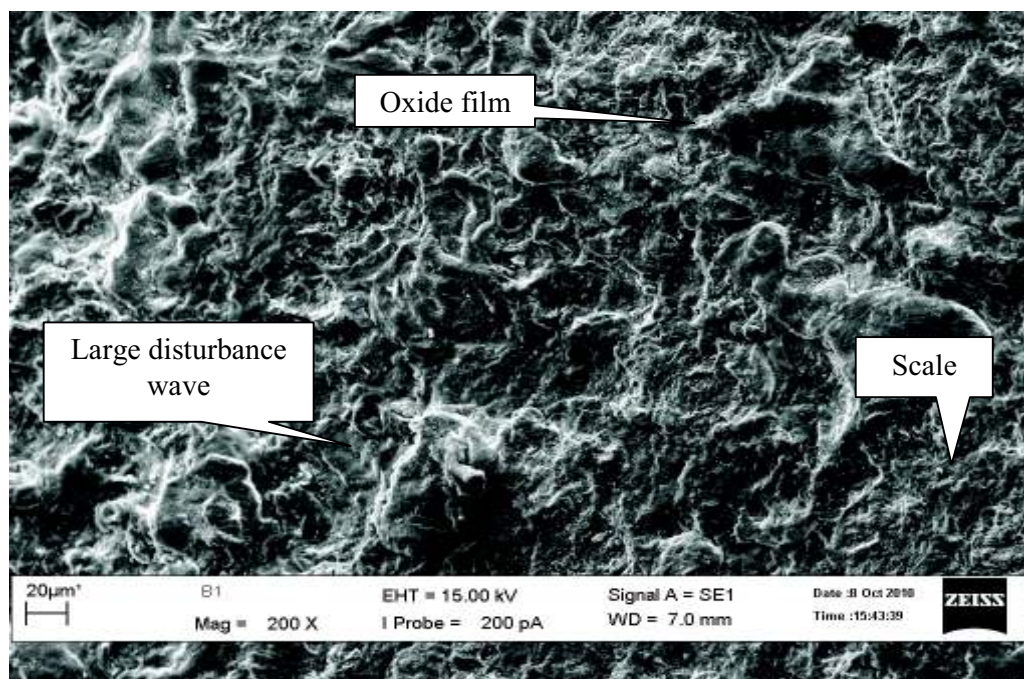
Figure 4.12: Surface Morphology of Uncoated Steel pipe exposure in clay
Magnification 200X

Figure 4.13: Surface Morphology of Uncoated Steel pipe exposure in loam

Magnification 200X

Figure 4.14: Surface Morphology of Uncoated Steel pipe for reference specimen

Magnification 200X

Surface morphology for uncoated specimens of the surface of steel pipe were observed by SEM. The observations were performed on the specimen surface after cleaning process. Different surface morphology could be found. SEM show the texture for the surface of specimen is varying with the others. The surface morphology was dense and uniform though some coarse surfaces were found by SEM. Although it uniform, the texture and coarse surface were distance for each other at the specimen that exposure in sand as shown in Figure 4.11 and clay as shown in Figure 4.12. The texture at the surface of specimen that exposure in loam as shown in Figure 4.13 and at atmosphere in Figure 4.14 is more closes compare with sand and clay. Besides that, the texture of all specimens that exposures in soil looks like undulated. The corrosion behaviors that match with this undulate pattern are erosion corrosion. Oxide films cover all the surface of the specimen, and in several places oxide films are observed to be peeled off by erosion corrosion. However, the degrees of erosion attacks are not so severe because the depths of the peeled-off places are shallow.

The surface morphology of uncoated steel pipe for magnification 30X at macro pitting from corrosion trace was shown in Figure 4.15 until Figure 4.17.
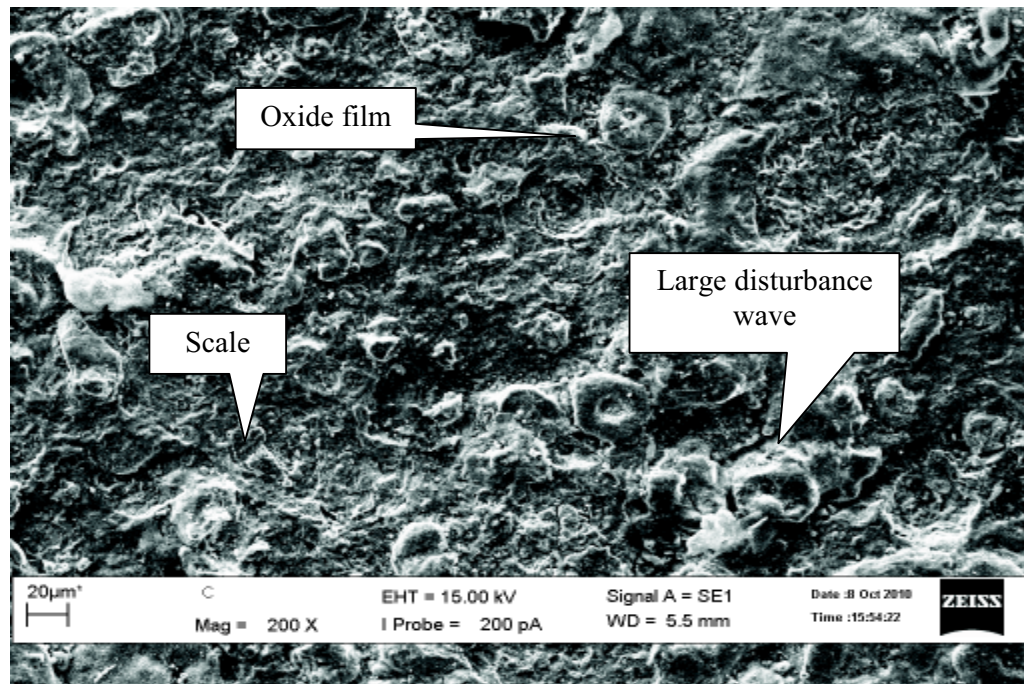

