

ABSTRACT

The project aim was to examine the corrosion process of C1018 carbon steel. Carbon steel finds its application in a variety of industries. Given that it is one of the most used metals in structural applications, it is essential to study how it can be corroded. Immersion test was conducted to analyze a number of C1018 specimens. 20% sodium chloride was used to determine how steel behaves when it is exposed to the solution. The various types of corrosion were studied to see which affects C1018 and the reasons why they act on the metal were determined. The results obtained were used to calculate the rate of corrosion. Weight loss and surface appearance of the metal were also used during the analysis. (Fouda, Rashwan, Shaban, & Hoyenda E. Ibrahim, 2017). This study is important because it helped to give insights on the environment in which C1018 can be used or not used in.

Table of Contents

ABSTRACT	i
1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Justification	3
1.4 Objectives	3
2 LITERATURE REVIEW	4
2.1 Overview	4
2.2 Corrosion process in steel	4
2.3 Types of corrosion	5
2.3.1 General corrosion	5
2.3.2 Localized corrosion	8
2.3.3 Metallurgical Influenced Corrosion	10
2.3.4 Mechanically Assisted Degradation	12
2.3.5 Environmentally Induced Cracking	14
<i>Stress Corrosion Cracking</i>	14
<i>Hydrogen Induced Cracking</i>	15
2.4 Factors Affecting Corrosion	17
3 METHODOLOGY	21
3.1 Overview	21
3.2 Equipment and materials used	22
3.3 Experiment procedure	22
4 RESULTS AND ANALYSIS	25
4.1 Experiment 1 Results	25

4.2	Experiment 2 Results.....	28
5	DISCUSSION.....	33
	Comparing the results obtained with the works of other authors.....	36
6	RECOMMENDATION	39
7	CONCLUSION	40
8	WORKPLAN	41
9	REFERENCES	42

List of Figures

Figure 1: Galvanic Corrosion (Li, 2009)	7
Figure 2: Pits on Metal Surface (Pessu, 2015).....	9
Figure 3: Areas Vulnerable to Crevice Corrosion ((Uhlig H., 1948))	10
Figure 4: Experiment 1 Samples after testing.....	25
Figure 5: A graph of Mass Loss against Time.....	27
Figure 6: A Graph of Corrosion Rate against Time.....	28
Figure 7: Experiment 2 Samples before testing.....	29
Figure 8: Experiment 2 Samples after testing.....	29
Figure 9: A Graph of Corrosion Rate against Time for Experiment 2	31
Figure 10: Image of Distribution of Rust on the Surface.....	32

List of Tables

Table 1: Properties of C1018	21
Table 2: Weight of Samples 1	25
Table 3: Dimension of Samples 1	26
Table 4: Sample Calculations	26
Table 5: Weight of Samples 2.....	29
Table 6: Dimensions of Samples 2	30
Table 7: Sample 2 Calculations	31

1 INTRODUCTION

1.1 Background

Carbon steel, is a steel mixture for which the carbon content goes up to 2.1% and for which elements like chromium, nickel, molybdenum or even zirconia is not present. Its properties can be changed based on the heat treatment applied to it i.e. carburizing, spheroidizing, annealing, quenching or normalizing; thus finds a wide range of application in most engineering projects. (Callister, 1997). Based on its varied areas of application, the material often suffers chemical, electrochemical or thermal corrosion, thus there is a need to determine its behavior under such environments. Corrosion can be defined as the process by which a material deteriorates due to chemical reaction with its environmental factors forming stable oxides or salts of the original metal compound such as rust (Ita BI, 1997). Although the term corrosion is generally used to mean the deterioration in metals, its use can be extended to wood, plastics, and concrete. In the corrosion of ceramics like concrete or polymers the process is commonly referred to as degradation or deterioration and can be minimized by reducing the surface exposed to the oxidation agents through processes like passivation or conversion of chromate.

Carbon steel is a descriptive term that is used to refer to non-carbon alloys that have a high composition of carbon. According to (E, 1998), metals are used in over 90% of all industrial applications with construction, power generation, chemicals, and oil industries being the primary users. Due to their availability, ease of fabrication, high strength, and low cost, steel, and iron are the most widely used metals in the manufacturing and fabrication industries (Umezurike, 1998). In the majority of industrial environments, the use and the situations all make it very conducive for corrosion to take place. Indoor corrosion on metallic components caused by oxides of Sulphur, nitrogen or carbon, the degree of humidity in the air, or heat thus leading to components failure The exposure of carbon steels to the corrosive environment more often than not leads to unprecedented failure with no detectable warning signs.

In the oil industries, for example, the pipelines are mainly made of steel pipes dug deep underground for transportation of fuel. These pipes suffer corrosion from the chemical attacks or rusting of the pipes due to extreme temperature or humidity conditions from the soil. The oil may also contain corrosive elements like brine, carbon dioxide elements, presence of weak organic

acids and hydrogen sulphides in a mixture of oil. Excessive corrosion to such pipes may lead to fuel leaks causing serious cases of fire or contamination of the soil (United States Patent No. US2466517A, 1948). In such cases cyclic amidine molecules containing nitrogen and hydrogen compounds are used to replace or stabilize the oxidized metal thus inhibiting corrosion. From (El-Lateef, Abu-Dief, & Mohamed, 2017) research it is also evident that the use of compounds from Schiff base can also inhibit the spread of corrosion in a carbon steel pipe used for the transportation of oil products. The bases pumped from the oil wells together with the oil help inhibit corrosion through the absorption on the steel surface thus forming an inner layer that prevents attacks from hydrochloric acid, mainly found in oil products. Their efficiency increases with concentration. Pipelines containing oil or gases mainly suffer four common corrosion-related effects such as weight loss, cracks due to stress, fatigue or galvanic corrosion. These are inhibited through the use of oil-based rust removers which penetrate into the pipe pores thereby dissolving the rust elements (Thompson, 2018). Painting of the pipe surfaces using epoxy coating has also been used to prevent chemical corrosion of the high quality gas pipes by cutting off direct contact of the corrosion factors and the steel material. For regions highly prone to corrosion attack in carbon steels, the use of polymers like polyethylene and PVC pipes can be the best alternative. Anticorrosive inhibitors can thus be classified into two main categories including the inorganic and organic inhibitors. The organic type are further classified as anodic inhibitors and cathodic inhibitors which reduce both the reactions at the anode and the cathode respectively. Organic corrosion inhibitors are mainly used in forming an oxide layer or absorbed (Dariva & Galio, 2014) on the surface of the metal.

Corrosion therefore, poses a great health hazard and can lead to substantial financial losses for the failed metallic parts. This makes it crucial for humans to understand how carbon steel interacts with its environment before using it. In this proposal, the behavior of carbon steel when exposed to corrosive agents will be explored.

1.2 Problem Statement

A study shows that carbon steel accounts for roughly 85% of the steel produced annually in the world (Fouda, Rashwan, Shaban, & Hoyenda E. Ibrahim, 2017). Corrosion is a natural process, and when carbon steel is exposed to certain environmental conditions, it wears out with time. These conditions could be moisture, oxygen or a corrosive medium. The type of corrosion process that occurs depends on the environment in which a metal is used. Since carbon steel finds its application in a variety of industries, damage to it can be disastrous. For example, in concrete reinforced structures, corrosion of steel as a result of chloride contamination or carbonation can lead to damages on the concrete (Ouzaa & Oucif, 2018) and eventually the whole structure.

1.3 Justification

The damages to carbon steel can be costly because of renovations. If not controlled, the corrosion effect normally results into serious costs like overhauling the whole system affected by corrosion e.g. in oil supply industries. Therefore, it is essential to study the behavior of corrosion in carbon steel to provide a recommendation on ways to prevent or control its corrosion. This project will focus mainly on conducting experiments on carbon steel 1018.

1.4 Objectives

The main aim of this project is to find the behavior of carbon steel when exposed to corrosive agents. Below are the specific objectives;

- To conduct immersion test to determine the rate at which corrosion takes place in various corrosive agents like acidic media.
- To analyze results that will be obtained from the experiments and compare with accepted facts.

2 LITERATURE REVIEW

2.1 Overview

Steel occurs in the form of a mixture of iron carbide (J.K & Khurmi, 1996). Carbon is used mainly because it adds to the strength and hardness of steel. Therefore, the quantity of carbon is usually regulated to obtain different types of steel. Steel can be categorized into the following groups: carbon steels, alloy steels, stainless steels and tool steels.

Carbon steels include low carbon steel, medium carbon steel, and high carbon steel. The types are differentiated through the percentage of their carbon content. Low carbon steel contains 0.08%-0.3%, medium carbon steel contains 0.3%-0.5% and high carbon steel contains 0.55%-1.4% carbon concentrations. Alloy steels contain elements other than carbon (for example, nickel, chromium, tungsten, cobalt, and vanadium) which are added to improve the general properties of steel. Stainless steels are a type of steel which is corrosion resistant when formed under the right conditions (J.K & Khurmi, 1996). It can be classified into austenitic, ferritic, duplex, precipitation hardening and martensitic steels. Tool steels contain different quantities of cobalt, tungsten, vanadium, and molybdenum that increase heat resistance and are used to make other tools such as cutting tools.

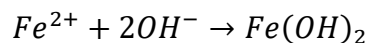
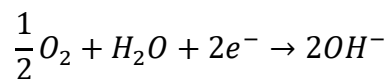
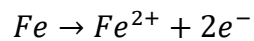
Low carbon steels are widely used in structural applications because they are cheap and readily available. Their general properties depend on the microstructure of the steel which is influenced by the chemical composition, method of manufacture, heat treatment and welding (Lipinski, Corrosion Effect of 20% NaCl Solution on Basic Carbon Structural S235JR Steel, 2017).

