INVESTIGATION OF STEEL PROTECTION WITH GLASS WOOL IN CORROSIVE MEDIA

BY

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CERTIFICATION

This is to certify that this project titled "Investigation of Steel Protection with Glass wool in Corrosive Media" was carried out by Kolade, Olawale Samson submitted in partial fulfilment for the award of Bachelor of Engineering (B.Eng.) degree in Materials and Metallurgical Engineering.

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DEDICATION

This project report is dedicated to God Almighty, the maker of heaven and earth who has kept me throughout my stay in this great institution and also during the course of my project.

ACKNOWLEGDEMENT

Firstly, I express my gratitude to God who has kept me safe and sound by His infinite mercies and has helped me to successfully complete this project.

Special thanks to my project supervisor, Engr. Dr. D.T Oloruntoba for overseeing and coordinating the project, as it would not have been a success without his support, guidance and his willingness to help always. I am highly indebted to the technologists of Materials and Metallurgical Engineering Department, Federal University of Technology, Akure (FUTA) for their great assistance throughout the project and also granting me access to use the equipment in the laboratory. I also thank the H.O.D, Materials and Metallurgical Engineering Prof. Abayomi Oni, the lecturers and non-academic staff of Materials and Metallurgical Engineering Department for their mentorship, training and great lessons.

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Finally we acknowledge my parents Mr and Mrs J.A Kolade, my brothers; Mr Kunle Kolade, Mr Gbenga Kolade, Mr Tunji Kolade and Mrs Olubukola Kolade for their prayers, financial support and encouragement.

ABSTRACT

Mild steel is a material that is widely used in engineering applications and in industries such as pulp and paper industry, power generation, underground structures, chemical and oil industries. An investigation has been carried out to evaluate the protection of mild steel samples of 10mm length by 15mm diameter with glass wool in various corrosive media. Glass wool of 1g, 1.5 g and 2 g were used to cover the mild steel samples with epoxy resin, hardener and accelerator which serves as a binder. Corrosion coupon test was carried out by subjecting the mild steel samples into various corrosive media namely 3.5 wt% NaCl, 0.5 M HCl, and 0.5 M H_2SO_4 for the period of 30days, the weight loss was obtained at 6 days interval for the exposure period of time and the corrosion rate was calculated from the values obtained. For sample 1, 4, 7 and 12 in 3.5 wt % NaCl, the corrosion rate was 0.035mmpy, 0.328mmpy, 0.1124mmpy, 5.8314mmpy respectively, the corrosion rate for sample 2, 5, 8 and 10 in 0.5M H_2SO_4 was 0.0531mmpy, 0.2435mmpy, 0.2936mmpy, 4.4123mmpy respectively and the corrosion rate for sample 3, 6, 9 and 11 in 0.5M HCl was 0.6542mmpy, 0.4303mmpy, 0.6210mmpy, 8.8900mmpy respectively. Potentiodynamic polarisation test was also carried out to obtain the corrosion potentials and corrosion current density and to determine the corrosion rate in the various environments. The corrosion rate for samples A, F, G and control in 3.5 wt % NaCl was 0.023115mmpy, 2.2194e-07mmpy, 0.41497mmpy, 0.17764mmpy respectively, for samples B, E, I, and control in 0.5 M HCl the corrosion rate was 0.056736mmpy, 0.111123mmpy, 2.9871mmpy, 4.8919mmpy respectively and for samples C, D, H and control in 0.5 M H_2SO_4 the corrosion rate was 0.078472mmpy, 1.269mmpy, 5.3999mmpy and 6.0988mmpy respectively. The two tests proved that glass wool gives an adequate protection to mild steel in H_2SO_4 and NaCl, but does not give adequate protection to mild steel and is susceptible to corrosion in HCl environment, this is because the chloride anions (Cl^-) present in the 0.5 M HCl environment have high concentration and aggressiveness.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The word “corrosion” is as old as the earth, but it has been known by different names. Corrosion is known commonly as rust, an undesirable phenomena which destroys the lustre of objects and shortens their life. Rusting is a term reserved for iron and steel corrosion, although many other metals form their oxides when corrosion occurs (Fontana, 2005). Shaw and Kelly, (2006) defined corrosion as the gradual destructive attack on a metal due to the exposure to its surrounding as a result of chemical and electrochemical attack from the environment. In addition, corrosion is the degradation of materials’ properties due to interaction with their respective environments, and corrosion of most metals is inevitable. While primarily associated with metallic materials, all material types are susceptible to degradation. Degradation of polymeric insulating coatings on wiring has been a concern in aging aircraft. Even ceramics can undergo degradation by selective dissolution. Like death and taxes, corrosion is something we hope to avoid; but ultimately it is something we must learn to deal with.

Corrosion cannot be defined without a reference to the environment. According to Bell (2016), no metal is immune to corrosion in all environments, but through monitoring and understanding the environmental conditions that are the cause of corrosion, changes to the type of metal being used can also lead to significant reductions in corrosion. Sea water because of its high chloride content corrode most metals by destroying the natural oxidative passivity acquired by many engineering alloy steel (Mattson, 1996). Furthermore, the most common reasons why a material fails or experiences failure is when the environment is not correctly assessed or when the material is exposed to an unexpected condition. For example, unexpected contamination of the material by chloride, pollution of air or water, and unexpected immersion the material in sea water. Carbon steel, the most widely used engineering material accounts for approximately 85% of the annual steel production worldwide. It is used in large tonnages in marine applications, nuclear production and refining, pipelines, mining, construction and metal-processing equipment, but it has a limitation of low resistance to corrosion (Key to Metals, 2001). At oil refineries, especially in the Hydrodesulphurisation (HDS) streamline part, the rate of metal loss either in the form of general or local corrosion is one of the highest. Thus, to achieve an optimal balance between production, inspection and maintenance, careful planning is required (Gergely *et al.*, 2016).

1.2 STATEMENT OF PROBLEM

Steel is an alloy of iron and carbon in which the carbon content ranges up to 2 percent. By far the most widely used material for building the world's infrastructure and industries, it is used to fabricate everything from sewing needles to oil tankers. In addition, the tools required to build and manufacture such articles are also made of steel. The main reasons for the popularity of steel are the relatively low cost of making, forming, and processing it, the abundance of its two raw materials (iron ore and scrap), and its unparalleled range of mechanical properties. (Encyclopedia Britannica Ultimate Reference Suite, 2014). Most companies such as the production, chemical and petrochemical companies involved in the storage and transportation of certain chemicals such as hydrochloric acid, sulphuric acid are faced with the problems of corrosion. These companies tend to spend so much money to prevent food contamination and protect vessels, storage tanks and pipelines made of steel from the deleterious effects of corrosion such as: loss of valuable chemicals, high maintenance and operating costs, plant shutdowns (Fontana, 2005). It has also been found out that engineers have not been able to completely prevent the corrosion of steel in various corrosive environment, hence the need for this project is to investigate protection of steel with glass wool in a corrosive media.

1.3 AIM OF THE STUDY

The aim of this project is to prevent the corrosion of steel with the use of glass wool bound with epoxy resin on exposure to several corrosive media.

1.4 OBJECTIVES OF THE STUDY

The specific objectives of this project are to;

- Coat mild steel with glass wool using epoxy resin as a binder.
- Investigate the performance of mild steel with glass wool and epoxy resin in various corrosive environment such as acidic environment; sulphuric acid (H_2SO_4), hydrochloric acid (HCl) and sodium chloride (NaCl).
- Compare the result of steel in acidic and chloride corrosive environments.

1.5 JUSTIFICATION OF THIS RESEARCH

All engineering materials such as metals, ceramics, polymers and composites are susceptible to corrosion attack. The severity of the attack however appears to be rampant in metallic materials. Apart from its drastic contribution to depletion of world mineral resources, huge financial loss and material wastage are incurred annually in combating and preventing corrosion. The total annual of floods, hurricanes, tornadoes, fires, lightning and earthquakes are less than the costs of corrosion (Fontana, 2005).

Although the costs attributed to corrosion damages of all kinds have been estimated to be of the order of 3 to 5 percent of industrialised countries' gross national product (GNP), the responsibilities associated with these problems are sometimes quite diffuse (Pierre, 2000). At least 35% of the above amount could have been saved by taking appropriate corrosion control measures. In UK, the corrosion cost is estimated to be 4-5% of the GNP (Uhlig, 1985). The impact of corrosion on the Nigerian economy is by no means less. Although Nigeria has not established an adequate record of corrosion, but the consequences of corrosion is felt in all areas of her economy. A large amount of money is being spent in the oil and gas sector to combat the corrosion of pipelines, storage tanks and oil rigs. Pipelines conveying environmentally harmful chemicals such as sulphuric acid and hydrochloric acid experience corrosion damage in form of leakage due to the corrosive nature of the products conveyed.

There is an ever increasing need to carry out research to investigate the corrosion behaviour of metal/metallic materials in various working environment with the aim of extending their service life and reliability. This project is meant to give theoretical and practical understanding of corrosion protection of steels when exposed to certain corrosive environment or media using glass wool as a means of protection to such steels.

1.6 CONTRIBUTION OF THE RESEARCH TO KNOWLEDGE

This research is expected to contribute knowledge towards the protection of steel using glass wool being a fibre materials of high thermal resistance and high temperature properties which offer good protection of carbon steel in a corrosive media.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW OF CORROSION

Metals and alloys (steel) are used as fabrication or construction materials in engineering. If the metals or alloy structures are not properly maintained, they deteriorate slowly by the action of atmospheric gases, moisture and other chemicals. This phenomenon of destruction of metals and alloys is known as corrosion. In industries such as pulp and paper industry, power generation, underground structures, chemical and oil industries, metals are used in over 90% of construction process (Osarolube *et al.*, 2004). Iron and steel are the most commonly used materials in the fabrication and manufacturing of oil field operating platforms because of their availability, low cost, ease of fabrication, and high strength (Umezurike, 1998; Nwoko and Umoru, 1998). Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment. Corrosion can be fast or slow. Sensitised 18-8 stainless steel is badly attacked in hours by polythonic acid. Railroad tracks usually shows slight rusting – not sufficient to affect their performance over many years. The famous iron pillar of New Delhi, India was made almost 2000 years ago and is almost as good as new. It is about 32 feet high and 2 feet in diameter. It should be noted, however, that it has been exposed mostly to arid conditions (Fontana, 2005).

According to Callister (2000), corrosion is defined as the destructive and unintentional attack of a metal; it is electrochemical and ordinarily begins at the surface. The problem of metallic corrosion is one of significant proportions; in economic terms, it has been estimated that approximately 5% of an industrialised nation's income is spent on corrosion prevention and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions. The consequences of corrosion are all too common. Familiar examples include the rusting of automotive body panels and radiator and exhaust components. Furthermore, corrosion is a prevailing destructive phenomenon in science and technology (Ita and Offiong, 1999).

2.1.1 Corrosive Environment

Corrosion cannot be defined without a reference to environment. All environments are corrosive to some degree. The following are typical corrosive environments: air and humidity, fresh, distilled, salt and marine water, natural, urban, marine and industrial atmospheres, steam and gases, like chlorine, ammonia, hydrogen sulphide, sulphur dioxide and oxides of nitrogen, fuel gases, acids, alkalis, soils. It may, therefore, be observed that corrosion is a potent force which destroys economy, depletes resources and causes costly and untimely failures of plants, equipment and components (Zaki, 2006)

2.1.2 Consequences of Corrosion

According to Zaki, (2006), the important consequences of corrosion are summarised below;

i. **Plant shutdowns**: The shutdown of nuclear plants, process plants, power plants and refineries can be due to corrosion and this may cause severe problems to the industry and consumers.

ii. **Loss of products**: Leaking containers, water and oil transportation lines and fuel tanks cause significant loss of product and may generate severe accidents and hazards. It is well known that at least 25% of water is lost by leakage.

iii. **Loss of efficiency**: Insulation of heat exchanger tubing and pipelines by corrosion products reduces heat transfer and piping capacity.

iv. **Contamination**: Corrosion products may contaminate chemicals, pharmaceuticals, dyes, packaged goods, etc. with dire consequences to the consumers.

v. **Nuclear hazards:** The Chernobyl disaster is a continuing example of transport of radioactive corrosion products in water, fatal to human, animal and biological life.

2.1.3 Factors that affect the rate of corrosion

Four elements need to be present for corrosion to occur and collectively referred to as the corrosion cell; an anode (+), a cathode (-), a metallic conductor and an electrolyte (http://www.capital-painting.com/factors-that-affect-the-rate-of-corrosion). The factors affecting corrosion are;

A. Environmental factors.

B. Metallurgical factors.

A. Environmental factors

i. **Aqueous Environment:** This is the environment that contains water. As the rate of water increases, corrosion rate increases.

ii. **Effect of Dissolved Oxygen:** Oxygen also increases the rate of corrosion. Corrosion can take place in an oxygen-deficient environment, but the rate of the corrosion reaction (and destruction of the metal) is generally much slower. In immersed conditions, if an electrolyte is in contact with one area of metal containing more oxygen than the electrolyte in contact with another area of the metal, the higher oxygen-concentration area is cathodic relative to the remaining surface. An oxygen concentration cell then forms, which results in rapid corrosion.

iii. **Temperature:** Corrosion reactions are electrochemical in nature and usually accelerated with increasing temperature; therefore, corrosion proceeds faster in warmer environments than in cooler ones (http://www.capital-painting.com/factors-that-affect-the-rate-of-corrosion).

iv. **Chemical Salts:** Chemical salts increase the rate of corrosion by increasing the efficiency (conductivity) of the electrolyte. The most common chemical salt is sodium chloride, a major element of seawater. Sodium chloride deposited on atmospherically exposed surfaces also acts as a hygroscopic material (i.e., it extracts moisture from the air), which then increases the corrosion in non-immersed areas (http://www.capital-painting.com/factors-that-affect-the-rate- of-corrosion).

v. **Humidity**: Humidity and time-of-wetness play a large role in promoting and accelerating corrosion rates. Time-of-wetness refers to the length of time an atmospherically exposed substrate has sufficient moisture to support the corrosion process. The wetter the environment, the more corrosion is likely to occur (http://www.capital-painting.com/factors-that-affect-the-rate-of-corrosion).

vi. **Pollutants:** Acid rain (a chemical by-product from manufacturing and processing plants), and chlorides (in coastal areas) promote corrosion. Acid gases, such as carbon dioxide, can also dissolve in a film of moisture in contact with the metal.

vii. **Microbial Influence**: Microorganisms in aqueous environment can cause various forms of localised attack including pitting, dealloying, enhanced corrosion hydrogen embrittlement.

B. Metallurgical factors

i. **Varieties of Iron and Steel:** A relative pure iron corrodes in acids at a much lower rate than iron and steel high in residual elements such as carbon, nitrogen, sulphur and phosphorus.

ii. **Effects of Composition:** The corrosion rate is reduced when steel is alloyed in the proportion of stainless (> 12% Cr) or higher silicon-iron or high nickel-alloy.

iii. **Effects of Stress:** Cold working causes stress as this leads to high corrosion rate of commercial steel in acids.

iv. **Galvanic effect through coupling of different steels:** When different steels like mild steel and low alloy steel are coupled, the potentials of both steels which were initially different becomes equal. Hence, the corrosion of mild steel is now increased, while that of low alloyed steel is decreased.

2.2 TYPES OF CORROSION

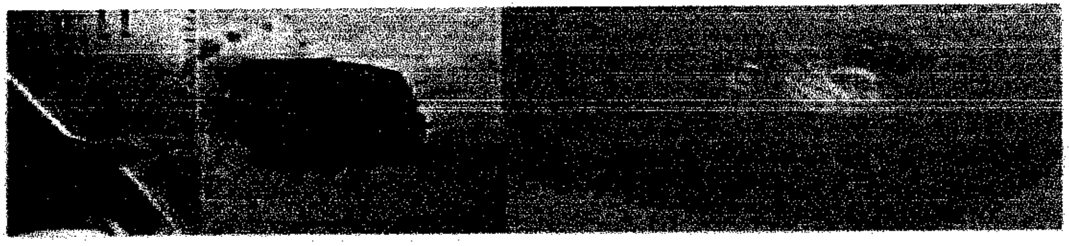
On this basis, the following corrosion forms can be defined:

i. Uniform (general) Corrosion.
ii. Galvanic (two–metal) Corrosion.
iii. Crevice Corrosion.
iv. Pitting Corrosion.
v. Microbial Corrosion.
vi. Erosion Corrosion.
vii. Cavitation Corrosion.
viii. Fretting Corrosion.
ix. Stress Corrosion Cracking.

2.2.1 Pitting Corrosion

Pitting corrosion is a localised form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. Pitting corrosion, which, for example, is almost a common denominator of all types of localised corrosion attack, may assume different shapes.

Pitting corrosion can produce pits with their mouth open (uncovered) or covered with a semi permeable membrane of corrosion products. Pits can be either hemispherical or cup-shaped (http://www.nace.org/pittting-corrosion).



A corrosion pit on the outside wall of a pipeline at a coating defect before and after abrasive blasting.

Figure 2.1: Corrosion Pit on the Outside Wall of a Pipeline

2.2.2 Uniform Corrosion

Uniform corrosion also called general corrosion is a type of corrosion in which the whole metal surface is corroded, the volume of metal decreases uniformly and corrosion products are formed. As corrosion occurs uniformly over the entire surface of the metal component, it can be practically controlled by cathodic protection, use of coatings or paints, or simply by specifying a corrosion allowance. In other cases uniform corrosion adds colour and appeal to a surface. Two classics in this respect are the patina created by naturally tarnishing copper roofs and the rust hues produced on weathering steels. The breakdown of protective coating systems on structures often leads to this form of corrosion. Dulling of a bright or polished surface, etching by acid cleaners, or oxidation (discolouration) of steel are examples of surface corrosion. Surface corrosion can indicate a breakdown in the protective coating system, however, and should be examined closely for more advanced attack. If surface corrosion is permitted to continue, the surface may become rough and surface corrosion can lead to more serious types of corrosion (http://www.nace.org/uniform-corrosion).

