
CORROSION ON MILD STEEL

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ABSTRACT

Corrosion process plays an important role in day to day basis. Corrosion of iron is commonly referred to as rusting. Mild steel is one materials that is commonly metal used on daily basis due to its high ductility, high machinability and toughness and find is application in industries and for household purposed such as: construction of structural beams, automobile parts, sheets, bridges and in building. Due to its use in many areas, it is exposed to a variety of corrosive environments and media. These media tend to have an interaction with mild steels either physically or chemically.

This study investigates the rate of corrosion in mild steel specimen immersed in various solutions of sodium chloride, sodium carbonate and sodium sulphate that are kept at different amount of concentration. This helps in determination of the most corrosive media that greatly affect the mild steel pipes placed in different environments. The weight loss method was employed where mild steel specimens were weighed and then immersed in the solutions maintain at different concentration for a period of 6 weeks. The specimens were retrieved from the solutions after every seven days where they were washed, weighed and then put in the respective solutions. From the experimental results, 1M of sodium carbonate had the highest rate of corrosion and there was no formation of coating on the surface of the specimen that was immersed in it. Specimen that was immersed in 1M of sodium sulphate had the lowest rate of corrosion that was accompanied by formation of black coating on the surface of the immersed specimen. Therefore, there was a clear indication the rate of corrosion rate is increased when the concentration of the solution that is responsible for formation of oxide is reduced. In environments where is no formation of oxides the rate of corrosion is intense and therefore such environments should be avoided.

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CORROSION IN MILD STEEL

1 CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION

Mild steel has over the past few years increased its fields of application and has been established as a very significant material in the construction and manufacturing industries. According to Wan Nik, et al, 2012, mild steel has gained the recognition for use in most of industrial application due to some of its favorable characteristics such as ease of availability and its excellent physical properties such as good strength, hard and can be bent, worked or can be welded into an endless variety of shapes for uses from vehicles (like cars and ships) to building materials. Compared to other materials previously used such as iron, mild steel is cheaper, has excellent strength and its machinability/workability is higher. More application of mild steel has been reported in marine industries such as in ship bodies, pipes, fabrication of weapons and tidal wind turbines. Since engineering majors in safety of structures, the rate at which corrosion occurs in mild steel in hostile environment has gained a lot of interest. Structural engineers and naval architects are increasingly interested in understanding the rate of loss of strength in mild steel.

Corrosion can be expressed as the deterioration of mild steel material which significantly affects the mechanical properties of mild steel components and structures. The deterioration can be usually as a result of electrochemical reaction of the metal surface with the surrounding (in this case the saline environment). Electrolysis process is the main drive for corrosion in mild steel, such that the mild steel surface emits electrons to the electrolyte in contact with the surface (saline water). Compared to fresh water, salty water has a higher rate of corrosion in mild steel. This is mainly due to increased electrical conductivity in salty water compared to fresh water. Aqueous corrosion is contributed by two factors that are aeration and electrical conductivity. The resultant corrosion is a formation of rust and where there is flow of the corrosive solution pitting is formed (Subir, 2009).

Afolabi, 2014, reported that corrosion reactions are electrochemical in nature which involves two types of reaction i.e. cathodic and anodic reactions. The anode is the metal surface that undergoes corrosion and the anodic reaction is for iron i.e. $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$. The iron undergoes oxidation process by losing electrons. The cathode is the part of the metal that does not corrode and instead provides a site for the chemical reaction to absorb the electrons generated at the anode. The electrons generated as the iron dissolves at the anode travel through the metal to the cathodic surface area. There are two primary reactions possible at the cathode, the “hydrogen evolution reaction” and the “oxygen absorption reaction.” Other reactions are possible but are encountered less often. In the hydrogen evolution reaction, the electrons combine on the surface of the metals with hydrogen ions in the electrolyte to form hydrogen molecules, which escape as gas bubbles. This consumption of electrons is called a reduction reaction and is as follows: $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$.

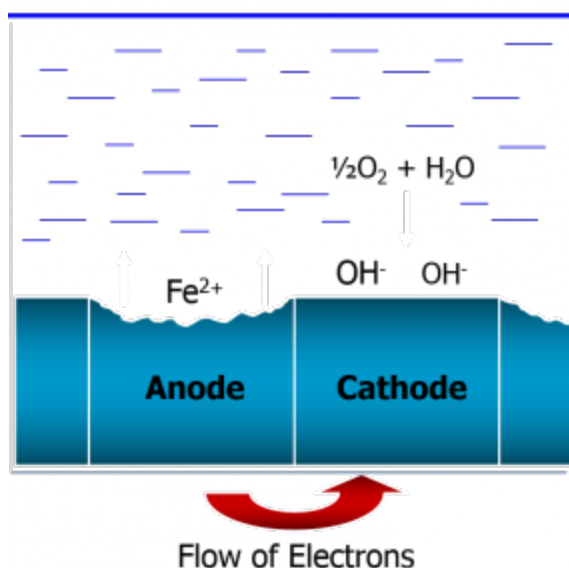


Figure 1: Corrosion reaction

This project aims to investigate the corrosion behavior of mild steel in NaCl , Na_2SO_4 and Na_2CO_3 environments that are maintained at different concentrations. These solutions can be used to reduce or increase the rate of corrosion of mild steel. Two methods were used which include weight loss method (gravimetric method) and potentiodynamic polarization test. The

most affordable, simple, reliable and convenient method to measure the rate of corrosion in mild steel is to implement the weight loss method. This method involves immersing samples/specimens of mild steel in salt solutions and measuring the weight loss of the material as a function of time (Prabhu, et al, 2008). Relative to metal density, exposed surface area, duration of exposure and some constant, the rate of corrosion of metal can be determined. Corrosion rate (CR), helps in understanding the vulnerability of metals to corrosion. Corrosion rate may be expressed in mils per year (mpy) of metals degraded. One (1) mil equals 0.001 inches. To facilitate the experiment, the specimen will be investigated for corrosion behavior at varying concentration of salt in order to determine the how corrosion is affected by salt concentration.

1.2 OBJECTIVES

1.2.1 Main objective

The project aims at investigation of corrosion rates at different environments of sodium chloride, sodium sulphate and sodium carbonate so as to determine which of the environment under test is most disastrous and therefore should be avoided.

1.2.2 Specific objectives

The main objective of this study is achieved through the following specific objectives:

- To carry out a laboratory experiment that simulate various environments by immersing of mild steel specimens in solutions of sodium, chloride, sodium carbonate and sodium chloride maintained a different concentration.
- To compute weight loss in the mild steel specimen by obtaining the initial weights of the specimens and then getting the difference between the initial weight and the final weights.
- To compute the rate of corrosion rate of the immersed mild steels from the weight loss obtained that helps in analysis of the results from the experiment carried out.

2 CHAPTER 2: LITERATURE REVIEW

This section addresses the effect of corrosion on metals, alloys and crystalline materials. The structure is as follows:

- General overview
- Conditions for corrosion
- Corrosion control
- Relationship between crystal structure and corrosion
- Effect of corrosion on mechanical properties
- Economic impact of corrosion
- Nanocrystal line Materials

2.1 GENERAL OVERVIEW

Structure safety is an important aspect in engineering. In fact, most structures are designed with a factor of safety of at least 4. However, all structures are bound to fail due to environmental factors such as fatigue, wear and corrosion. According to Branko (Popov, 2015), the safety of engineering structures is compromised by corrosion. Corrosion has been found to be the leading factor in catastrophic failure in aeroplane components, bridges and equipment used in industries.

