

DESIGN ALUMINIUM SACRIFICIAL ANODE

PROPERTIES IN SOIL CORROSION

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UNIVERSITI MALAYSIA PAHANG

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UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

**JUDUL: DESIGN ALUMINIUM SACRIFICIAL ANODE PROPERTIES IN SOIL
CORROSION**

SESI PENGAJIAN: 2012/2013

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DESIGN ALUMINIUM SACRIFICIAL ANODE PROPERTIES IN SOIL
CORROSION

MOHD NOR AMIR BIN NORDIN

A report submitted in partial fulfilment of the requirements for the award of
Diploma in Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

SUPERVISOR'S DECLARATION

I hereby declare that i have checked this project and in our opinion this project is satisfactory in terms of scope and quality for award of the Diploma of Mechanical Engineering.

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I hereby declare that the work in this thesis entitled “ Design Aluminium Sacrificial Anode Properties In Soil Corrosion ” is my own research except as cited in the references. The thesis has not been accepted for any diploma and not concurrently submitted in candidature of any other diploma.

Signature :

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**Specially dedicated to
My beloved family and those who have
Encourage and always be with me during hard time
And inspired me throughout my journey of learning**

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ABSTRACT

This thesis deal with the design aluminium sacrificial anode properties in soil corrossions. The main problem are sacrificial anode were used to prevent or to longer the time of corrosion of the underground pipeline metals, unfortunately the harmful chemicals such a mercury were added and it will cause the polutions to the living things and an aluminium sacrifial anode performance has lower current capacity and electrical potential. The scope is to conduct the experiment to prevent from adding harmful chemical element in Aluminum sacrificial anode. Thus, the performance is improved. There are many step before conduct the experiment. The first step is did some literature review about the corrosion and sacrificial anode behavior. Most currently sacrificial anode use magnesium, unfortunately there are some hazardous chemical mixed with it to increase their performance. Follow up with some study about an aluminium which is suitable to use on this experiment, the aluminium 6064 was decided to use in this experiment because it is suitable act as sacrificial anode. The aluminium was cutted in 5cm x 5cm for the suitable size. The aluminium was cleaned it surface by using manual grind machine. Then, the aluminium will go through some process which is heat treatment and forging process to change the grain size thus, change the performances. The sample of soil was taken at the UMP's contruction site with pH value 5.7. The experiment was conducted on Laboratory of Corrosion in Mechanical Engineering Universiti Malaysia Pahang. Finally the conclusion about this project and the recommendations for the future plan also attached together with this thesis.

ABSTRAK

Tesis ini membentangkan dengan reka bentuk ciri-ciri aluminium anod korban dalam hakisan tanah. Masalah utama adalah anod korban yang digunakan untuk mencegah atau untuk masa yang lebih lama daripada kakisan logam saluran paip bawah tanah, malangnya bahan kimia berbahaya seperti merkuri ditambah dan ia akan menyebabkan pencemaran kepada benda-benda yang hidup dan prestasi anod korban aluminium mempunyai lebih rendah kapasiti dan potensi elektrik. Skop adalah untuk menjalankan eksperimen untuk mengelakkan daripada menambah unsur kimia berbahaya dalam anode. Seterusnya prestasi korban Aluminium bertambah baik. Terdapat banyak langkah sebelum menjalankan eksperimen. Langkah pertama ialah melakukan beberapa kajian mengenai kelakuan anod hakisan dan korban. Anod yang kini korban penggunaan magnesium, malangnya terdapat beberapa bahan kimia berbahaya dicampur dengannya untuk meningkatkan prestasi mereka. Berdasarkan dengan beberapa kajian tentang aluminium yang sesuai untuk digunakan pada eksperimen ini, aluminium 6064 telah dipilih untuk digunakan dalam eksperimen ini kerana ia sesuai sebagai anod korban. Aluminium telah dipotong dalam 5cm x 5cm untuk saiz yang sesuai. Permukaan aluminium telah dibersihkan dengan menggunakan manual mengisar mesin. Seterusnya, aluminium akan melalui beberapa proses seperti rawatan haba dan proses menjalin menukar saiz bijirin dan menukar ciri-cirinya. Sampel tanah yang diambil di tapak pembinaan UMP dengan nilai pH 5.7. Eksperimen telah dijalankan ke atas Makmal Kakisan Kejuruteraan Mekanikal Universiti Malaysia Pahang. Akhirnya, kesimpulan mengenai projek ini dan cadangan untuk rancangan masa depan juga dilampirkan bersama-sama dengan tesis ini.

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LIST OF SYMBOLS

| | |
|-----|----------------------------|
| Kg | Kilogram |
| cm | Centimeter |
| % | percent |
| + | Positive |
| - | Negative |
| C.R | Carbon reference electrode |
| mV | Milivolt |

LIST OF ABBREVIATIONS

| | |
|-----|------------------------------|
| UMP | Universiti Malaysia Pahang |
| CP | Cathodic Protection |
| SEM | Scanning electron microscopy |

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

For most of us, corrosion is defined as the destruction or deterioration of a metal because of reaction with environment that is often called rust and is a curse we have to endure helplessly. Corrosion is electrochemical processes in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site. Differences in potential at different points along the pipe begin to develop. For example, because it is in a soil with low resistivity compared to the rest of the line, current would leave the pipeline at that anode site, pass through the soil, and reenter the pipeline at a cathode site. These potentials generate corrosion currents which leave the pipe to enter the soil at certain selective locations. Corrosion then occurs at these selective locations of the pipe structure. Internal or external corrosion of underground pipelines in soil or water results in selective and concentrated attacks at coating defects. There is no need to replace a complete piece of pipe if corrosion can be controlled at these selective locations (Gibala, R., Tirell, M., and Wert, C., 1993).

Corrosion is a very serious problem. Three areas in which corrosion are important are in economic, improved safety and conservation of resources. The leakage

of hazardous materials from a transport pipeline represents not only the loss of natural resources but also the potential for serious and dangerous environmental impact, and human fatalities. While pipelines are designed and constructed to maintain their integrity, diverse factors (e.g., corrosion) make it difficult to avoid the occurrence of leakage in a pipeline system during its lifetime. On the other hand, internal pipeline events that increase the risk of failure include the generation of defects due to corrosion or erosion and fatigue due to fluctuating pressure or temperature conditions. Although the transmission pipeline safety record has been improving over time, and human casualties, property loss, and environmental damage resulting from pipeline incidents are infrequent, when they do occur the consequences can be significant. For example, a 1999 liquids pipeline incident in Bellingham, Washington, resulted in the release of 277,000 gallons of gasoline into a stream in the middle of the city (Pipeline Rupture and Subsequent Fire 1999, Pipeline Accident Report. 2002 Washington). The gasoline ignited, killing three, injuring eight, and causing.

To solve this problem, cathodic protection which is sacrificial anode provides a valuable extra precaution against corrosion attack. This method only required simple installation which is anodes made from electrically dissimilar metals are buried in the ground near the pipeline, which acts as the anode, and the corrosive action of ground water is thereby arrested, the anodes being sacrificially consumed (British standard code of practice Cathodic Protection. 1973). To protect the pipeline from corrosion with effectively we must have good knowledge in corrosion.

By following the useable concept of the corrosion mechanism, it is easier to understand various conditions to be described which cause active corrosion cells on pipeline. The corrosion process as normally encountered in pipeline work is basically electrochemical in nature and that the presence of oxygen in some form is necessary. The amount of metal that will be removed is directly proportional to the amount of current flow. After we applied the cathodic protection by using sacrificial anode to the underground steel pipe, the general result is the original anode (steel pipe) became as

cathode and some other metal for example aluminium will become anode (National Research Council. 1988. Washington DC).

1.2 PROBLEM STATEMENT

Corrosion of underground steel pipeline is as a result of an electrochemical reaction. Corrosion is an electrochemical process in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site areas which corrosion is important is in economic , safety , and conservation of resources. Sacrificial anodes were used to prevent or to longer the time of corrosion of the underground pipeline metals, unfortunately the harmful chemicals such as mercury were added and it will cause the pollution to the living things.

Cathodic protection is the most important of all approaches to corrosion control. One of the types of cathodic protection is sacrificial anode. Corrosion occurs through the loss of the metal ions at anodic area to the electrolyte. Cathodic areas are protected from corrosion because of the deposition of hydrogen or other ions that carry current (Sandoval, A., Beruvides, M., Wiesner, T.F.2001). By using the sacrificial anode technique the steel pipe will be protected from corrosion but other metal that we used will be corrode. In designing this method we must analyze parameters such as factor affecting corrosion, the amount of anode and rate of corrosion.

1.3 OBJECTIVES OF STUDY

The objectives of this study are:

- i. To design the best performance of sacrificial anode without using any harmful chemical.
- ii. To increase the reactivity and electrical potential of sacrificial anode.

1.4 SCOPES OF PROJECT

The scope of this study includes:

- i. The experiment will be conducted to prevent from adding harmful chemical elements in Aluminum sacrificial anode. Thus, the performance is improved.