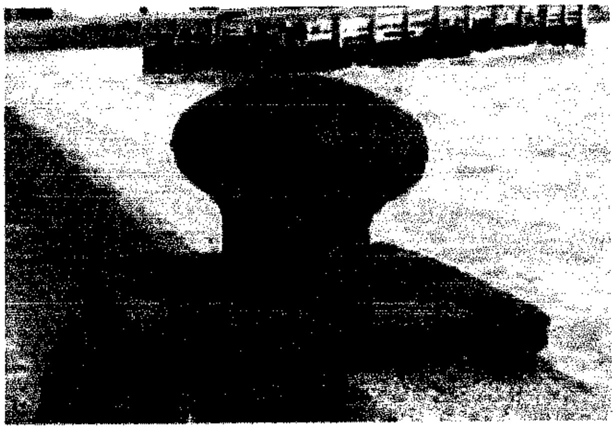


Figure 2.2: Uniform Corrosion

2.2.3 Galvanic Corrosion

Galvanic corrosion (also called 'dissimilar metal corrosion' or wrongly 'electrolysis') refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. It occurs when two (or more) dissimilar metals are brought into electrical contact under water. When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone. Either (or both) metal in the couple may or may not corrode by itself (themselves). When contact with a dissimilar metal is made, however, the self-corrosion rates will change: Corrosion of the anode will accelerate while the corrosion of the cathode will decelerate or even stop.

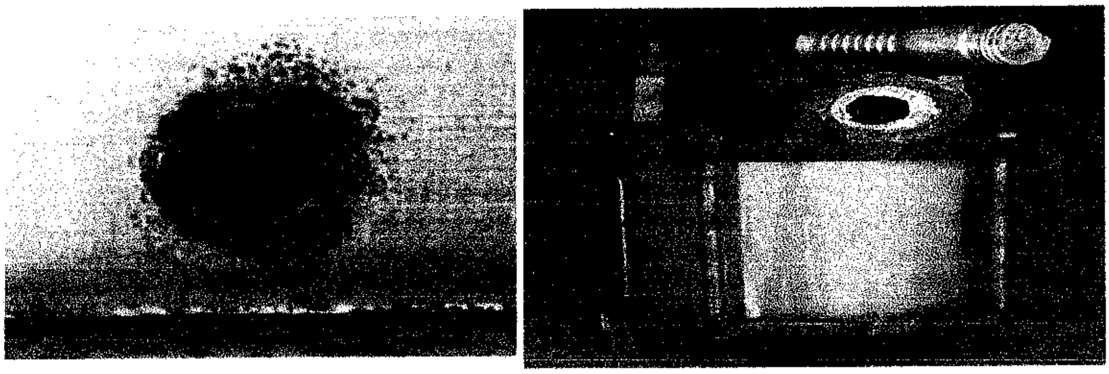


Figure 2.3: Galvanic Corrosion Resulting From Placing a Bronze Sea Strainer on an Aluminium Hose Barb

2.2.4 Crevice Corrosion

This form of corrosion is an intense local attack within crevices or shielded areas on metal surfaces exposed to corrosive solutions. It is characteristically encountered with metals and alloys which rely on a surface oxide film for corrosion protection.

The crevices can be inherent in the design of the equipment (e.g., plate heat exchangers) or inadvertently created by a bad design. Crevice corrosion can be initiated at metal to non-metallic sealing faces. Fibrous materials which have a strong wicking action are notorious in their ability to initiate crevice attack. Similarly, materials which have poor stress relaxation characteristics, i.e., have little or no ability to recover their original shape after being deformed, are also crevice creators – as are materials which tend to creep under the influence of applied loads and/or at elevated temperatures (Oldfield and Todd, 1984).

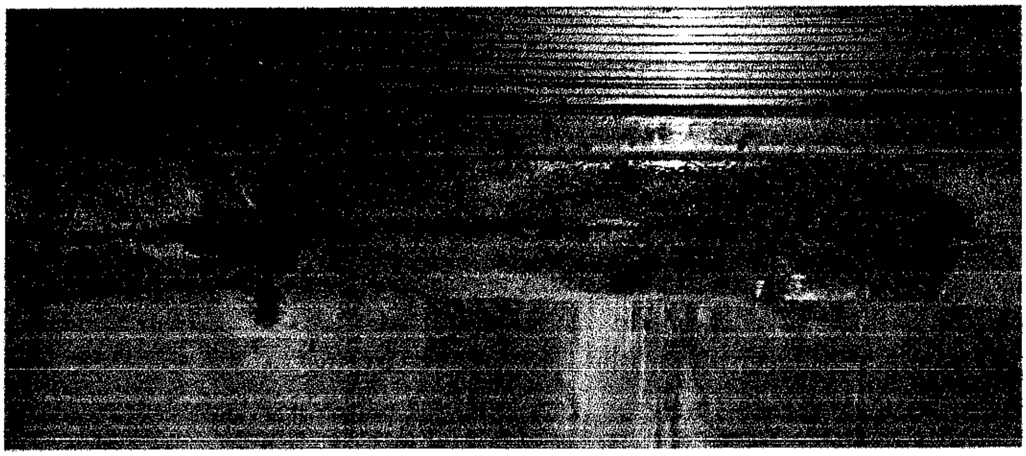


Figure 2.4: Metallic Structure Experiencing Crevice Corrosion

2.2.5 Cavitation Corrosion

According to Singh (1999), it is a specialised form of erosion corrosion caused by the formation and collapse of vapour-bubbles in corrosive liquid near a metal surface. It occurs on surface which are in contact with high-velocity-flowing liquids with frequent pressure changes. If pressure inside a water-filled container drops, water vaporises to form bubbles. The increase of pressure now makes the bubbles to collapse. Cathodic protection helps to reduce the damage caused by cavitation corrosion.

2.2.6 Erosion Corrosion

Erosion corrosion is an acceleration in the rate of corrosion attack in metal due to the relative motion of a corrosive fluid and a metal surface. The increased turbulence caused by pitting on the internal surfaces of a tube can result in rapidly increasing erosion rates and eventually a leak. Erosion corrosion can also be aggravated by faulty workmanship. For example, burrs left at cut tube ends can upset smooth water flow, because localized turbulence and high flow velocities, resulting in erosion corrosion. A combination of erosion and corrosion can lead to extremely high pitting rates. In offshore well systems, the process industry in which components come into contact with sand bearing liquids, this is an important problem. High hardness in a material does not necessarily guarantee a high degree of resistance to erosion corrosion (http://corrosiondoctors.org/formserosion/erosion.htm).

Figure 2.5: Inner Part of a Pipeline Experiencing Erosion Corrosion

2.2.7 Fretting Corrosion

Fretting corrosion or fretting fatigue occurs as a result of two materials, under load, when subject to relative motion. These materials are typically intended not to slide or move relative to the other material but in reality experience a microscopic level of motion commonly due to vibrations. Fretting is actually the wearing a way of materials in contact. In turn, these worn-away particles can react with the atmosphere or chemicals in the environment to form hard oxides that can increase the rate of fretting corrosion (engineer@fastener.com).

2.2.8 Stress Corrosion Cracking (SCC)

Stress corrosion cracking (SCC) of metals is an effect that occurs when both tensile stress and corrosion act on a metal simultaneously; if either stress or corrosion are removed, this effect arrests. The mechanism for SCC can be anodic dissolution which occurs as plastic deformation at the micro-crack tip breaks apart the protective surface oxide layer which allows the corrosive medium to attack the metal. The surface oxide layer reforms and the process repeats. Stress corrosion cracking needs a sustained load and a corrosive environment to propagate cracks (engineer@fastener.com).

Figure 2.6: Oil and Gas Pipeline after being attacked by Stress Corrosion Cracking.

2.2.9 Microbiologically Induced Corrosion

This type of corrosion is caused by bacterial activities. The bacteria produce waste products like CO_2, H_2S, and organic acids that corrode the pipes by increasing the toxicity of the flowing fluid in the pipeline. The microbes tend to form colonies in a hospitable environment and allow enhanced corrosion under the colony. The formation of these colonies is promoted by neutral water especially when stagnant. Numerous reports of the presence of microbes in reservoirs had been published. Escherichia contains hydrogenise, an enzyme that utilises molecular hydrogen and may be associated with cathodic hydrogen depolarisation, causing corrosion of steel casings and pipes in the oil field. Bacteria that form slime (some form of polysaccharides), such as Achromobacter sp., Flavobacterium sp., and Desulfuricans sp., will adhere to each other, forming a large mass. They also adhere to the walls of the pores, causing severe plugging problems at injection wells. Microbiologically induced corrosion (MIC) is recognized by the appearance of a black slimy waste material or nodules on the pipe surface as well as pitting of the pipe wall underneath these deposits. Figure below represent the scanning electron microscopy (SEM) photograph of Desulfovibrio desulfuricans and a pipeline affected by MIC corrosion respectively.

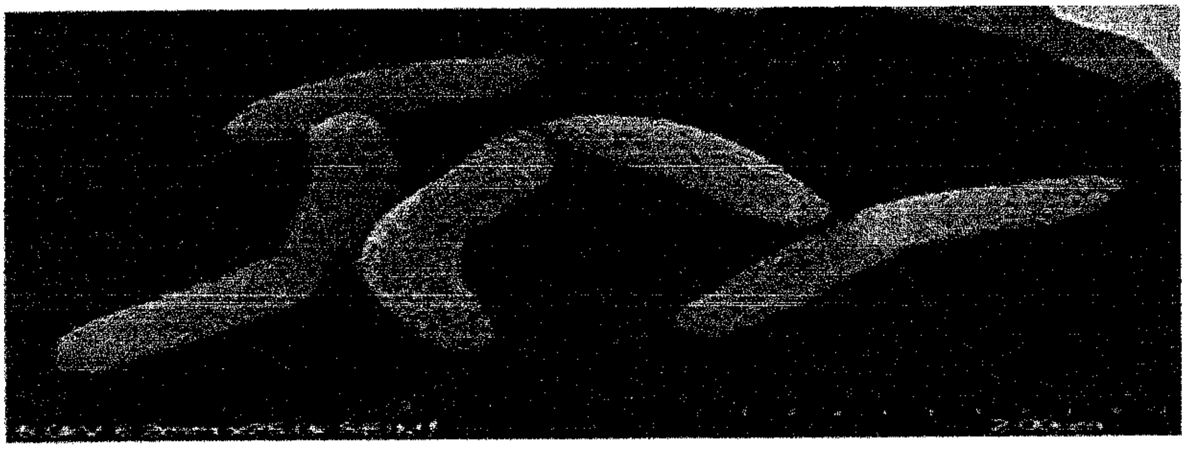


Figure 2.7: SEM Photograph of Desulfovibrio Desulfuricans

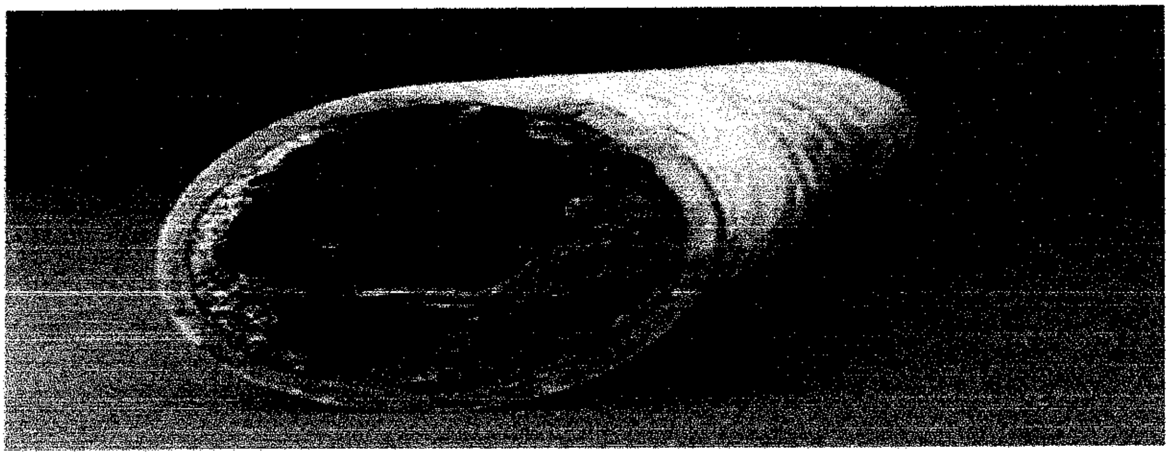


Figure 2.8: Pipeline affected by Microbial Induced Corrosion (MIC)

2.3 CORROSION PROTECTION TECHNIQUES

It is important to realise that corrosive attack on a metal can only occur at the surface of the metal, hence any modification of the surface or its environment can change the rate of reaction. There are some methods designed to protect metals from corrosion.

2.3.1 Cathodic Protection Technique

Cathodic protection is a method to reduce corrosion by minimising the difference in potential or potential difference between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source. When enough current is applied, the whole structure will be at one potential. Thus, anode and cathode sites will not exist. It is normally used in conjunction with coatings and can be considered as a secondary corrosion control technique. The cathodic protection system can be designed to prevent both oxygen-controlled and microbiologically controlled corrosion.

Cathodic protection works by converting unwanted anodic (active) sites on a metal's surface to cathodic (passive) sites through the application of an opposing current. This opposing current supplies free electrons and forces local anodes to be polarized to the potential of the local cathodes. The two methods of applying cathodic protection include;

i. Sacrificial (or galvanic) Anode Cathodic Protection (SACP)

ii. Impressed Current Cathodic Protection (ICCP)

2.3.1.1 Sacrificial Anode Cathodic Protection

In this type of application, the naturally occurring electrochemical potentials of different metals are used to provide protection. Sacrificial anodes are coupled to the structure under protection and conventional current flows from the anode to the structure as long as the anode is more active than the structure. As the current flows, all the corrosions occur on the anode which sacrifices itself in order to offer protection from corrosion to the structure.

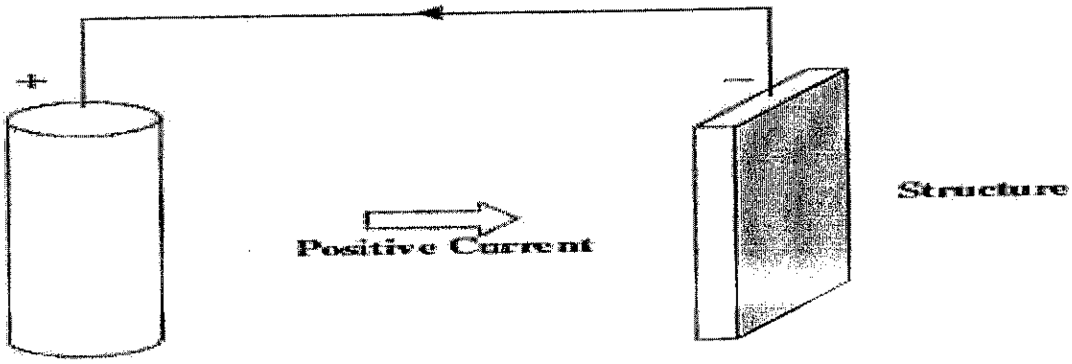


Figure 2.9: Sacrificial Anode Cathodic Protection

2.3.1.2 Impressed Current Cathodic Protection (ICCP)

In impressed current cathodic protection, the current is impressed or forced by a power supply. The power source must be able to deliver direct current, and examples are transformer rectifier units, solar generating units, or thermoelectric generators. The anodes are either inert or have low consumption rates and can be surrounded by carbonaceous backfill to increase efficiency and decrease costs. Typical anodes are titanium coated with mixed metal oxide or platinum, silicon iron, graphite, and magnetite. Impressed current cathodic protection to a buried pipeline by solar energy using photovoltaic generator as the power source. This method is applicable for various types of grounds and that the output current is high enough to protect the pipeline with low costs.

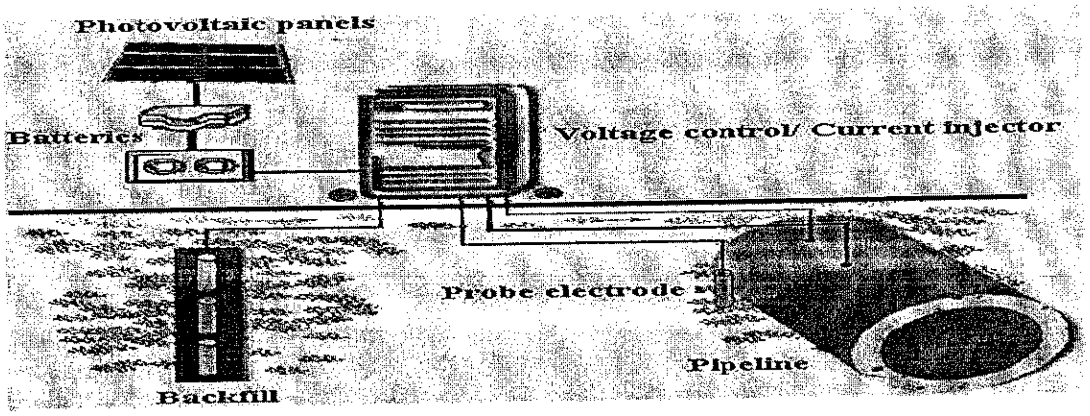


Figure 2.10: Impressed Current Cathodic Protection

2.3.1.3 Corrosion Inhibitors

A corrosion inhibitor is a chemical compound that, when added to a liquid or gas decreases the corrosion rate of a material, typically a metal or an alloy. The effectiveness of a corrosion inhibitor depends on fluid composition, quantity of water, and flow regime. A common mechanism for inhibiting corrosion involves formation of a coating, often a passivation layer, which prevents access of the corrosive substance to the metal. Permanent treatments such as chrome plating are not generally considered inhibitors, however. Instead corrosion inhibitors are additives to the fluids that surround the metal or related object (Gräfen *et al.*, 2002).

Corrosion inhibitors are chemicals that react with the metal's surface or the environmental gases causing corrosion, thereby, interrupting the chemical reaction that causes corrosion. Inhibitors can work by adsorbing themselves on the metal's surface and forming a protective film. These chemicals can be applied as a solution or as a protective coating via dispersion techniques (Bell, 2016).