Corrosion is a phenomenon that happens over a period of time. The rate of corrosion is determined by several factors; material composition, the environment, and electrochemical, metallurgical and chemical properties. As mentioned, corrosion is a slow-progressing process hence the extent of corrosion takes a long time to evaluate. For this reason, most industries underestimate its effect on structure and equipment design.

Natural processes tend to ‘flow’ towards the lowest possible energy states. For instance, steel and iron will often combine with other chemical elements with the aim of returning to their lowest energy states. The mentioned materials tend to combine with water and oxygen to form hydrated iron oxides or rust. Rust has a similar chemical composition to the original iron ore. This is one form of corrosion and it should be noted that oxygen and water are abundant in most natural environments (Popov, 2015).

Even though corrosion is a natural phenomenon that affect metals, it also affects crystalline materials. However, the rate of corrosion will vary on crystalline materials. Engineering materials have different microscopic structures. Ceramics are good examples of inorganic crystalline materials. Rocks and beach sand natural ceramics. Advanced ceramics are another group of crystalline materials which are made by refining natural ceramics. Advanced ceramics are used in manufacture of sections of sensors, actuators, capacitors, spark plugs, etc.

2.1.1 Definition of corrosion

Just like earthquakes, floods, tornados and volcanic eruptions, corrosion is a natural process of destruction. The only difference is that corrosion can be controlled or prevented. Corrosion can be defined as a spontaneous destruction of metals and alloys which is triggered by chemical, electrochemical and bio-chemical interactions between metals and its alloys (Ahmad, 2006). Acids (inorganic and organic), oxygen, moisture, chlorides and temperature are good examples of corrosive environments.

Metals or alloys are usually at their unstable states. However, they convert to a more stable state through thermodynamic processes. Stable states include hydroxides, oxides, salts and carbonates. The process of metals reverting back to their stable states (original compounds in ores and minerals) is called corrosion.

Corrosion can be electrochemical, chemical or biochemical. The reacting particles must come into contact with each other for corrosion to take place as a chemical reaction. Here, electrons transfer from one medium to another. Such a reaction is controlled by the ratio of activation energy to internal energy. A good example of a chemical corrosion is an interaction between a metal with nonconductive organic compounds. Biochemical corrosion often takes place in environments with microbial activities. Stagnant water, organic products and soil are great examples of such environments (Ahmad, 2006).

Electrochemical kinetics controls electrochemical corrosion. Faraday's law determines the rate at which transfers reactions take place in an electrochemical reaction. Here, the entire metal surface or local regions may be affected by corrosion which results in stain or pitting corrosion. It should

be noted that for corrosion to be classified as being electrochemical, it must be caused by an external electric current. Figure 3 below shows forms of localized corrosion.

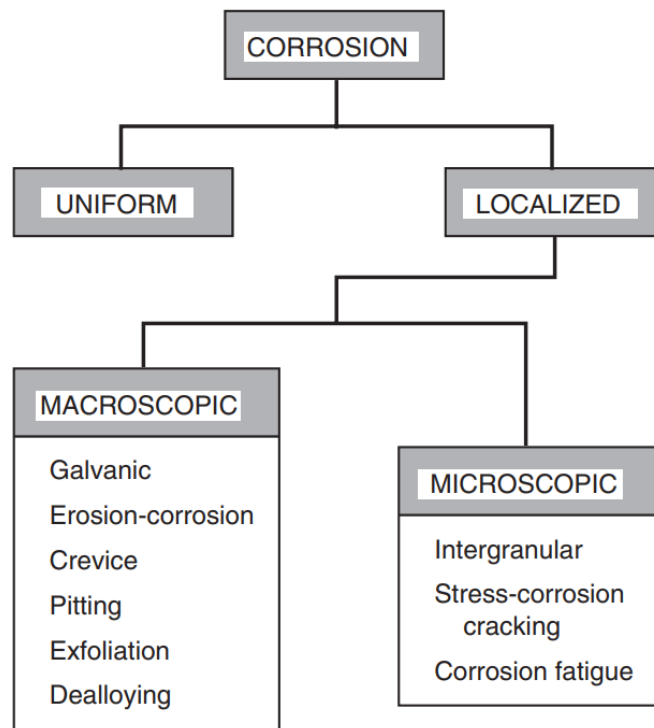


Figure 2 Forms of localised corrosion

2.1.2 What are crystalline Materials?

Material property and microstructure are determined by how atoms and ions are arranged.

Crystalline materials can be defined as solids which have distinctive internal structures that form unique faces or flat surfaces. The faces intersect forming characteristic angles which can be revealed using x-rays. Each crystalline material will give a distinct pattern when exposed to x-rays. The characteristic angle is independent of crystal size. However, it is determined by atomic, molecular and ionic arrangement (Askeland and Wright, 2010)

The Third Law of Thermodynamics asserts that crystalline materials are at their most stable physical states. This is due to the fact that a single crystal has atoms so closely packed together

such that the total potential energy is at minimum. The charge, bond order and size of atoms determine the packing structure or order (Aparicio and Ginebra, 2016).

2.2 BRAVAIS LATTICE

Crystalline materials have a specific packing order. The most common types of packing orders include simple cubic, rhombohedral, hexagonal, tetragonal, monoclinic and triclinic as shown in Figure 2 below.

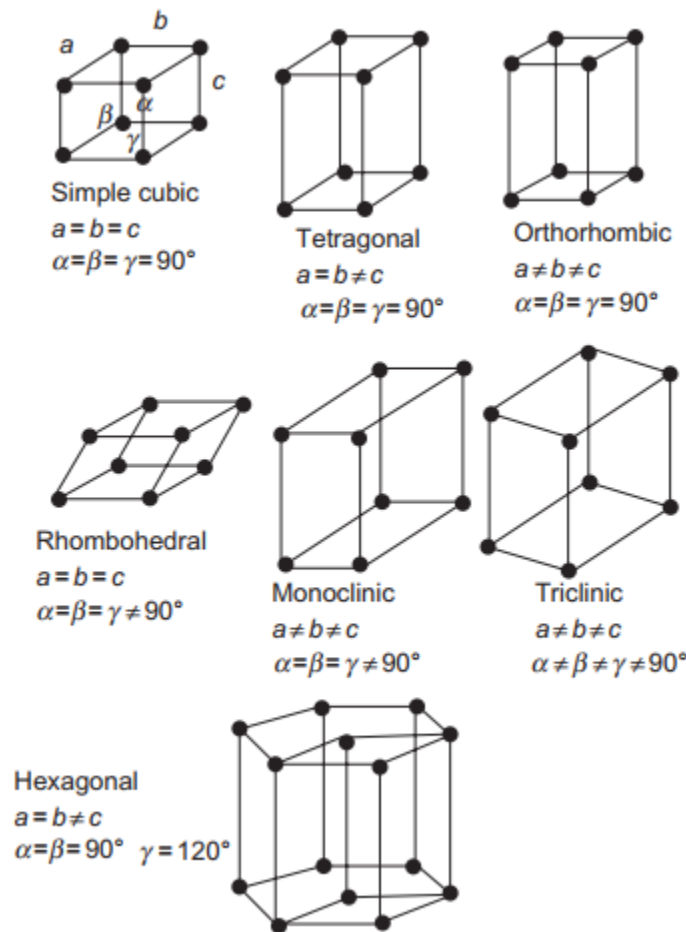


Figure 3 Bravais lattices

As shown in Figure 2, the seven lattices show the organization and structural relationship between atoms and show the packing order which determines the nature of the bulk crystal. The

structures shown above are known as unit cells and they remain unchanged as the crystal grows. Crystal growth can take place in any direction. There are different orders in which atomic or ionic arrangements can occur adapt (Askeland and Wright, 2010).

a. No-order

This arrangement takes place in plasma or monoatomic gasses where ions or atoms do not have an orderly arrangement.

b. Short-Range Order (SRO)

In this arrangement, the atoms extend only to the most adjacent neighbour. A water molecule is a good example of an SRO arrangement. For instance, each oxygen atom bonds covalently with two hydrogen atoms. There is no long-range order. This arrangement also exists in inorganic glasses and a majority of polymers.