1.5 PROJECT PLANNING

Figure 1.5 is the flow chart of the whole Final Year Project. To start this project, an appointment with supervisor is done to understand about the title project given and manage the schedule of weekly meeting. The meeting with supervisor was set up on Wednesday and Thursday every week.

The problem, objective and scope were identified based on the title given. Then the literature review was studied about the sacrificial anode and corrosion. After the studied supervisor will explain briefly how to conduct the experiment based on the title given.

The preparation of mid-term presentation of the Final year project is next. Before presenting, the supervisor will see through the presentation slides and comment on the corrections to be made. Then, the presentation will be presented to the three panel of judges.

Following up, the survey of the material is needed. The discussion with the supervisor had been made and the material started to order from University Malaysia Pahang store. The material started with the measuring of the material and follow up by

cutting of the material. After all material already get it the experiment was start at the Mechanical of Engineering Corrosion Lab. Then taking the result.

After that, the final report writing and presentation will be the last task to be accomplished before semester break. The supervisor will review the final presentation and revise the mistakes to be amended. The final presentation then again will be presented to three panels of judges. A draft report would be submitted to the supervisor to be point out the flaws. Corrections are done and the real final report is handed over as completion of the final year project.

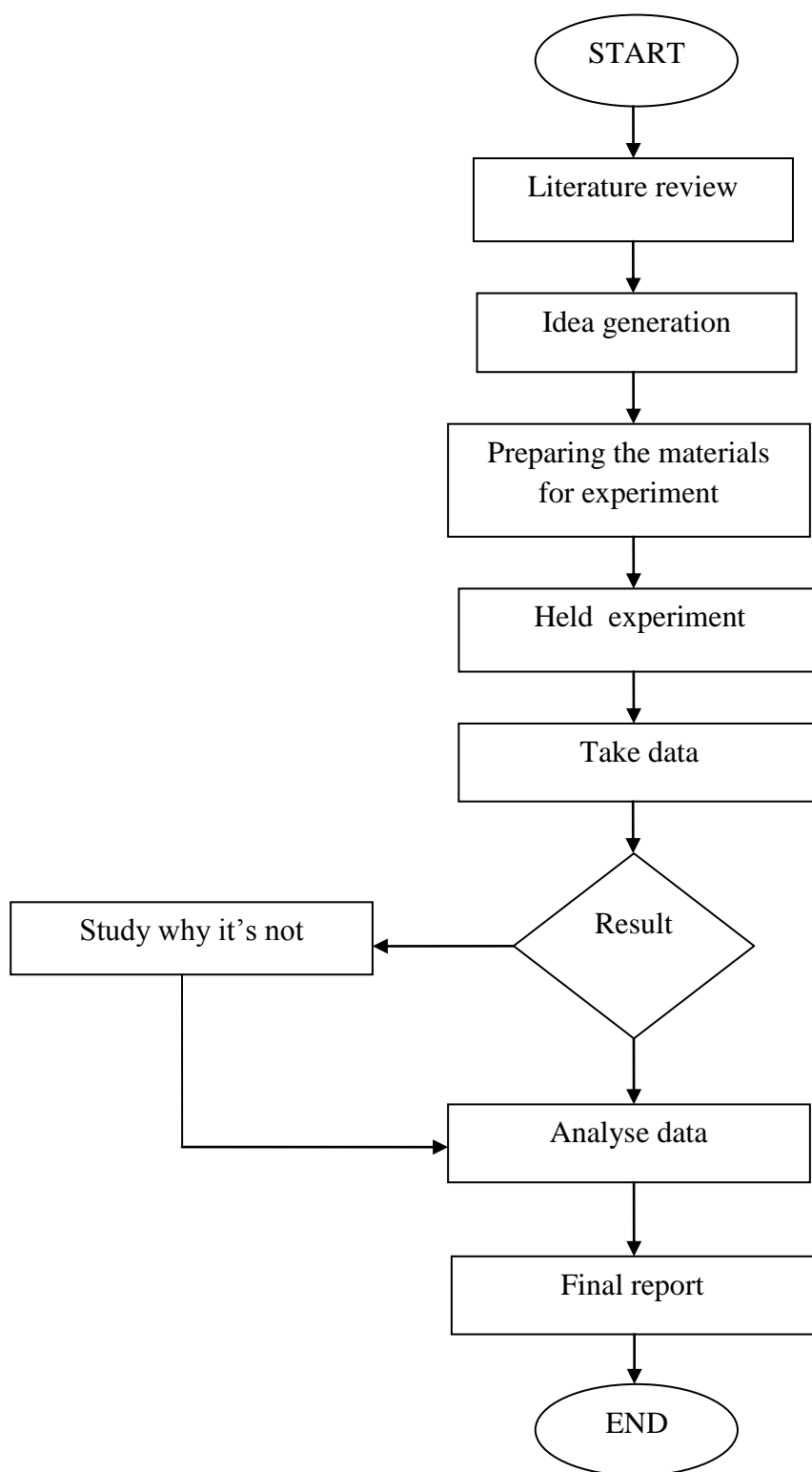


Figure 1.5 : Flow chart

GANTT CHART/PROJECT SCHEDULE

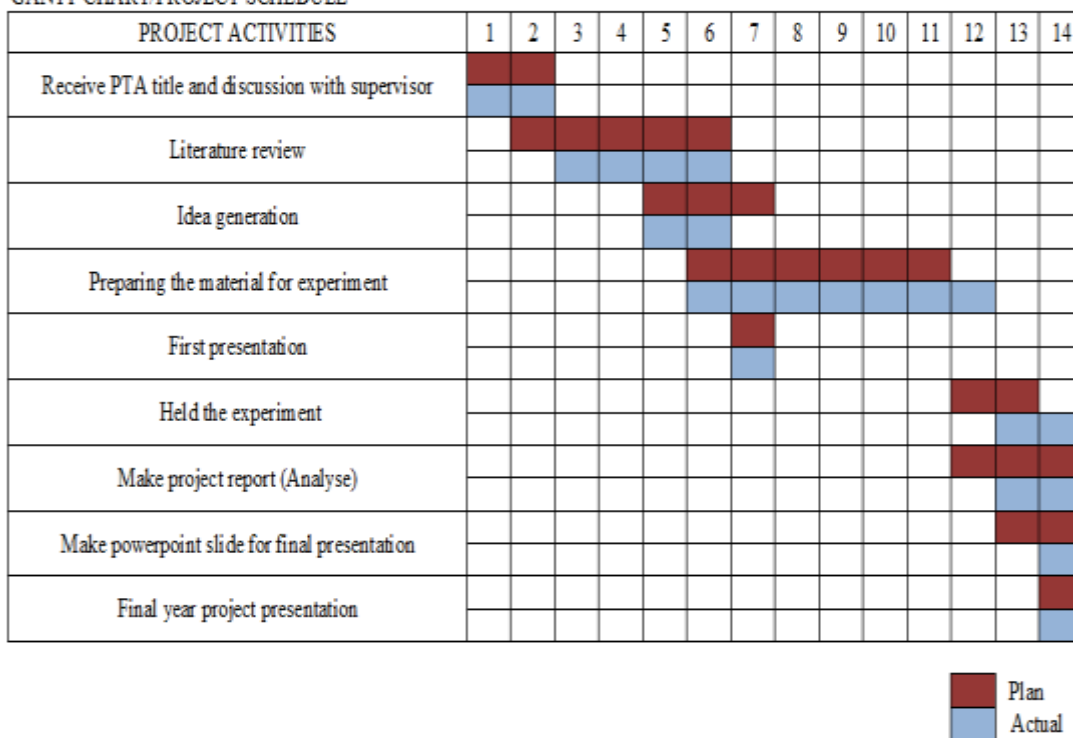


Figure 1.6 : Gant chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

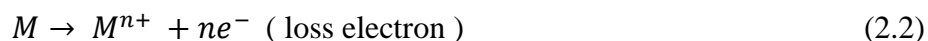
Corrosion is defined as the destructive result or deterioration of a metal or alloy or its properties because of a reaction with environment. Metal atoms in nature are present in chemical compounds. The same amount energy needed to extract metal from their minerals is emitted during the chemical reaction that produces corrosion. Corrosion returns the metal to its combined state in chemical compounds that are similar or even identical to the minerals from which the metals were extracted. Corrosion also has been called extractive metallurgy in reverse. Underground steel pipeline is one of equipment that subject to corrosion. For example are domestic water pipes, where corrosion attacks mostly on the internal and external of the surface of pipe.

2.2 MECHANISM OF CORROSION

Corrosion theorists are obliged to take into account considerations of the infinitely small and necessarily complex activities on the molecular and at the ionic, electronic and atomic levels. Figure 2.2.1 shows an illustration of corrosion reaction on pipeline. Three basic kind of corrosion can be listed as chemical, electrochemical and physical. For example, a common representation of the corrosion reaction maybe expressed with respect to iron, water and oxygen in this chemical reaction (National Association of Corrosion Engineers, 1984. Houston).