The inhibitors process of slowing corrosion depends upon:

i. Changing the anodic or cathodic polarization behaviour.

ii. Decreasing the diffusion of ions to the metal's surface.

iii. Increasing the electrical resistance of the metal's surface.

Major end-use industries for corrosion inhibitors are petroleum refining, oil and gas exploration, chemical production and water treatment facilities. The benefit of corrosion inhibitors is that they can be applied in-situ to metals as a corrective action to counter unexpected corrosion.

2.3.1.4 Protective Coatings

In order to protect metals from corrosion, it is necessary to cover the surface by means of protective coatings. These coatings act as a physical barrier between the coated metal surface and the environment. They afford decorative appeal and impart special properties like hardness, oxidation resistance and thermal insulation. Protective coatings can be broadly classified into two types; Organic coatings and Inorganic coatings.

Organic coatings consists of paints, varnishes, lacquers, enamels and Inorganic coatings are further classified into two types which are;

- **A.** Metallic coating.
- **B.** Non-metallic coating.

A. Metallic coating

There are four common types of metallic coatings. These are;

- i. **Electroplating**: A thin layer of metal often nickel, tin or chromium is deposited on the substrate metal (generally steel) in an electrolytic bath. The electrolyte usually consists of a water solution containing salts of the metal to be deposited.
- ii. **Mechanical plating**: Metal powder can be cold welded to a substrate metal by tumbling the part, along with the powder and glass beads, in a treated aqueous solution. Mechanical plating is often used to apply zinc or cadmium to small metal parts.
- iii. **Electroless plating**: A coating metal, such as cobalt or nickel, is deposited on the substrate metal using a chemical reaction in this non-electric plating method.
- iv. **Hot dipping:** When immersed in a molten bath of the protective, coating metal a thin layer adheres to the substrate metal.

B. Non-metallic coatings: These include; surface coating or chemical conversion coating, anodising, and enamel coating, vitreous or porcelain coating.

2.3.1.5 Metal Selection and Surface Conditions

Metal selection is one of the common corrosion protection technique used. The development of new alloys, designed to protect against corrosion in specific environments are constantly under production. Monitoring of surface conditions is also critical in protecting against metal deterioration from corrosion. Cracks, crevices surfaces, whether a result of operational requirements, wear and tear or manufacturing flaws, all can result in greater rates of corrosion. Proper monitoring and the elimination of unnecessarily vulnerable surface conditions, along with taking steps to ensure that systems are designed to avoid reactive metal combinations and that corrosive agents are not used in the cleaning or maintenance of metal parts are all also part of effective corrosion reduction program.

2.4 LIMITATIONS OF CORROSION PROTECTIVE TECHNIQUES

The corrosion protection techniques listed and discussed above have many limitations or disadvantages

2.4.1 Limitations of Sacrificial Anodic Protection

i. High starting current is required.

ii. Uncoated parts cannot be protected.

iii. Limited driving potential, hence, not applicable for large object

iv. The anode current is uncontrollable.

v. Water turbulence around the hull increases the noise level

vi. Frequent replacement is necessary when stray DC currents are present

vii. Fuel consumption is increased

viii. Replacement is usually necessary before scheduled overhaul (every 3 years) (http://electronicstechnician.tpub.com).

2.4.2 Limitation of Protective Coatings

i. Peeling of coatings from the metal surface.

ii. Expensive.

2.5 CORROSION MEASUREMENT

Corrosion measurement employs a variety of techniques to determine how corrosive the environment is and at what rate metal loss is being experienced. Corrosion measurement is the quantitative method by which the effectiveness of corrosion control and prevention techniques can be evaluated and provides the feedback to enable corrosion control and prevention methods to be optimised. There are various corrosion measurement techniques including;

2.5.1 Non-Destructive Testing Techniques

2.5.1.1 Eddy Current Inspection Technique

An eddy current is defined as a circulating electrical current induced in a conductive material by an alternating magnetic field. An eddy current system incorporates the electronic signal generator/processor and a probe containing at least one coil. The signal generator uses an alternating current to induce eddy currents in an electrically conductive material. In turn, the induced eddy currents induce an alternating current in the sensing coils. The fields in the generator and sensor coils are balanced by adjustments of frequency, amplitude, and distance. A change in the balance of the two fields indicates various flaws or material thinning.

The technique is commonly used off-line to identify defects in nonmagnetic metals such as heat exchanger tubing. Sophisticated, digitised, multichannel eddy current instruments are used extensively throughout industry. Computer-controlled robotic delivery systems to manipulate probes are used in areas such as manufacturing and nuclear power generation. With repeated surveys of the same area on a frequency determined by the severity of the corrosion, metal loss over time can be determined and long-term corrosion rates calculated.

2.5.1.2 Radiography

The thickness of corroded piping and other equipment can be deduced from radiographic images in several ways. With this technique, the difference in optical density of the film in a non-corroded area of the image compared with the optical density in the pitted area can be correlated with the difference in thickness of the two areas, and thereby the pit depth is determined. With repeated surveys of specific areas on a frequency determined from the severity of the corrosion, the changing depth and area of corrosion can be readily resolved and corrosion rates calculated. The method can be used on-line but is too insensitive to provide real-time measurements.

2.5.1.2.1 Benefits of Radiography

i. The radiographic technique can be used to determine the integrity of piping and equipment over large areas relatively inexpensively, using either manual techniques or automated, real-time radiographic inspection systems.

ii. This technique does not require access to the component being inspected; therefore, insulated, clad, bundled, or otherwise inaccessible piping can still be inspected and the extent and severity of corrosion determined. Techniques can then be used to determine the integrity of the corroded piping directly.

2.5.1.2.2 Limitations of Radiography

i. Absolute thickness of the inspected object is not normally discernible from the radiographic image.

ii. The precision of the calculated thickness is not high. Field results have shown that the tolerance of the data is ±10% of the calculated pit depth in the best case.

iii. Scale or other debris in the area of corrosion can significantly affect the accuracy of the calculated pit depths.

iv. The radiographic source-to-detection distance is limited by the strength of the source. In field radiography, this limits the technique to use on piping and other objects with cross-sections of around a metre or less.

2.5.2 Corrosion Monitoring

Corrosion monitoring is the practice of measuring the corrosivity of process stream conditions by the use of "probes" which are inserted into the process stream and which are continuously exposed to the process stream condition (www.metalsamples.com). The purpose of corrosion monitoring is to optimise balance between corrosion control and replacement costs. Each monitoring technique has inherent random error which is minimised by increasing number of techniques/monitoring points. Each monitoring technique has inherent random error which is minimised by increasing number of techniques/monitoring points (Gareth, 2010).

2.5.2.1 Corrosion Coupons (Weight Loss) Testing

Corrosion coupon measures corrosion rate by mass loss. The weight loss technique is the best known and simplest of all corrosion monitoring techniques. The method involves exposing a specimen of material (the coupon) to a process environment for a given duration, then removing the specimen for analysis. The basic measurement which is determined from corrosion coupons is weight loss, the weight loss taking place over the period of exposure being expressed as corrosion rate. The simplicity of the measurement offered by the corrosion coupon is such that the coupon technique forms the baseline method of measurement in many corrosion monitoring programs.

The technique is extremely versatile, since weight loss coupons can be fabricated from any commercially available alloy. In a typical monitoring program, coupons are exposed for a 90-day duration before being removed for a laboratory analysis. This gives basic corrosion rate measurements at a frequency of four times per year. The weight loss resulting from any single coupon exposure yields the "average" value of corrosion occurring during that exposure. A wide variety of corrosion phenomena may be studied which includes, but is not limited to: stress-assisted corrosion, bimetallic (galvanic) attack, differential aeration and heat-affected zones. Corrosion monitoring "probes" can be mechanical, electrical, or electrochemical devices.

2.5.2.1.1 Advantages of Weight Loss Coupons

i. The technique is applicable to all environments such as gases, liquids, solids/particulate flow.

ii. Provides some information on corrosion modes and rates in a relatively simple and easy to interpret form.

iii. Provides a time-averaged picture over the course of the exposure.

iv. Visual inspection can be undertaken.

v. Corrosion deposits can be observed and analysed.

vi. Weight loss can be readily determined and corrosion rate easily calculated.

vii. Localised corrosion can be identified and measured.

viii. Inhibitor performance can be easily assessed.

2.5.2.1.2 Disadvantages of Weight Loss Coupons

i. Tests locations of coupons is limited.

ii. It does not permit continuous monitoring.

iii. The installation, retrieval, assessment, and installation of new coupons requires human interaction and cannot readily be automated.

iv. Effects of varying operating conditions cannot be evaluated.

v. Time is involved in preparing coupon and evaluating corrosion rate.

vi. It is usually not possible to determine when corrosion initiated and terminated when examining a coupon and thus it is assumed to have corroded at a constant rate throughout the exposure period.

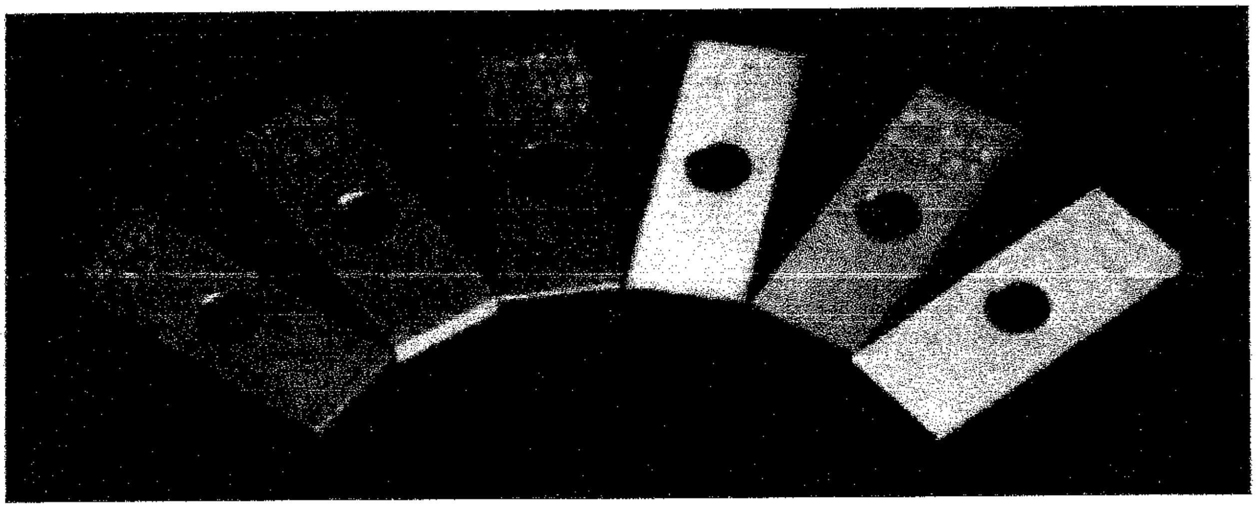


Figure 2.11: Weight Loss Coupons

2.5.2.2 Electrical Resistance (ER) Technique

The electrical resistance technique operates on the principle that the electrical resistance of a measuring element (wire, strip, or tube of metal) increases as its conductive cross-sectional area decreases as the result of corrosion, erosion, or a combination of both. In practice, the electrical resistance ratio between a measuring element exposed to the test environment and a reference element protected from the environment is made to compensate for resistance changes due to temperature. Because the resistance of the measurement element is very small, very sensitive measurement electronics are used. The general assumption that the cross-sectional area of the measurement element reduces uniformly as metal loss occurs is made in this method. The technique is an online, or side-stream, method that provides real-time measurements when sufficiently sensitive probes are used (http://www.nace.org).

Electrical resistance technique uses change in electric resistance produced by change in cross-sectional area (C.S.A) resulting from corrosion. Electrical resistance (ER) corrosion probes functioning is based on measuring the resistance of a sensing element. The change in the electrical resistance of an element (wire, tube or strip) is measured using Wheatstone bridge arrangement. This is then related to the change in cross-sectional area and hence provides indication of metal loss. The electrical resistance technique will not work if corrosion is localised and gives poor performance in thermally noisy systems (Gareth, 2010).

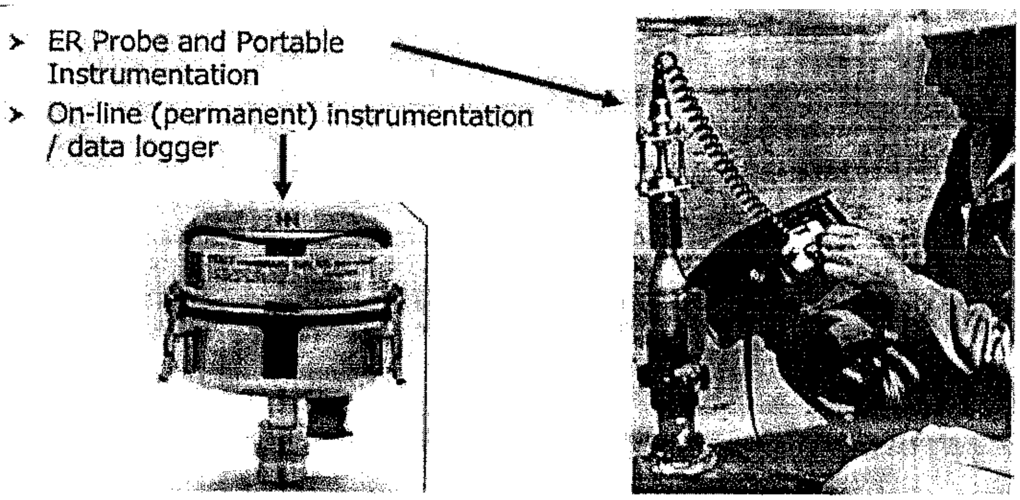


Fig 2.12: ER Probe to Monitor Corrosion in a Pipeline

2.5.2.2.1 Advantages of Electrical Resistance (ER) Technique

i. They provide representative data for general corrosion

ii. Direct measurement of material loss

iii. Can be used in any environment (conducting and non-conducting) and does not require continuous aqueous phase.

iv. Different types of probe elements available to cover different requirements, i.e. High sensitivity, Long life and Flush or protruding shapes.

v. Shows time evolution of corrosion rate.

vi. Can be used to monitor erosion (e.g. by sand) as well as corrosion.

vii. This technique enables continuous monitoring, which is important for control of corrosion in process equipment, when knowledge of the rate of attack is needed on an ongoing basis.

viii. Process upsets and other corrosive conditions can be detected quickly to enable remedial action to be taken before significant damage to process equipment occurs.

ix. Measurements are made without the need to withdraw coupons from the system.

x. The technique is useful in monitoring and determining corrosion inhibitor additions.

xi. This technique is useful for the optimization of a corrosion inhibition program, especially for batch treatment programs. It provides information about the inhibitor film persistence and the treatment frequency.

2.5.2.2.2 Limitation of Electrical Resistance (ER) Technique

i. They do not have the ability to accurately detect localised attack. In other words, probes are less sensitive to effects of localised attack, which increase the element resistance on only a small area of the element, except near the end of probe life on loop element probes, where the localised attack completely corrodes through the element, increasing its resistance to infinity.

ii. Corrosion rate determination requires a longer time (normally a few hours to a few days) than for electrochemical techniques, for those environments in which electrochemical techniques can be used.

iii. In some situations, partially conductive deposits such as iron sulphide reduce apparent corrosion rates or show some apparent metal gain. Some element shapes are much less sensitive to this than others.

2.5.2.3 Linear Polarisation Resistance (LPR) Monitoring

The LPR technique is based on complex electro-chemical theory. For purposes of industrial measurement applications it is simplified to a very basic concept. In fundamental terms, a small voltage (or polarization potential) is applied to an electrode in solution. The current needed to maintain a specific voltage shift (typically 10 mV) is directly related to the corrosion on the surface of the electrode in the solution. By measuring the current, a corrosion rate can be derived. The advantage of the LPR technique is that the measurement of corrosion rate is made instantaneously. This is a more powerful tool than either coupons or ER where the fundamental measurement is metal loss and where some period of exposure is required to determine corrosion rate. The disadvantage to the LPR technique is that it can only be successfully performed in relatively clean aqueous electrolytic environments. LPR will not work in gases or water/oil emulsions where fouling of the electrodes will prevent measurements being made.

2.5.2.4 Galvanic Monitoring

The galvanic monitoring technique, also known as Zero Resistance Ammetry (ZRA) is another electrochemical measuring technique. With ZRA probes, two electrodes of dissimilar metals are exposed to the process fluid. When immersed in solution, a natural voltage (potential) difference exits between the electrodes. The current generated due to this potential difference relates to the rate of corrosion which is occurring on the most active of the electrode couple. Galvanic monitoring is applicable to the following electrode couples: bimetallic corrosion, crevice and pitting attack, corrosion assisted cracking, corrosion by highly oxidizing species and weld decay. Galvanic current measurement has found its widest applications in water injection systems where dissolved oxygen concentrations are a primary concern. Oxygen leaking into such systems greatly increases galvanic currents and thus the corrosion rate of steel process components. Galvanic monitoring systems are used to provide an indication that oxygen may be invading injection waters through leaking gaskets or deaeration systems.

2.5.2.5 Biological Monitoring

Biological monitoring and analysis generally seeks to identify the presence of Sulphate Reducing Bacteria - SRB's. This is a class of anaerobic bacteria which consume sulphate from the process stream and generate sulphuric acid, a corrosive which attacks production plant materials.

2.5.2.6 Hydrogen Penetration Monitoring

In acidic process environments, hydrogen is a by-product of the corrosion reaction. Hydrogen generated in such a reaction can be absorbed by steel particularly when traces of sulphide or cyanide are present. This may lead to hydrogen induced failure by one or more of several mechanisms. The concept of hydrogen probes is to detect the amount of hydrogen permeating through the steel by mechanical or electrochemical measurement and to use this as a qualitative indication of corrosion rate.