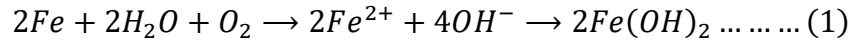
c. Long-Range Order (LRO)

This arrangement is present in most semiconductors, metal and alloys, some polymers and ceramics. Some materials exhibit atomic arrangements in which atoms extend to lengths of greater than 100 nm. Atoms in an LRO arrangement form a regular or grid-like pattern which is repetitive in three dimensions. These materials are known as **crystalline materials**. A single crystal is a crystalline material with one large crystal. Single crystals are important in optical and electronic applications due to their 'resistance nature to corrosion'. Polycrystalline materials are made of numerous small crystals which have different space orientations. These small crystals are known as grains. Grain boundaries can be defined as the borders between crystals.

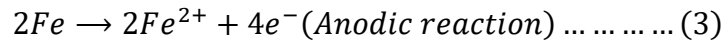
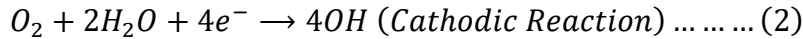
Misalignments take place at grain boundaries. Most crystalline materials in engineering applications are polycrystalline and good examples include aluminium alloys and steels used in aircraft and constructions respectively.

2.3 CONDITIONS FOR CORROSION INITIATION

Unlike irreversible electrode processes, corrosion does not require the application of an external current. In neutral or alkaline solutions, the corrosion of iron is as shown below:



Equation (1) can be broken down into cathodic and anodic reactions as:



From equation (2), it is evident that metals corrode through anodic reactions. In metals, corrosion is initiated by electrochemical reactions as a result of:

i. Different concentrations

This takes place when identical metals come in contact with different concentrations. Here, the metal immersed in less concentrated solution dissolves from the electrode and its ions are deposited on the electrode present in the highly concentrated solution.

ii. Exposure to temperature difference

This occurs in presence of electric current. Here, the metal exposed to lower temperatures dissolves and deposits at higher temperatures. The lower temperature region is the anode while the higher temperature is the cathode (Davis, 2001).

iii. Presence of impurities

Iron and silver are usually protected by tin or zinc due to their potential difference. Here, corrosion may occur due to different grain boundaries or crystal orientation in the metal. Impurities or contaminants can also be in form of molecules or atoms. Such atomic impurities can affect the properties of the material.

iv. Environmental conditions

The environmental conditions in which the metal is exposed determines the rate of corrosion. This is due to some presence of ions on certain conditions such as salty environment that accelerate the rate of deposition of this ions at the metal since it is positively charged and thus leading to increased corrosions at this region.

2.4 CORROSION CONTROL

a. Coatings

There are two types of coatings used for corrosion protection; metallic and non-metallic (organic and inorganic). The main objective of the coating is to isolate the underlying metal from corrosive media.

Metallic coatings can be from either a noble metal (such as tin) or a more active metal. Use of noble metals is common as the noble metal is more resistant to corrosive medium. In case a more active metal is used as the coating, it will 'sacrifice' itself to the corrosive substance. Zinc is a good example of an active metal which is used as a metallic coating (Davis, 2001).

Organic coatings isolate the metal from corrosive environment. Rather than forming a barrier layer, organic coatings supply corrosion inhibitors.

Inorganic coatings serve like barrier coatings. Good examples include ceramics, porcelain enamels and glass linings. Ceramic coatings such as silicides and carbides are ideal for heat resistant and wear resistant applications respectively.

b. Material Selection

Metals and alloys exhibit inherent and unique corrosion behaviour which ranges from low corrosion resistance (active metals) to high corrosion resistance (noble metals). In addition, the resistance to corrosion of a metal is dependent on environmental conditions. The rate of corrosion is therefore given by:

$$\frac{\text{environment corrosivity}}{\text{corrosion resistance}} = \text{rate of corrosion}$$

c. Cathodic Protection

This protection is suitable in electrolytic environments. The cathodic protection reduces the effect of corrosion causing current. Corrosion protection acts by forcing the current to flow to the metal structure without causing any damage. A sacrificial anode system adapts the use of active

metals such as magnesium and zinc which are connected to the structure with the aim of providing the cathodic-protection current.

d. Design

Rational design principles can eliminate numerous corrosion problems while reducing the cost and time incurred during corrosion repair and maintenance. Usually, corrosion takes place in crevices or dead spaces where corrosive medium becomes more active. For instance, in areas where stress-corrosion cracking is probable, the components can be designed in such a way that they operate below the threshold stress for cracking. In machine components where corrosion is expected, the design should be able to cater for maximum interchangeability of critical parts (Davis, 2001).

2.5 RELATIONSHIP BETWEEN CRYSTAL STRUCTURE AND CORROSION

Metals are sometimes applied as protective coatings through methods such as electrolysis. During these processes, preferred orientations are usually developed. This orientation exists between the protective metal and the base metal. It is important to note that initial corrosion processes are important and in such as case, effects of crystal orientation and structure are important.

Ceramics are engineering materials which are used in applications where corrosion-resistant properties are required. The advantages of ceramics over other classes of materials include; high melting temperature, high hardness, good wear resistance and high level of chemical inertness in corrosive environments.

Alloys are not homogenous pure materials but are a mixture of multiple phases. Each phase comes with a characteristic crystallographic structure and chemical composition. Therefore, when such structures are exposed to different corrosive environments, each phase exhibits different corrosion behaviour. This implies that the constituents of the alloy play a significant role in corrosion (Ahmad, 2006).