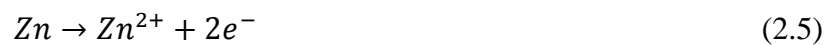


This indicates that the initial reaction of iron with oxygen in pure water is to form ferrous hydroxide. Corrosion would not occur if one of these elements is absent entirely. Corrosion involves both an anodic and cathodic reactions. The anodic reaction involves metal dissolution (corrosion) (R. Roberge.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



Examples in addition equation (2.2) are:





The cathodic reaction or oxidation consumes (gain electrons) the electrons and the cathodic reaction depends on the type of environment:

(i) In acid environments:

Hydrogen evolution



(ii) Neutral & Alkaline



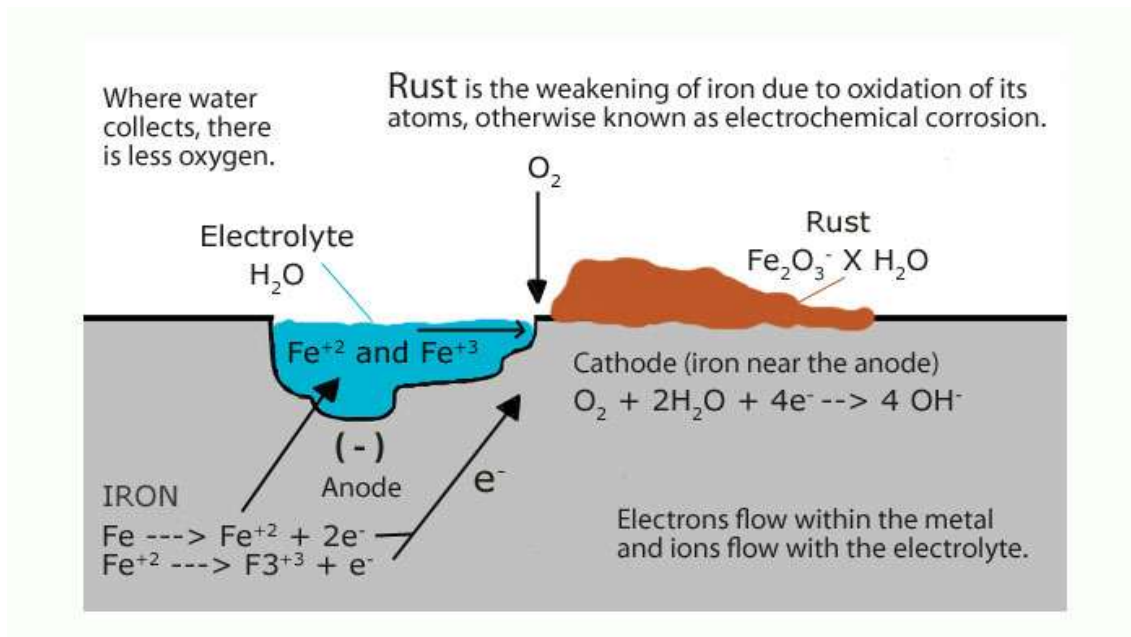


Figure 2.2.1 : An illustration of corrosion reaction on pipeline.

For example reaction Eq.(2.2), defined as anodic reaction, is an oxidation in which M valence increase from 0 to 2+ , liberating electron, e while Eq.(2.6), defined as cathodic reaction, is a reduction in which the oxidation state of hydrogen decrease from 1+ to 0, consuming electrons. (Jones, D.A., Uhling, H.H, Revie R.W 1982).

2.2.1 Corrosion of Steel

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

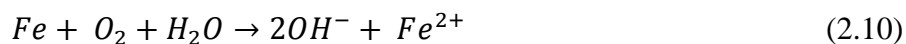


The corrosion reactions can be illustrated using chemical terminology as follow equation (2.8). This is simple way of describing the process where iron is removed as charged particle called ions (Fe^{2+}) and electron(e^-) carry current to balance the electric charge. Clearly a balancing reaction must occur at the cathode and under ordinary natural exposure conditions this can be represented as follows:

Cathodic reaction:



In short, hydroxyl ions are produced at the cathode .These two reactions can combined in a chemical equation (2.10):



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



This is simple form of rust which unstable and is eventually oxidized (i.e. react with oxygen) to form the familiar reddish brown rust, chemically denoted $FeOOH$. This is the form of rust usually produced in air, natural water and soils. However, underacidic conditions hydrogen is produced at the cathode and the corrosion product may be Fe_3O_4 (magnetite).

2.2.2 Forms of Corrosion

Figure 2.2.2 shows forms of corrosion that occur to the metal structure. The several type or forms of corrosion are: (Jones, D.A., Uhling, H.H, Revie R.W. 1982)

- (i) **General corrosion:** General corrosion or rusting is the most familiar form of steel corrosion. It can be call a uniform corrosion also,the process which is oxygen in the air will become oxidizing agent, and the water necessary for the reaction is readily available in the form of rain.
- (ii) **Pitting corrosion:** A no uniform, the form of corrosion that occurs at a specific spots where deep pits form. This type of corrosion is need a present of chloride ion. This type of corrosion usually can be seen frequently in structures exposed in coastal areas.
- (iii) **Galvanic corrosion:** This type of corrosion usually occur when two types of metals with different electrical potential are connected in the presence of moisture or an aqueous solution, one will act as the anode and chatode. This principle is used protect the metal for example sacrificial anode process.
- (iv) **Stress-corrosion:** This corrosion form occur when it under stress, the corrosion processes proceed more faster, it also can lead to brittle failure of metal as corrosion tends to be localized. This kind of corrosion always occur in prestressing tendons in concrete.
- (v) **Crevice corrosion:** This form of corrosion occurs when moisture and contaminants retained in crevices accelerate corrosion

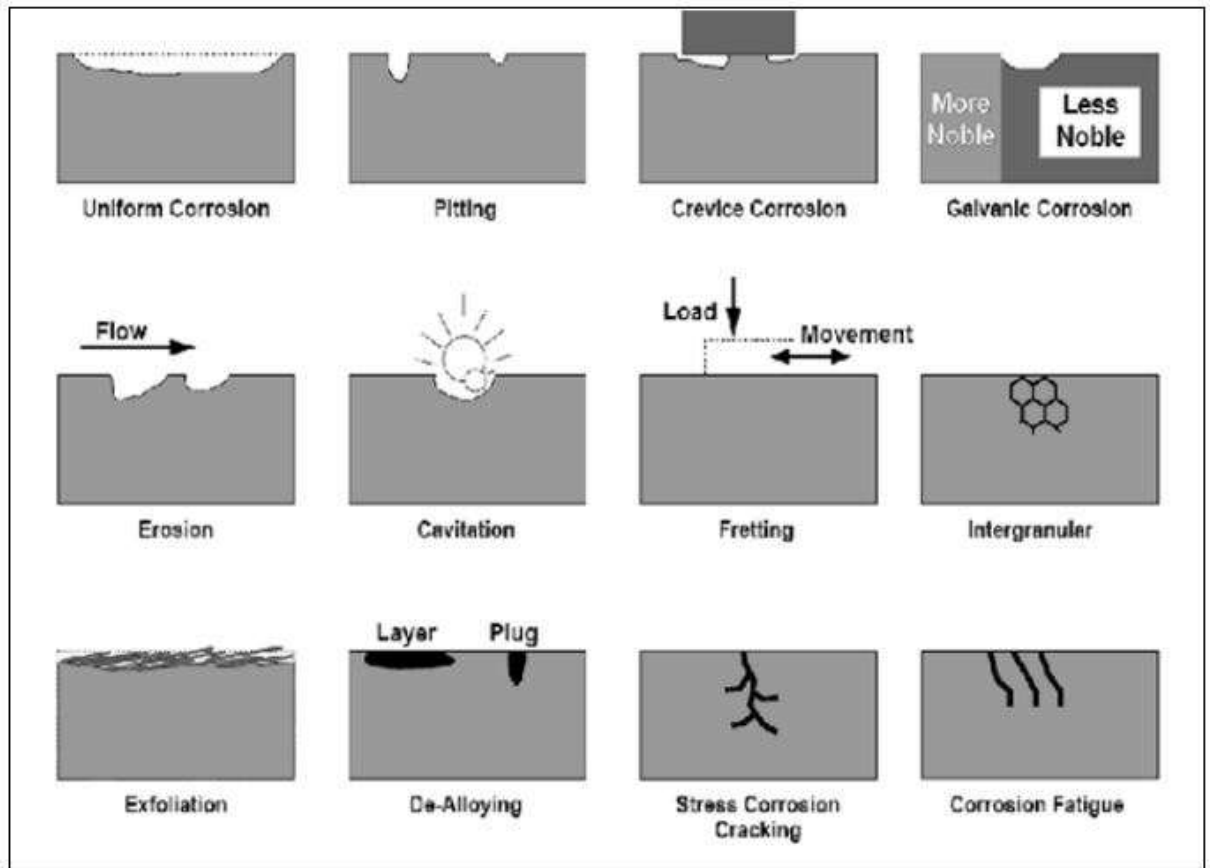


Figure 2.2.2 Form of Corrosion

Source: Roberge, P.R. 1999

2.3 CORROSION 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 a 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 base on (figure 2.3.1) have been classified :

- i. A - Surface soil (usually dark in color due to organic matter).
- ii. O. Organic horizon (decaying plant residues).
- iii. E. Eluviation horizon (light color, leached).
- iv. B. Accumulation horizon (rich in certain metal oxides).
- v. C. Parent material (largely nonweathered bedrock).