2.6 MINERAL WOOL

Mineral wool is the general name for mineral fibres, or man-made mineral fibres. The term "man-made mineral fibres" is generally used to refer solely to synthetic materials including fibreglass, ceramic fibres and stone wool. According to International Agency for Research on Cancer, IARC, (1988), synthetic vitreous fibres are inorganic substances, largely composed of aluminium and calcium silicates that are derived from rock, clay, slag, or glass. Naturally occurring mineral fibres such as asbestos are crystalline in structure, while synthetic vitreous fibres are amorphous materials. There are several methods of categorising synthetic vitreous fibres based either on origin, chemical structure, morphology, application, or method of manufacturing. The most recent classification scheme proposed by the IARC has divided these compounds into two broad classes: filaments and wools. The filaments contain continuous glass filaments, while the wools contain glass wool, rock (stone) wool, slag wool, refractory ceramic fibres, and other newly engineered bio-soluble fibres (IARC 2002).

2.6.1 Glass Wool

Glass wool, also known as fibre glass wool, lime glass, glass beads is an insulating material made from fibres of glass or bonded glass fibre arranged using a binder into a texture similar to wool. Glass wool is also known as a synthetic mineral fibre (SMF), meaning that it is a fibrous product manufactured by the process of blowing or spinning a molten mineral raw material into a fibrous "woollen" product that is used for insulation. Glass wool consists of fine, long, inorganic fibres bonded together by high temperature binder. These fibres (each of approximately 6-7 microns diameter) are distributed to trap millions of tiny pockets of air in it, thereby creating as an excellent thermal and acoustic insulation wool). The light weight of glass wool also offers significant advantages during transport and installation.

In addition, glass wool is chemically inert and has no impurities such as iron shots, sulphur and chloride. The product is non-corrosive to metal and does not support mould growth (http://www.natindco.in/insualting-products/glasswool).

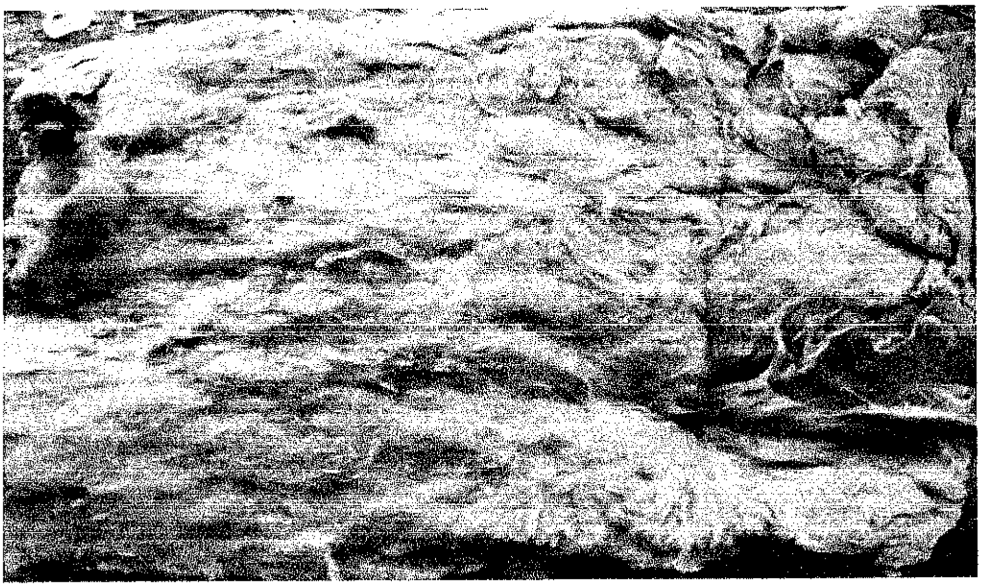


Plate 2.1: Glass Wool

2.6.2 Chemical Structure of Glass Wool

The basis of textile grade glass fibres is silica, SiO_2. In the polymer it forms SiO_4 groups which are configured as a tetrahedron with the silicon atom at the centre, and four oxygen atoms at the corners. These atoms then form a network bonded at the corners by sharing the oxygen atoms. The vitreous and crystalline states of silica (glass and quartz) have similar energy levels on a molecular basis, also implying that the glassy form is extremely stable. In order to induce crystallisation, it must be heated to temperatures above 1200°C for long periods of time. Although pure silica is a perfectly viable glass and glass fibre, it must be worked with at very high temperatures which is a drawback unless its specific chemical properties are needed. These materials also impart various other properties to the glass which may be beneficial in different applications.

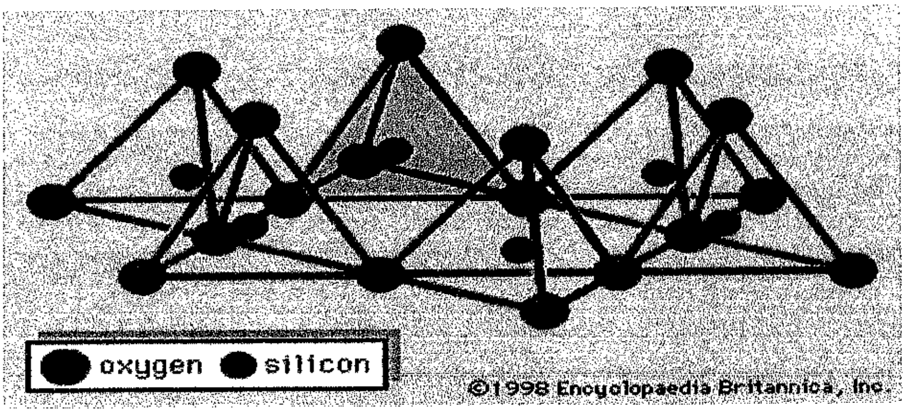


Figure 2.13: Molecular Structure of Glass Wool

2.6.3 Chemical composition of Glass Wool

'C' glass (chemical glass) is glass type used to produce glass wool. It is chemically resistant, corrosion resistant and is also used in composites that come into contact with mineral acids and as a reinforcement material in bituminous roofing sheet. The chemical resistance is determined by the relative amounts of the acidic oxides (SiO_2, B_2O_3), basic oxides (CaO, MgO, Na_2O, K_2O), and amphoteric oxides (Al_2O_3).

Table 2.1: Chemical Composition of Glass Wool (Source: Thermal Insulation Manufacturers Association (TIMA), 1993)

Chemical constituents	**Percentage composition**
SiO_2	55-70
Al_2O_3	0-7
B_2O_3	3-12
K_2O	0-2.5
Na_2O	13-18
MgO	0-5
CaO	5-13
TiO_2	0-0.5
Fe_2O_3	0.1–0.5
FeO	-
Li_2O	0-0.5
SO_3	0-0.5
S	-
F_2	0-1.5
BaO	0-3
ZrO_2	-
P_2O_5	-
Cr_2O_3	-
ZnO	-

2.6.4 Properties of Glass Wool

i. Form: Slabs, rolls.

ii. Colour: yellow.

iii. Fire hazard: non-combustible.

iv. Odour: light odour may occur.

v. Density: 10-250 kg/m^3.

vi. Melting point: >704°C

vii. Solubility in water: Insoluble.

viii. Decomposition temperature : >300°C

ix. Glass wool is not toxic.

x. Glass wool is stable without known negative environmental effects.

2.6.5 Applications or Uses of Glass Wool

Glass wool being a versatile material is seen to have been used in other areas or for other purposes even before its usage in corrosion protection of steels.

i. It provides efficient thermal insulation in piping and flat surfaces such as cavity wall insulation, ceiling tiles and curtain walls.

ii. It reduces energy consumption.

iii. It reduces the fluctuations of temperature in buildings that creates a safer work environment and also improves comfort and efficiency of the employees.

iv. It is an excellent acoustic insulator (acoustic panels) or sound proof because it reduces noise pollution and provides a safer workplace environment in areas where loud noise could cause hearing problems.

v. It makes a place fire-safe because it is incombustible to a great extent and can be used as a fire barrier in certain applications that protects the people in case of a fire.

2.6.6 Production of Glass Wool

The basic materials for glass wool manufacture include sand, soda ash, dolomite, limestone, sodium sulphate, sodium nitrate, and minerals containing boron and alumina. Glass wool is produced by drawing, centrifuging or blowing molten glass and comprises cylindrical fibres of relatively short length (compared to filaments). In the production of glass fibres, finely-powdered sand is used as the major source of silica, and kaolin clay and synthetic aluminium oxides are the most common sources of aluminium. Boric oxide is introduced primarily from colemanite (a natural calcium borate), boric acid and boric acid anhydride. Powdered dolomite [$CaMg(CO_3)_2$] or burnt dolomite ($MgO.CaO$) is used to introduce magnesium oxide (magnesia) and calcium oxide. Uncalcined and calcined limestone are used as magnesia-free sources of calcium oxide. Fluorspar (CaF_2) is used to introduce fluoride. Sodium sulphate is added to the glass mixture as a firing agent and to assist in dissolving residual grains of sand. Iron oxide (Fe_2O) may be added to assist the fibre-drawing process (Harben and Bates, 1984).

Permutations are made by adding other substances, such as oxides of aluminium, titanium, and zinc as stabilisers and oxides of magnesium, lithium, barium, calcium, sodium, and potassium as modifiers. By varying the amounts and types of stabilizers and modifiers, one can alter the physical properties of glass fibers. Stabilisers contribute to chemical durability; the intended use determines the amount of stabilizer added (National Centre for Biotechnology Information, NCBI, 2000). Glass wool furnaces are predominately gas fired, but also that a substantial number of furnaces are electrically heated.

The processes involved in making glass wool can be summarised in the following steps;

i. **Formulation and composition**: The raw materials such as silica sand (network former), cullet, glass, fluxing agent, lubricants and antistatic and wetting agents etc. are selected in the right proportions and quantities.

ii. **Melting**: The selected raw materials are first sent through a furnace and melted at very high temperature of about 1100°C in an electric furnace.

iii. **Fiberising**: The melted droplets drop through the furnace and are spun into fibres. Depending on the materials, spinning is accomplished by rotating flywheels, spinners or formed by centrifugation through drilled circular baskets, where after, binding products and elements specific to the usage are added. The fibres are gathered in a mat form in a collection chamber and then conveyed to an oven where it is cured under controlled conditions to the required thickness and density. Fibre diameters vary widely, some are as small as 1 μm and the average is 3-15 μm (NCBI, 2000).

iv. **Forming:** Binders (such as urea-phenolic resins, which undergo a heat curing process that converts the binders to insoluble polymers) are then added to the fibres. The fibres are gathered in a mat form in a collection chamber and then conveyed to an oven where it is cured under controlled conditions to the required thickness and density. The binder reacts to the heat, forming the fibres into wool.

v. **Cutting**: Cutters shape the material into rolls, batts, or boards, with cut scraps recycled back into the production process (National Academy of Science, 2000)

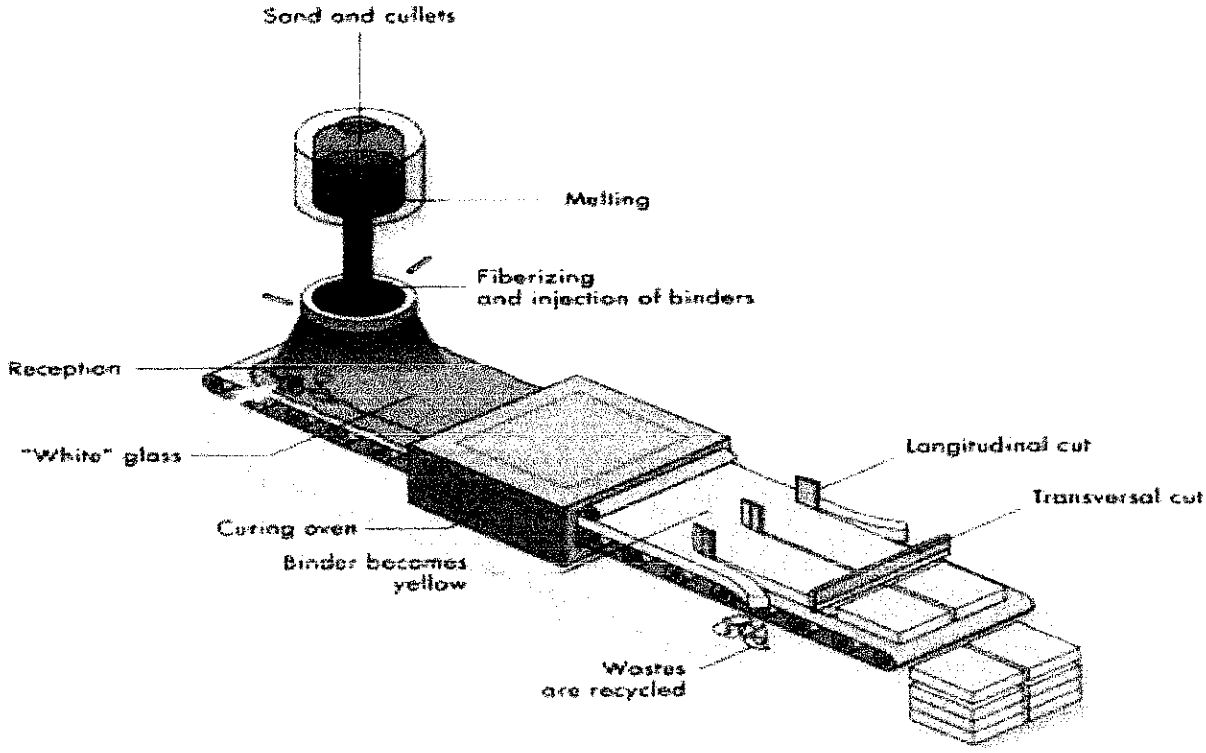


Figure 2.14: Schematic Illustration of Glass Wool Production

2.6.7 Advantages of Glass Wool

The advantages of glass wool are as follows;

i. Non-combustible

ii. Non-toxic

iii. Resistant to corrosion

iv. Low weight by volume

v. Low thermal conductivity

vi. Stable chemical property

vii. Low moisture absorption rate

viii. Fire resistant

2.6.8 Handling and Adverse Effects of Glass Wool

The usage or the handling of glass wool when used as a protective measure on steels can result in temporary itching discomfort on the skin if not properly handled or when working on overhead (buildings), there is always the possibility of free falling fibres. The potential symptoms of glass wool include irritation of eyes, dyspnoea (breathing difficulty), sore throat, hoarseness and cough, discomfort, temporary skin irritation, particularly where there is rubbing from clothing such as cuffs and collars tickling and dryness of the nose, throat and respiratory tract, especially for those who suffer fever, asthma or bronchitis. These can be reduced by wearing gloves and loose fitting long sleeve clothing to minimise direct skin contact. It is good work practice to avoid exposure to any dust when working in poorly ventilated, or enclosed spaces. In these instances, wear a dust mask, as directed on the pack.

2.7 STEEL

Steel is an alloy of iron and carbon in which the carbon content ranges up to 2 percent (with a higher carbon content, the material is defined as cast iron). By far the most widely used material for building the world's infrastructure and industries, it is used to fabricate everything from sewing needles to oil tankers. In addition, the tools required to build and manufacture such articles are also made of steel. As an indication of the relative importance of this material, in 2006 the world's raw steel production was about 1.2 trillion tons, while production of the next most important engineering metal, aluminium, was about 33 million tons. The main reasons for the popularity of steel are the relatively low cost of making, forming, and processing it, the abundance of its two raw materials (iron ore and scrap), and the very attractive mechanical properties it possess.

2.7.1 Types of Steel

According to the World Steel Association (2017), there are over 3,500 different grades of steel encompassing unique physical, chemical, and environmental properties. In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determine the properties of each steel grade. The carbon content in steel can range from 0.1-1.5%, but the most widely used grades of steel contain only 0.1-0.25% carbon. Elements such as manganese, phosphorus, and sulphur are found in all grades of steel. According to the American Iron and Steel Institute, (2017), steel can be broadly categorised into four groups based on their chemical compositions:

A. Carbon Steels
B. Alloy Steels
C. Stainless Steels
D. Tool Steels

A. Carbon Steels

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorized into three groups depending on their carbon content:

i. Mild steel (0.025 – < 0.1 % carbon),

ii. Low carbon steel (0.1 – < 0.3 % carbon),

iii. Medium carbon steel (>0.3 – < 0.6 % carbon) and

iv. High carbon steel (>0.6 – < 0.9 % carbon).

B. Alloy Steels

Alloy steels contain alloying elements (e.g. manganese, silicon, nickel, titanium, copper, chromium, and aluminium) in varying proportions in order to manipulate the steel's properties, such as its hardenability, corrosion resistance, strength, formability, weldability or ductility. Applications for alloys steel include pipelines, auto parts, transformers, power generators and electric motors (http://www.thebalance.com).

C. Stainless Steels

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. With over 11% chromium, steel is about 200 times more resistant to corrosion than mild steel. These steels can be divided into three groups based on their crystalline structure: austenitic, martensitic and ferritic stainless steels

D. Tool Steels

Tool steels contain tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment. Steel products can also be divided by their shapes and related applications:

i. Long/Tubular Products include bars and rods, rails, wires, angles, pipes, and shapes and sections. These products are commonly used in the automotive and construction sectors.

ii. Flat Products include plates, sheets, coils, and strips. These materials are mainly used in automotive parts, appliances, packaging, shipbuilding, and construction. Other Products include valves, fittings, and flanges and are mainly used as piping materials (Bell, 2017).

2.7.2 Classifications of Steel

The types of Steel can also be classified by a variety of different factors:

i. **Composition:** Carbon range, Alloy, Stainless.
ii. **The production method:** Continuous cast, Electric furnace.
iii. **Finishing method used:** Cold Rolled, Hot Rolled, Cold Drawn (Cold Finished).
iv. **Form or shape:** Bar, Rod, Tube, Pipe, Plate, Sheet, and Structural.
v. **De-oxidation process (oxygen removed from steelmaking process):** Killed and Semi-Killed Steel.
vi. **Microstructure:** Ferritic, Pearlitic, Martensitic, etc.
vii. Physical Strength (Per ASTM Standards).
viii. **Heat Treatment:** Annealed, Quenched and Tempered.
ix. **Quality Nomenclature:** Commercial Quality, Drawing Quality and Pressure Vessel Quality (https://www.metalsupermarkets.com/metals/).