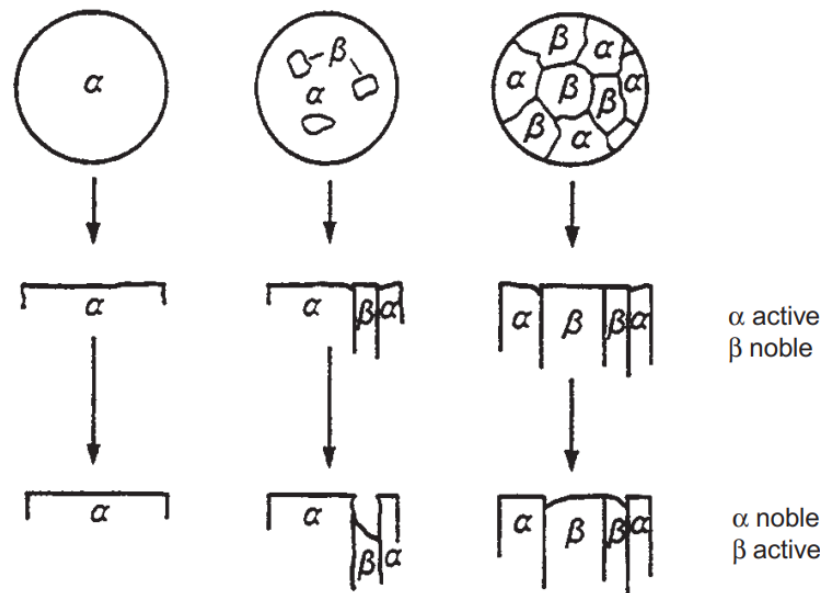


Figure 4 Corrosion behaviour and microstructure

Figure 3 demonstrates the relationship between microstructure and corrosion behaviour in three alloys. In scenario 1, alpha is more active than beta phase i.e. beta phase is more resistance to corrosion than alpha. In second scenario, beta phase remains almost unattacked while alpha phase on adjacent sides of beta particles is attacked. In third scenario, alpha phase is attacked while beta phase still remains unattacked. This was due to the fact that the alpha was active and beta was noble. These scenarios are also evident in situations where alpha is noble and beta is active.

2.5.1 Lattice, Basis, Unit Cells and Crystal Structure

A lattice can be defined as a collection of points or lattice points which are arranged in a periodic pattern in such a way that the surroundings of each point in the lattice are identical. It is important to note that a lattice is infinite in extent and is mathematically constructed.

A basis or motif is a group of at least one atom located in a specific way with respect to each other and is linked to each lattice point. The basis may contain atoms of one or more types.

A crystal is obtained by placing atoms of the basis on every lattice point. A unit cell is only defined by specifying the following; lattice parameters and/or ratios between axial lengths, atomic coordinates and interaxial angles.

2.6 EFFECT OF CORROSION ON MECHANICAL PROPERTIES

In structures, mechanical strength is the most affected property by corrosion. Even though other properties are affected, they do not lead to failure as frequently as in the case where strength deteriorates (Askeland and Wright, 2010). However, not all cases of corrosion will lead to a decrease in mechanical strength. For instance, corrosion might lead to healing of flaws and cracks in the surface layers of a specimen when diffusion of impurities takes place. Loss of strength can take place due to:

- Crack growths
- Formation of low strength phases
- Melting of secondary phases at high temperatures
- Surface cracking arising from polymorphic transitions in crystalline phases at the surface.

Stress corrosion cracking occurs when a material is subjected to a corrosive environment while being loaded mechanically. Here, both stress and corrosion must be active. If either is absent, cracking will not occur.

2.6.1 How are metals affected by corrosion?

The effect of corrosion on metal and alloys depend on the stability of the metal. As mentioned earlier, platinum, gold, tin and a few metals only occur naturally in pure form. Pure metals are known to contain more bound energy which puts them at a higher energy state than how they exist in ores. How a metal is affected by corrosion depends also on the type of corrosion. The most popular types of corrosion include; uniform corrosion, galvanic corrosion, pitting corrosion, crevice corrosion and filiform corrosion (Popov, 2015).

Uniform corrosion

This form of corrosion takes place over a large fraction of the metal surface area and reduces the thickness of the metal. Here, the corroding metal must be metallurgically and compositionally uniform. Uniform corrosion is usually controlled by metallic and organic coatings, inhibitors, and at times cathodic protection. Examples of uniform corrosion are; tarnishing of silver ware and electrical contacts, rusting of steels and corrosion of structural steels.

Galvanic corrosion

Galvanic corrosion is as a result of potential difference between two metals which are electrically connected. The metal or alloy with higher negative potential will corrode while the more positive one is the cathode. The cathode is protected from corrosion by the anode. Good examples of galvanised dissimilar metals include; a solder on a copper wire, steel fasteners in an aluminium foil and stainless steel in contact with galvanized steel.

Pitting corrosion

This is an extremely localized attack that results in holes in alloys or metals. Pitting corrosion is the most destructive localised form of corrosion. Pits can be defined as small holes or cavities whose depth is equal to or greater than the surface diameter. In practical situations, pits penetrate the metal leading to equipment failure.

Crevice corrosion

Crevices are usually formed in condensers, at welds and in between metals and valves. Crevice corrosion is triggered by small volumes of solution that get trapped in crevices. It leads to a destruction of mechanical joint strength in structures made of aluminium, stainless steel, titanium and copper. For this corrosion to take place, the solution must penetrate the crevice.

Filiform corrosion

This corrosion is observed in steel and aluminium which have thin organic coatings. Corrosion resistant alloys of copper, stainless steel and titanium are not susceptible to filiform corrosion.

2.6.2 Economic Impact of Corrosion

In the United States alone, metal corrosion costs the economy about \$300 billion annually. About a third of these costs are as a result of application of corrosion resistant materials and implementation of best corrosion-related technical practices such as machine or structure design (Davis, 2001). According to Davis, the elements that increase the cost of corrosion include:

- Repair and maintenance
- Replacement of buildings or equipment
- Product loss
- Corrosion control
- Technical support
- Design and insurance
- Equipment and parts inventory

Automobile and aircraft industries are the most affected by corrosion. Some of the corrosion is avoidable while a huge percentage is unavoidable.

2.7 USE OF NANOCRYSTALLINE MATERIALS AS COATINGS

A class of materials whose crystalline size is smaller than 100 nm are known as **nanocrystalline materials**. There are several techniques that can be used to synthesis nanocrystalline materials; mechanical milling, plastic deformation, inert gas condensation and electrodeposition.

Nanocrystalline materials are known to have higher ductility, hardness, fatigue strength and wear resistance than crystalline materials.

Nanocrystalline materials have a high-volume fraction of grain boundary and hence their corrosion behaviour may be different from respective counterparts. Nickel-Aluminium (NiAl) intermetallic phase shows good oxidation and corrosion resistance as it forms an adherent, dense and protective aluminium oxide layer. Even though this compound has proved to be suitable for corrosion resistance applications, the crystalline size still plays a major role in rate of corrosion.

Tavoosi et al. (TAVOOSI et al., 2015) conducted an experiment to investigate the effect of crystalline size on corrosion. It was reported that the corrosion resistance property of NiAl coating increased as the annealing time increased. This was because annealing time reduced the volume fraction of grain boundaries and tripe junctions as active sites for corrosion attack.

2.8 SUMMARY

From literature, corrosion has been defined as a natural occurring process which affects mechanical properties of active metals. However, the rate of corrosion will not be similar in all metals and alloys. Factors that affect the rate of corrosion include:

- Environmental conditions
- Pressure
- Temperature
- Impurities present in metals and alloys

Corrosion can be controlled by the use of coatings, cathodic protection, material selection and design considerations. Even though metals are affected by corrosion, crystalline materials have proven to be more resistant to corrosion. Crystalline materials are also resistance to wear and have a high melting points. A good example of a crystalline material is ceramics. Nanocrystalline materials, such as NiAl compounds, are an improvement to crystalline materials as they are more ductile, wear and corrosion resistance, and have more endurance. These compounds can be used as coatings to protect metals exposed to corrosive environments.