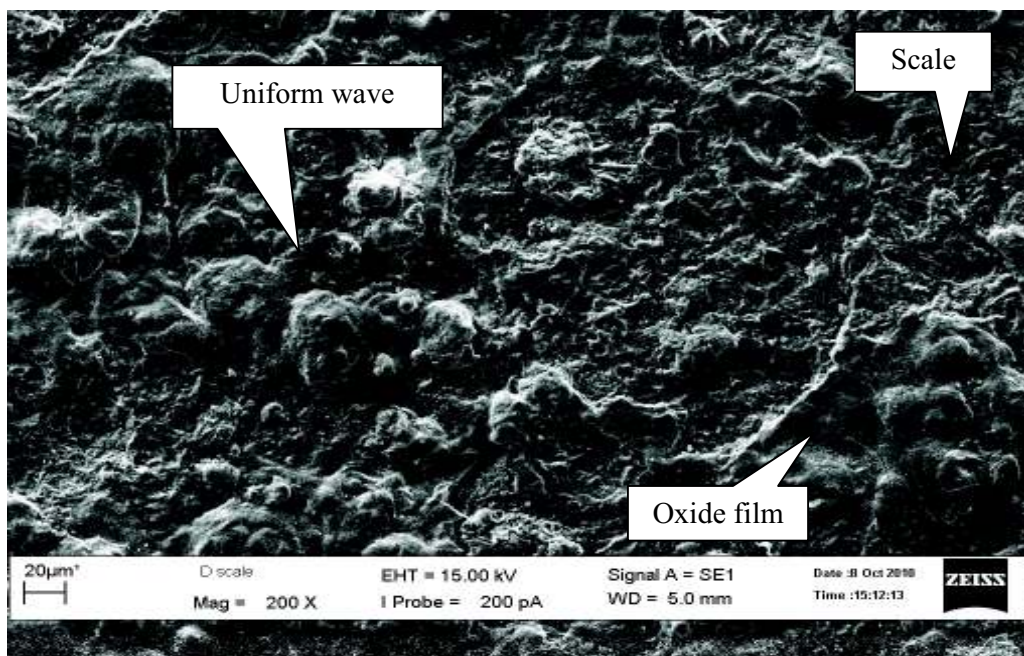**Figure 4.15:** Surface Morphology of Uncoated Steel pipe exposure in sand Magnification 30X

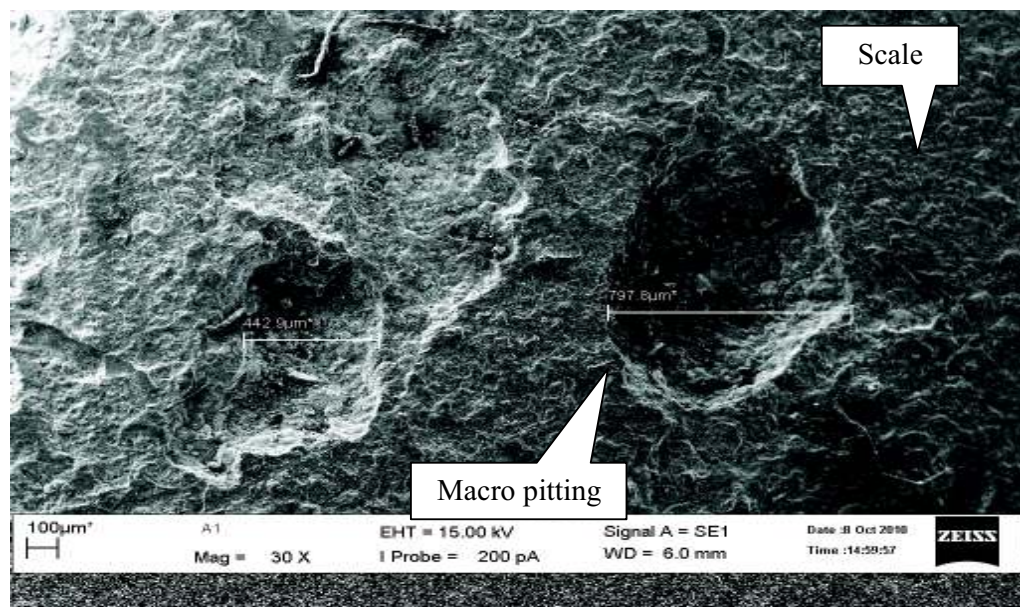**Figure 4.16:** Surface Morphology of Uncoated Steel pipe exposure in clay