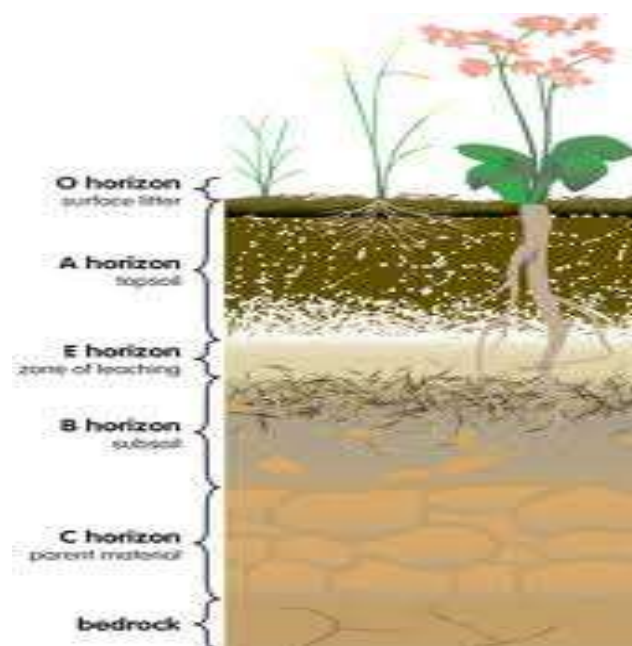


Figure 2.3.1 : soil horizons.

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.

2.4 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 2.4.1). 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 (figure 2.4.2).

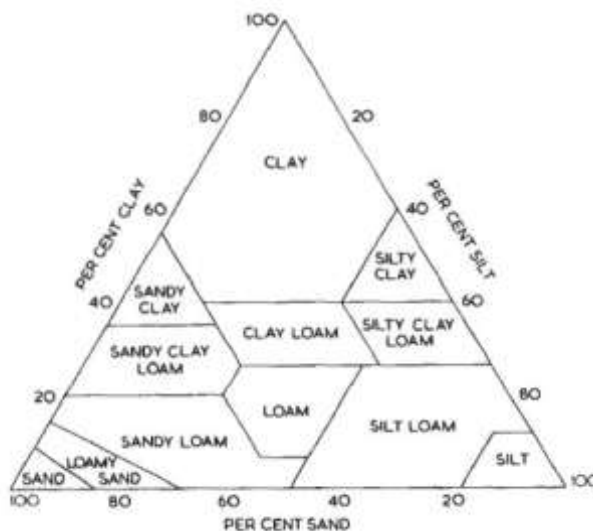


Figure 2.4.2 : Soil classification system

2.5 FACTOR AFFECTING UNDERGROUND CORROSION.

2.5.1 Soil Resistivity

Soil resistivity depends on the natural ingredient the amount of salt dissolved in the soil and moisture content. For the sacrificial anode applications , galvanic anodes are used generally in those cases where relatively small increments of current are required in areas where soil resistivity is low that enough to permit obtaining the desired current with a reasonable number of anodes (Bashi, S.M., Mailah, N.F., Mohd M.A. 2003). Table 2.5.1 shows that the effect of soil resistivity to the corrosion rate. The corrosion rate is increase when the soil resistivity is increase.

Table 2.5.1 : Relationship Soil Resistivity and Corrosion Rate

| Soil resistivity (Ohm – meter) | Type of corrosion rate (Mils/year) |
|---|---|
| < 25 | Severely corrosive (>13) |
| 26 – 30 | Moderately corrosive (9-12) |
| 51 – 100 | Mildly corrosive (4-9) |
| > 100 | Low corrosive (<4) |

Source: National Power Energy conference (PEcon) 2003

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 shown in **figure 2.5.2** .

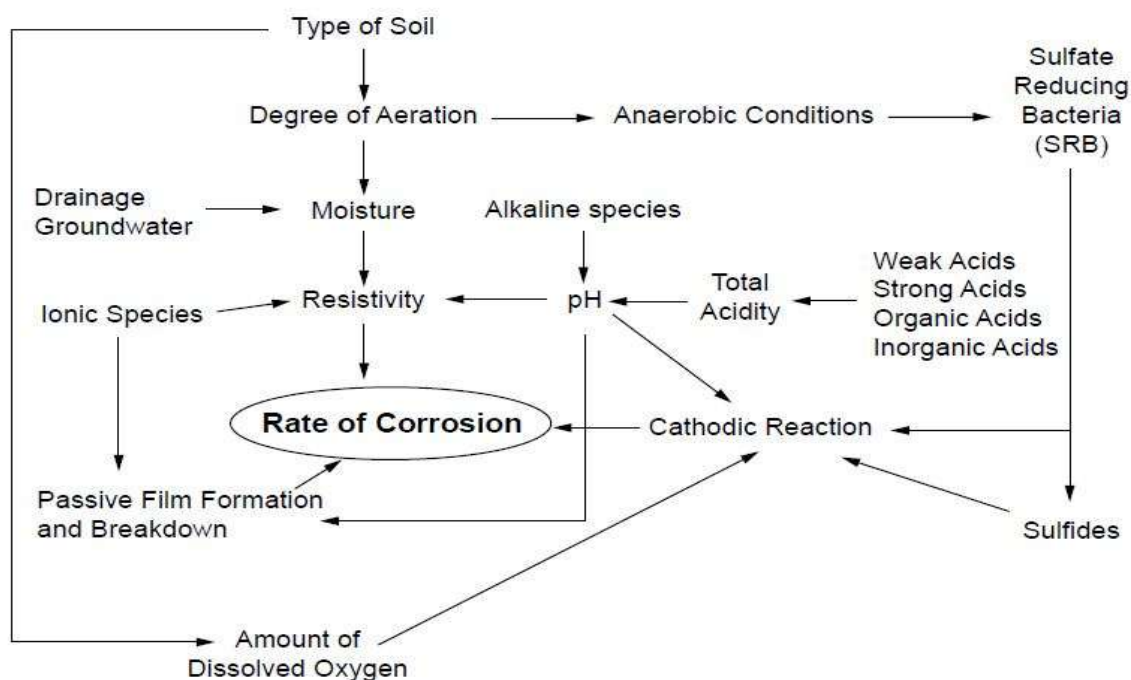


Figure 2.5.2 Relationship of variables affecting the rate of corrosion in soil. For simplicity, only the MIC effects of sulfate-reducing bacteria are shown

2.5.3 Moisture

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 ground water 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.

Table 2.5.3: Particle Sizes in Soil Texture

| Catagory | 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 |

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.

2.5.4 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, water logged 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.

2.5.5 pH Value Of Soil

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. Table 2.5.5 below shows the pH value of soil.

Table 2.5.5 : pH value of soil

| Type of soil | pH value range | Corrosion rate |
|------------------------|----------------|----------------|
| Extremely acid | < 4.5 | |
| Very strongly acid | 4.5 to 5.0 | |
| Strongly Acid | 5.1 to 5.5 | |
| Medium Acid | 5.6 to 6.0 | |
| Slightly Acid | 6.1 to 6.5 | |
| Neutral | 6.6 to 7.3 | |
| Mild Alkaline | 7.4 to 7.8 | |
| Moderately Alkaline | 7.9 to 8.4 | |
| Strongly Alkaline | 8.5 to 9.0 | |
| Very strongly Alkaline | 9.1 > | |

Source: National Power Energy conference (PEcon) 2003

2.6 CATHODIC PROTECTION

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. It's also can be defined as eliminations of corrosion by making the metal a cathode by means of an impressed current or attachment to a galvanic anode. Current flows because of a potential difference between the anode and cathode. The anode potential is more negative than the cathode potential, and the difference is the driving force for the corrosion current. The total system is anode, cathode, electrolyte, and metallic connection between anode and cathode is termed a corrosion cell. For corrosion to occur, the following conditions are required (Gibala, R, Tirell, M, Wert, C. 1993).

- (i) Electrodes.
Present of anode and cathode

- (ii) Electrical potential.
Present of electrical potential between the anode and cathode.

- (iii) Conductive path.
A metallic conductive path electrically connecting the anode and cathode must exist.
.