3 CHAPTER 3: EXPERIMENTAL METHODOLOGY

Materials, techniques and experimental procedure employed in this study are focused in this chapter. So as to achieve the objectives, weight loss method is employed in determination of corrosion rate of the mild steel specimens rather than polarization method. The weight loss method involves full immersion of the test specimen or the coupons into a solution of different concentration and the test specimen's weight loss is considered as a function of time. The loss of weight of the material is used in determination of corrosion rate of the specimen after a stipulated duration of time. In weight loss method, measurements of the coupons are taken during the exposure and after the removal from the corrosive agent in accordance to American Standard of Material and Testing, 2000a (ASTM G162-99).

The experiment was carried out for a duration of 4 weeks that is 1008 hours. The laboratory testing involved simulation of mild steel specimen when they are exposed to various concentration in the soil. The test solutions were prepared in a 500 ml beaker while the mild steel specimens were polished and placed in the solutions. After every seven days, the specimens were removed from the solutions and were carefully placed in other solutions that had the same concentration. In the experiment, every specimen was assumed to have a uniform strength, uniform thickness and uniform rate of corrosion. Therefore, the weight loss of the specimen from retrieval at different time was correlational to each other.

3.1 EXPERIMENTAL APPARATUS AND REAGENTS

- Mild steels specimens
- Solutions of different concentrations (NaCl, Na₂CO₃ and Na₂SO₄)
- Distilled water
- 500 ml beakers
- Volumetric flask
- Acetone

3.2 EXPERIMENTAL PROCEDURE

Immersion test method was employed in the experiment since it produces reliable results. The experiment was carried by immersing of mild steel specimens in seven containers that contained different solutions with different concentrations. One container contained distilled water while the rest contained sodium chloride, sodium sulphate and sodium carbonate in concentrations of 0.5M and 1M respectively. Before the experiment was carried out the mild steels specimens and the test solutions were prepared as explained below. Figure 5 shown below is the setup of the immersion test that was carried out.



Figure 5: The setup of the immersion test

3.3 SAMPLE PREPARATION

The specimens were mechanically polished using 400, 800 and 1200 emery paper respectively to ensure uniform surface and the removal of the already existing oxide cover. The specimens were then lubricated using distilled water. They were then cleaned by buffing, degreased in benzene, and washed by 50% acetone. They were dried in air and stored in desiccators. They were then weighed for their original weight before corrosion.

The mild steel specimen is cut and prepared at precision with measurements as 2cm by 2cm by 0.03mm. The composition of the mild steel was checked to ensure that all the specimen had the same chemical composition to ensure the repeatability of the experiment and to ensure

that the results are comparable and reliable. The chemical composition of the specimens was such as: C-0.22%, S-0.0018%, Ni-0.25%, Mn-0.62%, P-0.022%, Mo-0.5%, Si-0.28%, Cr-0.095%, Cu-0.20% and the remaining portion is iron (Mehra, & Soni, 2002).

3.4 PREPARATION OF TEST SOLUTIONS

The corrosive agents used were NaCl, Na₂CO₃ and Na₂SO₄ and were prepared using the following steps.

- i. 250 ml was measured and was put in six beakers
- ii. 1M of sodium carbonate solution- 26.5 g of sodium carbonate pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.
- iii. 0.5M of sodium carbonate solution- 13.25 g of sodium carbonate pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.
- iv. 1M of sodium sulphate solution- 35.5 g of sodium sulphate pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.
- v. 0.5M of sodium sulphate solution- 17.25 g of sodium sulphate pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.
- vi. 1M of sodium chloride solution- 14.625 g of sodium chloride pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.
- vii. 0.5M of sodium carbonate solution- 7.313 g of sodium carbonate pellet were weighed using a digital electronic balance and was put in a 250 ml volumetric flask. The solution was shaken vigorously and distilled water was added until the meniscus level was reached.



Figure 6: Preparation of the corrosive agents

3.5 CORROSION STAGE

The specimens were weighed using a digital weighing balance and were then fully immersed in test solution with varying concentration of sodium chloride, sodium carbonate, sodium sulphate and distilled. The specimens were also exposed to the corrosive solutions for a duration of 7 days that is 168 hrs. After this period of exposure, the specimens were removed, washed, degrease, dried and then they were weighed to obtain the final weight that was used in computing the weight loss.

3.6 CLEANING THE SPECIMEN

The mild steel coupons were first dipped in distilled water for a about 3-5 minutes. This was followed by the specimens washed using ordinary fresh water using a brush and then soaking them in acetone for 5minutes. The specimens were then dried in sun and weighed to obtain the initial weight using a digital electronic weighing balance. The specimens were soaked inside the solutions where after 7 days, the specimens were removed from the solution and cleaned using the same procedure. The weight of the each measured and the weight loss of each specimen was computed.

3.7 DETERMINATION OF THE CORROSION RATE

According to Oparaodu, and Gideon, 2014, corrosion rate was calculated by assuming that corrosion occurred uniformly over the entire surface of the specimen. The expression implemented in the calculation of the corrosion rate is as follows

$$\text{Corrosion rate}(mm/y) = 87.6 \times (W / DAT)$$

Where W = weight loss in milligrams, D = metal density in g /cm³, A = area of sample in cm², T = time of exposure of the metal sample in hours.

The surface area of each specimen was calculated using the following formula:

$$\text{Surface area } (A) = 2 [(L \times W) + (W \times T) + (L \times T)]$$

Where,

L is the length of the specimen

W is the width of the specimen

T is the thickness of the specimen

4 CHAPTER 4: EXPERIMENTAL RESULTS AND ANALYSIS

The results in the experiment were dependent on the method of data collection since the experiment involved quantitative analysis of the weight of the specimens. The weight loss of each specimen was computed by determining the difference between initial weight of each specimen and the final weight. The corrosion rates of the various mild steel specimen in different solutions were computed using the formula stated above. At the end of six weeks, the study was completed and the following observations in different solution were made.

4.1 0.5M AND 1M CONCENTRATION OF SODIUM CARBONATE (Na_2CO_3)

At the end of 6 weeks that is 1008 hours, both concentration of Na_2CO_3 that is 0.5M and 1M solutions of sodium carbonate were clear and the specimens that had been immersed were clean and had no film. Figure 7 shown below is a photo of the solutions and the immersed specimen after 1008 hours.



Figure 7: Immersed pieces of mild steel in 0.5M and 1M solution of Na_2CO_3

4.2 0.5M AND 1M CONCENTRATION OF SODIUM CHLORIDE (NaCl)

By 7th day of the experiment, black film had been formed in the mild specimens that had been immersed in both 0.5M and 1M solution of sodium chloride. There were brown particles in both

solutions and this was an indication that there was presence of iron chloride which is brown in colour. Figure 8 shown below shows results after the end of the experiment.



Figure 8: Changes in 0.5M and 1m solutions of sodium chloride at the end of the experiment.

4.3 0.5M AND 1M CONCENTRATION OF SODIUM SULPHATE (Na_2SO_4)

In both concentration of sodium sulphate, a black coating had been formed on the immersed specimens and therefore there was existence of corrosion. The black coating was suspected to be presence of iron sulphate. This occurred after the first week.

4.4 DISTILLED WATER

There was a black coating on the mild steel specimen that was immersed in distilled water at the end of the first seven days of the experiment. The distilled water solution had also turned brown. This was a clear indication that black oxide coating had been formed on the surface of the immersed specimen.