Magnification 30X
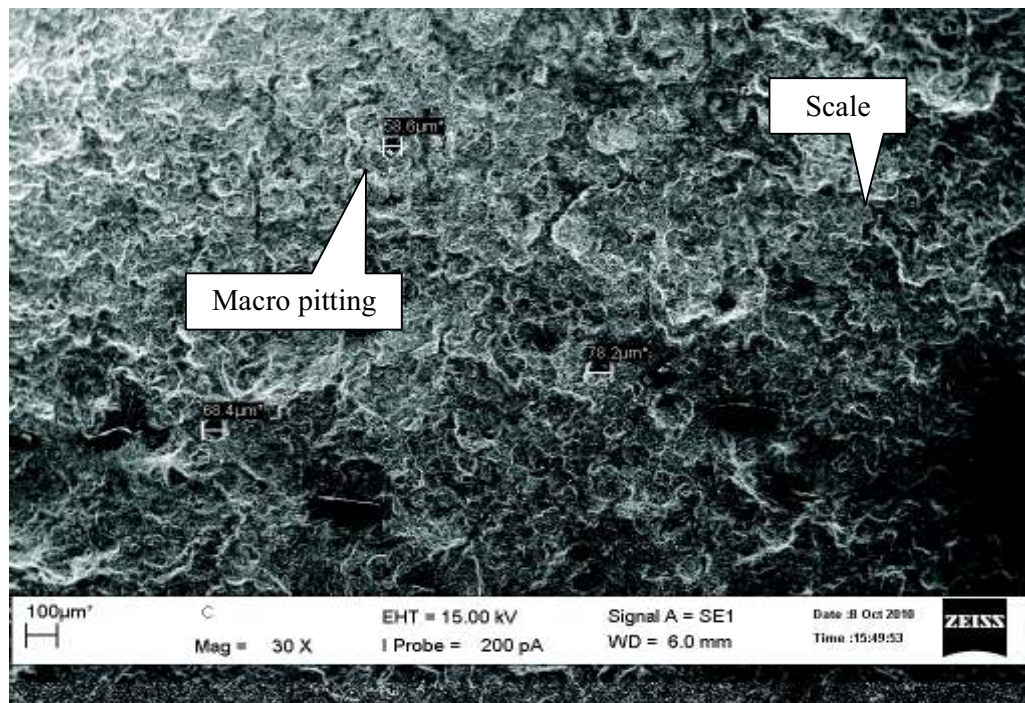
Figure 4.17: Surface Morphology of Uncoated Steel pipe exposure in loam

Magnification 30X

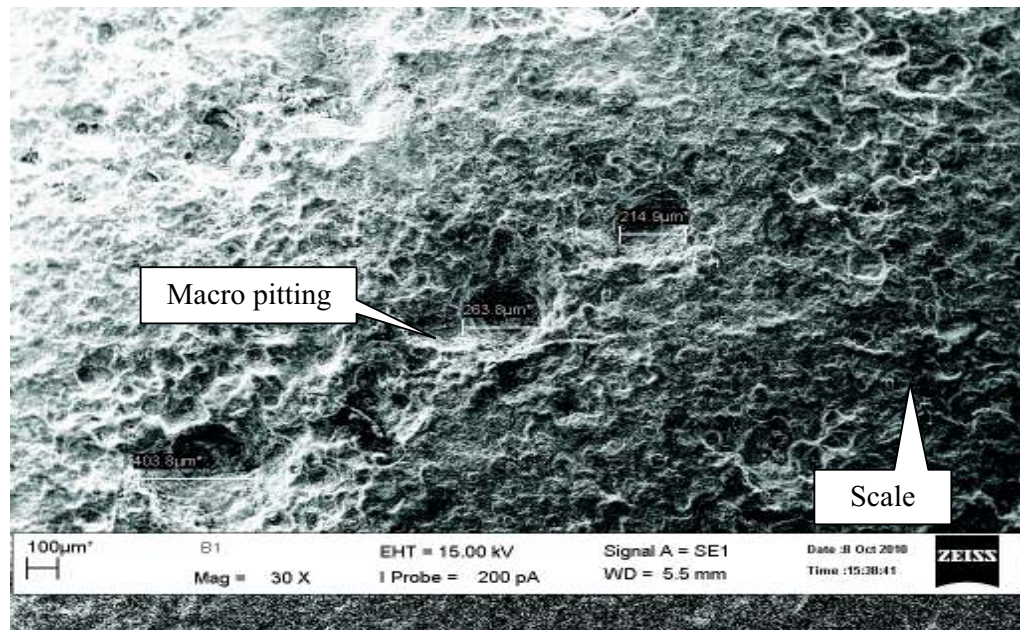The macro pitting due to corrosion was measured by using SEM. Table 4.2 shows the summary of macro pitting measurement by SEM examination and Figure 4.18 show the pitting measurement in different soil resistivity by Assuming that only high values of diameter were taken into the measurement.