According to Lipinski, microstructure affects the nature of structural stresses within the material, and this is a factor that can cause corrosion if not controlled. Corrosion properties are essential when it comes to designing the type of metal to use for specific applications.

2.2 Corrosion process in steel

Corrosion is damage to metal as a result of a chemical reaction between the metal and its surrounding. This greatly depends on temperature, pH value, and presence of oxygen, chloride or sulfide ions. Corrosion can be classified differently according to factors causing it. This includes chemical and electrochemical process, high and low temperatures and dry and wet corrosion (Natarajan, 2012). Corrosion caused by dry gases, usually at high temperatures, is known as

chemical corrosion while the one caused by liquids is electrochemical. Electrochemical reactions usually occur when more than one reaction happens on a metal surface leading to a change of the metal to a non-metallic state (Cramer & Covino, 2003). According to Wiersma, anodic and cathodic reactions need to take place to retain a balance of charge. An anodic reaction is where the metal loses its electrons while in cathodic reaction; there is a gain of electrons (Wiersma, 2004). A metal exposed to air reacts with oxygen to form an oxide which coats it and can prevent a further reaction from taking place, depending on the metal composition, however, removal of the rust leads to exposure of the metal leading to further corrosion. The basic corrosion process of steel can be seen when iron reacts with oxygen and water to form rust. The process can be summarized as follows:



2.3 Types of corrosion

Corrosion exists in many different types of corrosion depending on the type of metal and the factors causing the corrosion. The different types of corrosion can be classified as follows (Natarajan, 2012):

2.3.1 General corrosion

General corrosion involves corrosion by steady thinning. During general corrosion, the entire surface area of the metal that is exposed to the corrosive environment is converted to oxide form and there is uniform thinning. In general thinning, corrosion does not penetrate deep and localized attack is rare. Forms of general corrosion include; atmospheric corrosion, galvanic corrosion, stray-current corrosion, general biological corrosion, molten salt corrosion, corrosion in liquid metals and high-temperature corrosion (Natarajan, 2012). Steel is mainly affected by the following:

✓ *Atmospheric corrosion*

It involves corrosive attack on metal that occurs when the surface of the metal is exposed to air as opposed to when sunk in liquid. In common metals, it is the most prevalent form of corrosion and a source of global concern due to its impact in the service life of everyday tools and equipment and its impact on the durability of structural materials. Atmospheric corrosion is the uniform corrosive action that acts on the surface of a metal. It is usually triggered when the surface becomes wet due to moisture resting on its surface (Callister, 1997). The moisture can be a result of rain, fog or condensation. By itself, atmospheric corrosion is a very complex process subject to several factors that affect it. The diverse nature of the factors that cause atmospheric corrosion make it difficult to predict its pattern. Factors such as relative humidity, weather conditions, air pollutants and pressure, all affect atmospheric corrosion leading to great variance from one geographic location to the other. These natural factors are tough to control, but some of them can be monitored and managed to reduce their effects. In a bid to simplify its complexity, atmospheric corrosion can be divided into damp, dry and wet environments. In dry atmospheric corrosion, attack occurs due to the negative free energy of oxide formation. Damp areas provide moisture which promotes the process of corrosion. The subject of atmospheric corrosion has been an intriguing one and has seen many publications to its name.

✓ *Galvanic corrosion*

Galvanic corrosion is also known as bimetallic corrosion and is the quick deterioration of a metal due to electric contact with a dissimilar metal (Jones, 1996). It occurs when two metals of different nature are in contact in the presence of an electrolyte. What results is the aggravated corrosion of one metal at the point of contact with the other metal being protected from corrosion as shown in the figure below;

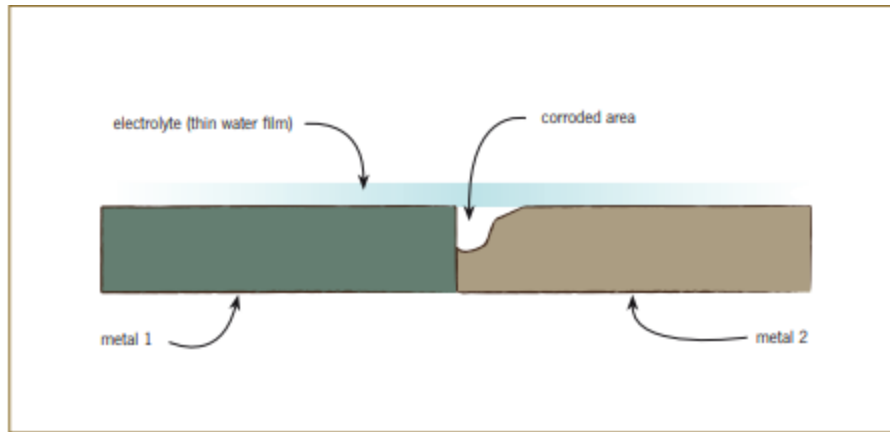


Figure 1: Galvanic Corrosion (Li, 2009)

This phenomenon occurs since different metals will have different electrode potential which facilitates the formation of an electrochemical cell if there is a conductive electrolyte. The potential difference formed between them is enough to drive an electric current between the metals. For a galvanic cell to be formed, a cathode, anode, electrolyte and a metallic path for the electron current to pass through must all be present. To prevent galvanic corrosion, it is crucial to eliminate the factors that are necessary for galvanic corrosion to take place; for instance, the electrolyte. It is also plausible to insulate dissimilar metals or add inhibitors to aqueous systems so as to eliminate cathodic depolarizers.

✓ *Aqueous corrosion*

The technical definition of aqueous corrosion is the deterioration of a material and its properties due to an electrochemical reaction that results from a wet environment. Aqueous corrosion is a broader category of corrosion, and for it to occur, the presence of an anode, cathode, metallic path and conductive electrolyte is required (Edwards, 2013). Aqueous corrosion is term that is used to describe several corrosion mechanisms that require the following components, an anode where the actual rust forms. It's the surface where the actual corrosion takes place. A cathode which provides a platform where oxygen is reduced to hydrogen, an electrolyte consists of anions and cations and its where conductive electrolyte takes place and a metallic path for electrons to pass.

Aqueous corrosion takes many forms which include; uniform attack, pitting corrosion, bimetallic corrosion and crevice corrosion.

✓ *General biological corrosion*

From its name, biological corrosion refers to the deterioration of metals that is directly or indirectly aided by the activities of microorganisms. Micro-organisms influence corrosion by releasing an acidic metabolic by-product which accelerates the corrosion of steel (Johnston, 2008). Generally, micro-organisms can directly or indirectly influence the integrity of most industrial metals. Microorganisms that are viable to aid in corrosion can be found in a surprisingly wide range of pressure, salinity, PH, and temperature. The interaction of organisms and the corrosion process is complex and ranges from chemical interaction, surface science, microbiology to bacteriology. The interactions are entirely dependent on the presence of water.

➤ *Direct Involvement in the Corrosion Process*

Sulfate Reducing Bacteria (SRB) are best known mechanism through which Micro-organisms directly influence corrosion on steel surfaces. During metabolism, they reduce sulfate to sulfide present in natural waters and soils. Where steel is applied in industrial environments, biodegradable materials such as hydrocarbons present in such an environment provides nutrients for microbial growth which promotes biological corrosion.

2.3.2 Localized corrosion

✓ *Pitting corrosion*

This is a localized attack type of corrosion which leads to the formation of tiny holes (pits) on a metal surface (Satyendra, 2018). Pitting corrosion is popular in passivating metals. Pits usually have surface diameters less than or equal to their depth (Fontana & Greene, 1967). Metals such as stainless steel have a thin oxide layer (passive layer) on their surfaces which contributes to the metal's corrosion resistance. The thin oxide layer can experience a local breakdown caused by chloride ions or other halogens. When this happens, the corrosive material starts acting on the active part of the surface and can progress quickly. Pits infiltrate the metal surface in a vertical direction (Gibson, 2017).



Figure 2: Pits on Metal Surface (Pessu, 2015)

According to Fontana and Greene, pitting can be described as a very destructive form of corrosion because it can lead to sudden equipment or structure failures despite them having a small percentage of weight loss. They are also hard to detect and predict using laboratory tests because they take a long time to form. The ability of a metal to resist pitting corrosion can be evaluated from the metal's alloy content using pitting resistance equivalent number (BSSA, 2016). Resistance is higher with an increased equivalent number (IMO, 2017). It is not clear why pitting occurs in specific areas of a metal surface and not their surroundings (Fontana & Mitra, 1986), but some factors can contribute to localized corrosion. These factors include partial homogeneity of the metal surface, the presence of scratches or rough areas and the presence of impurities.

Pitting corrosion can be prevented by minimizing exposure of stainless steel to the corrosive agent (BSSA, 2016), using a resistant material, a protective coating and inhibitors and ensuring that fluids flow with high velocity on the metal surface (Nimmo & Hinds, 2003).

✓ *Crevice Corrosion*

It's a localized form of corrosion that attacks carbon steel in cracks or crevices that form between two surfaces. When joining two pieces of metals, there is a likelihood of the formation of narrow spaces and openings between the metals. According to (D. Addari, 2008), crevice corrosion is triggered by a concentration difference of chemical constituents. In most cases, concentration difference of oxygen sets up a differential aeration cell (Also known as an electrochemical concentration cell). On the outside of the crevice which acts as a cathode, the pH and oxygen

concentration are high, but the concentration of chlorides is low. The reverse is true; the high level of chlorides on the inner surface makes the situation worse.