- (iv) Electrolyte.
The anode and cathode are immersed in an electrically conductive electrolyte that is ionized. Usual soil moisture or water fulfills this condition.

- (v) Current.
An electric current will flow, and where the current leaves a metallic object, metals will be consumed.

Cathodic protection reverses the current flow by installing ground beds of **sacrificial anodes**. No longer does the current leave the structure. Now the structure receives current flow, inhibiting corrosion. The structure is the cathode, and thus, the term cathodic protection.

2.7 CATHODIC PROTECTION SYSTEMS

Cathodic protection is a method to reduce corrosion of the metal by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source. When enough current is applied, the whole structure will be at one potential; thus, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls. There is the one type of cathodic protection systems: sacrificial anode. (Denny, A.J, Uhling, H.H., R W Revie. 1985).

(i) Galvanic systems or sacrificial anode

A sacrificial anode protection is the system that makes use of the corrosive potentials for different metals. Without cathodic protection, one area of the structure exists at a more negative potential than another, and corrosion results. If a much less inert object (that is, with much more negative potential, such as magnesium anode) is placed adjacent to the structure to be protected, such as a pipeline and a metallic connection (insulated wire) is installed between the object and the structure, the object will become the anode and the entire structure will become the cathode. That is, the new object corrodes sacrificially to protect the structure. Thus, the galvanic cathodic protection system is called a “sacrificial anode cathodic protection system” because the anode corrodes sacrificially to protect the structure or pipeline. Galvanic anodes are usually made of either magnesium or zinc

because of these metals higher potential compared to steel structures. Figure 2.7 shows those cathodic protections with sacrificial anode.

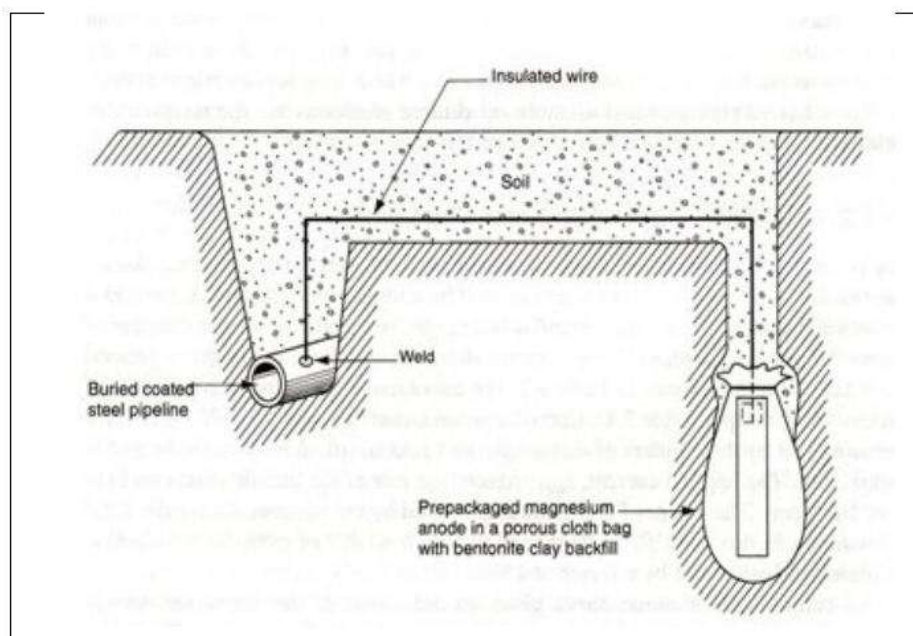


Figure 2.7 : Cathodic protections with sacrificial anode

Source: Uhling, H.H. and Revie, R W. 1985

2.8 CATHODIC PROTECTION SYSTEMS BY SACRIFICIAL ANODE

As mentioned before, the corrosion cell resulting from dissimilar metals in contact. In a corrosion cell, one metal will be act as anode and another one will be chatode that will corrodes. So, by using the sacrificial anodes technique, very strong anodic metal is connected to the pipeline. This metal will corrode and in so will discharge current to the pipeline. In a corrosion cell, current flows from the anode

through the electrolyte to the cathode. Cathodic protection methods attempt to control the direction of the corrosion current. A sacrificial anode is an anode electrically connected to the system to be protected. The basic idea is to force certain parts to be cathodic or anodic with respect to the other in order to control the current direction. If a sacrificial anode is chosen that is anodic to every metal in the pipeline system, the anode will corrode while the pipeline is protected (Roberge, P.R. 1999).

An example of a sacrificial system is the use of magnesium anodes in connection with the pipeline system. The magnesium is buried into the ground within the same electrolyte as the pipeline. The pipeline and the anode are were connected, and as the magnesium corrodes, the pipeline is protected. The magnesium should be alloyed to prevent passive layering. A passive layer is an oxide film that forms naturally on the surface of most metals.

This passive layer becomes a protective coating on an anode and prevents further corrosion. If the sacrificial anode does not corrode, the protection current is not produced. If this happens, the pipeline will begin to corrode. In the other words, sacrificial anode operates by reactive metals that have different natural potentials caused direct current to flow when both are electrically connected. There are many material use for sacrificial anode such as Magnesium, Zinc, and Aluminum, .This because in the table of reactive of metal these material is high tendency of relese thier electron thus is more reactive then steel.

The sacrificial anode also can be described as a metal which will have a voltage difference concerning the corroding structure and will discharge current that will flow through the environment to the structure. The amount of electricity that can be obtained from sacrificial anode depends on the electrochemical equivalent of the metal used and efficiency of working anode. For the galvanic couple between dissimilar metals in the galvanic series, the more noble metal is cathodically protected, while the more active is dissolved. At the active sacrificial anode, electrons will flow to the cathodic structure (Bayliss D.A, Deacon D.H 1990). The anodic section at the cathode structure for example will produce.



It's reduced by the surplus of electron provided by the sacrificial anode and at the same times, the reduction of dissolved oxygen by reaction



Or the evolution of hydrogen by reaction is accelerated



Figure 2.8 shows comparison between condition of metal that act as cathode with cathodic protection of sacrificial anode technique.

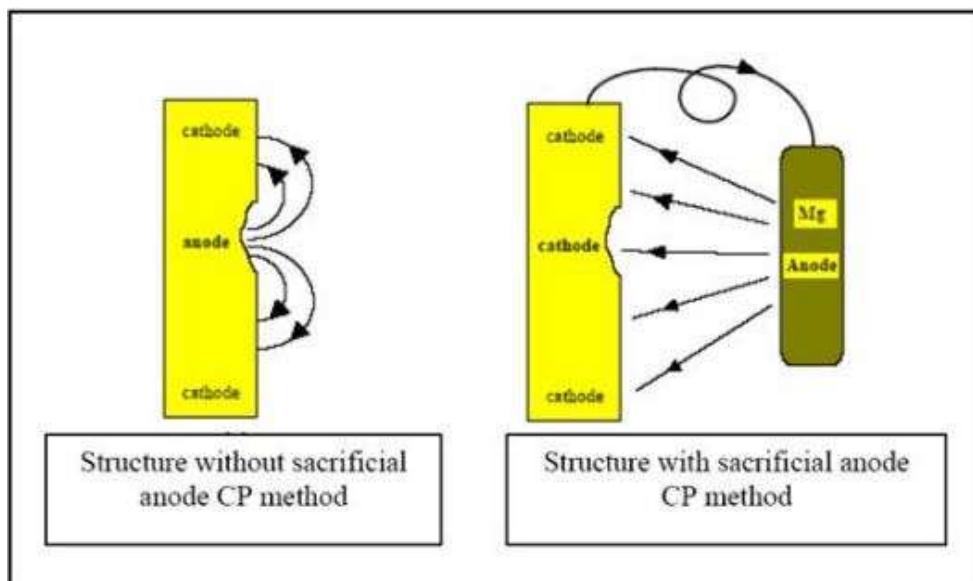


Figure 2.8 : Comparison between Natural Condition Corrosion and with Cathodic Protection Applied.

Source: Jones, D.A .1993

For soil use, aluminum, magnesium and zinc are use as sacrificial anode. Usually magnesium anode is used almost in soil. This is because it's very active anodic corrosion potential which is sufficient to overcome the large soil resistivity than are often prevent.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter are about the determination of corrosion rate associated with the microstructure of aluminium after doing some treatment such as heat treatment and forging treatment. The methodology of this project is illustrated in the flow chart and Gantt chart shown in **Figure 3.1** and **Figure 3.2**. The schematic diagram is very important to ensure the whole process is in the right track instead providing a clear picture to readers on what this experiment all about. Chronologically, the title of this project was studied and the scopes together with the objectives. The next is collecting information from journal research, related articles, reference books and internet. The next phase is the preparation of specimen for the experiment. That does include heat treatment and pressing or forging treatment together with the medium (soil with pH value is 5.6).