Table 4.2: measurement of pitting diameter

Specimen	Type of soil	Pitting diameter (µm)
A	Sand	797.8
B	Clay	403.8
C	Loam	78.2
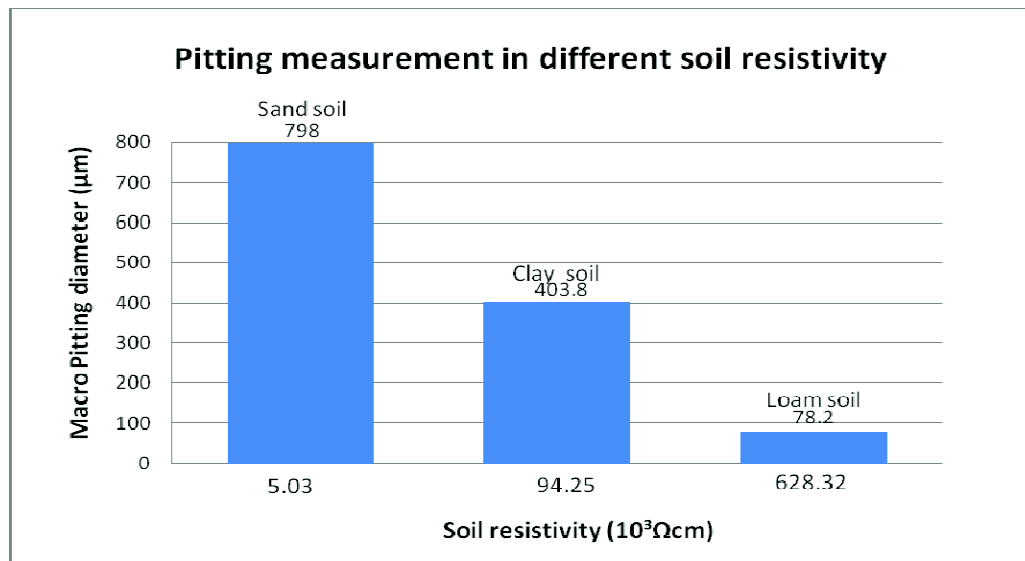
Figure 4.18: Pitting measurement in different soil resistivity

From the result, it is shown that the specimen that exposure in sandy soil produced bigger size of pitting compares with other two types of soil. Size of macro pitting at specimen that buried in sand is 797.8 µm while the size of macro pitting for specimen that buried in clay and loam is 403.8 µm 78.2 µm respectively.
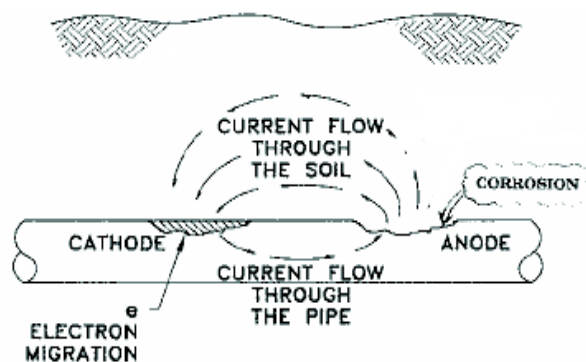
Figure 4.19: Current flow through the soil

Source: Keith Malmedal 2002

The macro pitting diameter of specimen that buried in sand show that it produce large macro size pitting because of low resistance of soil. The low rate of resistance makes the current or electron easily to flow through the soil. Besides that, the presence sea water that commonly contain of chlorides in significantly will aggravates the conditions for formation and growth of the pits through an autocatalytic process. The pits become loaded with positive metal ions through anodic dissociation. The Cl− ions become concentrated in the pits for charge neutrality and encourage the reaction of positive metal ions with water to form a hydroxide corrosion product and H+ ions. Now, the pits are weakly acidic, which accelerates the process. The process of pitting corrosion was show in Figure 4.19.

4.5   Corrosion rate determination

Weight loss measurements were carried out by weighing the specimens before and after exposure in different soils for 50 days. Cleaning procedure was performed for each sample in hydrochloric acids before take final weight of sample. The weight loss was calculated by initial and final weight of the specimen. From this weight loss value, corrosion rate were determined. Corrosion rate has been determined by using Equation 3.2.

$$corrosion\ rate = \frac{K \times W}{A \times T \times D} \tag{Eq. 3.2}$$

$$
\begin{aligned}
A_{cylinder} &= 2\pi r^2 + 2\pi rh \\
&= 2\pi r(r+h)
\end{aligned}
\tag{Eq. 4.1}
$$

$$
\begin{aligned}
A_{cylinder} &= A_{cylinderOD} - A_{cylinderID} \\
&= 2\pi r_{OD}(r_{OD}+h) - 2\pi r_{ID}(r_{ID}+h) \\
&= [2\pi(2.6cm)(2.6cm+8cm)] - [2\pi(2.2cm)(2.2cm+3cm)] \\
&= 173.1646cm^2 - 140.9946cm^2 \\
&- 32.17cm^2
\end{aligned}
$$

$$A_{specimen} = 32.17cm^2$$

$$
\begin{aligned}
T &= 50days \times \frac{24hours}{1day} \\
&= 1200hours
\end{aligned}
\tag{Eq. 4.2}
$$

$$D = 7.84g/cm^3$$

Sample calculation for specimen A

$$
\begin{aligned}
W &= weight\ before - weight\ after \\
&= 109.342g - 108.749g \\
&= 0.593g
\end{aligned}
\tag{Eq. 4.3}
$$

$$
\begin{aligned}
CR &= \frac{KW}{ATD} \\
&= \frac{(3.45 \times 10^6)(0.593g)}{(32.17cm^2)(1200hours)(7.84\,g/cm^3)} \\
&= 6.76mpy
\end{aligned}
$$

The corrosion rates were determined in unit of mpy (miles per year). By using Equation 3.2, the corrosion rate was obtained. Equation 4.1 were used for calculate the area of cylinder pipe or the area of specimen. Equation 4.2 had shown the time of exposure that converted from day to hour. While the Equation 4.3 were weight different

between before and after exposure. The results for corrosion rate were represented in Tables 4.3.