Crevice corrosion in carbon steel is influenced by factors such as crevice type (whether the crevice is occurring between metals or between metal and non-metal), crevice geometry (the gap size, depth and the roughness of the surface), and environmental factors such as pH, temperature and oxygen concentration. Crevice corrosion can be prevented by use of welded joints instead of using rivets for joining, avoiding creation of stagnant conditions and eliminating crevices in existing lap joints.

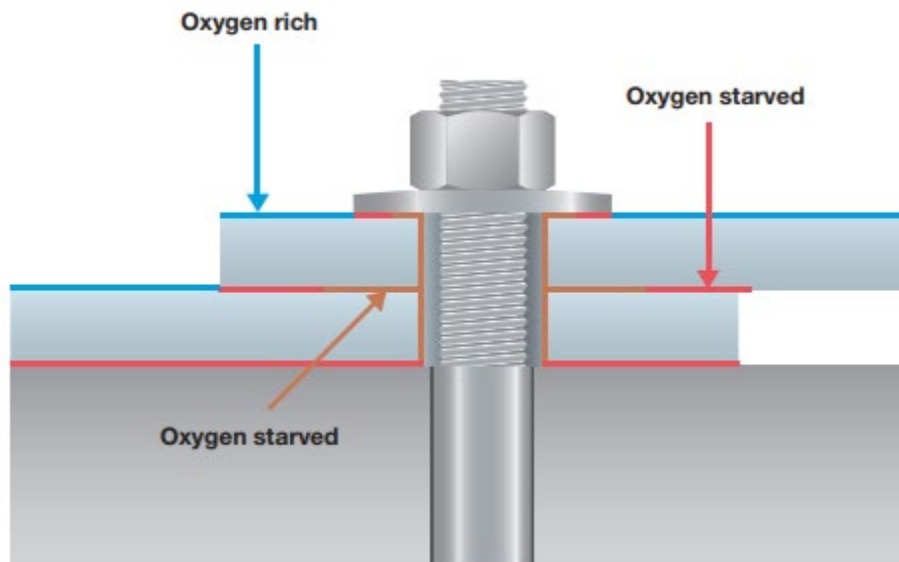


Figure 3: Areas Vulnerable to Crevice Corrosion ((Uhlig H., 1948)

2.3.3 Metallurgical Influenced Corrosion

Metallurgical activities such as annealing, fabrication and shaping creates strains on the texture of materials. This strains leads to catalyzed pitting process as a result of development of anodic regions at such points. After it starts, pits of corrosion can combine to create points of possible catastrophic damage (Recep, et al., 2018).

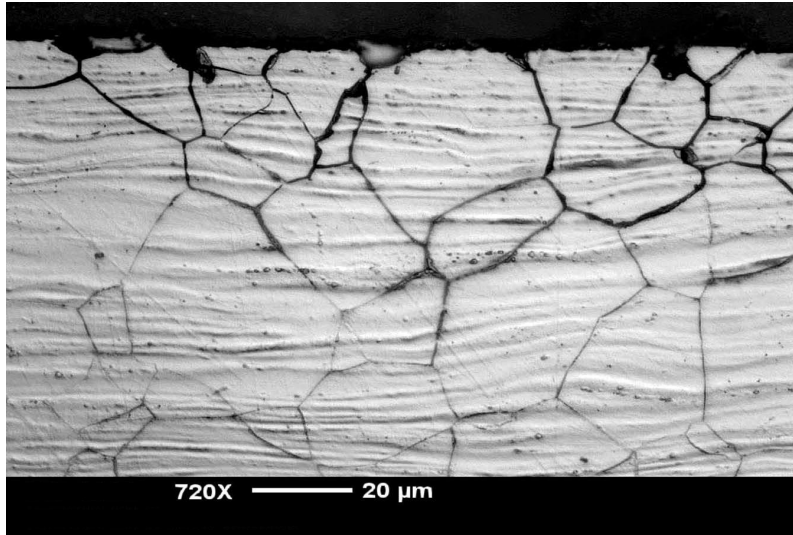


Figure 1: Diagram of a section of a material attacked by intergranular corrosion as viewed under microscope.

Intergranular corrosion occurs when the borders of crystallites of carbon steel are more prone to corrosion than their inner parts. Intergranular corrosion basically occurs due to exhaustion of alloying element at the boundaries of grains of the element. For its identification, it requires investigation of the microstructure under a microscopy process.

Intergranular corrosion in carbon steels have since been attributed to inclusions of manganese sulfide. The growth of pit occurs at the inclusions of manganese sulfide or in the adjacent matrix around the inclusion. Points with high concentrations of manganese sulfide develop macropits through the combination of several micropits resulting in accelerated process in which macropit keep increasing (Martin, 2014).

Steel grades with low carbon content are more resistant to intergranular corrosion than other types of metals. Intergranular corrosion can be prevented by use of post-weld heat treatment, use of stainless steels with low carbon grade and use of treated types with titanium or niobium alloys (Polsky, Yakushin, Dzhumayev, Petrovsky, & Safonov, 2016).

2.3.4 Mechanically Assisted Degradation

✓ *Erosion Corrosion*

Erosion corrosion is a catalyzed rate of corrosion activities in materials due to relative motion of metal surface and the corrosive fluid. High rates of turbulences that are caused by pitting on the inner surfaces of pipes and tubes leads to highly accelerating rates of erosion which end up causing leakage. When left to accumulate the burrs can prevent smooth flow of fluid by causing localized turbulence. This leads to increased pitting activities in pipes and tubes. For it to occur there should be an interaction between corrosive fluid, solid tiny particles and a metal that is susceptible to this kind of erosion (El-Sherik, 2017).

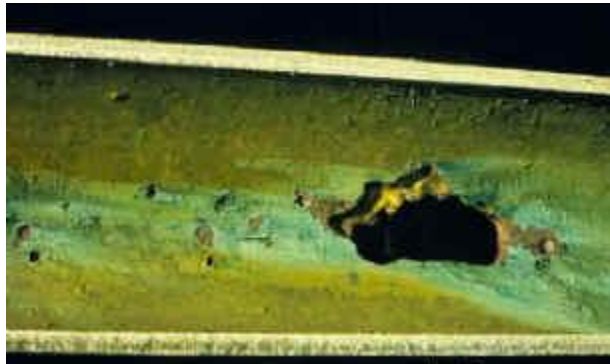


Figure 4: Erosion corrosion on inner surface of a pipe

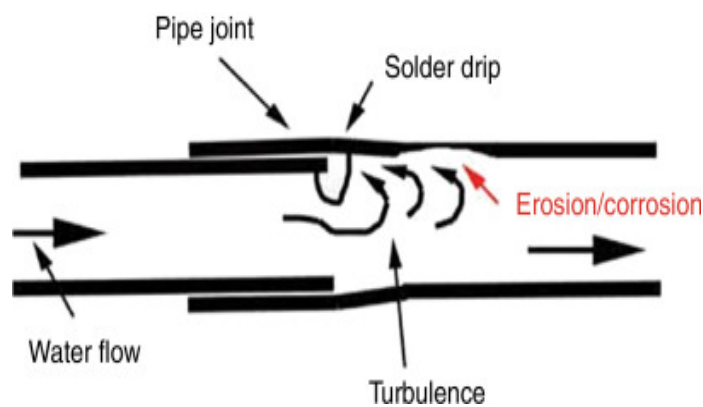


Figure 4: Erosion corrosion mechanism inside a pipe

It mostly occurs in soft alloys of metals such as aluminum, copper and lead. Alloys that create a surface film in an environment that is susceptible to corrosion usually have a limiting velocity which when exceeded, corrosion is significantly accelerated. Apart from cavitation, corrosion problems that are caused by flow are generally referred to as erosion corrosion, including flow facilitated dissolution and impingement attack (Abdel, et al., 2018). Process of material selection is very significant in reducing the destructions that might be caused by erosion corrosion. It is important to note that material with high hardness does not assure one guarantee one with good level of resistance to erosion corrosion. Design features of a material are the ones that matter.

Erosion corrosion can be prevented by turbulence reduction by streamlining piping and promoting laminar flow, avoiding use of pipes with rough inner surfaces, avoiding sudden changes in the direction of flow, increasing the thickness of areas that are vulnerable to corrosion, properly aligning flanged and welded sections of pipes, controlling the velocity of fluids, minimizing corrosion by using cathodic protection or corrosion inhibitors and use of materials that are more resistant (Myer, 2018).

✓ *Corrosion Fatigue*

Corrosion fatigue occurs due to merged activities of corrosive environment and cycling stresses. The process of fatigue is believed to cause rupturing of the film that is supposed to act as a protective layer. This causes speeding up of corrosion process. Simultaneous exposure of a metal to a corrosive environment causes rupturing to occur at much lower loads than in dry air after a very short period of exposure. It is mainly associated with cycling boilers, desecrators and other equipment that rotate (WebCorr Corrosion Consulting Services, 2019).

Occurrence of corrosion fatigue results in several parallel cracks on the surface of the material, some of the cracks sometimes might be round, especially when corrosion occurs adjacent to welded joints. Corrosion fatigue cracks are detected using appropriate nondestructive testing methods which include magnetic particle method and ultrasonic method.

The fracturing in fatigue corrosion is brittle forming transgranular morphologies like the ones that occur in stress corrosion cracking. In a corrosive environment the level of stress presumed for a material to have infinite life is reduced or eliminated completely. For Corrosion fatigue there is no limit for fatigue load (Craig, et al., 2003).