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 MATERIALS

The materials and equipment used are;

i. Glass wool

ii. Mild steel

iii. Epoxy resin

iv. Phenalkamine (epoxy resin hardener)

v. Cobalt (iii) acetylacetonate (epoxy resin accelerator)

vi. Flexible copper wires

vii. Mounting cups

viii. Aluminium foil tape

ix. Vernier calliper

x. Ruler

xi. Hacksaw

xii. Electric digital weighing machine

xiii. Grinding/polishing machine

xiv. Emery papers

xv. Plastic bowls

xvi. Hydrochloric acid (HCl)

xvii. Tetraoxosulphate (vi) acid (H_2SO_4)

xviii. Sodium Chloride (NaCl), and

xix. Distilled water.

The mild steel used for this research was obtained in the form of ribbed rod with its chemical composition determined by Atomic Emission Spectroscopy (AES) and the results presented in Table 3.1.

Table 3.1: Chemical Composition of Mild Steel

Elements	C	Mn	Si	P	S	Al	Ni	Fe
Wt %	0.18	0.42	0.17	0. 02	0. 03	0. 006	0. 007	Balance

3.2 METHODOLOGY

3.2.1 Cutting

The mild steel rod of 1m length and 15mm diameter was purchased at Akure, Ondo State, Nigeria. The steel rod was held firmly in the bench vice and cut using hack saw into fifteen sections of 10mm length and 15mm diameter. The already cut samples were labelled accordingly from 1 to 30.

3.2.2 Grinding or Polishing

Twelve mild steel samples were ground so as to remove damage from cutting, to give the sample(s) flat surface, and to remove the metallic chips approaching the area of interest.

The grinding was carried out with the grinding machine at the metallography laboratory, Federal University of Technology, Akure (FUTA). Grinding is process of the rubbing the flat surface of steel samples against various sizes of the emery paper, also called abrasives or silicon carbide (SiC) paper which ranges from very coarse 60 grit to very fine 800 grit sizes (P60D, P120, P220C, C 320 CW, P400C, P600, P800 and P1000). During grinding, little pressure was applied against the emery paper so as to avoid irregular surface and heat generation which is very dangerous. Water was also applied grinding. After grinding on each emery paper, the metal surfaces were cleaned adequately before being ground on the next grade of emery paper so as to avoid the transfer of mesh particles that could affect the grinding result negatively.

3.2.3 Dimension and Weight Measurement

After the grinding of the steel samples, the initial length and initial diameter were measured using ruler and vernier calliper respectively and the weight was measured using an electric digital weighing machine at the Federal University of Technology, Akure (FUTA) corrosion laboratory. The measurement after grinding was spelt out in Table 3.2.

Table 3.2: Measurements of Length, Diameter and Weight of the Samples after Polishing

Samples	Initial weight, Wo (g)	Initial diameter, Do (mm)	Initial length, Lo (mm)	Total surface area A (mm^2)
1.	15.8542	15.15	10.85	877.0540
2.	14.9352	15.50	10.20	874.1830
3.	15.2379	15.00	10.05	827.1315
4.	15.6450	14.97	10.05	845.9378
5.	14.9767	15.00	10.01	825.2463
6.	14.8830	15.02	10.00	826.3466
7.	15.2133	15.01	10.00	825.5607
8.	14.2771	15.20	10.04	842.4582
9.	16.2524	15.05	10.90	871.2648
10.	15.6587	15.50	10.02	865.4168
11.	15.9210	15.06	9.89	824.2886
12.	15.4674	15.00	10.05	827.1315

3.2.4 Cold Mounting

Cold mounting or embedding is when a resin is mixed with a hardener (or accelerator) to provide the mounting compound, and then polymerisation process takes place to form block. In some cases, this process gives-off heat. Cold mounting procedure was used to mount the remaining three samples. Flexible copper wire was attached to the one surface of each sample suing an aluminium foil tape. Each sample was placed in a mounting cup with the help of mounting clips and a mixture of resin (50ml of unsaturated polyester, 10 ml of accelerator and 10 ml of hardener) was poured. The resin was then allowed to solidify (cure) and removed carefully out of the mounting cup.

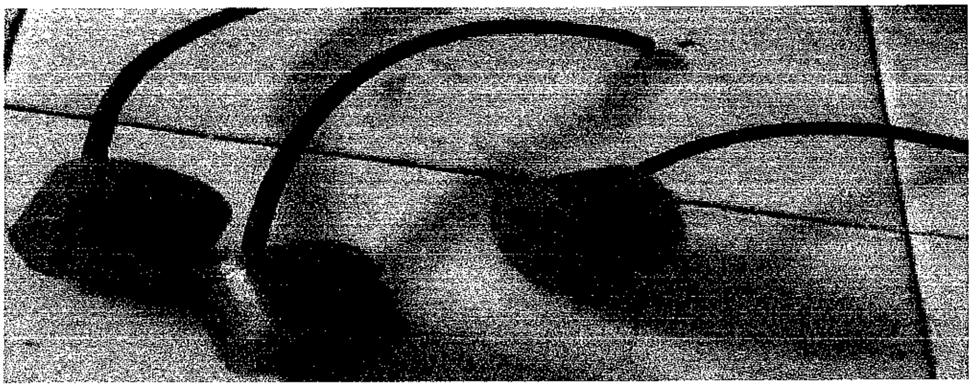


Plate 3.1: Mounted Mild Steel Samples Used as the Control for the Test

3.2.5 Weight Measurement of Glass Wool

1.0g × 3, 1.5g × 3and 2.0g × 3 of glass wool were measured using the electric digital weighing machine.

Table 3.3: Weight of Glass Wool

Samples	1	2	3	4	5	6	7	8	9	10	11	12
Weight of glass wool (g)	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0	0	0	0

3.2.1.6 Preparation of Resin

Flexible copper wire was attached to the surface of each polished mild steel sample using an aluminium foil tape. A mixture of resin (15ml of Epoxy resin, 10ml of accelerator and 10ml of hardener) was used to wet each gram of glass wool, and then after that the wet glass wool was used to cover the samples completely leaving no surface exposed. The samples were allowed to solidify (cure) for about two hours.

3.3 PREPARATION OF CORROSIVE MEDIA

Tetraoxosulphate (VI) acid (H_2SO_4), hydrochloric acid (HCl), and sodium chloride (NaCl) solutions were prepared in 0.5 M, 0.5 M and 3.5wt% respectively. All the reagents used were of analar grade and distilled water was used for the preparation of all solutions.

3.4 SAMPLES IN THEIR RESPECTIVE CORROSIVE MEDIA

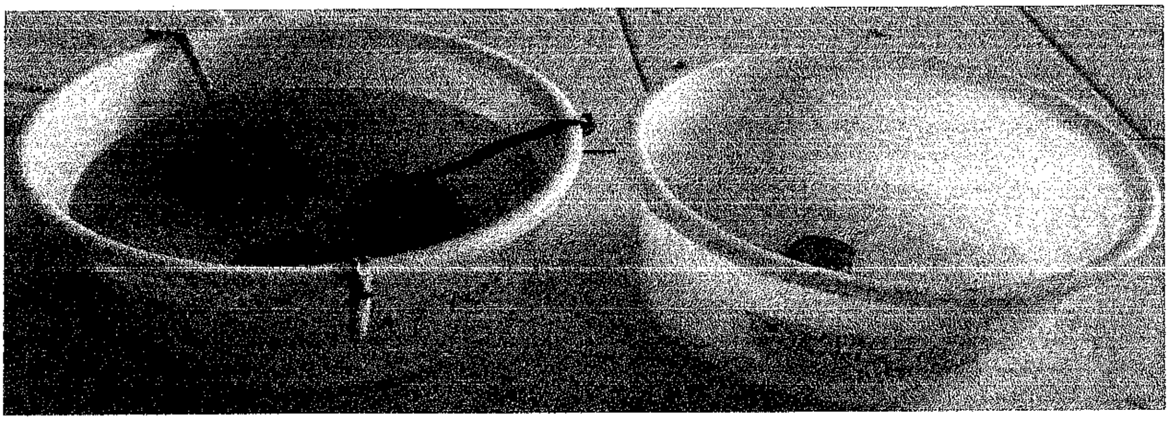


Plate 3.2: Samples 1, 4, 7 and 12 in 3.5wt% NaCl

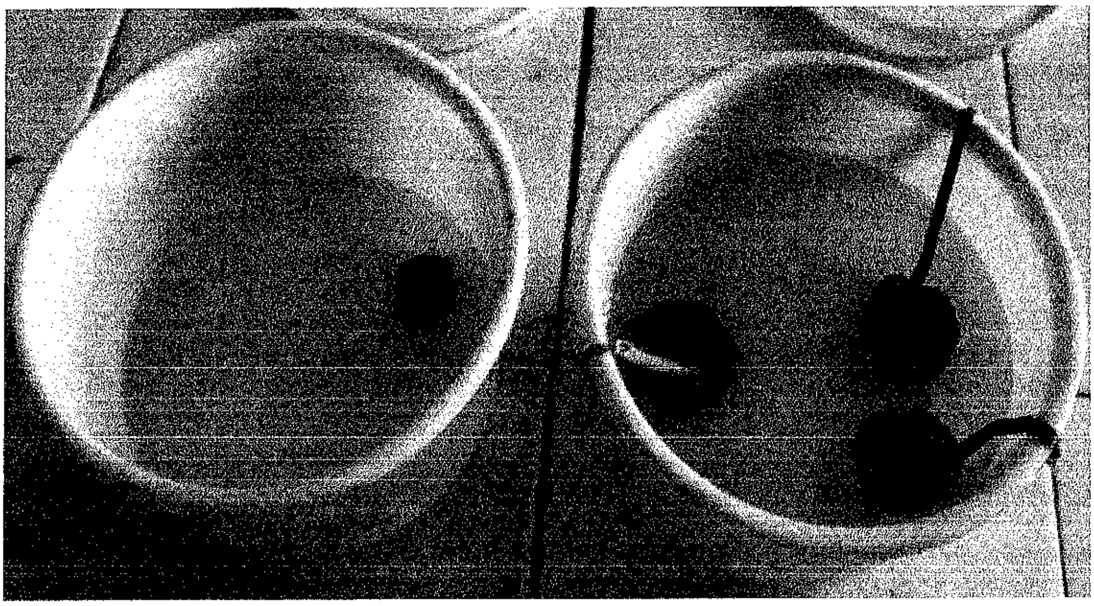


Plate 3.3: Sample 3, 6, 9 and 11 in 0.5 M HCl

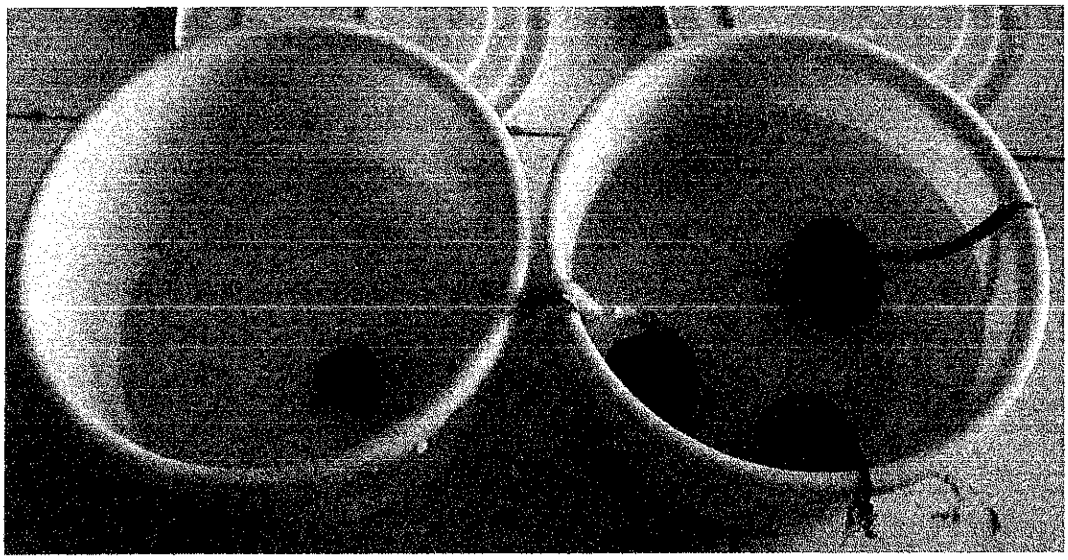


Plate 3.4 : Sample 2, 5, 8 and 10 in 0.5 M H_2SO_4

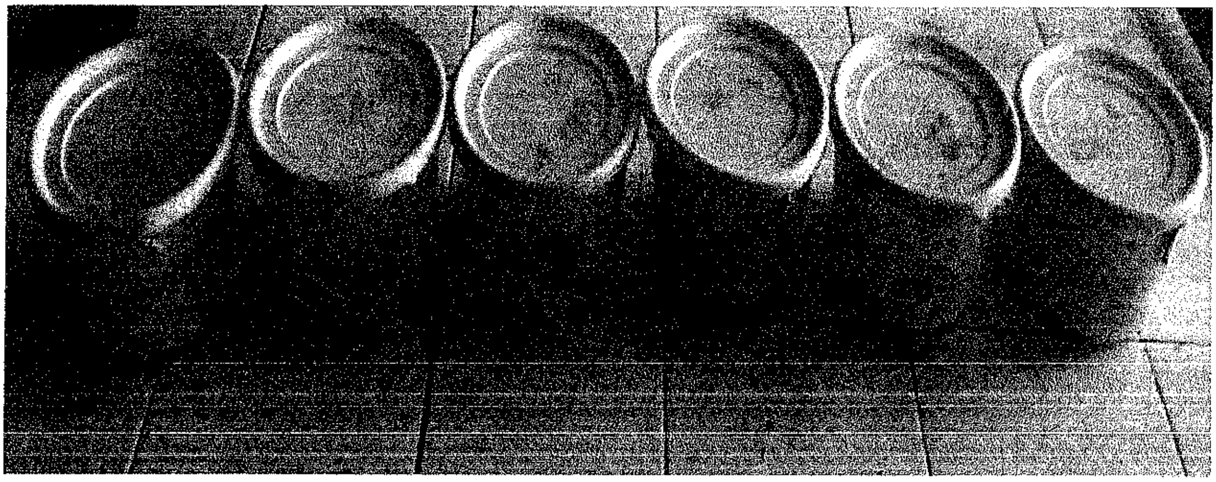


Plate 3.5: Samples in their various Corrosive Media

3.4.1 Appearance of the Samples after Immersion in the Various Corrosive Environment for 30 days

0.5 M HCl environment

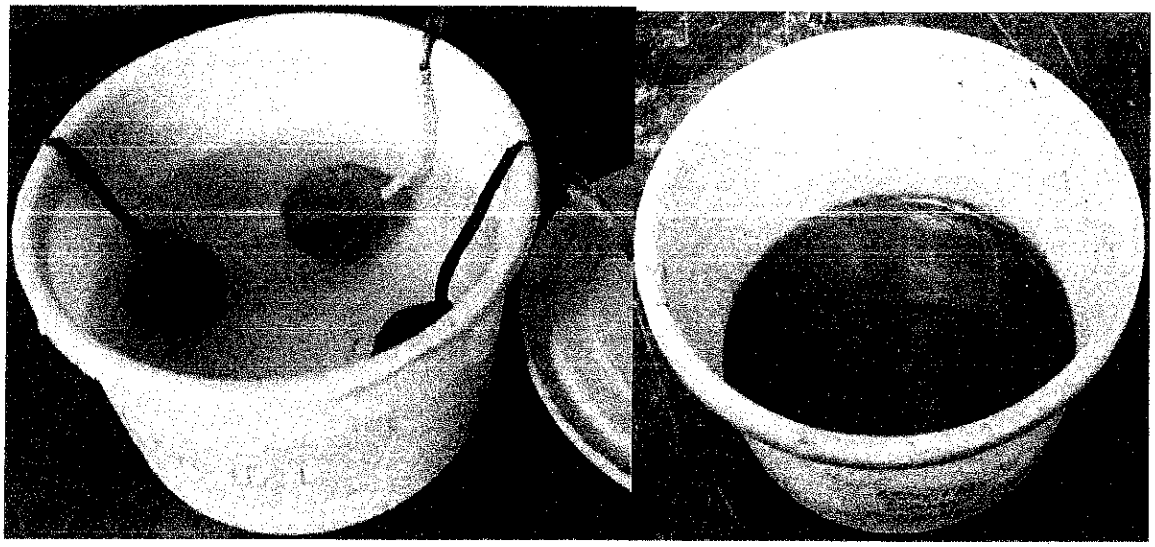


Plate 3.6: Appearance of Samples 3, 6, 9 and 11 in 0.5 M HCl after 30 days

0.5 M H_2SO_4 environment

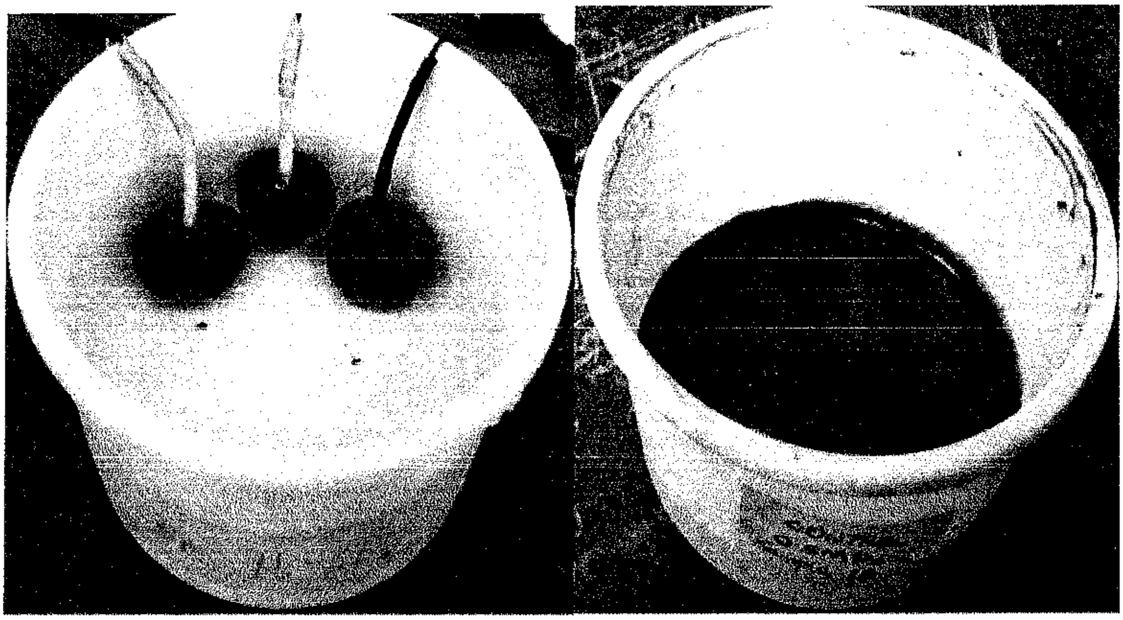


Plate 3.7: Appearance of Samples 2, 5, 8 and 10 in 0.5 M H_2SO_4 after 30 days

3.5wt% NaCl environment

Plate 3.8: Appearance of Samples 1, 4, 7 and 11 in 3.5 wt% NaCl after 30 days

3.5 CORROSION TESTS

3.5.1 Weight Loss/Gain Test

The initial weight (W_o) of all the mild steel samples covered with glass wool were measured using the electric digital weighing machine. Samples 2, 5 and 8 coated with 1 g, 1.5 g and 2 g of glass wool respectively were fully immersed in 0.5 M H_2SO_4, samples 3, 6 and 9 coated with 1 g, 1.5 g and 2 g of glass wool respectively were fully immersed in 0.5 M HCl and samples 1, 4 and 7 coated with 1 g, 1.5 g and 2 g of glass wool respectively were fully immersed in 3.5wt% NaCl. Samples 10, 11 and 12 without glass wool (referred to as blank) were fully immersed in H_2SO_4, HCl, and NaCl, which serves as the control. The samples were removed from the corrosive media after 24 hours and dried with a dry clean cloth to remove liquid and other impurities before the final weights (W_1) were determined. This progressed for the stipulated immersion time of 30 days. The weight loss/gain, ΔW in grams was determined from the difference between the final weight (W_1) and initial weight (W_o) of the samples before immersion. The corrosion rate was calculated using the formula below;

$$C.R = \frac{3.65 \times 10^5}{A.D.T} . \mathrm{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where;