Table 4.3: Corrosion rate of each specimen

Specimen	Coating	Surface Area (cm²)	Weight Loss, (g)	Time exposure (hours)	Corrosion rate, (mpy)
A (Sand)	Coated	32.17	0.593	1200	6.76
	Uncoated	32.17	1.340	1200	15.27
B (Clay)	Coated	32.17	0.558	1200	6.36
	Uncoated	32.17	1.176	1200	13.41
C (Loam)	Coated	32.17	0.516	1200	5.88
	Uncoated	32.17	0.878	1200	10.01
D (Atmosphere)	Coated	32.17	0.133	1200	1.52
	Uncoated	32.17	0.715	1200	8.15

From Table 4.3, it is shown that the corrosion rate for uncoated steel pipe was the highest with 15.27 mpy when it exposed in sand. The corrosion rates for uncoated steel pipe that exposed at atmosphere are the lowest which is 8.15 mpy. The corrosion

rates for uncoated steel pipe that exposed in clay and loam was 13.41 mpy and 10.01 mpy respectively.

The corrosion rate for coated steel pipe that exposed at the atmosphere was the lowest which is 1.52 mpy. The corrosion rates for loam, clay and sand was 5.88 mpy, 6.36 mpy and 6.76 mpy respectively. From the experiment result, it is clearly shown that the corrosion rates for coated steel pipes are largely different while exposure in soil with the coated steel pipe that exposed at atmosphere.

Referring to the Table 4.3, the result of corrosion rate for both the coated and uncoated steel pipe with the highest value of corrosion rates are about 6.76 mpy and 15.27 mpy respectively. This highest value happens at the steel pipe that exposure in sand. However the lowest highest value of corrosion rates happens at steel pipe that exposed at atmosphere which is 1.52 mpy for coated steel pipe and 8.15 mpy for uncoated steel pipe. Figure 4.20 show the corrosion rates for coated and uncoated specimen that exposed at atmosphere and exposure in soil.
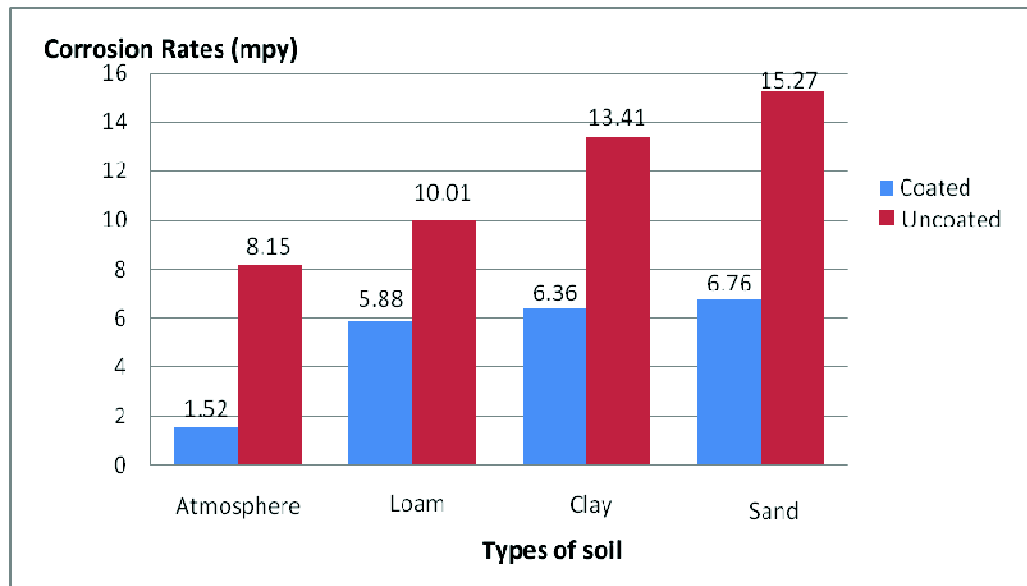
Figure 4.20: Corrosion rates for coated and uncoated

The Figure 4.20 shows the high corrosion rates happen at the steel pipe that exposure in sand followed by clay, loam and lastly the lowest corrosion occurs while exposed at the atmosphere. Thus, it was generally observed that there was a gradual decrease in weight which gave rise to increasing weight losses. However, these losses were relatively more in uncoated specimen and low in samples that were coated with paint. This difference is because samples uncoated were not covered or protected with paint and thereby well-exposed to easy corrosion attack than samples coated that were carefully covered with paint materials.

The specimen that was exposed at atmosphere in controlled conditions that inhibited corrosion and no significant loss in weight was noted when compared to other samples. Surprisingly, the unexpected results were obtained for the corrosion rates of uncoated steel pipe that exposed at atmosphere. Even though it not exposure in soil, the corrosion rates that was calculate show not much different with other uncoated steel pipe that exposure in soils. This situation happens because of the presence of air and the room humidity that affect uncoated specimen. The specimen that exposed at atmosphere record the lowest corrosion rate among all the specimen because there are no movement of electron and presence of ion that make the corrosion to occurs. Besides that, the specimen that exposed at atmosphere was placed in paper box at the hostel so that there are no contact between the specimen and the surface of room floor.