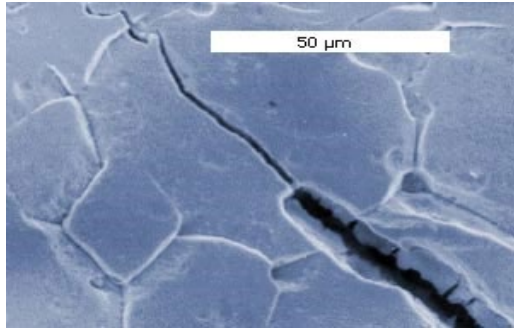


Figure 2: A picture of a primary corrosion-fatigue crack that has been broadened by reactions of secondary corrosion.

There is no metal that is not susceptible to effects of corrosion fatigue if it is left in a corrosive environment. Various methods that can be used to control fatigue corrosion include reducing or getting rid of cyclic stresses, ensuring well distribution of stresses throughout the parts of the component, avoiding designs that transmit vibrations, protection of materials against rapid changes in pressure, temperature and loading, using high natural frequency for reduction of resonance corrosion fatigue, eliminating internal stresses on materials, choosing proper shape of vital parts and use of materials that are less resistant in an environment which is not prone to corrosion (Corrosion Doctors, 2019).

2.3.5 Environmentally Induced Cracking

✓ Stress Corrosion Cracking

This is a type of corrosion that occurs due to combinations of materials that are susceptible to corrosion in an appropriate corrosive environment under constant tensile stress. The extent of effects of stress corrosion cracking on a material occurs between fatigue material threshold and dry cracking. Tensile stress behind the corrosion is usually in form of residual stresses or stresses that are applied directly on the material. Stress corrosion cracking causes a lot of complexities for example in pipelines that are buried in the ground (Corrosion Doctors, 2019).

Stress corrosion cracking basically occurs due to combined action of the following three components; susceptible material, presence of specific species of a material and effects of tensile stresses.

Residual stresses occur due to practices on metal materials such as welding, grinding, cold deformation, machining, heat treatment and forming. The resulting stresses are usually of high magnitudes and should not be underestimated. Destructive stresses can also be generated by assembling of corrosion products.

Stress corrosion cracking is usually occurs with cracks that penetrate deep into the material while the surface of material remains without any fractures. The cracks are signified by microstructures with transgranular or intergranular morphologies. The macroscopy of stress corrosion cracking have brittle appearances. It is known to be a catastrophic type of corrosion because it is not easy to detect the cracks, and its damage is unpredictable.



Figure 1: SCC in 316 stainless steel chemical processing piping system (The photo obtained from Metallurgical Technologies)

Effective ways of preventing occurrence of SCC include avoiding the use of chemical types that can cause SCC, bringing in compressive stress by methods such as shot-peening, proper choice of materials that are not susceptible to cracking in a given environment, proper management of hardness and amounts of residual stresses and proper control and management of operating temperature and potential of the alloy electrochemically (WebCorr Corrosion Consulting Services, 2019).

✓ *Hydrogen Induced Cracking*

This is a common type of wet hydrogen sulfide cracking due to high amounts of hydrogen which causes metals to blister. Blistering effects occur parallel to the surface and to the direction of hoop stress. Effects of aqueous hydrogen charging of steel in wet refinery process conditions causes the occurrence of HIC. It can also take place at a somehow low temperatures, mostly due

to atomic hydrogen from wet H₂S corrosion reactions that get into the steel and gather inclusions in it. Hydrogen sulfide interferes with normal hydrogen recombination process. Instead of escaping from the corroding surface, the atoms of hydrogen are pushed into the metal surface leading to weakness and corrosion (Laura, et al., 2014).

Hydrogen induced cracking mostly affect pipes and vessels in hydrogen and hydrogen sulfide processing factories. Materials that are highly susceptible to HIC are low metal alloys and high-strength steels such as nickel and titanium. Steels that have tensile strength below 1000 MPa and hardness of below HRC are not prone to hydrogen induced cracking. It is extreme in arc welding, where hydrogen is usually released from moisture and some other organic compounds (Laura, et al., 2014).



Figure 3: Picture of hydrogen induced cracks

Testing of HIC involves analytical methods than include analyzing internal hydrogen from production and external sources of hydrogen like cathodic protection. In case of steels, the specimens for testing in the laboratory should be at least harder than the expected final parts because fabrication process might interfere with the resistance ability of the material towards hydrogen induced cracking. Hydrogen induced cracks can be prevented through the following practices; controlling levels of stress, minimizing the contacts between metals and hydrogen especially during fabrication and water electrolysis, baking to remote hydrogen and by using proper electroplating remedies and methods (Milos, et al., 2016).

2.4 Factors Affecting Corrosion

✓ *Oxygen Concentration*

Oxygen is one of the primary requirements for corrosion to take place; its concentration has a direct impact on corrosion as well as the rate of corrosion. High level of oxygen leads to a high rate of corrosion. In an aqueous environment, the initial rate of corrosion is high as oxygen is in direct contact with the metal. However, as the rust film forms, it acts as an oxygen barrier which lowers the rate of oxygen diffusion reducing the corrosion rate. If oxygen is removed, the corrosion rate of steel at room temperature is negligible (J. Lamb and R. Eliassen). Dissolved oxygen (DO) refers to the total volume of oxygen that is in a given amount of water. Usually, oxygen dissolves in water as a byproduct of photosynthesis from aquatic biota and the normal process of oxygen dissolving through the air-water interface. The amount of DO in water decreases with increase in altitude. This is because gas solubility decreases with increase in relative pressure.

✓ *Temperature*

Corrosion is a chemical reaction and it is a well-known fact that temperature increases the rate of almost every chemical reaction. Increased temperature increases the energy of atoms allowing them to react faster. In an aqueous environment, increase in temperature allows dissolved oxygen to escape making it available to 'fuel' corrosion. In a system where oxygen circulation is minimum, an increase in temperature increases the rate of corrosion up until all the oxygen is consumed. In an environment or media where corrosion is accompanied by the release of hydrogen, an increase in temperature increases the rate of corrosion (O. Bauer, 1936). However in a high PH solution, increase in temperature increases the rate of formation of protective film which reduces the rate of corrosion.

✓ *Influence of Velocity (In Vessels)*

If a vessel of steel is carrying fluid, the velocity of the fluid affects the rate of corrosion. The higher the agitation (Velocity), the higher the rate of corrosion provided that other factors required for corrosion are present. Formation of rust loosens the particles in the surface where rust is being formed. As such, high velocity in vessels washes away this particles exposing the

metal to further corrosion. Consequently, increasing flow velocity effectively increases corrosion rate.

✓ *pH Level*

The measure of hydrogen ions concentration is the one referred to as pH. The pH scale ranges from 0-14 with values below 7 describing acidic substances and a value higher than 7 describing alkaline substances. A pH of 7 is described as a neutral pH. Low pH increases the rate of corrosion by providing a lot of hydrogen ions which promote corrosion. A pH of higher than 7 implies that hydrogen ions are in short supply hence the rate of corrosion in such an environment is slowed down. When acids dissolve in water, they emit hydrogen ions which are positive charges while alkaline solutions produce hydroxide ions which are negative in nature. Once rust is formed, it protects the inner metal from continued corrosion. However, in acidic conditions the rust breaks down paving way for even further corrosion to take place.

✓ *Presence of Dissolved Salts*

Increase in salt concentration increases the rate of corrosion. Salts such as sodium chloride salts can affect the rate of corrosion of steel. The higher the salt concentration, the higher the percentage of corrosion (Chappell, 1912). Corrosion is a reduction-oxidation reaction, as such electrons must be transferred from the metal which loses electrons to oxygen. Adding salt to a solution increases the rate of reaction as salt increases conductivity in water. However, if the metal is completely submerged in water with very high salt concentrations and poor aeration, the rate of corrosion actually slows down. This is because salt reduces the amount of dissolved oxygen.

✓ *Metal Composition*

In steel, the amount of carbon has shown no influence on the corrosion rate in freshwaters. However, in salty water, an increase in carbon content increases the rate of corrosion. When carbon steel is quenched from high temperatures, the result is steel having the structure martensite. Martensite has a low corrosion rate in dilute acids and the interstitial carbon reacts with the acid to form amorphous carbon. On cooling, the carbon forms pearlite that corrodes at a faster rate.

✓ *Heat Treatment*

In steel, heat treatment refers to the process of heating and cooling it in a controlled manner to change its physical and mechanical properties without altering its original geometry. Heat treatment is usually carried out with the aim of increasing the strength of steel and improving manufacturing properties such as formability and machinability. Heat treatment of high carbon steel tends to slow down corrosion of steel.

✓ *Metal Quality (Impurities)*

Impurities in a metal promote corrosion. Steel of high quality (With no impurities), will corrode slowly than that one with impurities as its corrosion resistance is not compromised. Impurities increase the rate at which electrons are transferred from the metal to the oxygen. By doing so, the rate of corrosion is higher.

✓ *Inhibitors*

The presence or absence of inhibitors affects the rate of corrosion. An inhibitor is a substance that if added to an environment will lower the rate of corrosion. Corrosion inhibitors are referred to as retarding catalyst and they exist in numerous types (D. Brasher, 1968). Adsorption type inhibitor adsorbs on the surface of the metal affecting both the anodic and cathodic processes and suppressing metal dissolution.

Scavengers are inhibitors that act by getting rid of the corrosive agents from a solution. They work best by removing dissolved oxygen in solutions where it will promote corrosion. Hydrogen evolution poisons are inhibitors that lower the rate of corrosion in a hydrogen-rich environment. Inhibitors are one of the solutions that is being widely used in industrial equipment to help curb corrosion menace. The main aim of adding corrosion inhibitors is to extend service lifetime of steel equipment. Currently, corrosion inhibitors offers a great solution to corrosion menace as they are cost effective and they allow usage of less expensive metal in a highly corrosive environment.