C.R = corrosion rate (mm/yr)

W= Weight loss/gain (g)

D = metal density (g/cm^3)

T = exposed time (days)

A = coupon total surface area (mm^2)

3.5.2 Potentiodynamic Polarisation Test

The corrosion of the samples were tested using potentiodynamic polarisation test which employs three electrode configuration, consisting of reference, counter, and working electrodes. The reference electrode was silver/silver chloride electrode (Ag/AgCl), the counter electrode was a platinum rod and the working electrode was mild steel (Fe). The electrolytic media simulated for the electrochemical analysis consists of dilute 0.5 M HCl, 0.5 M H_2SO_4 solution and 3.5 wt% NaCl as the last test medium. Nine (9) samples namely A, B and C were covered with 1.0g of glass wool, samples D, E and F were covered with 1.5 g of glass wool and samples G, H and I were covered with 2.0 g of glass wool. Furthermore, samples A, D and G covered with 1.0 g, 1.5 g and 2.0 g of glass wool respectively were immersed in H_2SO_4, samples B, E and H covered with 1.0 g, 1.5 g and 2.0 g respectively were immersed in hydrochloric acid and samples C, F and I covered with 1.0 g, 1.5 g and 2.0 g respectively were immersed in sodium chloride .The electrodes were connected to the terminals of a potentiostat, was accomplished at a scan rate of 1.1mV/s, dwell time was 600s and the corrosion currents recorded.

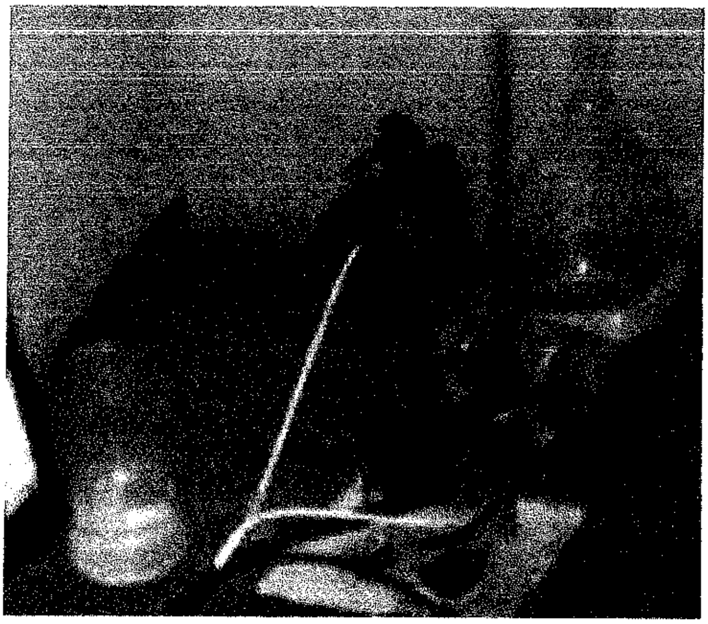


Plate 3.9: Potentiostat Polarisation Apparatus Showing Their Electrodes

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Weight Loss/Gain Test

After the stipulated immersion time of 30 days, the weight loss/gain, ΔW in grams was determined from the difference between the final weight (W_1) and initial weight (W_o).

Table 4.1: Weight of the Samples Taken at 6 Days Interval for 30 Days

Sample	Weight of glass wool (g)	Initial weight W_o	Weight at 6th day (in g)	Weight at 12th day (in g)	Weight at 18th day (in g)	Weight at 24th day (in g)	Weight at 30th day (in g)
1	1.0	25.1246	25.1448	25.1665	23.0184	25.2184	25.2757
2	1.0	24.9298	24.9276	24.9457	24.4699	25.1037	25.0676
3	1.0	23.1236	23.0575	23.0652	23.3872	23.2000	23.1786
4	1.5	25.0982	25.1286	25.1419	23.0870	25.2118	25.2485
5	1.5	25.1168	25.5198	25.9535	26.4643	26.9810	27.0623
6	1.5	24.0019	24.0886	28.7600	23.7057	24.5528	24.5190
7	2.0	27.9400	28.0335	28.0729	28.1276	28.2270	28.3095
8	2.0	27.3660	27.6415	27.3084	27.7354	27.8437	27.8657
9	2.0	27.6613	28.3344	23.7238	29.0802	29.5102	29.5787
10	0	15.6587	13.8384	13.4523	13.3224	13.2087	13.1801
11	0	15.9210	14.3511	14.0653	14.0255	14.0357	14.0290
12	0	15.4674	14.2549	14.2501	14.2320	14.2366	14.2401

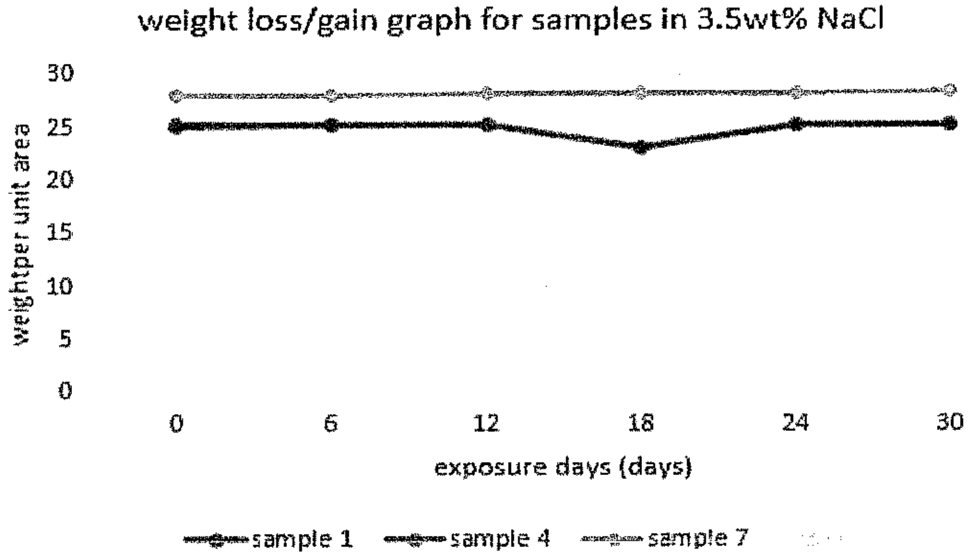


Figure 4.1: Weight Loss/Gain Graph of Samples 1, 4 and 7 in 3.5 wt% NaCl

In figure 4.1 above, the weight of the sample 1 increased on the 6th and 12th day, reduced on the 18th day and gained weight on the 30th day. The weight of the sample 4 in 3.5 wt% NaCl increased on the 6th and 12th day, reduced on the 18th day and gained weight on the 30th day. The weight of sample 7 increased in 3.5 wt% NaCl throughout the exposure time (30 days).

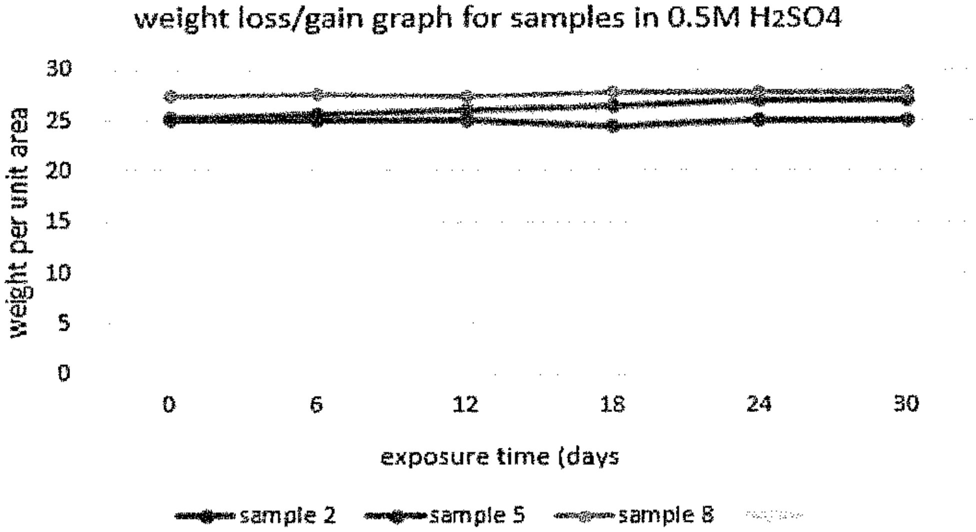


Figure 4.2: Weight Loss/Gain Graph of Samples 2, 5 and 8 in 0.5 M H_2SO_4

In figure 4.2, the weight of the sample 2 in 0.5 M H_2SO_4 reduced on the 6th and 12th day, reduced on the 18th day, gained weight on the 24th day and reduced slightly on the 30th day. The weight of the sample 5 in 0.5 M H_2SO_4 increased on the 6th and 12th day, reduced on the 18th day, gained weight on the 24th day and the 30th day. The weight of the sample 8 in 0.5 M H_2SO_4 increased on the 6th, reduced on the 12th day and increased from the 18th day till the 30th day.

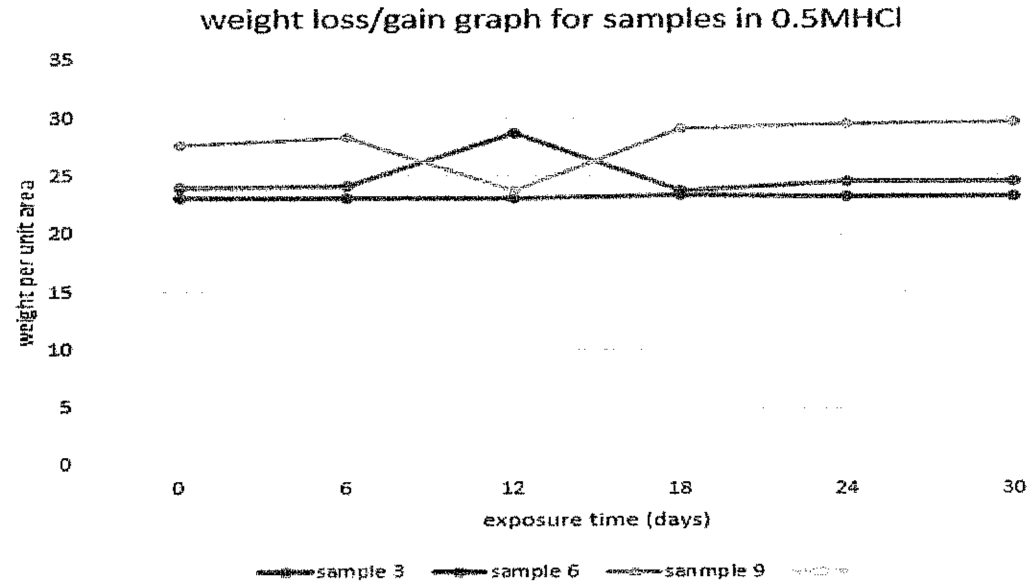


Figure 4.3: Weight Loss/Gain Graph of Samples 3, 6 and 9 in 0.5 M HCl

In figure 4.3, the weight of the sample 3 in in 0.5 M HCl reduced on the 6th, increased on the 12th and 18th day, reduced on the 24th day and the 30th day. The weight of the sample 6 in in 0.5M HCl increased on the 6th and 12th and 18th day, reduced on the 24th day and the 30th day. The weight of the sample 9 in 0.5 M HCl increased on the 6th, reduced on the 12th day and increased throughout from the 18th day to the 30th day.

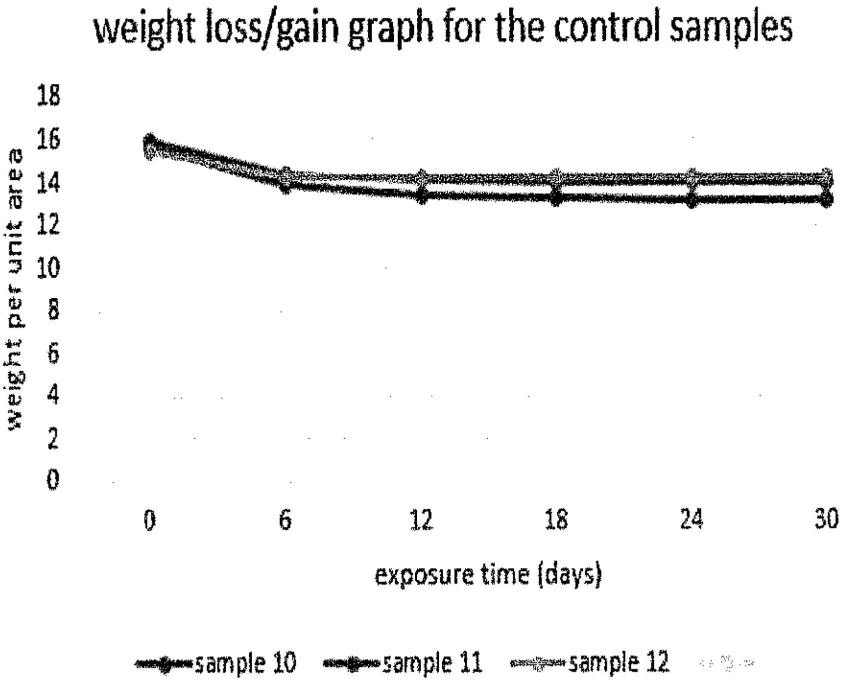


Fig 4.4: Weight Loss/Gain Graph of Samples 10, 11 and 12 in 0.5 M H_2SO_4, 0.5 M HCl and 3.5wt% NaCl respectively.

In figure 4.4, the weight of the uncovered sample 10 in 0.5 M H_2SO_4 reduced throughout the exposure time of 30 days. The weight of the uncovered sample 11 in 0.5 M HCl reduced throughout the exposure time of 30 days the weight of the uncovered sample 12 in 3.5 wt% NaCl reduced throughout the exposure time of 30 days.

4.2 IMAGES OF SAMPLES AFTER BREAKING THE GLASS WOOL COATING FROM THE MILD STEEL

Plate 4.1: Images of Samples after breaking the Glass Wool Coating from the Mild Steel.

After breaking the glass wool, the final weight of the samples were taken using the electrical digital weighing machine so as to calculate the corrosion rate of the samples in their various corrosive media using equation (1)

Table 4.2: Weight Loss and Corrosion Rate

Samples	Corrosive media	Weight loss (g)	Corrosion rate (mmpy)
1	3.5 wt % NaCl	0.02	0.035
2	0.5M H_2SO_4	0.03	0.0531
3	0.5M HCl	0.35	0.6542
4	3.5 wt % NaCl	0.18	0.328
5	0.5M H_2SO_4	0.13	0.2435
6	0.5M HCl	0.23	0.4303
7	3.5 wt % NaCl	0.06	0.1124
8	0.5M H_2SO_4	0.16	0.2936
9	0.5M HCl	0.35	0.6210
10 (control)	0.5M H_2SO_4	2.47	4.4123
11(control)	0.5M HCl	4.74	8.8900
12 (control)	3.5 wt % NaCl	3.12	5.8314

From table 4.2, it can be deduced that the corrosion rate of the mild steel samples coated with various amount of glass wool when immersed in 0.5 M H_2SO_4 and 3.5 wt% NaCl were not susceptible to corrosion, but the mild steel samples coated with various amount of glass wool when immersed in 0.5 M HCl were susceptible to corrosion. This is because the chloride anions (Cl^-) present in the 0.5 M HCl are of high concentration and are aggressive. This means that glass wool supports the corrosion protection of steel in 0.5 M H_2SO_4 and 3.5 wt% NaCl, but does not give adequate protection to steel in 0.5 M HCl.