4.5.1   Effect of soil resistivity on corrosion rate

Figure 4.21 shows the relationship of effect between soil resistivity and the corrosion rates for the coated and uncoated steel pipe. All specimens were exposure in various soils such as loam, clay and sand.
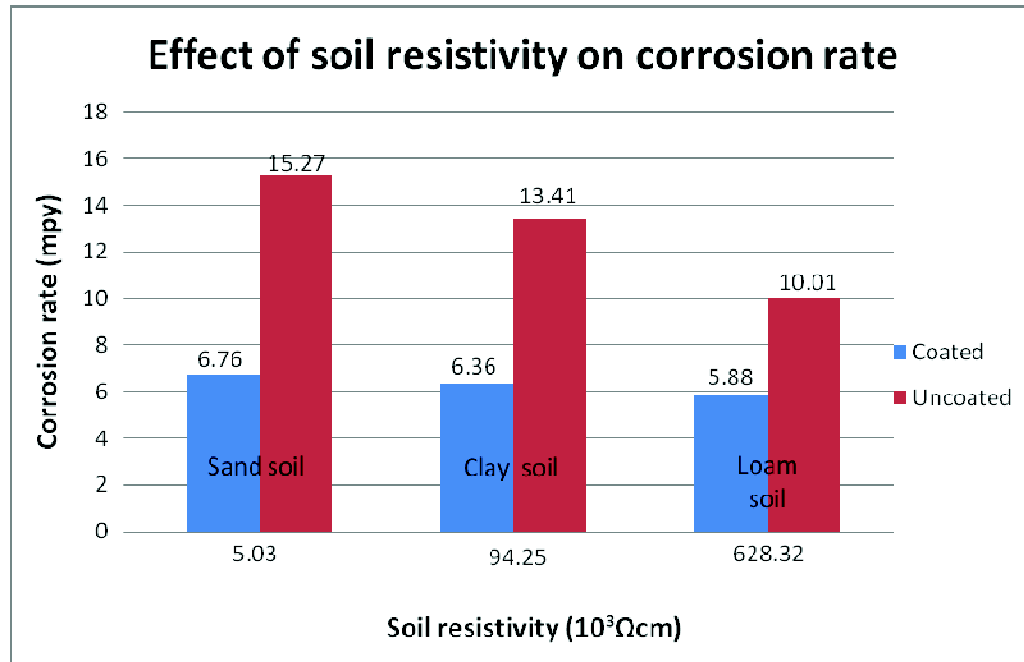
Figure 4.21: Effect of soil resistivity on corrosion rates

From Figure 4.21, the corrosion rates for the coated and uncoated specimen were increase with the decreases of soil resistivity. For uncoated specimen, the value of corrosion rates that was plotted is extremely high compare with the coated specimen. From the all type of soil, the uncoated steel pipe that exposure in loam was recorded the lowest corrosion rate with 10.01 mpy with high value of resistivity which is 628.32 kΩ·cm. The specimen that exposure in sand recorded the highest corrosion rate compare to the specimen that exposure in clay and loam with corrosion rates of 15.27 mpy at 5.03 kΩ·cm of resistivity. However, for the uncoated steel pipe that exposure in clay, the corrosion rate that was measured was 13.41 mpy with soil resistivity is 94.25 kΩ·cm. It was show that the specimen that exposure in clay have the value of corrosion rates in between of specimen that exposure in sand and clay.

Thus, it clearly show that the corrosion rate for steel pipe that exposure in sand is highest corrosion rate compare to the corrosion rate for steel pipe at atmosphere and in other soil. Soil sand has low resistivity that make the corrosion rates on the steel pipe corrosive more than other type of soil. This is because the sand is a naturally occurring granular material composed of finely divided rock and mineral particles. Because of

that, the electron can easily move through this mineral particle to form the corrosion compare with the other particle that highly variable of composition depending on the local rock sources and condition. Besides that, the salty mineral inside the sand more or less become a factor that influence the resistivity of soil.