✓ *Metallurgical factors*

The corrosion characteristics of a metal or an alloy are a subject to its structure. A good example is a case where sulfide inclusions are added to pure iron. This leads to corrosion even in environments regarded to as mild-corrosive. The crystal structure of the metal also determines the electrochemical behavior during the corrosion factors. Other metallurgical factors that affect corrosion include bulk composition (in alloys), surface condition, and grain boundary.

3 METHODOLOGY

3.1 Overview

In general, this project aims to study the behavior of steel when exposed to a corrosive environment. An immersion test was conducted using sodium chloride solution, and the corrosion was observed visually using a microscope and by weight measurement of the specimen. The data collected was used to determine the rate of corrosion.

The specimens used were of type 1018 low carbon steel. This is because they are easily available. It is made by carburizing low carbon steel to make its surface hard. It can be easily formed, bent and welded. The specimens were cut from a steel plate of 3.2mm thickness and machined to approximately 50mm by 50mm dimension. Some of the properties of 1018 low carbon steel are listed below:

Table 1: Properties of C1018

Chemical composition	Element	Content
	Carbon, C	0.14-0.20%
	Iron, Fe	98.81-99.26%
	Manganese, Mn	0.60-0.90%
	Phosphorus, P	0.040%
	Sulfur, S	0.050%
Physical properties	Density	7.87g/cc
Mechanical properties	Tensile stress (ksi)	64
	Yield stress (ksi)	54
	% elongation	15
	Reduction of area (%)	40
	Brinell hardness	126

3.2 Equipment and materials used

- 200g sodium chloride
- Distilled water
- C1018 carbon steel
- Course and fine abrasive paper (no. 50 up to no. 120)
- Acetone for cleaning
- Ethanol for cleaning
- Wide-mouth jar
- Stopwatch
- Weighing machine
- Microscope

3.3 Experiment procedure

i. Preparation of Sodium Chloride solution

20% Sodium Chloride (NaCl) solution was prepared. This was achieved by adding 200g of sodium chloride into 800ml solution of distilled water in a volumetric flask. The content was stirred until sodium chloride dissolved fully in water. Water was added into volumetric flask until the volume 1000ml.

ii. Preparation of the specimen

C1018 was cut into ten pieces of dimension $(50 \times 50 \times 3.2)mm$ each. The samples were polished using abrasive paper up to 600 grits, starting from the course paper to the finest paper. The surfaces were cleaned first by acetone then followed by ethanol and then left to dry naturally. Each sample was weighed on an accurate weighing machine.

The working beakers/jars were cleaned with detergent and rinsed thoroughly with distilled water. The jars were rewashed with ethanol and left to dry. The inside of the beakers was then rinsed with 20% sodium chloride.

iii. First experiment

Five samples were immersed in wide mouth jars each containing 100ml of 20% NaCl at room temperature. The samples were retrieved after four hours and rinsed with distilled water, acetone and ethanol respectively. The specimens were air-dried before they are reweighed and re-immersed into the corrosive agent. The same procedure was repeated in intervals of four hours. The experiment was stopped at the first sign of rust. However, there was time limitation of four weeks. After the experiment, samples were cleaned and mass loss was calculated. A graph of corrosion rate against time was also obtained for analysis purposes. This experiment is useful for the study of corrosion of materials in an atmospheric environment (1).

iv. Second experiment

The above procedure was repeated and performed for the remaining samples, but data was recorded at intervals of twenty four hours for 168 hours (seven days). The process went on even after rusting occurred. Mass loss and corrosion resistance were also calculated for this experiment. An observation of the distribution of rust was also made.

Open beakers were not used due to evaporation and contamination. Care was taken when grinding the surfaces of specimens with abrasive paper to avoid hardening the material. Glass rods were used where the specimen needed to be supported. The working conditions for this experiment included ambient temperature atmospheric pressure. There solutions were stagnant and as such no flow velocity present (Flow velocity negligible).

Experiment calculations

The following calculations were useful for the analysis of the experiment;

Overall mass loss = initial mass – final mass

Corrosion resistance: $CR = \frac{W}{St}$, where W = weight loss, S = area of the specimen and t = time immersed in the corrosive agent

Corrosion rate:

$$\text{Corrosion rate in mm/year} = r_{\text{corr}} = \frac{8760 \times m}{S \times t \times \rho} \dots \dots \dots 1$$

$$\text{Corrosion rate in g.m}^2 = r_{\text{corr}} = \frac{10000 \times m}{S \times t} \dots \dots \dots 2$$

where m = average mass loss in grams, S = surface area of the specimen in mm^2 ,

t = time taken in the solution in hours, ρ = density of the specimen in g.mm^2

4 RESULTS AND ANALYSIS

4.1 Experiment 1 Results

Experiment 1 studies corrosion rate of C1018. Corrosion rate of a material is important when it comes to selection of material to use for specific applications. The rate of corrosion is used to predict future corrosion of the material in a certain environment. The images, dimensions and weight of samples during and after the experiment are as shown below:



Figure 4: Experiment 1 Samples after testing

Sample #	Starting Mass (g)	Mass @ 4h	Mass @ 8h	Mass @ 12h	Mass at 16h	Mass @ 20h	Mass @ 24h
1A	62.443	62.442	62.438	62.432	62.429	62.425	62.422
1B	61.866	61.865	61.86	61.851	61.842	61.836	61.825
1D	62.446	62.444	62.444	62.444	62.443	62.443	62.443
1E	62.636	62.632	62.629	62.619	62.615	62.609	62.608
1F	63.307	63.307	63.304	63.3	63.299	63.295	63.29

Table 2: Weight of Samples 1

Sample #	Sample Dimension @ Start	Sample Dimension @ 24h	Surface area (mm ²)
1A	51.69 x 49.69 x 3.20	Unchanged	5785.7842
1B	51.80 x 49.52 x 3.20	Unchanged	5778.72
1D	52.24 x 49.50 x 3.20	Unchanged	5822.896
1E	51.71 x 49.49 x 3.20	Unchanged	5765.9358

1F	52.87 x 49.50 x 3.20	Unchanged	5889.298
Average Surface Area			5808.5268

Table 3: Dimension of Samples 1

The average original surface area of the samples was used throughout the calculations. The average mass was obtained from the samples and weight loss was calculated for each interval.

The overall weight loss was found to be:

$$\text{Overall mass loss} = \text{initial mass} - \text{final mass} = 62.5396 - 62.5176 = 0.022g$$

Therefore, corrosion resistance can be given as:

$$CR = \frac{W}{St}, \text{ where } W = \text{weight loss and } S = \text{area of the specimen}$$

$$CR = \frac{0.022}{5808.5268 \times 24} = 1.5781 \times 10^{-7} g.mm^{-2}$$

Equation 1 is used to calculate rate of corrosion with reference to change in dimension of samples while Equation 2 uses change in mass to obtain corrosion rate. Since the change in dimension was negligible, Equation 2 was applied.

Time, h	Average mass, g	Weight loss, g	Corrosion rate, g.mm ⁻²
0	62.5396		
4	62.538	0.0016	0.000688643
8	62.535	0.003	0.000645603
12	62.5292	0.0058	0.00083211
16	62.5256	0.0036	0.000387362
20	62.5216	0.004	0.000344321
24	62.5176	0.004	0.000286934

Table 4: Sample Calculations

From the results, a graph of mass loss against time can be plotted as follows:

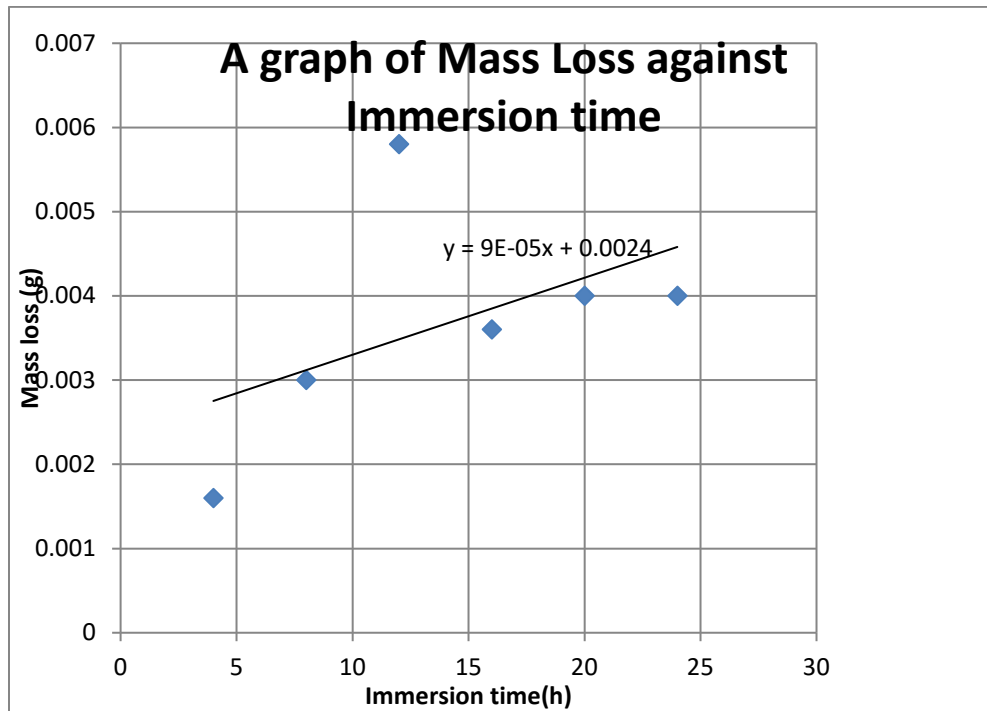


Figure 5: A graph of Mass Loss against Time

From the plotted graph, it was established that the relationship between mass loss and time is linear. The longer the immersion time, the higher the mass loss and vice versa.