The weights of all the test mild steel specimens were measured before they were immersed in the various solutions. After every 7 days, the specimens were removed from the solutions where they were cleaned up and the final weights of the specimens after the 7 days were recorded. These weights were used in computation of weight loss for each specimen. The weight loss of each

specimen was computed by determining the difference between initial weight of each specimen and the final weight. The weight loss of each specimen was computed and recorded in table 1 below.



Figure 9: Colour changes in NaCl and distilled water at the end of 1008 hours



Figure 10: Change in weight of specimen dipped in 1M of NaCl solution after 7 days

4.5 TABLES OF RESULTS

Table 1: Weight loss of specimens immersed in different solutions

TIME (hours)	WEIGHT LOSS IN DIFFERENT SOLUTIONS						
	0.5M Na ₂ CO ₃	1M Na ₂ CO ₃	0.5M NaCl	1M NaCl	0.5M Na ₂ SO ₄	1M Na ₂ SO ₄	H ₂ O
168	-0.29	-0.43	-0.36	-0.29	-0.21	-0.183	0.21
336	-0.405	-0.52	-0.27	-0.3	-0.09	-0.21	0.184
504	-0.25	-0.45	-0.35	-0.23	-0.14	-0.16	0.26
672	0.22	-0.39	-0.25	-0.19	0.065	-0.25	0.29
840	-0.47	-0.48	-0.36	-0.21	0.11	-0.184	0.35
1008	-0.32	-0.55	-0.15	-0.16	0.05	0	0.4

Corrosion rates for different specimens after every 168 hours were computed in using the recorded weight loss of the specimens in table 1 using the following equation.

$$Corrosion\ rate(mm/y) = 87.6 \times (W/DAT)$$

Where W = weight loss in milligrams, D = metal density in g /cm³, A = area of sample in cm², T = time of exposure of the metal sample in hours. Where the surface area of each specimen was:

$$\begin{aligned}
 Surface\ area\ (A) &= 2 [(L \times W) + (W \times T) + (L \times T)] \\
 &= 2 [(2 \times 2) + (2 \times 0.3) + (2 \times 0.3)] = 10.4\ cm^2
 \end{aligned}$$

The results of the computed corrosion rates for each specimen are recorded in table 2 below.

Table 2: Values of corrosion rates for various specimen in different solutions

TIME	0.5M	1M	0.5M	1M NaCl	0.5M	1M	H ₂ O
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(hours)	Na ₂ CO ₃	Na ₂ CO ₃	NaCl		Na ₂ SO ₄	Na ₂ SO ₄	
168	-0.5736	-0.8046	-0.6543	-0.5246	-0.3980	-0.3459	0.2012
336	-0.3918	-0.4905	0.2348	-0.2612	-0.2845	-0.2044	-0.0920
504	-0.1750	-0.2846	-0.2054	-0.1288	-0.1391	-0.0976	0.0838
672	-0.1069	-0.1895	-0.1174	-0.0883	-0.0948	-0.1204	0.0755
840	-0.1835	-0.1835	-0.1076	-0.0777	-0.0847	-0.0687	0.0705
1008	-0.0965	-0.1581	-0.0422	-0.0442	-0.0474	0.0000	0.0671

4.6 GRAPHS AND ANALYSIS

Graphs of corrosion rate (mm/Y) of the specimen in each solution against the amount of time in time were plotted and are attached below. This helped in the analysis of how the rate of corrosion varies with time depending on the concentration and the type of solution in which a specimen is immersed.

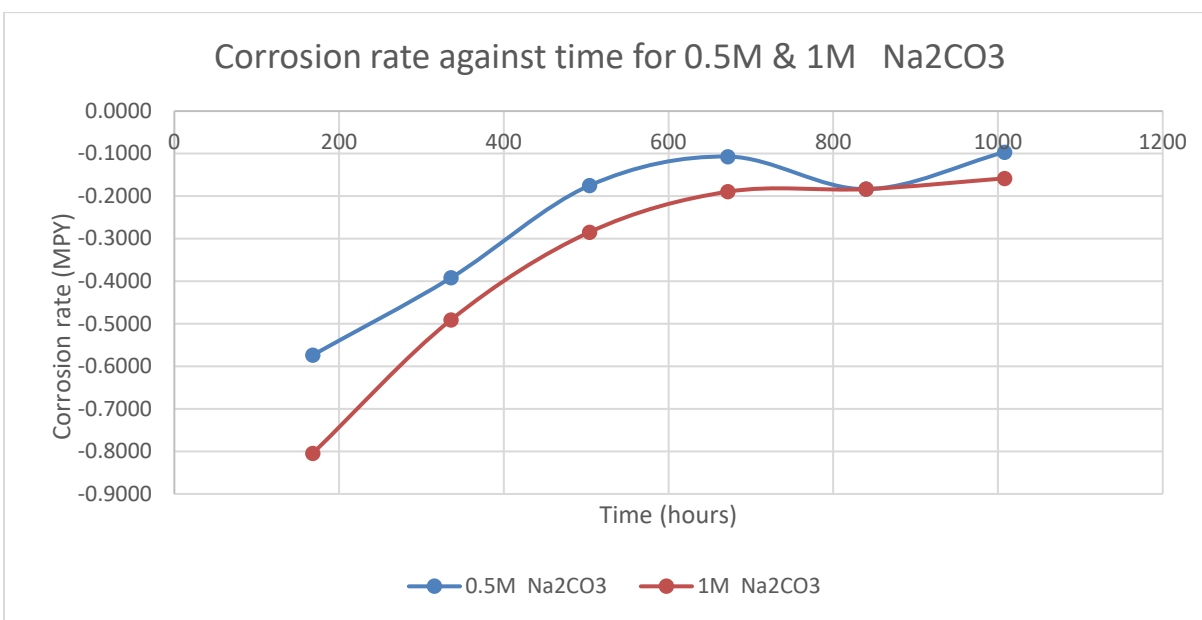


Figure 11: Corrosion rate for specimen placed in 0.5M and 1M of sodium carbonate solution

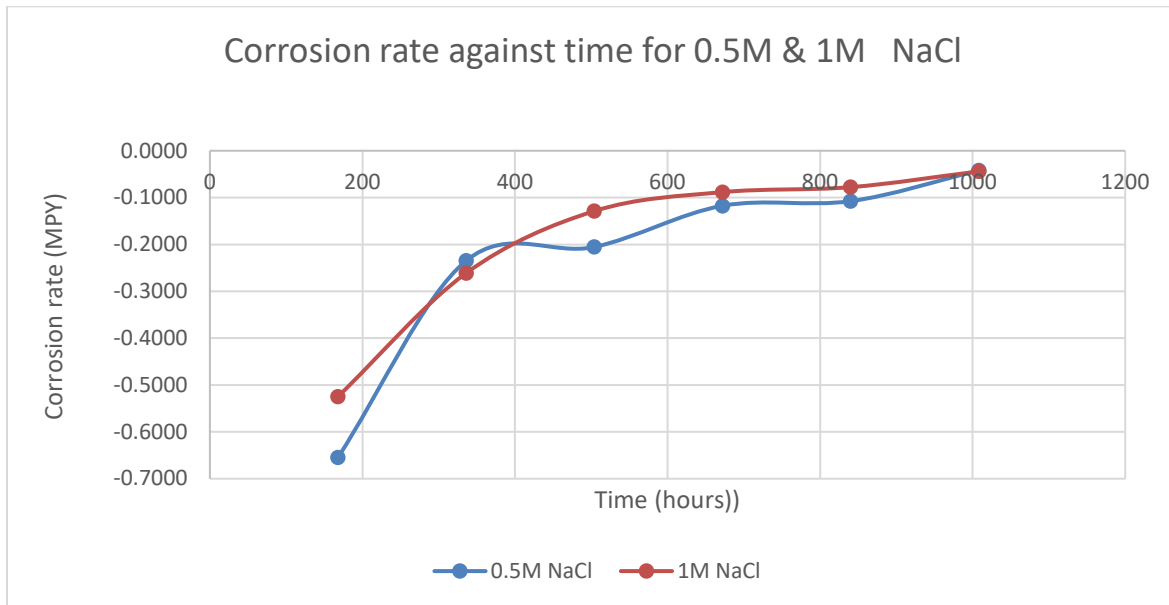


Figure 12: Corrosion rate for specimen placed in 0.5M and 1M of sodium chloride solution