4.3 TAFEL PLOTS OF THE MILD STEEL SAMPLES COATED WITH GLASS WOOL

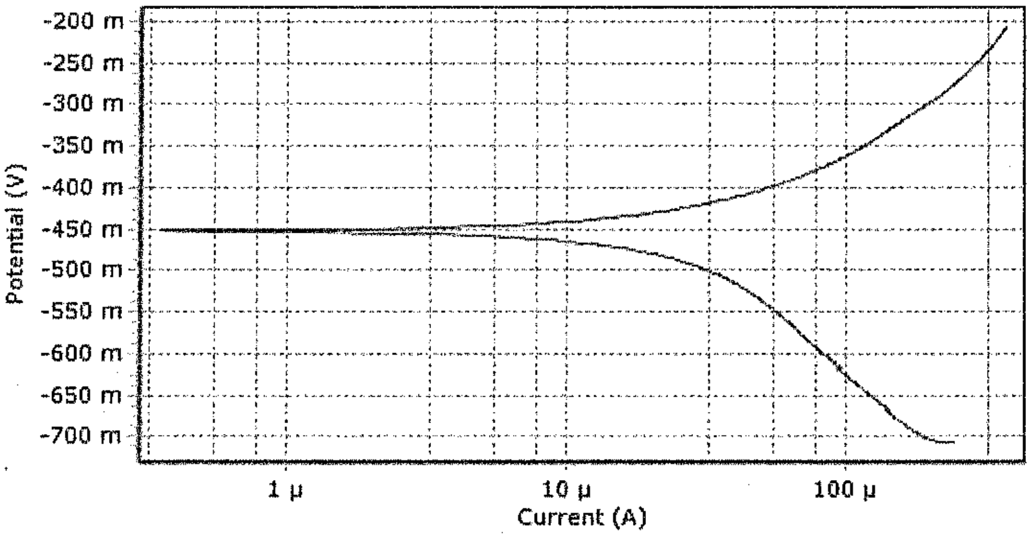


Figure 4.5: Tafel Plot of Sample A in 3.5wt% NaCl.

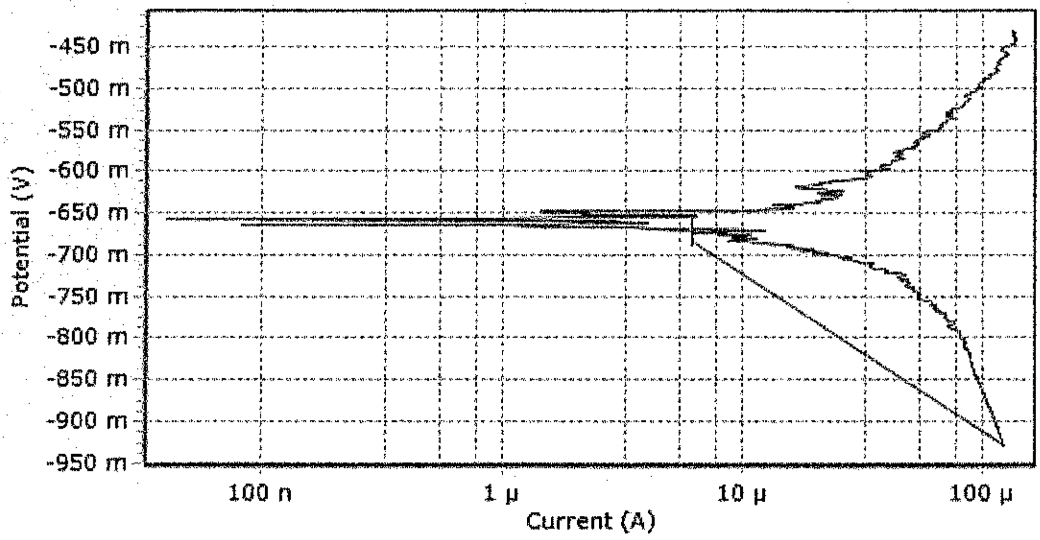


Figure 4.6: Tafel Plot of Sample B in 0.5 M HCl.

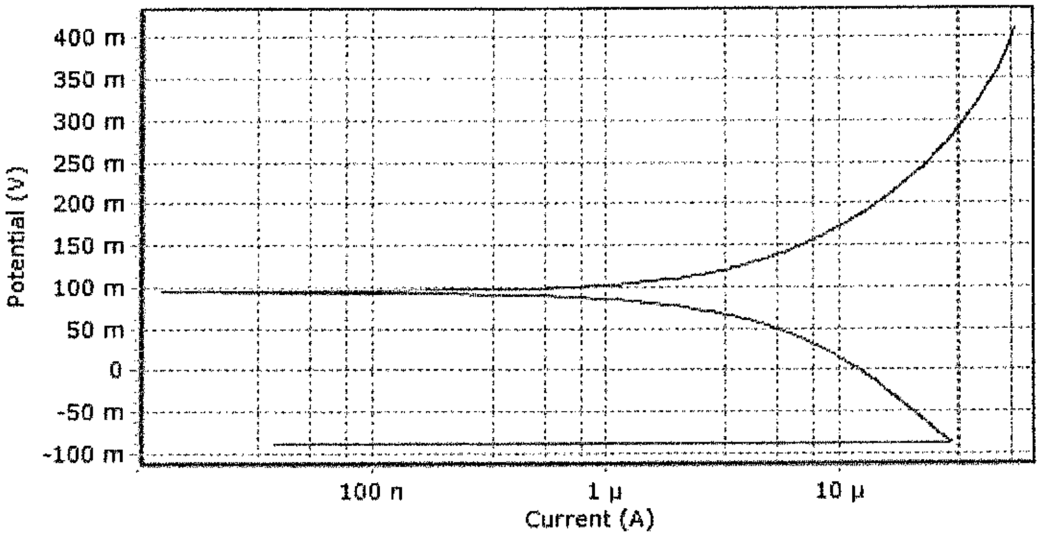


Figure 4.7: Tafel Plot of Sample C in 0.5 M H_2SO_4

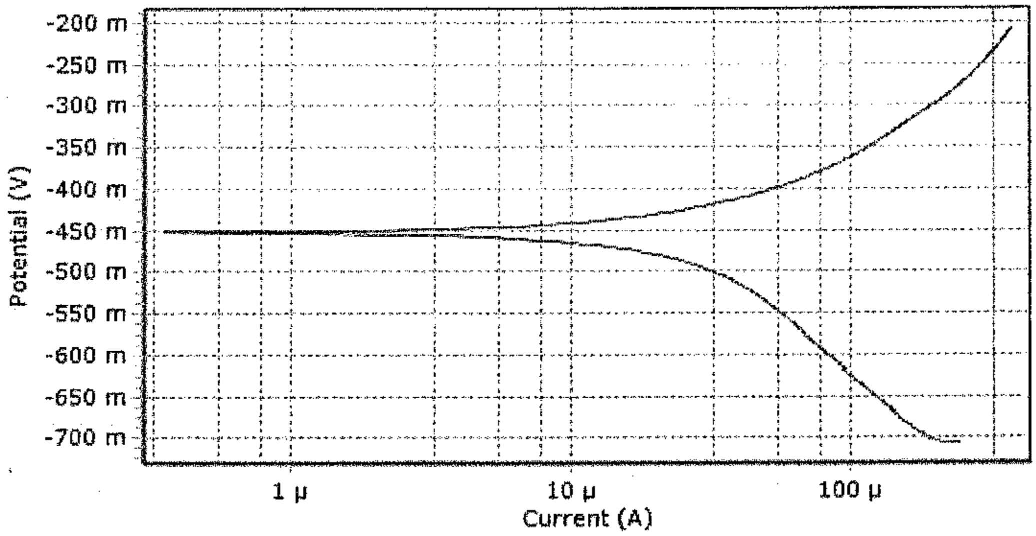


Figure 4.8: Tafel Plot of Sample D in 0.5 M H_2SO_4

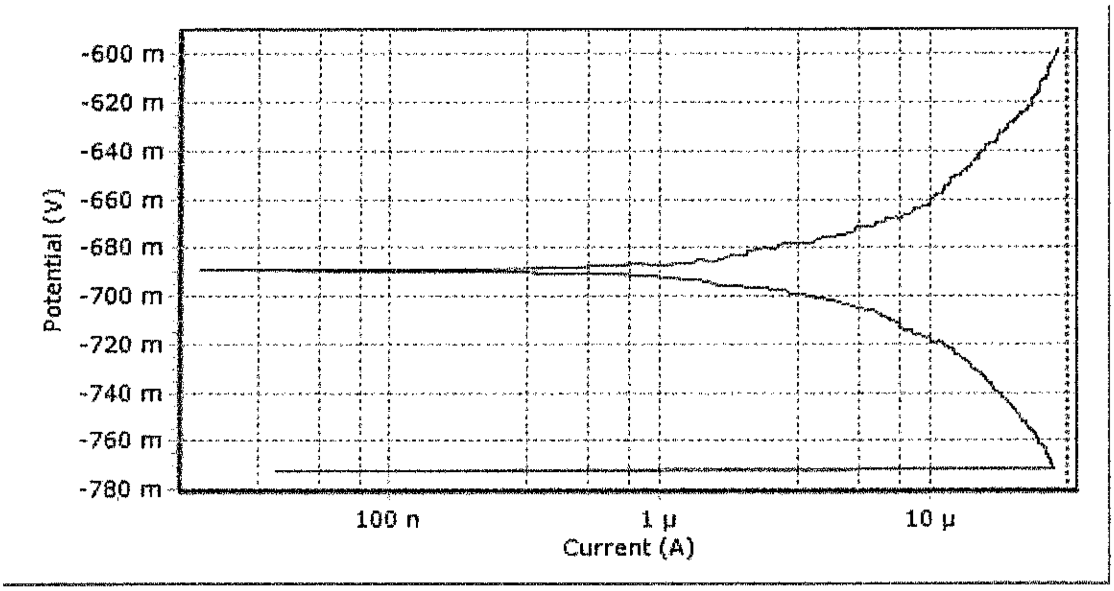


Figure 4.9: Tafel Plot of Sample E in 0.5 M HCl

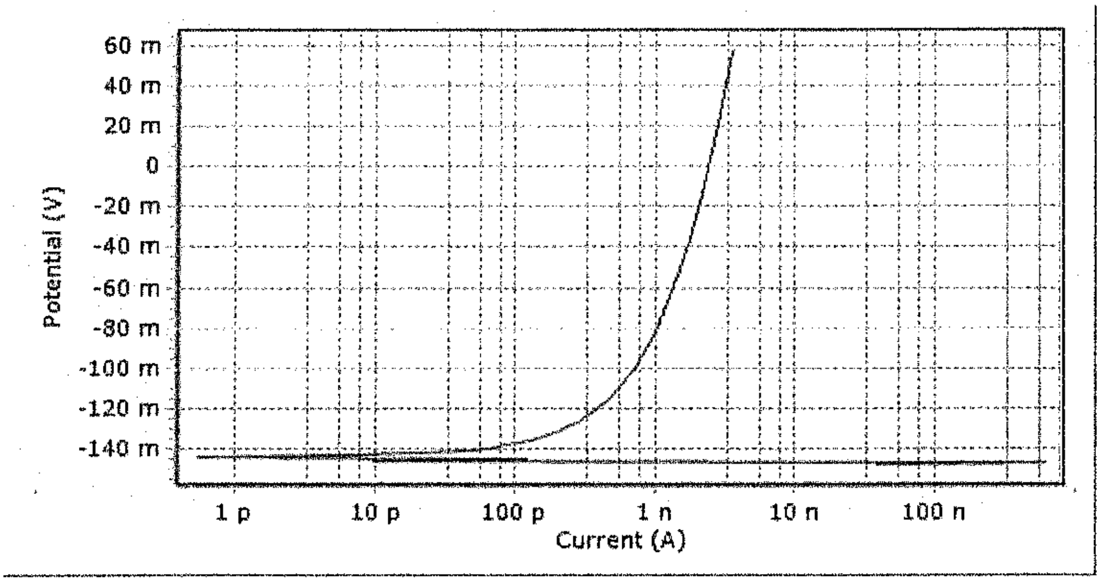


Figure 4.10: Tafel Plot of Sample F in 3.5wt% NaCl.