A graph of corrosion rate against immersion time is as shown below:

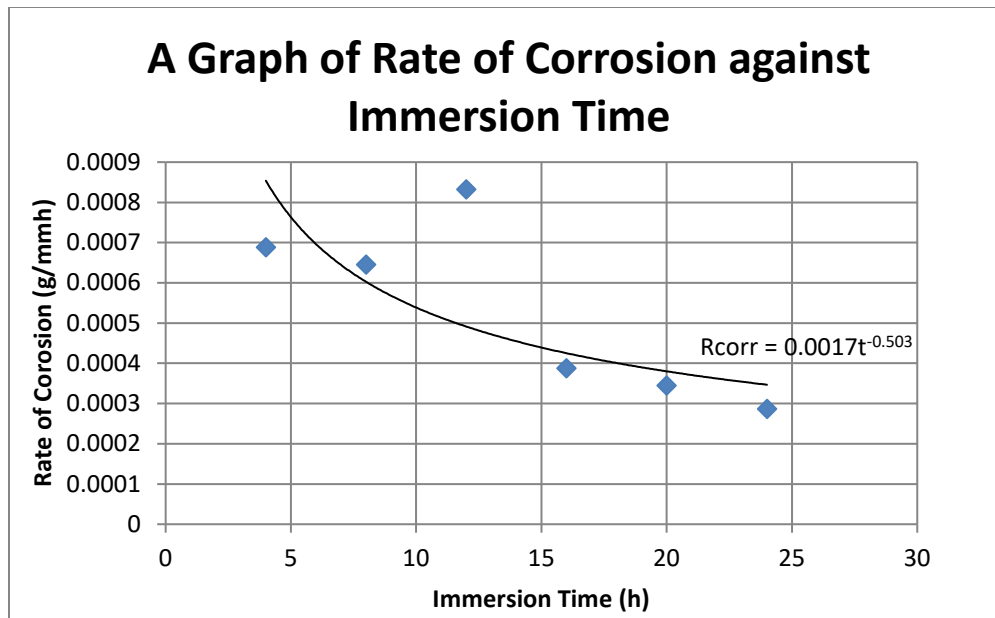


Figure 6: A Graph of Corrosion Rate against Time

From the graph above, it can be seen that the rate of corrosion against time curve is exponential and that the rate reduces with increase in time.

4.2 Experiment 2 Results

Experiment 2 is used to study the degree of corrosion of the samples. The results recorded before, during and after the experiment are as shown below:

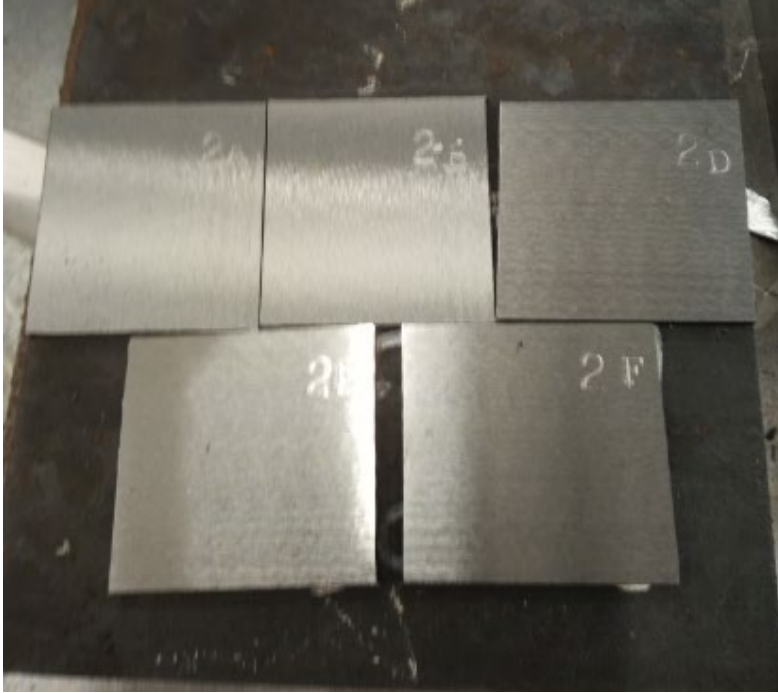


Figure 7: Experiment 2 Samples before testing



Figure 8: Experiment 2 Samples after testing

Samp le #	Starting Mass (g)	Mass @ 24h	Mass @ 48h	Mass @ 72h	Mass @ 96h	Mass @ 120h	Mass @ 144h	Mass @ 168h
2A	63.062	63.062	63.057	63.051	63.04	63.029	63.021	63.012
2B	62.566	62.543	62.541	62.533	62.524	62.515	62.509	62.501
2D	63.532	63.511	63.508	63.501	63.5	63.499	63.497	63.497
2E	62.431	62.404	62.405	62.404	62.402	62.401	62.401	62.4
2F	64.169	64.162	64.159	64.152	64.15	61.148	61.146	64.145

Table 5: Weight of Samples 2

Sample #	Sample Dimension @ Start	Sample Dimension @ 24h	Surface area
2A	49.41 x 52.09 x 3.20	Unchanged	5797.1338
2B	49.33 x 51.45 x 3.20	Unchanged	5721.049
2D	51.86 x 49.41 x 3.20	Unchanged	5772.9332
2E	51.25 x 49.42 x 3.20	Unchanged	5709.838
2F	51.48 x 49.37 x 3.20	Unchanged	5728.5752
Average			5745.90584

Table 6: Dimensions of Samples 2

The average mass was obtained and the weight loss was found to be:

$$\text{Overall mass loss} = \text{initial mass} - \text{final mass} = 63.152 - 63.111 = 0.041g$$

Corrosion resistance was then determined to be:

$$CR = \frac{W}{St}$$

$$CR = \frac{0.041}{5745.90584 \times 168} = 4.2473 \times 10^{-8} g \cdot mm^{-2}$$

Equation 2 was used to calculate corrosion rate since the dimension of the samples were unchanged. The results were tabulated as shown below.

Time	Average Mass	Weight Loss	Corrosion rate
0	63.152	—	—
24	63.1364	0.0156	0.001131240
48	63.134	0.0024	0.000087018
72	63.1282	0.0058	0.000140196
96	63.1232	0.005	0.000090644

120	62.5184	0.6048	0.008771463
144	62.5148	0.0036	0.000043509
168	63.111	-0.5962	-0.006176240

Table 7: Sample 2 Calculations

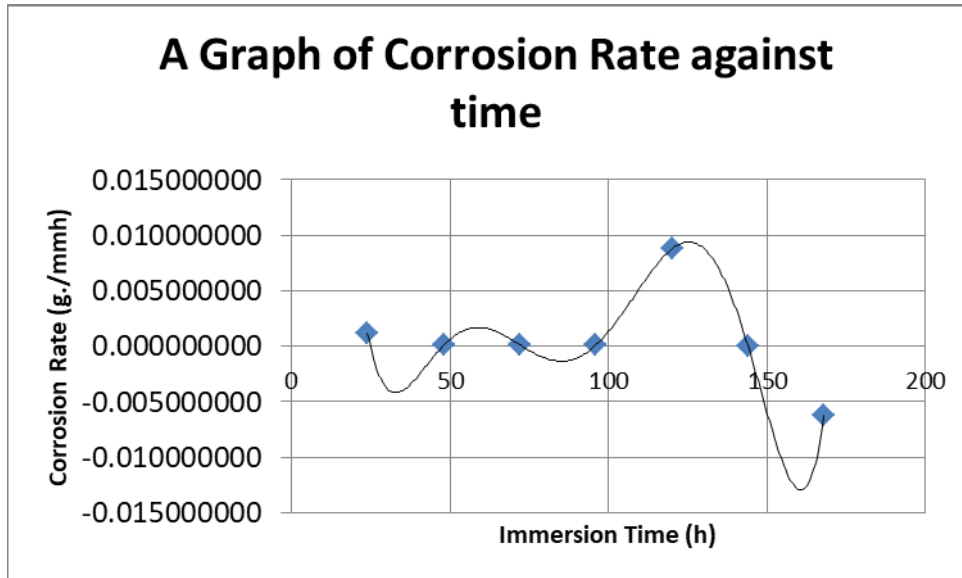


Figure 9: A Graph of Corrosion Rate against Time for Experiment 2

The graph shows a polynomial curve representing corrosion rate against time. This is unpredictable pattern and deviates from the theoretical values probably as a result of errors that might have occurred during the experiment.

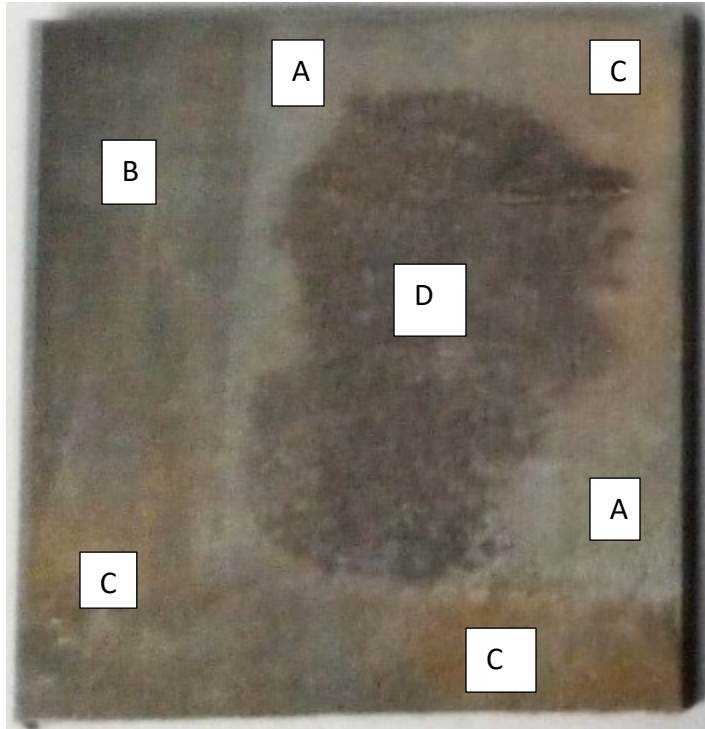


Figure 10: Image of Distribution of Rust on the Surface

It can be seen that rust formation is unevenly distributed on the surface of the metal. A shows the part that is unstained, B shows the part that has just started to rust, C shows the partially corroded region while D represents full corrosion or complete formation of rust. The shiny grey metal surface becomes coated with light brown and dark brown patches of rust. The surface of the metal also becomes rough.