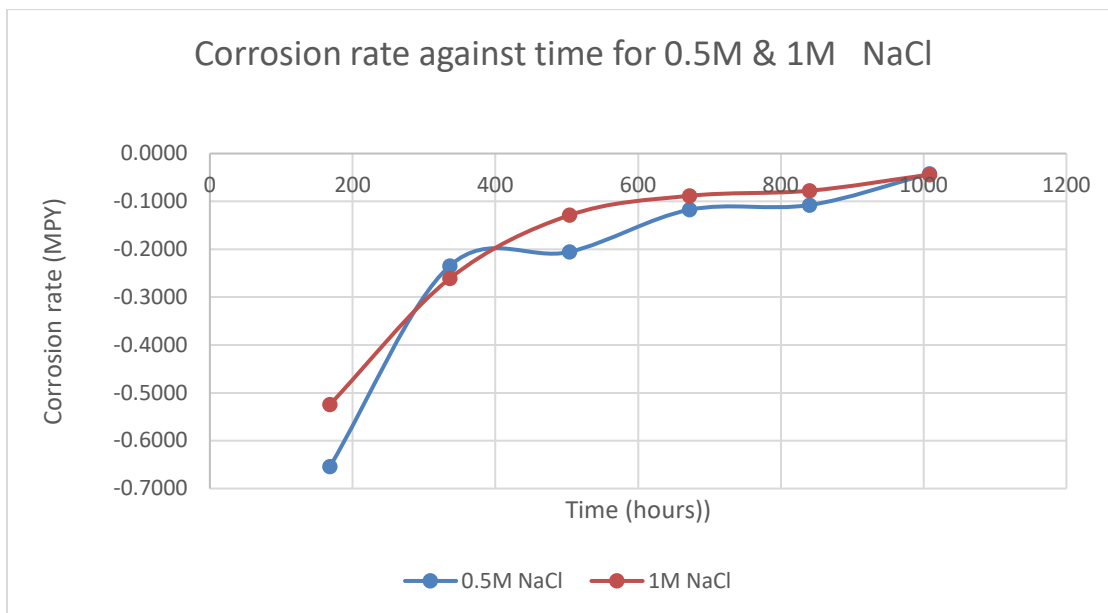


Figure 13: Corrosion rate for specimen placed in 0.5M and 1M of sodium sulphate solution

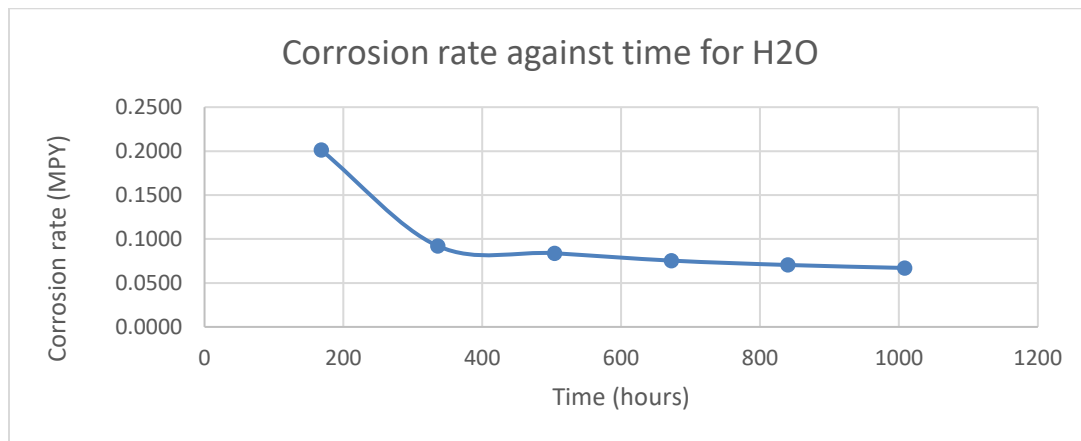


Figure 14: Corrosion rate for specimen placed in distilled water

5 CHAPTER 5: DISCUSSION OF THE RESULTS

After three days, the specimen that was immersed in distilled water was fully covered with a black coating and the distilled water had changed to a brownish colour. At the end of seven days, the distilled water turned brown indicating that there was a reaction that was taking part. When specimen containing iron is exposed to moisture as in the case when the specimen was immersed in distilled water, the iron oxides to form iron hydroxide that is brown in colour. This reaction leads to weight loss since the weight of the specimen that was immersed in distilled water had rapidly decreased after the end of 168 hours.

For the specimen immersed in sodium chloride, after the first seven days a black coating had been formed on the specimen on both concentrations of sodium chloride. Both 0.5M and 1M solutions of sodium chloride had brown particles in them. After the next 7 days, the 0.1M

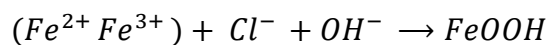
solution of sodium chloride turned brown while the other solution of 0.5M sodium chloride was black in colour. Both specimens that were immersed in 0.5M and 1M concentration of sodium chloride solution had a dark black colour when they were washed and dried. The weight of these two specimens had increased rather than a weight after the first seven. The weight of the immersed specimen then the weights were decreased gradually.

Specimens that were immersed in both concentration of sodium carbonate had increase in weight for the first 168 hours but later the weight started reducing. There was no colour change in both solution upto the end of the experiment. For specimens that were immersed in sodium sulphate, they were coated with a black coating for the first seven days and the weight of the specimen was increased suddenly for the first days but the weight was slowly decreased after the experiment. The presence of the black coating on the specimen showed that there was a reaction that was taking place.