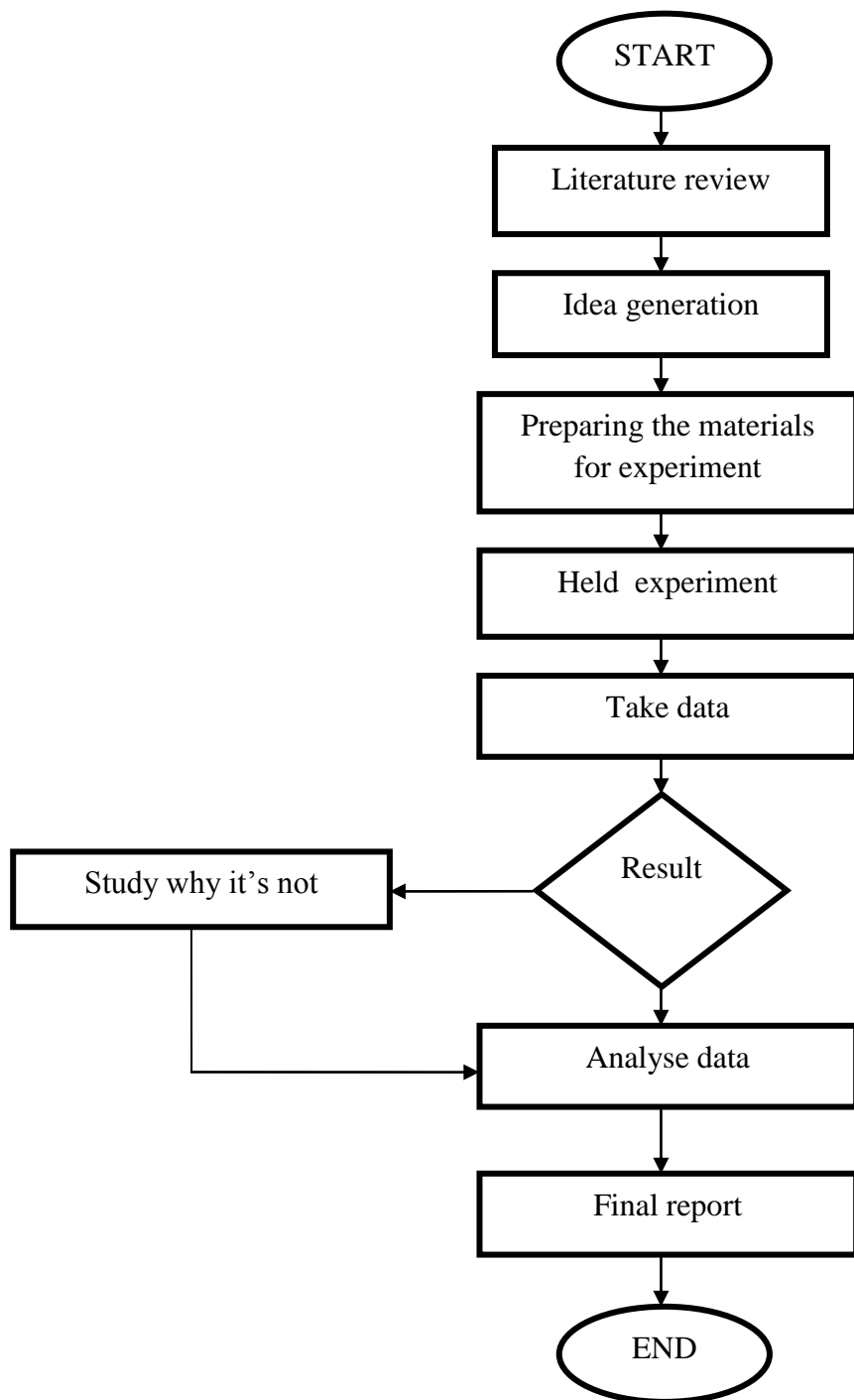


Figure 3.1 : Flow chart

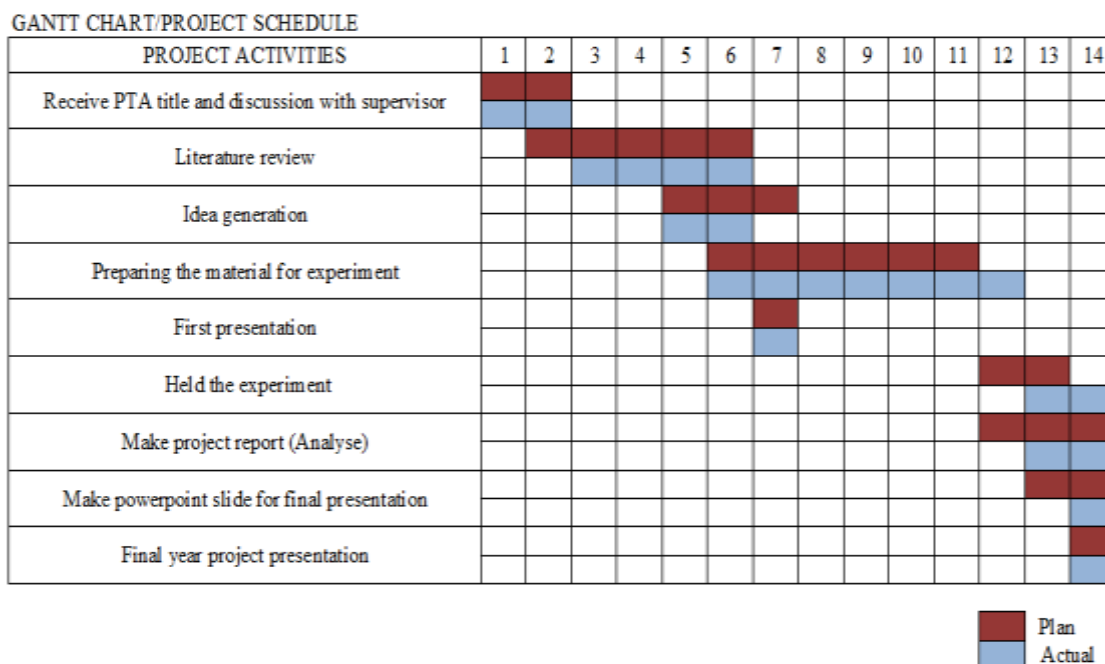


Figure 3.2 : Gant chart

3.2 PREPARATION OF MATERIALS

There are two elements will be used the in the experiment, the first element acts as sacrificial anode and another one is steel to acts as chatode.

3.2.1 Aluminium 6064

Both aluminium and zinc anodes are used in cathodic protection of pipeline on underground. Zinc was the first material to be so used and is therefore considered the traditional anode material. However, aluminium has several outstanding advantages and is fast becoming the anode material of choice.

The efficiency of any anode material depends on its electrochemical properties. First among these is the open circuit potential. For aluminium the open circuit potential is

1.07 V with respect to Ag/AgCl while for zinc it is 1.0V This translates to a better driving potential for aluminium anodes which means that for the same anode configuration, aluminium anodes can deliver 30% more current than zinc anodes.

Secondly, the current capacity of aluminium anodes is 2500 amp. hr/kg. as compared to 780 amp. hr/kg. for zinc anodes. Higher the current capacity, lower is the consumption of the anode and hence, consumption rate of the anodes in kgs/amp. yr is of the order of 3.4 kgs. for aluminium anodes compared to 11.5 kgs. for zinc anodes.

Thus, aluminium when used as an anode material, because of its higher electrical capacity and lower density, translates into lesser weight and / or lesser" anode numbers and offers tremendous economies with improved performance.

Thus, aluminium when used as an anode material, because of its higher electrical capacity and lower density, translates into lesser weight and/or lesser" anode numbers and offers tremendous economies with improved performance.

Base on the experiment, the aluminium will be used as sacrificial anode because it easy to get and not expensive. The aluminium 6064 were choosen because of it performance to test in the experiment.The properties of aluminium 6064 will shown on the figure 3.2.1

Type 6064 is a controlled lead alloy designed to be RoHS and IMDS/ELV compliant, and is an alternative to 6262. The alloyoffers very good machinability along with good corrosion resistance. It also has excellent coating acceptance (anodizeresponse). It can be used in place of 6262. Physical and mechanical properties are equivalent to 6262. The properties of aluminium 6064 will shown on the table 3.2.1.