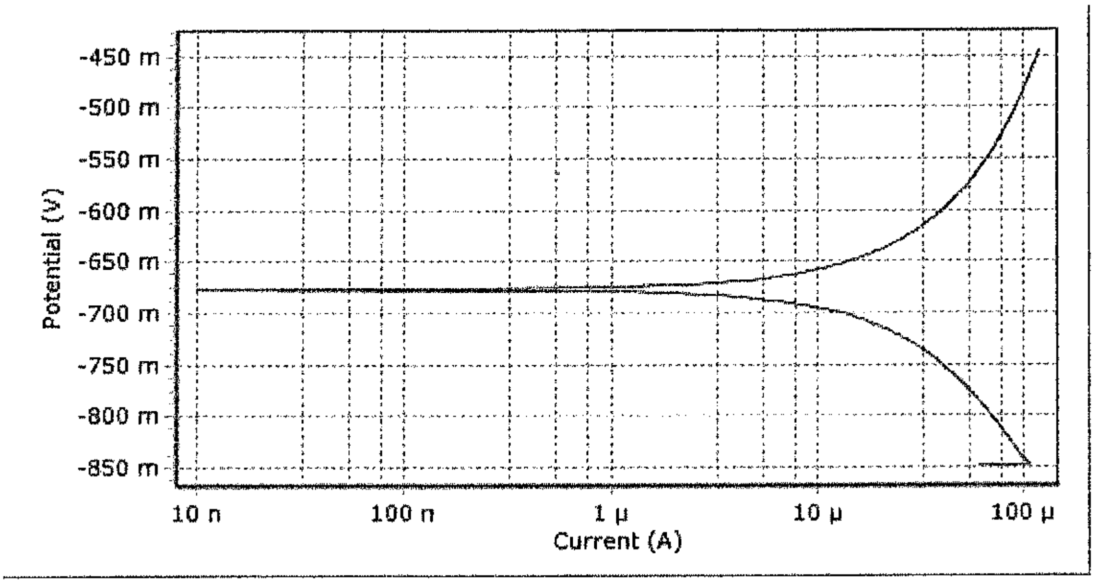


Figure 4.11: Tafel Plot of Sample G in 3.5wt% NaCl

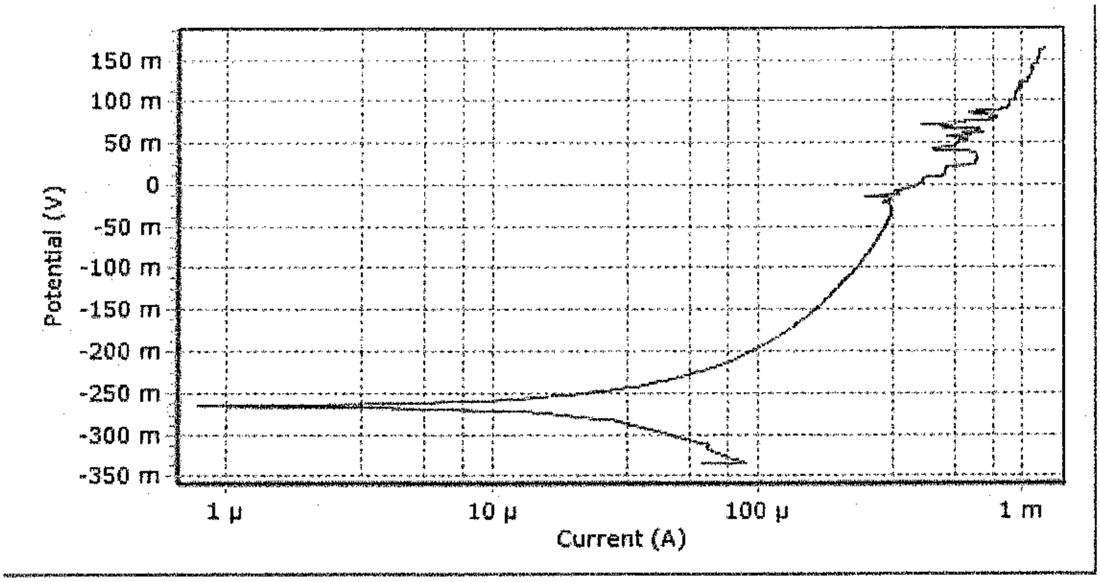


Figure 4.12: Tafel Plot of Sample H in 0.5 M H_2SO_4

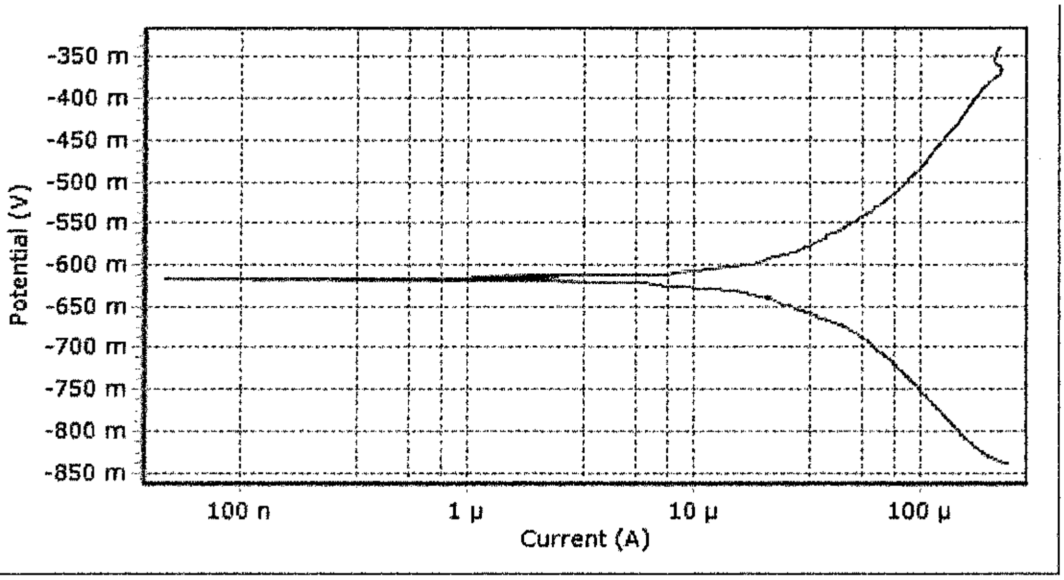


Figure 4.13: Tafel Plot of Sample I in 0.5 M HCl

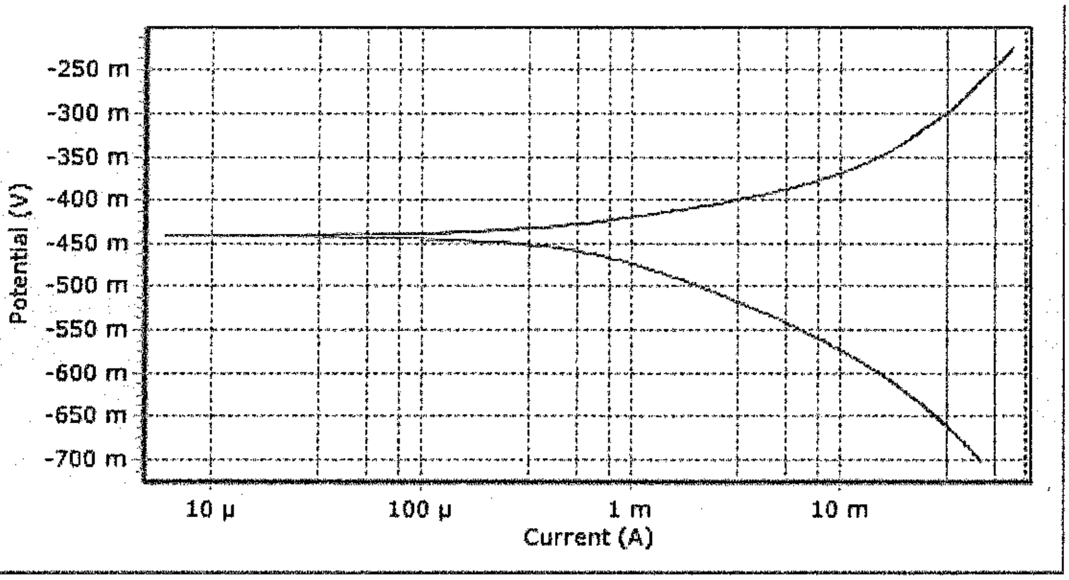


Figure 4.14: Tafel Plot of Control Sample in 0.5 M H_2SO_4

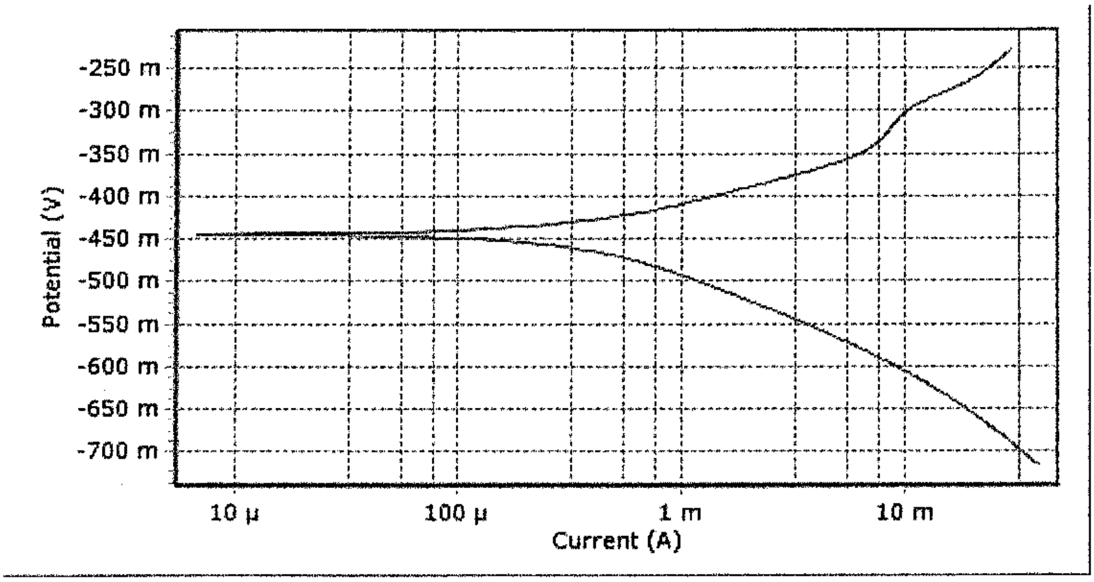


Figure 4.15: Tafel Plot of Control Sample in 0.5 M HCl

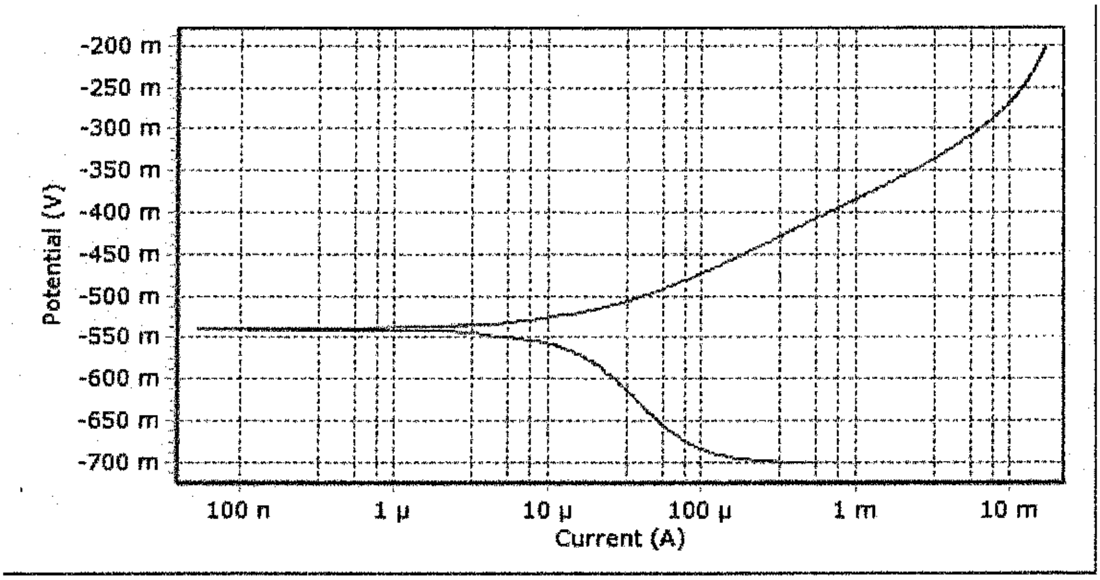


Figure 4.16: Tafel Plot of Control Sample in 3.5wt% NaCl

Table 4.3: Results of Potentiodynamic Polarisation Test

Samples	Corrosive media	Potential, E	Current density, I	Corrosion rate (mmpy)	Cathodic beta	Anodic beta
A	3.5 wt% NaCl	-248.317 mV	-1.992 µA	0.023115	163.321 mV	110.271 mV
B	0.5 M HCl	-661.85 mV	-4.889 µA	0.056736	50.036 mV	716.476 mV
C	0.5 M H_2SO_4	93.887 mV	-6.762 µA	0.078472	263.815 mV	256.433 mV
D	0.5 M H_2SO_4	-452.573 mV	-109.364 µA	1.269	2.224 V	328.983 mV
E	0.5M HCl	-689.216 mV	-9.585 µA	0.111123	123.916 mV	153.238 mV
F	3.5 wt% NaCl	-127.645 mV	19.126 pA	2.2194e-07	18.63 mV	6.287 EV
G	3.5 wt% NaCl	-676.812 mV	-35.762 µA	0.41497	295.047 mV	328.1 mV
H	0.5 M H_2SO_4	-265.498 mV	-465.363 µA	5.3999	1.987 mV	1.105 V
I	0.5M HCl	-617.237 mV	-257.43 µA	2.9871	2.278 V	1.043 V
Control	0.5 M H_2SO_4	-440.938 mV	-525.593 µA	6.0988	99.619 mV	51.876 mV
Control	0.5 M HCl	-444.324 mV	-421.587 µA	4.8919	116.423 mV	77.221 mV
Control	3.5 wt% NaCl	-539.453 mV	-15.308 µA	0.17764	193.237 mV	80.027 mV

According to Velrani *et al.*, (2014), the corrosion potential Ecorr for mild steel corrosion in 3.5 wt% NaCl was obtained to be -0.748 V. For this project, this value was taken as the standard or minimum requirement value for mild steel corrosion in 3.5 wt% NaCl environment. It was obtained that the corrosion potential, Ecorr for the control sample in 3.5 wt% NaCl environment is -0.5395V. The corrosion potential, Ecorr for the sample A being covered with 1 g of glass wool was -0.248 V, when compared with the standard, it was discovered that sample A has a higher value of corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion. The corrosion potential, Ecorr for the sample F being covered with 1.5 g of glass wool was -0.127 V, when compared with the standard, it was discovered that sample F has a higher corrosion potential value, Ecorr or has a low negative corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion. The corrosion potential, Ecorr for the sample G being covered with 2 g of glass wool was -0.676 V, when compared with the standard, it was discovered that sample G has a higher corrosion potential value, Ecorr or has a low negative corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion.

For this project, the corrosion potential Ecorr for mild steel corrosion in 0.5 M HCl environment to was obtained to be -0.519 V (Noor and Al-Moubaraki, 2008). It was obtained that the corrosion potential, Ecorr for the control sample in 0.5 M HCl environment is -0.444V. The corrosion potential, Ecorr for the sample B being covered with 1g of glass wool was -0.6619 V, when compared with the standard, it was discovered that sample B has a lower value of corrosion potential or has a higher negative corrosion potential. This depicts that the mild steel sample or material is susceptible to corrosion. The corrosion potential, Ecorr for the sample E being covered with 1.5 g of glass wool was -0.689 V, when compared with the standard, it was discovered that sample E has a low corrosion potential, Ecorr value or has a high negative corrosion potential than the standard. This depicts that the mild steel sample or material is susceptible to corrosion. The corrosion potential, Ecorr for the sample I being covered with 2 g of glass wool was -0.6172 V, when compared with the standard, it was discovered that sample I has a low corrosion potential value, E corr or has a low negative corrosion potential. This depicts that the mild steel sample or material is susceptible to corrosion.

According to Priyaa and Saratha (2014), the corrosion potential Ecorr value for mild steel corrosion in 0.5 M H_2SO_4 was obtained to be -0.5514 V. For this project, this value was taken as the standard or minimum requirement value for mild steel corrosion in 0.5 M H_2SO_4 corrosive environment. It was obtained that the corrosion potential, Ecorr for the control sample in 0.5 M H_2SO_4 environment is -0.4410 V. The corrosion potential, Ecorr for the sample C being covered with 1g of glass wool was +0.093 V, when compared with the standard, it was discovered that sample C has a higher value of corrosion potential or has a positive corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion. Both anode and cathode were protected. The corrosion potential, Ecorr for the sample D being covered with 1.5 g of glass wool was -0.4525 V, when compared with the standard, it was discovered that sample D has a higher corrosion potential value, Ecorr or has a low negative corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion. The corrosion potential, Ecorr for the sample H being covered with 2 g of glass wool was -0.205 V, when compared with the standard, it was discovered that sample G has a higher corrosion potential value, Ecorr or has a low negative corrosion potential. This depicts that the mild steel sample or material is not susceptible to corrosion.

CHAPTER FIVE

CONCLUSION AND RECOMMEMDATION

5.1 CONCLUSION

Within the limits of experimental error, conclusions drawn based on observations and result of this project are:

i. Epoxy resins, adhesives like acrylic adhesive and super glue were tested for binding glass wool. Both acrylic adhesive and super glue were able to bind the glass wool to mild steel but the cost of super glue is too high considering large scale production, the epoxy resins also failed when used without adding hardener and accelerator which makes it unsuitable for industrial use, also for acrylic adhesive the exposed glass wool peeled off, so therefore the best materials for binding glass wool to the mild steel surface is by mixing the epoxy with the hardener and accelerator for adequate and proper cure of the samples.

ii. The results obtained from the weight loss and potentiodynamic polarisation test proved that glass wool is able to give adequate protection to mild steel in acidic environment (H_2SO_4) and NaCl, but does not support the protection of mild steel in HCl environment due to the aggressiveness of chloride anions in the solution.

5.2 RECOMMENDATION

i. Scanning electron microscopic (SEM) and x-ray diffraction (XRD) test should be done so as to view the structure and the susceptibility of the mild steel to corrosion when in the various corrosive media.

ii. Glass wool should be investigated for thermal insulation of steel for engineering materials.

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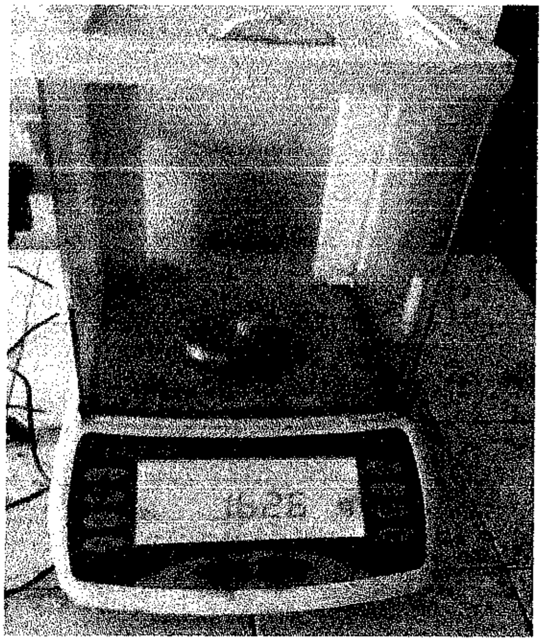
APPENDICES

Appendix A

Materials and Equipment used

Mild steel samples

Epoxy resin and hardener



Electric digital weighing machine

Grinding/Polishing Machine

Appendix B

Appendix B 1

Preparation of 0.5 M H_2SO_4

Specific gravity (s.g) of H_2SO_4 = 1.84

$$= 1.84 \times 1000 = 1840 \text{ g/dm}^3$$

Minimum assay of H_2SO_4 = 98% = 0.98

$\therefore$ $0.98 \times 1840 \text{ g/dm}^3 = 1803.2 \text{ g/dm}^3$ (mass concentration) Molar mass = 98.07 g/mol

$$Molar\ concentration = \frac{mass\ concentration}{molar\ mass}$$

$$= \frac{1803.2}{98.07} = 18.4 \text{ M } (C_A)$$

Recall that $C_AV_A = C_BV_B$

C_A (molar concentration of HCl) =18.4 M

V_A (volume of HCl) =?

C_B = 0.5 M

V_B (volume of distilled water that the acid will be diluted in) = 0.7 L

$$V_A = \frac{0.5 \times 0.7}{18.4} = 0.0190 \text{ L} = 19 \text{ mL}$$

This implies that 19mL of H_2SO_4 will be diluted in 700 mL of distilled water.

Appendix B2

Preparation of 0.5 M HCl

Specific gravity (s.g) of $H_2SO_4 = 1.18$

$$= 1.18 \times 1000 = 1180 \text{ g/dm}^3$$

Minimum assay of $H_2SO_4 = 35.4\ \% = 0.354$

$\therefore\ 0.354 \times 1180 \text{ g/dm}^3 = 417.72 \text{ g/dm}^3$ (mass concentration) Molar mass = 98.07 g/mol

$$Molar\ concentration = \frac{mass\ concentration}{molar\ mass}$$

$$= \frac{417.72}{35.6} = 11.7 \text{ M } (C_A)$$

Recall that $C_AV_A = C_BV_B$

C_A (molar concentration of H_2SO_4) =11.7 M

V_A (volume of H_2SO_4) =?

$C_B = 0.5$ M

V_B (volume of distilled water that the acid will be diluted in) = 0.7 L

$$V_A = \frac{0.5 \times 0.7}{11.7} = 0.0299 \text{ L} = 29.9\text{mL} \cong 30 \text{ mL}$$

This implies that 30 mL of HCl will be diluted in 700 mL of distilled water.

Appendix B 3

Preparation of 3.5wt% NaCl

The concentration of the solution was prepared according to the following formula

The conc. NaCl % = $\frac{\text{amount of NaCl (g)}}{\text{volume (1L)}}$

1% NaCl = 35g of Sodium Chloride dissolved in 1000 ml of H_2O.

Appendix C

Calculation of corrosion rate

$$C.R = \frac{3.65 \times 10^5 \times W}{A.D.T}$$

C.R = corrosion rate (mm/yr)

W= Weight loss/gain (g)

D = metal density (g/cm^3)

T = exposed time (days)

A = coupon total surface area (mm^2) **A= $2\pi r^2$+ 2πrl**

Sample 1

$$C.R = \frac{3.65 \times 10^5 \times 0.02}{877.0540 \times 7.87 \times 30} = 0.035 \text{ mmpy}$$

Sample 2

$$C.R = \frac{3.65 \times 10^5 \times 0.03}{874.1830 \times 7.87 \times 30} = 0.0531 \text{mmpy}$$

Sample 3

$$C.R = \frac{3.65 \times 10^5 \times 0.35}{827.1315 \times 7.87 \times 30} = 0.6542 \text{ mmpy}$$

Sample 4

$$C.R = \frac{3.65 \times 10^5 \times 0.18}{845.9378 \times 7.87 \times 30} = 0.328 \text{ mmpy}$$

Table 1: Corrosion rate of mild steel samples in their respective corrosive media

Samples	Corrosive media	Weight loss (g)	Total surface area (A)	Corrosion rate (mmpy)
1	3.5 wt % NaCl	0.02	877.0540	0.035
2	0.5M H_2SO_4	0.03	874.1830	0.0531
3	0.5M HCl	0.35	827.1315	0.6542
4	3.5 wt % NaCl	0.18	845.9378	0.328
5	0.5M H_2SO_4	0.13	825.2463	0.2435
6	0.5M HCl	0.23	826.3466	0.4303
7	3.5 wt % NaCl	0.06	825.5607	0.1124
8	0.5M H_2SO_4	0.16	842.4582	0.2936
9	0.5M HCl	0.35	871.2648	0.6210
10 (control)	0.5M H_2SO_4	2.47	865.4168	4.4123
11(control)	0.5M HCl	4.74	824.2886	8.8900
12 (control)	3.5 wt % NaCl	3.12	827.1315	5.8314