4.5.2   Effect of coating on corrosion rate at different type of soil

Coating is a covering that is applied to the surface specimen. Coatings are applied to improve surface properties of the specimen so that it can reduce corrosion rate of the steel pipe besides can improve the corrosion resistance and scratch resistance. Figure 4.22 show the effect of coating on corrosion rate at different type of soil.
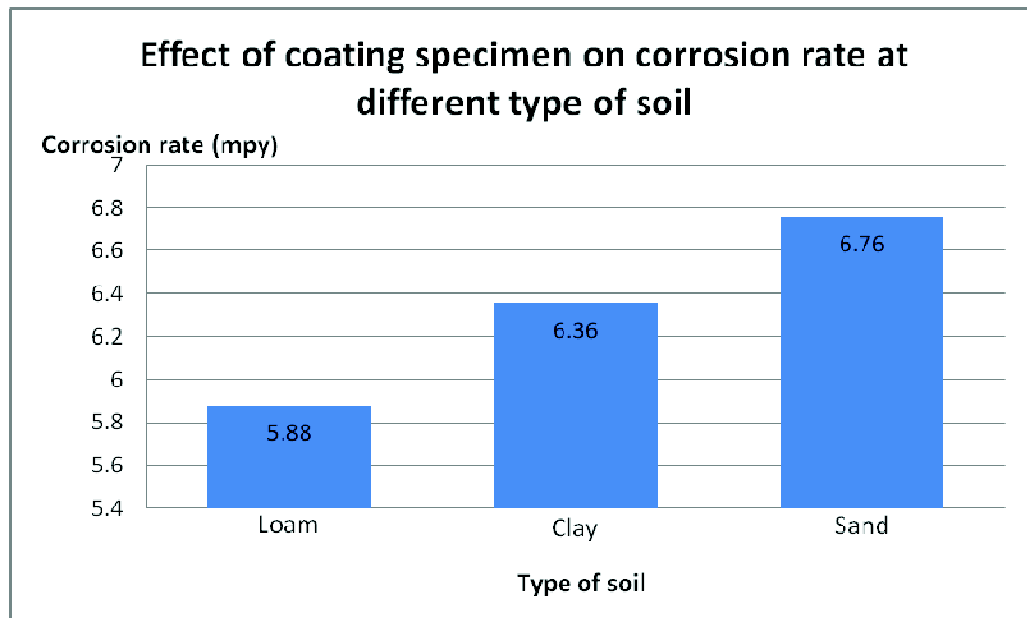
Figure 4.22: Effect of coating on corrosion rate at different type of soil

From Figure 4.22, it shown that the specimen exposure in sand has recorded the highest corrosion rate which is 6.76 mpy with only 5.03 kΩ·cm resistivity of soil. The specimen that exposure in clay recorded the less corrosion rate compare to the specimen that exposure in sand with 6.36 mpy at 94.25 kΩ·cm of resistivity. For the coated steel pipe that exposure in loam, the corrosion rate that was recorded was 5.88 mpy with soil

resistivity is 628.32 kΩ·cm. It was show that the specimen that exposure in loam have the lowest corrosion rates compare with the specimen that exposure in sand and clay.

Corrosion protection of underground structures by protective coatings is one of the most proven methods. The coated specimen gives better performance to reduce corrosion rate of steel pipe. This is because the coating protection is effective at the specimen that exposure in soil. The corrosion rate can be reducing by applying coating on the steel pipe through the pipeline system. In contrast to the behavior of rust on steel, the formation of an oxide affords protection against corrosion. If the resistivity of electrolyte is increased and the electron flux is retarded, the rate of corrosion is decreased. By applying coatings of high resistivity, the flow of electric current to the metal surface is impeded. Also, the higher the thickness of the coating, the higher would be the electrical resistance of the coating. A much higher resistance to the current flow would, therefore, be offered. Thus increasing the electrical resistance of metals by coating offers an excellent method of corrosion prevention. The specimen metal prevents the corrosion by releasing electrons into the surface. Besides that, by applying coating for good corrosion resistance there are various characteristics of coating such as have high degree of adhesion to the substrate, minimum discontinuity in coating porosity, have high resistance to the flow of electrons, a sufficient thickness and a low diffusion rate for ions such as chloride Cl− and for hydrogen H. Thus, coating is an effective method to control corrosion

4.6   Summary

The corrosions rates and soil resistivities for the samples at the different soils were presented in Table 4.4**.** Also, the nature of the corrosion by visual examination is shown in Section 4.3. Impressively, the weight losses were reflected in the calculated corrosion rates. It was observed that specimen covered with paint materially generally had lower corrosion rates than specimens that were left open to attack by the soil environment. Similarly, there was a general decrease in corrosion rates with time. The overall results of the study including surface morphology and corrosion rates for coated and uncoated steel pipe after exposed in soil for 50 days was summarizes in Table 4.4.

Table 4.4: The overall results

Specimen		Soil Resistivity (Ωcm)	Corrosion rate (mpy)	Surface morphology	Corrosion behavior
Coated	Exposed at atmosphere	-	1.52	Not observed by SEM	Uniform or general corrosion
	Exposure in loam	628.32	5.88		
	Exposure in clay	94.25	6.36		Paint flaking by visual assessment
	Exposure in sand	5.03	6.76		
Uncoated	Exposed at atmosphere	-	8.15	Dense and uniform, coarse surface and the texture is vary with each other.	Uniform corrosion
	Exposure in loam	628.32	10.01		
	Exposure in clay	94.25	13.41		Erosion corrosion and macro pitting at certain part
	Exposure in sand	5.03	15.27		

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1   Introduction

This chapter will mainly discussed about the research and recommendation that can applied for the future work. The conclusions were done according to the result that was obtained in Chapter 4. The research about the effect of soil resistivity to the corrosion behavior to the pipe system can be use for future work.

5.2   Conclusion

Soil resistivity is a function of soil moisture and the concentrations of ionic soluble salts and is considered to be most comprehensive indicator of soil corrosivity. Typically, the lower the resistivity, the higher will be the corrosivity since ionic or electron current flow is associated with soil corrosion reactions, high soil resistivity will arguable slow down corrosion reactions. Soil resistivity generally decreases with increasing water content and the concentration of electron species. Several conclusions could be drawn from the study are:

(i)   Sand soil has and less resistivity and highest corrosion rates compare with loam and clay soil.

(ii)   The corrosion behaviors that observed were uniform corrosion, macro pitting corrosion and atmospheric corrosion.

(iii)   Coated steel pipe has lower corrosion rate compare to uncoated steel pipe.