Table 3.2.1 : Properties of aluminium 6064**TYPICAL MECHANICAL PROPERTIES**

| Temper | Tensile (.500" Dia. Specimen) | | | | | Hardness Rockwell "E" 100kg 1/16" Ball | Shear | | Fatigue* | |
|-----------|-------------------------------|-----|-------|-----|--------------------|--|----------------------------|-----|-----------------------------------|-----|
| | Ultimate | | Yield | | Elongation/4D % | | Ultimate Shearing Strength | | Endurance Limit – R.R. Moore Type | |
| | KSI | MPa | KSI | MPa | | | KSI | MPa | KSI | MPa |
| T6, T6511 | 52.0 | 360 | 48.0 | 340 | 14 | 95 | - | - | - | - |

*5x10E4 cycles of reversed stress

MINIMUM MECHANICAL PROPERTIES

| Temper | Tensile (.500" Dia. Specimen) | | | | | Hardness Rockwell "E" 100kg 1/16" Ball | Shear | | Fatigue* | |
|-----------|-------------------------------|-----|-------|-----|--------------------|--|----------------------------|-----|-----------------------------------|-----|
| | Ultimate | | Yield | | Elongation/4D % | | Ultimate Shearing Strength | | Endurance Limit – R.R. Moore Type | |
| | KSI | MPa | KSI | MPa | | | KSI | MPa | KSI | MPa |
| T6, T6511 | 38.0 | 262 | 35.0 | 241 | 10 | 90 | - | - | - | - |

COMPARATIVE CHARACTERISTICS

| Temper | Corrosion Resistance | | Cold Workability ³ | Machinability ³ | Anodize Response ³ | Brazeability ⁴ | Weldability ⁴ | | |
|-----------|----------------------|---------------------|-------------------------------|----------------------------|-------------------------------|---------------------------|--------------------------|-----|------|
| | General ¹ | Stress ² | | | | | Gas | Arc | Spot |
| T6, T6511 | B | A | C | B | A | - | B | B | B |

1 Ratings A through E are relative ratings in decreasing order of merit, based on exposures to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial and seacoast atmospheres without protection. Alloys with C, D and E ratings generally should be protected at least on faying surfaces.

2 Stress-corrosion cracking ratings are based on service experience and laboratory tests of specimens exposed to the 3.5% sodium chloride alternate immersion test.

A= No known instance of failure in service or in laboratory tests.

B= No known instance of failure in service; limited failures in laboratory tests of short transverse specimens.

C= Service failures with sustained tension stress acting in short transverse direction relative to grain structure; limited failures in laboratory tests of long transverse specimens.

D= Limited service failures with sustained longitudinal or long transverse applied stress.

3 Ratings A through D for Workability (cold), A through E for Machinability and A through C for Anodize Response, are relative ratings in decreasing order of merit.

4 Ratings A through D for Weldability and Brazeability are relative ratings defined as follows:

A= Generally weldable by all commercial procedures and methods.

B= Weldable with special techniques or for specific applications that justify preliminary trials or testing to develop welding procedures and weld performance.

C= Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D= No commonly used welding methods have been developed.

CHEMICAL COMPOSITION LIMITS

| | | | | | | | | | | | Others | |
|----------|------|-----|------|------|-----|------|------|------|------|------|--------|-------|
| Weight % | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Pb | Bi | Each | Total |
| Minimum | 0.40 | - | 0.15 | - | 0.8 | 0.05 | - | - | 0.20 | 0.50 | - | - |
| Maximum | 0.8 | 0.7 | 0.40 | 0.15 | 1.2 | 0.14 | 0.25 | 0.15 | 0.40 | 0.7 | 0.05 | 0.15 |

TYPICAL PHYSICAL PROPERTIES

| Characteristic | | English | Metric |
|---------------------------------------|--|--|--|
| Nominal Density (68 °F/20 °C) | | 0.098 lbs./in. ³ | 2.72 Mg/m ³ |
| Melting Range | | 1078 °F - 1204 °F | 582 °C - 652 °C |
| Specific Heat (212 °F/100 °C) | | - | - |
| Coefficient of Thermal Expansion | Linear 68 °F-212 °F 20 °C-100 °C | 13.0 micro in./in.-°F | 23.4 micro m/m-°K |
| | Volumetric 68 °F/20 °C | 3.78 x 10 ⁻⁵ in. ³ /in. ³ -°F | 68 x 10 ⁻⁶ m ³ /m ³ -°K |
| Thermal Conductivity (68 °F/20 °C) | | 99.1 BTU/ft. - hr. - °F | 172 W/m - °K |
| Electrical Conductivity (68 °F/20 °C) | Equal Volume | | 44% IACS |
| | Equal Weight | | 145% IACS |

The specimen of 5cm x 5cm x 1cm block aluminium was cut into 6 pieces and 6 mild steel is needed to act as cathod as shown on the figure 3.2.2. Four pieces of it were annealed at 350°C for 60 minutes equivalent to an hour using furnace machine. Then immersed in distile water for a night. Two pieces from the 4 pieces of quenching treatment were taken for forging treatment at 300 kg/cm. The deformation of aluminium is 2 mm. There is no treatment for the rest. Table 3.2.2 shown the detail about the process.



Figure 3.2.2 : On the left is aluminium and the right is mild steel

Table 3.2.2 : Data of specimens

| PIECES | TREATMENT |
|--------------------|---------------------------|
| (Aluminium) | |
| 2 | None |
| 2 | Heat Treatment |
| 2 | Heat Treatment + Pressing |

3.2.3 Heat treatment

Process in which a metal is heated to a certain temperature and the cooled in a particular manner to alter its internal structure for obtaining desired degree of physical and mechanical properties such as brittleness, hardness, and softness.

Base on the experiment the four pieces aluminium were heated by furnace machine as shown on figure 3.2.3 about 350°C which is below crytalisation point (428°C) to change their properties. After 1 hour heated that aluminium were straightly deep into the cold water.



Figure 3.2.3 : Furnace machine.



Figure 3.2.3 : the specimen (aluminium) were entered into Furnace machine.

3.2.4 Forging or Pressing

A process of working metal to a finished shape by hammering or pressing and is primarily a "hot" operation. It is applied to the production of shapes either impossible or too costly to make by other methods or needing properties not obtainable by casting. Categories of forgings include Hammer, Press, Drop or Stamping.

2 of 4 pieces went through the pressing process by manual forging machine shown on figure 3.2.4 base on the experiment that were held this process not to change the shape of aluminium but to change the microstructure of aluminium. The pressure to pressing the aluminium is under it tensile strenght.This process will change the microstructure of aluminium.Thus, effect it performance. figure 3.2.5 .



Figure 3.2.4 : Manual Forging Machine



Figure 3.2.5 : The specimen were pressed

3.2.6 Taking The Microstructure

After going all the treatment, the microstructure and the grain structure had been taken by using microscope/SEM figure 3.2.7 But before taking the microstructure, the aluminium need to etching by immerse in 15% NaOH solution, grinded and polished by using manual figure 3.2.6 The reason its need to be grind is to clean the surface and to get the good grain structure.



Figure 3.2.6 : Manual hand grind machine



Figure 3.2.7 : Microscope / SEM

3.3 SETUP THE EXPERIMENT

The 4cm x 4cm area of aluminium and mild steel were buried into the soil in the container. The aluminium were connected to the mild steel by crocodile wire. The 1 liter of distilled water were pour into the soil to existing the potential current, thus the electrolysis occur in soil. The experiment will be held for 1 week to get the better accuracy and better result. The figure 3.3.1 shown experiment were setup.

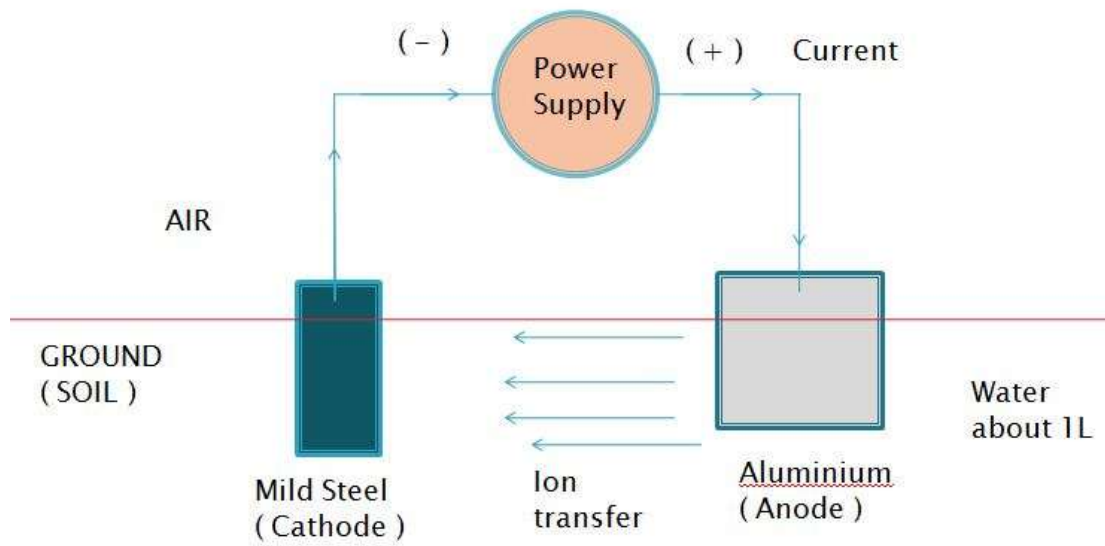


Figure 3.3.1 : Experiment were setup



Figure 3.3.1 : Experiment were setup.