The results obtained from the experiment that is performed are analysed in tables and graphs attached and are used to explain the aim and purpose of the experiment. The specimens immersed in distilled water was observed to have a high corrosion rate at the first days since oxidation of iron is faster in presence of oxygen that dissolved in distilled water but the corrosion rate was decreasing as the time in terms of hours were decreased. 0.1M of sodium carbonate had high rate of corrosion that was followed by 0.5M of sodium chloride and the solution with the lowest rate of solution was 1M of sodium sulphate. Sodium carbonate solution had intense effect of corrosion on the specimens compared to other salt solutions that were used in the experiment. This is because sodium carbonate did not form any coating and therefore effect of corrosion of much experienced on the surface of specimen immersed in this solutions. 0.5M sodium chloride solution and 1M sodium chloride took more time before the coating was formed on the surface of the immersed specimen as compared to both concentration of sodium sulphate and therefore these solutions were ranked after the both concentrations of sodium carbonate. low concentrations of sodium chloride are more corrosive as compared to higher concentration of sodium chloride. This is because higher concentration of sodium chloride leads to more formation of protective coating that reduced the rate of corrosion rather than in lower concentration solution of sodium chloride where there is lesser formation of the iron chloride (Popov, B. (2015). Corrosion rate in

distilled water is lesser compared to corrosion in salts because there is faster reaction of iron in water that lead to formation a black oxide at a faster rate. The oxide coating reduces the rate at which corrosion occurs on the surface of the immersed specimen.

The main component in mild steel is iron which undergoes corrosion through electrons transfer. When sodium chloride solution was used a corrosive agent , sodium ions and chloride ions were produced by the sodium chloride solution. Both sodium ions and chloride ions increases the ability of the electrolyte solution to carry ions and the rate of corrosion is accelerated. The more the concentration of sodium chloride, the higher the transfer of ions in the solution and there is more reaction occuring (Subir, P. (2009). The electrons are easily moved in a solution containing sodium chloride than in distilled water. This is used to hypothesis why the in the result obtained there was a faster rate of corrosion in the specimens that were immersed in sodium chloride solution. Figure 10 shown above show that the corrosion rates for 1M of solid chloride are higher as compared to corrosion rate of 0.5M of soium chloride. This is a clear indication that when a mild steel specimen are placed in different concentration of sodium chloride solutions, the rate of corrosion is intense at the specimen placed in the solution containing a higher concentration of sodium chloride. In environments containing sodium chloride,the corrosion process may be associated by presence of oxygen. Sodium chloride solutions contribute high amounts of chloride ions that leads to formation of FeOOH as illustrated in equation below(Ahmad, Z. 2006).



In addition to the formation of FeOOH, chchloride ions Cl^{-} absorbs the surface of immersed mild steel that competes with the oxide and hydroxil ions that are dissolved in elecrolYTE. The chloride ions in sodium chloride leads to the hydration of the metal ions and therefore movement of the metal ions is favoured and moves to the solution(Afolabi et al. 2014) The rate at which the metal is dissolved is reduced due to the effect of the oxygen dbsorbed. This explain why there was an slight increase in weight of the mild steel specimens that were immersed in both concentrations of sodium oxide solutions. Askeland, D. and Wright, W. (2010). Found that the slight increase in weight loss could have also resulted due to presence of iron ions that were continously added into the solutions that were caused by corrosion the mild steel specimens. Oparaodu et al.(2014)

stated the reduction in rate of corrosion of the mild steel specimen immersed in the sodium chloride solution with higher amount of concentration resulted due to reduction in the solubility of the sodium chloride solution that was caused by deposition of the corroded particles and therefore the process of corrosion was slowed down. The reduction of corrosion rates at higher concentration of sodium chloride could also have been caused due to an increment in the viscosity of the electrolyte solution that lead to slowing down of the movement of the metal ions as demonstrated in Wan Nik et.al (2012).

The chloride ions do not participate in chemical reaction involved in the corrosion of metals according to (Mehra & Soni). These ions are used as an accelerator medium that is a catalyst in the electrolysis process. They help in the removal of the metal ions that iron ions that found at the anode through formation of compounds that are soluble and therefore the reaction at the anode is faster and therefore the rate of corrosion is much accelerated when there is presence of the chloride ions. This explains why the rate of corrosion of the mild steel specimen immersed in 1M sodium chloride solution was lesser as compared to the mild steel specimen that was placed in 0.5M sodium chloride solutions. Moreover, the rate of corrosion at higher concentration is evident since at high concentration of sodium chloride solution reduces the concentration of oxygen that results in rate of corrosion. The chloride ions from the sodium chloride solution leads to increased amount of acidity levels that leads to promotion of corrosion.

The mild steel specimen placed in distilled had a corrosion rate higher than the specimens that were placed in other salt media such as in sodium chloride, sodium carbonate and sodium sulphate. This resulted due to presence of low corrosion resistance in distilled water was higher as compared to the specimen placed in salt solutions. The rate of corrosion in an immersed specimens highly depends on the amount of oxygen that is dissolved in solution. The specimen immersed in distilled water had less build up of a coating and therefore the corrosion rate were higher as compared to when the specimen were placed in salt solution.

For specimens dipped in sodium sulphate solution, the rate of corrosion of the specimens immersed in sodium sulphate is lesser compared to the rate of corrosion experienced in other salts. This is because at first, the corrosion of iron in mild steel is suddenly increased due to

presence of electrochemical corrosion reaction that leads to formation of iron sulphate coating. The deposited particles of iron in sodium sulphate solution leads to the saturation of the solution and therefore the reduction in solubility of the solution. This leads to reduction in the corrosion rate in specimens that were immersed in sodium sulphate concentration. The reduction of corrosion rates in both solutions of sodium sulphate solution due to the presence of formation of a coating and decelerates further formation of coating and thus reducing the amount of corrosion.

The rate of corrosion of metals especially depends highly on the environmental conditions, impurities and amount of concentrations of the salts in which the metals are exposed to as demonstrated in (Askeland and Wright 2010). The rate of corrosion in mild steel may be reduced through application of protective coatings where the piece of mild steel is coated using a protective coat. Since corrosion in metals is caused by chemical reaction such as exposure of the metal to water, sulphur, chlorine and oxygen, these harmful environmental conditions may be avoided so as to reduce the rate of corrosion. The use of sacrificial coating may be employed as a way of reducing corrosion in mild steel. This may be done through employment of cathodic and anodic protection. The use of corrosion inhibitors may be employed where chemicals are used to react with the surface of the mild steel specimen and therefore form a protective coating on the surface of the mild steel specimen. This aids in the reduction of the corrosion rate of the metal.

6 CHAPTER 6: CONCLUSION

The corrosion rate of mild steel can be investigate using the weight loss method. The method was selected due to its simplicity, reliability and affordability and convenience. The experiment was carried out in varying concentration of salt and at different time intervals. This is to determine how salt concentration and time affects corrosion.

The rate of corrosion is affected by the nature of mild steel that is the chemical properties of the material and the environmental conditions that are represented by the chemical concentrations of the solutions.

The rate of corrosion in mild steel also depends on the oxygen concentration dissolved in the solution. High concentration of oxygen dissolved in corrosive media leads to formation of more coating on the surface of mild steel that decreases the rate of corrosion.

The ranking of the corrosive media in terms of the rate of corrosion of the immersed mild steel specimen that were tested from the corrosive media with a high corrosive rate were as follows: 1M of sodium carbonate, 0.5M of sodium chloride, 1M of sodium chloride, 0.5M of sodium carbonate, 0.5M of sodium sulphate and 1M of sodium sulphate.

6.1 RECOMMENDATIONS AND FUTURE WORK

- a) Future researchers should employ both the weight loss method and also polarization method in computation of corrosion rates of the specimens.
- b) Future researchers should employ and develop advanced ways in the interpretation and analysis of the experimental data.
- c) The time in which the experiment is carried out should be prolonged so that better and consistent results may be obtained.
- d) The use of the data obtained for different solutions should be used in developing of models that would be used in determining the life time of the mild steel specimen.

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