(iv)   The lower soil resistivity the higher corrosion rates of the steel pipe.

(v)   Steel pipe that exposure in loam produce small hole distance compare with sand and clay soil.

5.3   Recommendation

For the future work, there are various aspects that should be taken into consideration to improve this research so that the performance or result can be better such as:

(i)   Using Wenner Four-Point Probe because of the way how control it is easier and have better resistance reading.

(ii)   Use more driven rod in the ground for either series or continuously to get better result of resistivity.

(iii)   Use different type of material for earth rod such as aluminum rod or steel rod. Different rods give different resistivity and from the various rods the comparison can be made to find which rod is better to find soil resistance.

(iv)   Longer exposure period of specimen in order to get clearer forms of corrosion that occurs.

(v)   Use different type of steel.

(vi)   Add more depth of exposure of the specimen because the soil resistivity was also is affected. The soil resistivity will be lower with increasing of depth.

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APPENDIX A

APPENDIX A

Specimen and spray for coating

Preparing the coated specimen

Soils sample

While take measurement of soil resistance at sand beach

Reading of Earth Tester meter at sand beach

Spade soil that use for bury the specimen

APPENDIX B

APPENDIX B

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WAS Sample Testing of different Qualities

Chemical Composition Results

Probe Nr. / sample 1D :1   Gnmdwerkstoft / material :Cu300

Kunde / customer :chandran laa   Abmessung / dimension :copper ingot

Kom.-Nr. / commision :10%   Zusatzwerkstoff / filler metals :no

Labor Nr. / lab-no. :foundry UMP   Warmebehandlung / heat treatment :no

PTQ·Nr. / PTa-no. :   Schmelze-Nr. / heat-no. :no

Spektralanalyse Foundry-MASTER   Werkstoff / grade :

	Fe	C	Si	Mn	P	S	Cr	Mo
1	98,4	0,111	0,167	0,480	> 0,100	0,0577	0,0760	0, 0129
2	98,4	0,112	0,170	0,465	> 0,100	0,0611	0,0762	0,0143
3	98,4	0,113	0,169	0,482	> 0,100	0,0581	0,0767	0,0141
Ave	98,4	0,112	0,169	0,476	> 0,100	0,0592	0,0763	0,0138

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0,0882	<0,0010	0,0103	0,394	0,0034	<0,0020	<0,0020	<0,0150
2	0,0932	<0,0010	0,0093	0,408	<0,0020	<0,0020	<0,0020	<0,0150
3	0,0898	0,0017	0,0095	0,392	<0,0020	<0,0020	<0,0020	<0,0150
Ave	0,0904	0,0010	0,0097	0,398	<0,0020	<0,0020	<0,0020	<0,0150

	Pb	Sn	B	Ca	Zr	As	Bi
1	<0,0250	0,0135	<0,0010	0,0002	0,0020	0,0103	<0,0300
2	<0,0250	0,0134	<0,0010	0,0001	0,0022	0,0089	<0,0300
3	<0,0250	0,0136	<0,0010	0,0001	<0,0020	0,0078	<0,0300
Ave	<0,0250	0,0135	<0,0010	0,0001	<0,0020	0,0090	<0,0300

Ort *1* town   Datum / date   Prufer / tester   Sachverstandiger / engineer
                        05/10/2010

Worldwide AnalY1icai Systems AG
Wellesweg 31, 47589 Uedem (Germany)

APPENDIX C

Weight before and weight after for corrosion rate calculation

Specimen	Coating	Surface Area (cm²)	Weight Before, (g)	Weight After, (g)	Weight Loss, (g)	Time exposure (hours)	Corrosion rate, (mpy)
A (Sand)	Coated	32.17	109.342	108.749	0.593	1200	6.76
	Uncoated	32.17	109.047	107.707	1.340	1200	15.27
B (Clay)	Coated	32.17	109.305	108.747	0.558	1200	6.36
	Uncoated	32.17	108.991	108.869	1.176	1200	13.41
C (Loam)	Coated	32.17	109.385	108.869	0.516	1200	5.88
	Uncoated	32.17	108.746	107.868	0.878	1200	10.01
D (Atmosphere)	Coated	32.17	109.276	109.143	0.133	1200	1.52
	Uncoated	32.17	108.979	108.264	0.715	1200	8.15

APPENDIX D

PROJECT GANTT CHART

WEEK (S)

PROJECT ACTIVITIES	FINAL YEAR PROJECT 1 (FYP 1)														FINAL YEAR PROJECT 2 (FYP 2)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
GOT PROJECT TITLE	█	█																										
MEETING WITH SUPERVISOR			█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
RESEARCH AND COLLECT INFORMATION			█	█	█	█	█	█	█	█	█																	
PROBLEM STATEMENT				█	█																							
LITERATURE REVIEW			█	█	█	█	█	█	█	█																		
PROJECT METHODOLOGY					█	█	█	█	█	█	█																	
PROPOSAL WRITING						█	█	█	█	█	█	█	█	█	█													
MATERIAL PREPARATION												█	█	█	█	█	█											
SETUP EXPERIMENT															█	█	█	█	█	█								
EXPOSURE THE SPECIMEN																	█	█	█	█	█	█	█					
CLEANING THE SPECIMEN															█	█								█	█			
ANALYSIS																							█	█	█	█	█	
REPORT WRITING																					█	█	█	█	█	█	█	█