3.4 DATA ANALYSIS

The experiment will carry out to determine the **elctical potential** for every specimen in soil. Potentionstatic experiment will carry out for 5 days.

Table 3.4 : Electrochemical parameters

| Process for Speciment (aluminium) | <i>I</i>_{corr} (μAcm^2) | <i>E</i>_{corr} (mVSCE⁻¹) | β_c (m dec⁻¹) |
|--|---|---|--|
| No treatment 1 | | | |
| No treatment 2 | | | |
| Heat treatment | | | |
| Heat treatment | | | |
| Heat + Forging treatment 1 | | | |
| Heat + Forging treatment 2 | | | |

3.4.1 Corrosion Rate

$$\text{Corrosion rate} = (K \times W) / (A \times T \times D) \quad (2.15)$$

Where,

K = Constant in corrosion rate equation (Table 3.4.1)

W = Mass loss (kilogram)

A = Area (cm^2)

T = time for exposure (hour)

D = Density (g / cm^3)

Table 3.4.1 : Constant in corrosion rate equation.

| Corrosion rate units desired (mpy) | Constant (K) in corrosion rate equation |
|--|---|
| Mils per year (mpy) | 3.45×10^6 |
| Inches per year (in./yr) | 3.45×10^3 |
| Inches per month (ipm) | 2.87×10^2 |
| Millimeters per year (mm/yr) | 8.76×10^4 |
| Micrometers per year ($\mu\text{m}/\text{yr}$) | 8.76×10^7 |
| Picometers per second (pm/s) | 2.78×10^6 |
| Grams per square meter per hour ($\text{g}/\text{m}^2/\text{h}$) | $1.00 \times 10^4 \times d(a)$ |
| Milligrams per square decimeter per day (mdd) | $2.40 \times 10^6 \times d(a)$ |
| Micrograms per square meter per second ($\mu\text{g}/\text{m}^2/\text{s}$) | $2.78 \times 10^6 \times d(a)$ |

(a) Density is not needed to calculate the corrosion rate in these units. The density in the constant *K* cancels out the density in the corrosion rate equation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter concludes about the result gained from the experiment and some discussion made from analysis of the result. The aim of this chapter is to analyse the result of the project, which includes the design of aluminium sacrificial anode properties in soil corrossions.

4.2 RESULT

4.2.1 Electrical potential

The electrical potential were measured by using voltmeter for the 1 week. A voltmeter is an instrument used for measuring electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters show in figure 4.2.1 give a

numerical display of voltage by use of an analog to digital converter. The result of potential electric show on table 4.2.2 .



Figure 4.2.1 : The voltmeter used to get the result

Table 4.2.2 : the result of Electrical Potential

| Day | Specimens | | | | | |
|-----|----------------------|-------|------------------------|--------|-------------------------------------|-------|
| | No treatment (mV) | | Heat treatment (mV) | | Heat treatment + Forging (mV) | |
| | Mild Steel | C.R | Mild Steel | C.R | Mild Steel | C.R |
| 1 | 97.0 | 470.0 | 50.0 | 520.0 | 40.3 | 549.0 |
| 2 | 98.7 | 758.0 | 117.9 | 792.0 | 90.6 | 599.0 |
| 3 | 141.1 | 835.0 | 226.0 | 851.0 | 125.3 | 672.0 |
| 4 | 195.2 | 946.0 | 331.2 | 954.0 | 220.4 | 732.1 |
| 5 | 246.1 | 1037 | 383.0 | 1046.0 | 265.7 | 845.0 |

C.R = Carbon Reference Electrode

After the analysis and taking the data, the result base on mild steel at table 4.2.1, on the day 1 the specimen with electrical potential of aluminium with no treatment is leading the others two thus, the reactivity of aluminium on it is high. After achive on day 3 the mild steel with heat treatment start to leading the others two. Then it shows that the reactivity of aluminium is higher, Becuase of the grain structure of aluminium with heat treatment had changed it performance.

Finally, the result on the day 5 with good reactivity was shown on mild steel with heat treatment. An aluminium for heat treatment + forging also shown a good result but there are some effect that cause the grain structure is like similar to aluminium with heat treatment.

The figure 4.2.3 shown the result of the experiment after 1 week. The aluminium connected with yellow crocodile wire is with no treatment. The aluminium connected with green crocodile wire is with forging + heat treatment,thus the corrosion on the mild also shown but it is not clearly like the aluminium with no treatment. The last one is the aluminium with heat treatment was shown. The corrosion on the mild steel was shown base on the data.



Figure 4.2.3 : The Aluminium with no treatment



Figure 4.2.3 : The aluminium with forging + heat treatment



Figure 4.2.3 : The aluminium with heat treatment

4.3 DISCUSSION

Base on the result, we can conclude that the grain structure of aluminium is one of main affect that contribute to thier reactivity process. The aluminium with no treatment is already going through rolling process then the grain structure is closed to each other. The result shown the reactivity of aluminium with no treatment for the day 5 are 246.1 mV base on the mild steel. An aluminium with heat treatment is best result base on the experiment. This is because the aluminium were going through the heat treatment process. During this process the boundary of the grainstructure is seperate from each other and there are many grainboundary exist. The reactivity of aluminium is high base on the characteristic of grainstructure.

The result like similar as aluminium with no treatment is aluminium with heat treatment + forging. The aluminium were going through heat treatment process during this phase the grain structure is saperate, but the aluminium is applied by forging process. During this process the aluminium were press at a certain pressure then the grain structure is going back closed to each like grainstructure of aluminium with no treatment.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, consists of future of recommendation for improvement of the final year project and conclude overall project task. However there were problems faced during the course of this project. The measures taken to rectify these problems have been identified and applied. There will be future works and project limitations also given as a guide of previous research that has been done.

5.2 PROBLEM FACED DURING THE PROJECT

During the preparation of materials of sacrificial anode, the aluminium selection is actually use by aluminium with casting not the aluminium that already go through rolling and shaping process. That is because of lack of exposure on this field caused a problem as the information about the sacrificial anode.

The next problem was faced when to taking the analysis of data. The voltmeter that use to measured electrical potential difference was broken, this is because there are many student that are use the voltmeter on thier project especially for the degreee student. Because of this problem the data can not be taken for a short time. Thus, the experiment result were slow.

The problem was also face while to taking the microstructure of aluminium. When the aluminium specimen were checked by Microscope / SEM at Engineering Material Lab the microstructure on the aluminium can not be seen clearly. The aluminium surface need to grind by using Manual hand grind machine to clean and smooth the surface. This process taking a long time to get the clear image of microstructure in this project.

The last problem was faced when to setup the experiment. Firstly, the aluminium and the mild steel can not be connected by using copper wire then decided to use crocodile wire. Secondly, the crocodile wire can not be clip on the mild steel because of it thickness and limitation of crocodile wire clip. Then the mild steel was drill in the center to get the suitable thickness that can be clip by crocodile wire.

5.3 CONCLUSION

In conclusion, the project objctive were achieved. The objective of design aluminium sacrificial anode properties in soil corrossions was reached. The best design was choosen which is the aluminium with heat treatment and the experiment was finish within the time limit given. The literiture review about sacrificial anode had been learnt in from the research and the supervisor. The informations and the experience from this project were develop the student to more interesting about the corrosion engineer. Then, this experience also can be contribute and share to others peoples that can be generate a better technology in future. Beside that, probelm solving skills during conducting the experiment were learnt. It acts as a motivator in facing the challenges as a professional engineer in this globalised era.

5.4 RECOMMENDATION AND IMPROVEMENTS

Recommendation for similar project in the future are as follows. First of all would be early do some research about the sacrificial anode and mechanism of corrosion to be more easier when conduct the experiment. Other than that, the future project also can be improved by improving the material design which mean not only for the properties but on the shapes and sizes of material used. The setup apparatus on the lab must be checked properly to avoid any unusual happen that will cause the experiment impaired. Then, for the placed of the experiment held can be improved by conducting the experiment in the real environment which mean to the original place of pipeline. Finally, the future project must be improved by doing many treatment to the aluminium sacrificial anode and increase the manipulated variables of the project.

REFERENCES

Jones, D.A., Uhling, H.H,Revie R.W (1982) Mechanism of Corrosion.

Pierre R. Roberge, Handbook of Corrosion Engineering. History of Sacrificial anode and Literature Review for sacrificial anode

List of Personal Protective equipment (online)

<http://www.spms.com.my/safety.htm>

<http://www.forasia.cn/products.asp?pdid=3010>

Example of Machines (online)

<http://www.drilling-machine.net/>

<http://www.bombayharbor.com/company/67807/product.html>

Material Used (online)

<http://www.kaiseraluminum.com>

APPENDIX A

Personal Protective Equipment



Leather glove



Hot Metal Holder



Safety goggles

APPENDIX B

Figure of Machine use



Drilling Machine



Bend saw machine

APPENDIX C

Material Used



Aluminium 6064



Crocodile wire