5 DISCUSSION

The aim of the experiment was to study behavior of carbon steel when exposed to corrosive agents. From the first experiment, it was observed that the rate of corrosion decreases with increase in time. This is because during the initial stages the surface of the metal is fully exposed to the corrosive agent, sodium chloride, which acts on it rapidly. However, with time, corrosion takes place and there is formation of rust on the surface. This effectively reduces the total surface area exposed to the sodium chloride solution and this reduces the rate of reaction on the C1018. Generally, corrosion of steel follows the following exponential law (M. Morcillo*, 2011);

$$C = At^B, \text{ where } C = \text{metal loss}, t = \text{exposure time}, A \& B = \text{constants}$$

According to Morcillo* et al, the equation shows that corrosion rate is determined by diffusivity properties of the coating which sets apart the reactants. The value of B can be used to study the behavior of the rust layer. If the value is close to 0.5, it can be concluded that most of the products remained on the surface of the metal; if it is less than 0.5, there could be a reduction in diffusion coefficient of the corrosion layer due to factors such as compaction, agglomeration and recrystallization. Any value above 0.5 shows an increase in diffusion coefficient which may be as a result of rust detachment, flaking or cracking. From the equation of the curve, B is 0.503 (this value can be said to be close to 0.5). This shows that most of the rust remained on the samples surface. Morcillo* et al explains that B depends on the metal, corrosive agent and conditions of exposure. The distribution of the rust on the metal surface is uneven due to difference in the microstructure properties of the carbon steel. This could be a manufacture's error. The rust forms more on the weakest sections of the grain arrangement and the strong section resists corrosion.

Generally, the experimental values differ slightly from the theoretical value. This can be attributed to some errors that might have occurred during the experiment. Various errors that could have occurred include; difference in temperature during the morning, noon and evening hours, inaccurate measurement of weight and dimensions and machining errors during cutting of the samples. Temperature plays a big role in how corrosion behaves and since the samples relied on atmospheric temperature which changes, the change might have influenced the formation of rust. During periods of high temperatures, the rate of corrosion is effectively accelerated, the vice versa is true.

The chemical composition of carbon steels plays an important role in its corrosion resistance properties. The corrosion properties of carbon steels depend on the carbon content as well as the composition of alloying elements such as tin, chromium, manganese, silicon, nickel, molybdenum, etc.

Chromium is the major additive to carbon steel to improve its corrosion properties. At least 13% of chromium is needed in the steel alloy for it to be effective. At this percentage or more, the corrosion properties of carbon steels are vastly improved. The oxidation of iron is prevented through various conditions with the dominant one being the formation of a thin layer of chromium oxide that prevents the iron from rusting. The higher the composition of chromium in the steel alloy, the more the corrosion resistance. Chromium helps to improve other mechanical properties like strength and hardness.

Nickel is another common element in steel that improves its corrosion resistance. Addition of nickel to austenites produces austenitic stainless steels with about 8% nickel composition in the alloy. A higher percentage of the alloying element will result to improved corrosion resistance properties.

Vanadium also helps improve the corrosion properties of steel by helping to control the grain size of the steel, keeping it all. Vanadium forms vanadium carbide when added to steel, which blocks the formation of grains. The finer grain structure helps improve the properties of steel.

Manganese is frequently used in steels especially with the heat treating process. When steels are heat treated and quenched to improve their properties, the process must be done at a fast rate which consequently makes the process unstable. Addition of manganese allows the process to be carried out at a slow rate and achieve similar properties. Molybdenum, just like chromium, also has a positive effect on the corrosion resistance properties of steels. It also helps improve other properties such as hardenability, toughness and tensile strength of steel. This is achieved by reducing the required quench rate during the heat treatment process.

Other elements can also be added to the alloy steels at low composition to improve the corrosion resistance. An alloy of steel can comprise of several of these elements combined at different

percentages. The elements can be combined at various compositions to ensure there is a balance with the other properties needed for the steel alloy such as the strength, hardness, toughness, etc.

The varying percentages of carbon lead to changes in strength, hardness, ductility, weldability and melting points. These changes in composition bring about different uses of carbon steels depending on the working environments and working loads. Corrosion brings about adverse effects on the working of carbon steels in their environment. These in turn bring about negative effects on the outside world. These effects include economic, health, technological, safety and cultural effects.

Economic effects bring about adverse effects on the economic scale. The costs can be accumulated directly or indirectly. Direct costs are felt when corroded carbon steels are replaced. The cost of purchase, transportation and replacement of these materials are always on high. Costs are also incurred through the study of corrosion as it involves a lot of input in terms of the study equipment. Costs are also increased from the research and study of ways of eliminating corrosion. This is an indirect effect on the cost analysis of corrosion.

In the recent years, through the improved technology in the health sector, carbon steels have been utilized in the body implants such as pacemakers, hip joints, pins and plates. With this advancement in technology, corrosion still remains a threat to the pure success of these techniques. Corrosion of these materials could lead to inflammation of body tissues, failure of implants and can even propagate failure to other body parts. Corrosion of these carbon steels could also lead to generation of toxic gases from the chemical reactions involved in the corrosion especially where several alloys are used.

Technological advancements have not been pardoned by the effects of corrosion. Corrosion affects technology both positively and negatively. With the need to produce carbon steel materials which can withstand highly corrosive environments, higher pressures and temperatures, corrosion still remains a setback. Since a lot of costs are incurred in the advancement of technology, this corrosion has brought about a limitation since attention is diverted in the generation of new carbon steel alloys. On the positive side, the inventions of new carbon steel alloys which are corrosion resistant are being put to study leading to the improvement of technology.

Corrosion brings about an adverse effect on structures proving a significant problem in terms of safety. Corrosion of structures can lead to loss of lives and even severe injuries on the persons involved. Corrosion of carbon steels lead to failure of several structures such as concrete walls and floors, automobiles, aircraft, gas pipelines, boilers, roofs, bridges, ships, etc. Corrosion leads to deterioration and degradation of culturally and artistically significant artifacts which are of greater concern to even international levels such as statues in Italy, Venice. With the deterioration of such artifacts, the cultural values of communities involved will have been put to test thus affecting their cultural way of life.

From these effects caused by corrosion, several methods of corrosion prevention have been developed. These include; rusting on carbon steels can be eliminated by the addition of chromium to at least 12%. At concentrations of above 12%, the composition of the oxide film usually forming naturally on the carbon steel surface will be altered /cite (Ispatguru). Surface treatment of all carbon steels to prevent direct contact of the metals with the airborne pollutants and gases and also corrosive liquids. Surface treatment also increases the metals resistance to corrosion. Galvanization of carbon steels can also be done to increase the corrosion resistance of carbon steels. Another way of reducing corrosion is through the investment of highly-efficient air filters to prevent the incoming of air pollutants into rooms having carbon steel structures.

Comparing the results obtained with the works of other authors

The above results can be related to the work of other authors and scientists. Abbasov et al, 2013 looked on the influence concentration of novel surfactants based on corn oil on the corrosion behavior of carbon steel in carbon dioxide. This was done by varying temperatures. This research narrowed down on weight loss, LPR corrosion rate and extrapolation of cathodic and anodic tafel lines method. It was discovered that surfactants are most efficient in inhibiting the corrosion of carbon steel in carbon dioxide saturated brine. Moreover the inhibition efficiency was noted to increase with the increase in surfactant concentration. Also, inhibition efficiency was noted to decrease with increase in temperature

Zeng & Cong 2016 also researched on effect of sodium chloride concentration on the corrosion rate of carbon steel in carbon dioxide saturated solutions. The scope of salt concentration in the experiments done varied between 0.01%-010%wt. In this project, instantaneous rate of corrosion

no of C1018 under freely corroding condition was determined using electrochemical impedance spectroscopy and linear polarization resistance. The results obtained from both methods indicated that the highest corrosion rate was obtained when the concentration of sodium chloride was lowest (0.01%wt) (Zeng & Cong, 2016). Potentiodynamic polarization tests done indicated that cathodic reaction was under diffusion or mixed control. Moreover, limiting currents were noted to increase with decreased concentration of sodium chloride. On the other hand, potentiostatic test done showed that adsorption prevailed at high salt concentration during anodic polarization. Additionally anodic currents were noted to increase with increase in the concentration of sodium chloride. Microelectrode technique was used during the cathodic and anodic polarization tests. Below are the diagrammatic results obtained by the research conducted by Zeng & Cong, 2016.

