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Evaluation of Piper Sarmentosum Leaves Extract as an Eco-Friendly Corrosion Inhibitor for Carbon Steel in 5M HCl, Lake Water and 3.5 wt.% NaCl Medium

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE) WITH HONOURS

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Faculty of Mechanical Technology and Engineering

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Ahmad Syamil Bin Ahmad Kamarul Helmy

Bachelor of Mechanical Engineering Technology (Maintenance) with Honours

2024

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AHMAD SYAMIL BIN AHMAD KAMARUL HELMY

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Maintenance) with Honours

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

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I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Technology Maintenance) with Honours.

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DEDICATION

I dedicate this thesis to my loving parents, who have been my unwavering source of support and encouragement throughout this arduous journey. Their endless love, sacrifices, and belief in my abilities have been the driving force behind my accomplishments.

To my parents, thank you for instilling in me the values of perseverance and determination. You have taught me to never settle for mediocrity and to always strive for excellence. Your unwavering faith in my abilities has given me the strength to overcome every obstacle that came my way.

I am eternally grateful to my thesis supervisor, Ts. Dr. Mohd Fauzi Bin Mamat, whose guidance and expertise have been instrumental in shaping this research. Your insightful feedback, constant encouragement, and commitment to excellence have been invaluable. Furthermore, I extend my gratitude to friends and colleagues shared their knowledge and gaveme excellent advice on how to complete this study.

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ABSTRACT

Carbon steel is a type of steel that contains varying amounts of carbon, typically between 0.05% and 2.0% carbon content. It is one of the most used materials in manufacturing due to its strength, durability, and affordability but it has poor corrosion protection. Corrosion is a natural process that occurs when metals and alloys degrade due to chemical reactions with their environment. It is a complex electrochemical process that involves the transfer of electrons between a metal and an electrolyte solution. Corrosion inhibitors are chemical compounds that can be added to a corrosive environment to reduce or prevent corrosion of metals and alloys. Corrosion inhibitors work by interfering with the electrochemical reactions that cause corrosion, either by forming a protective layer on the metal surface or by modifying the chemistry of the environment. A green inhibitor, also known as an eco-friendly or environmentally friendly inhibitor, refers to a corrosion inhibitor that is derived from natural or renewable sources and exhibits minimal environmental impact. This study's aim is to evaluate the Piper sarmentosum leaves as an extract of an eco-friendly corrosion inhibitor for carbon steel in three different environments: 5M HCl, lake water, and 3.5 wt.% NaCl. Next, to investigate the influence of the immersion period on the inhibition efficiency of the green inhibitors, and to evaluate the effectiveness of green inhibitors derived from natural sources which is piper sarmentosum extract in preventing corrosion of metal surfaces in three different mediums, and also to compare the inhibition efficiency of piper sarmentosum leaves as plant-based green inhibitors of low carbon steel in three different mediums. The method that used in this study is by conducting mechanical testing which is to assess the microstructure and hardness study of low carbon steel. The substrate was divided into two group, the different of the two group is the presence of piper sarmentosum extraction. The carbon steel substrate was immerse in those three environment for observation within the number of days necessary to determine which extraction is the best inhibitor for low carbon steel. After the result was obtained the specimen will have visual inspection to calculate the weight loss, and corrosion rate. Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDX) were used to examine the mechanism of inhibitor adsorption on the surface of low carbon steel materials. To demonstrate the eco-friendly inhibitor's corrosion-preventative efficacy, a scanning electron microscopy (SEM) investigation was conducted on the surface of low carbon steel.The total weight loss on days 35 for solution with inhibitor was 2.318 gram for 5M HCl, 0.028 gram for 3.5 wt.% NaCl and 0.019 gram for lake water compared to solution without inhibitior which is 2.364 gram for 5M HCl, 0.086 gram for 3.5 wt% NaCl and 0.184 gram for lake water. The inhibitor extraction had reduce carbon's steel corrosion rate from 0.314 mm/year, 0.0011 mm/year and 0.0007 mm/year to 0.0312 mm/year, 0.0004 mm/year and 0.0003 mm/year repectively. SEM and EDX analysis proved that the specimen with inhibitor surface has least pitting which is corroded compared to specimen without inhibitor surface. The inhibitor efficiency of 5M HCl is the highest which is 65.45% compared to the others. The inhibitor effectiveness in 5M HCl is the best by considering the value of corrosion rate and the value of inhibitor efficiencies. In general, the presence of inhibitor, be it chemical or green inhibitors, will significantly slow the rate of corrosion.