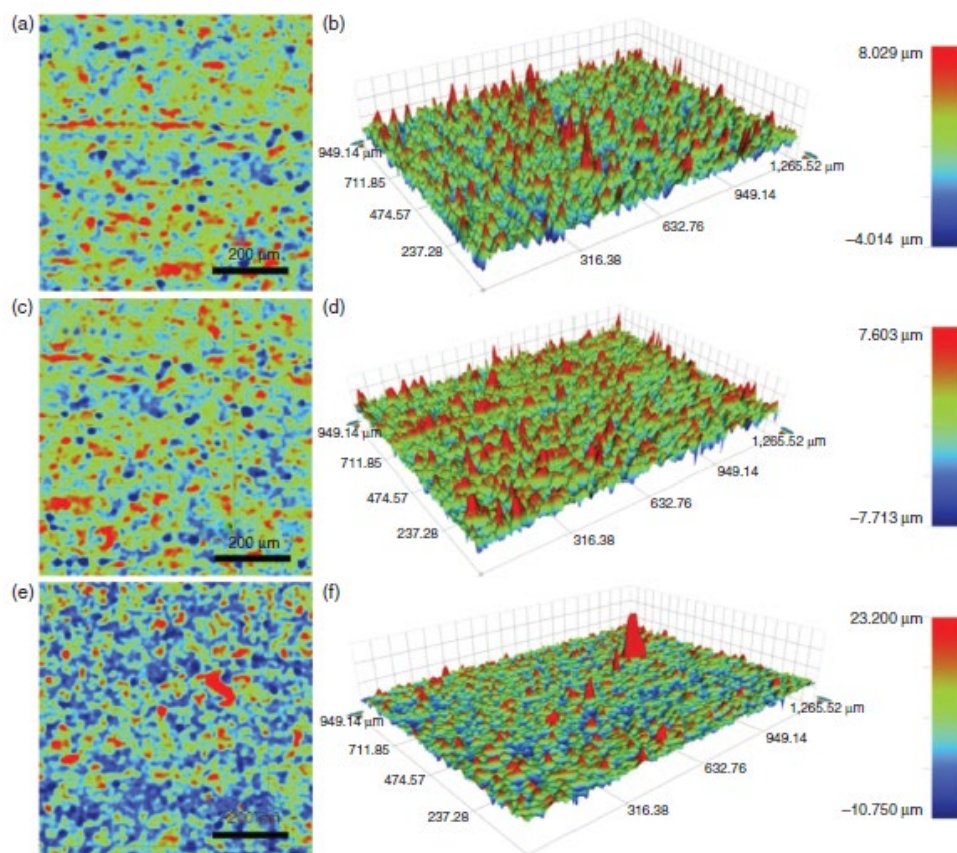


Figure 11: The optical images of C1018 electrodes in varied concentration of sodium chloride solutions with carbon dioxide saturation. a-0.001%, c-0.1% and e-10%, the corresponding 3D microscopic images for the SEM pictures are b, d and f (Zeng & Cong, 2016).

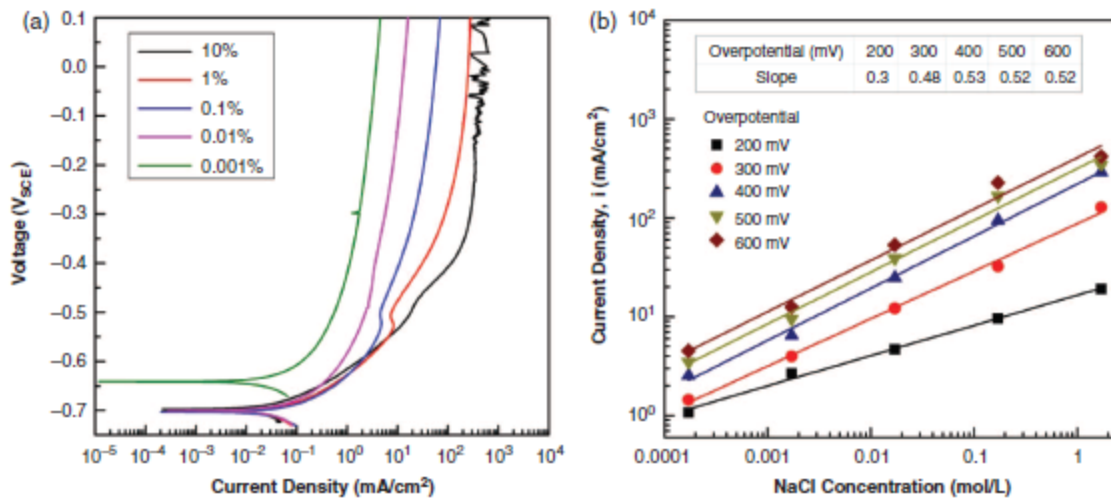


Figure 12: Curves of Anodic polarization of C1010 wire electrode in varied concentration of sodium chloride solution. b- Plot of corresponding densities at selected overpotentials vs. sodium chloride concentration (Zeng & Cong, 2016)

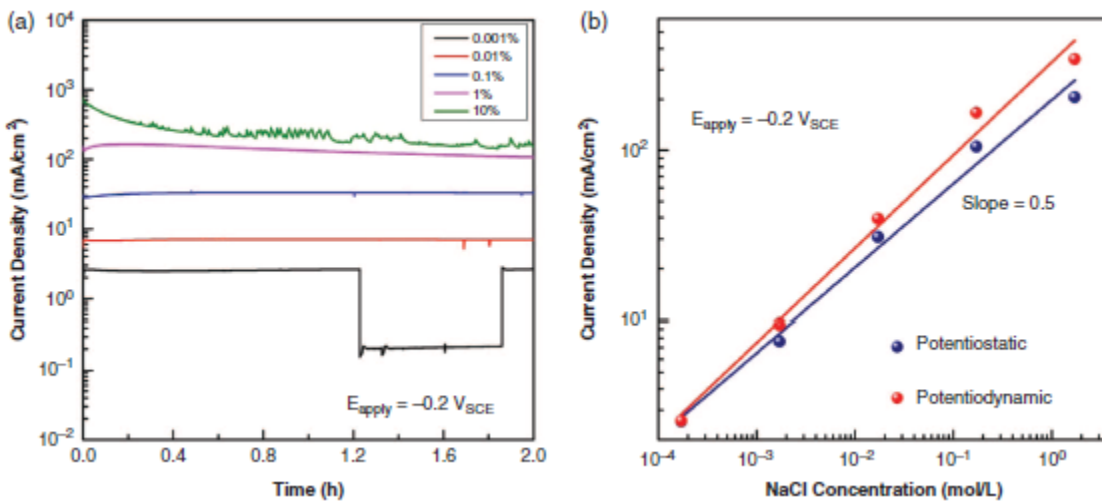


Figure 13: Curves of potentiostatic hold of C1010 wire electrode in varied concentration of sodium chloride. b- The steady state current densities at $E_{pp} = -0.2 V_{SCE}$ vs. sodium chloride concentration plots (Zeng & Cong, 2016).

Corrosion can also be reduced through the introduction of inhibitors which are environmentally benign. This is a recent invention which is still on the research and needs further investigation.

6 RECOMMENDATION

This study is limited to corrosion of Carbon Steel C1018 by 20% sodium chloride only. To fully analyze the effect of corrosion on C1018, I would recommend studying it in different concentrations of the corrosive agent. This can also involve different levels of exposure conditions such as temperature, velocity of fluid flowing past the metal, pH, pressure, inhibitors and impurities. Analysis of surface roughness of the metal should also be studied to give the properties of the rust formed.

In order to avoid some of the experimental errors, future experiments should be conducted in an enclosed chamber where parameters such as temperature can be controlled. Additionally, control experiments should be carried out side by side in a controlled environment so as to establish how various factors influence the rate of corrosion.

7 CONCLUSION

The research on the behavior of the behavior of carbon steel under varied conditions has been conducted by many authors. This has been prompted by the importance of steel in the engineering manufacturing industry. It must be noted that steel is among the highest utilized metals in the global during engineering works. However, rust continues to be a thorn in the flesh in its utilization. Based on this project's work and the work of other authors it can be concluded that

- The rate of corrosion decreases with increase in time. This is because the surface is fully exposed during the initial stages the surface of the metal is fully exposed to the agents of corrosion. The distribution of the rust on the metal surface is uneven due to different microstructure properties of the carbon steel.
- The chemical composition of carbon steels plays an important role in its corrosion resistance properties. The corrosion properties of carbon steels depend on the carbon content as well as the composition of alloying elements such as tin, chromium, manganese, silicon, nickel, molybdenum, etc.
- Economic effects bring about adverse effects on the economic scale. The costs can be accumulated directly or indirectly.
- Corrosion brings about an adverse effect on structures proving a significant problem in terms of safety.
- Corrosion can also be reduced through the introduction of inhibitors which are environmentally benign. The inhibition efficiency was noted to increase with the increase in surfactant concentration. Also, inhibition efficiency was noted to decrease with increase in temperature

Therefore, based on the results, it is clear that C1018 does not do well in Sodium Chloride environment. In the event that it is necessary to use the metal in a salty environment, precautions should be put in place to ensure longevity of use. The metal can be galvanized or coated to prevent or generally reduce rate of corrosion. If the metal is used to transfer products, it should be cleaned regularly to avoid contamination of the product. It is important to carefully select the appropriate metal to use to avoid the cost impact that comes along with using a metal in a non-conductive environment. From the above results, it is evident that a salty environment increases

the rate of corrosion in steel. The main aim of this project was to study how C1018 (low carbon steel) behaves when subjected to corrosive conditions. The results obtained were as expected hence the experiment was a success.

8 WORKPLAN

No	Description	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019	Mar 2019	April 2019	May 2019
1	Literature review								
2	Methodology								
3	Acquisition of materials								
4	Experiments and Analysis								
6	Progress presentation								
7	Report writing								
8	Final presentation								

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