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ABSTRAK

Keluli karbon ialah sejenis keluli yang mengandungi jumlah karbon yang berbeza-beza, biasanya antara 0.05% dan 2.0% kandungan karbon. Ia adalah salah satu bahan yang paling banyak digunakan dalam pembuatan kerana kekuatan, ketahanan, dan kemampuannya tetapi ia mempunyai perlindungan kakisan yang lemah. Kakisan adalah proses semula jadi yang berlaku apabila logam dan aloi Merosot kerana tindak balas kimia dengan persekitarannya. Ia adalah proses elektrokimia yang kompleks yang melibatkan pemindahan elektron antara logam dan larutan elektrolit. Penghalang kakisan adalah sebatian kimia yang boleh ditambah kepada persekitaran yang menghakis untuk mengurangkan atau mencegah kakisan logam dan aloi. Penghalang kakisan berfungsi dengan mengganggu tindak balas elektrokimia yang menyebabkan kakisan, sama ada dengan membentuk lapisan pelindung pada permukaan logam atau dengan mengubah kimia persekitaran. Perencat hijau, juga dikenali sebagai penghalang mesra alam atau mesra alam, merujuk kepada penghalang kakisan yang berasal dari sumber semula jadi atau boleh diperbaharui dan menunjukkan kesan alam sekitar yang minimum. Matlamat kajian ini adalah untuk menilai daun kadok sebagai ekstrak perencat kakisan mesra alam untuk keluli karbon dalam tiga persekitaran yang berbeza 5M HCl, Air Tasik, dan 3.5 wt.% $NaCl$. Seterusnya, untuk menyiasat pengaruh tempoh rendaman pada kecekapan perencatan perencat hijau, dan untuk menilai keberkesanan perencat hijau yang diperoleh daripada sumber semula jadi iaitu ekstrak daun kadok dalam mencegah kakisan permukaan logam dalam tiga medium berbeza, dan juga untuk membandingkan kecekapan perencatan daun kadok sebagai perencat hijau berasaskan tumbuhan keluli karbon rendah dalam tiga medium berbeza. Kaedah yang digunakan dalam kajian ini adalah dengan menjalankan ujian mekanikal iaitu untuk menilai kajian struktur mikro dan kekerasan keluli karbon rendah. Substrat dibahagikan kepada dua kumpulan, yang berbeza dari dua kumpulan adalah kehadiran pengekstrakan daun kadok. Substrat keluli karbon telah direndam dalam tiga persekitaran untuk pemerhatian dalam bilangan hari yang diperlukan untuk menentukan ekstraksi mana yang merupakan perencat terbaik untuk keluli karbon rendah. Selepas keputusan diperolehi spesimen akan mempunyai pemeriksaan visual untuk mengira penurunan berat badan, dan kadar kakisan. Mikroskopi elektron pengimbas (SEM) dan Spektroskopi sinar-x penyebaran tenaga (EDX) digunakan untuk memeriksa mekanisme penyerapan perencat pada permukaan bahan keluli karbon rendah. Untuk menunjukkan keberkesanan pencegahan kakisan perencat mesra alam, penyelidikan mikroskop elektron pengimbas (SEM) telah dijalankan pada permukaan keluli karbon rendah.Jumlah penurunan berat badan pada hari 35 untuk larutan dengan perencat ialah 2.318 gram untuk 5M HCl, 0.028 gram untuk 3.5 wt.% $NaCl$ dan 0.019 gram untuk air tasik berbanding dengan larutan tanpa penghalang iaitu 2.364 gram untuk 5M HCl, 0.086 gram untuk 3.5 wt% $NaCl$ dan 0.184 gram untuk air tasik. Pengekstrakan perencat telah mengurangkan kadar kakisan keluli karbon dari 0.314 mm/tahun, 0.0011 mm/tahun dan 0.0007 mm/tahun kepada 0.0312 mm/tahun, 0.0004 mm/tahun dan 0.0003 mm / tahun secara repektif. Analisis SEM dan EDX membuktikan bahawa spesimen dengan permukaan perencat mempunyai lubang yang paling sedikit yang dikakis berbanding spesimen tanpa permukaan perencat. Kecekapan perencat 5M HCl adalah yang tertinggi iaitu 65.45% berbanding yang lain. Keberkesanan perencat dalam 5M HCl adalah yang terbaik dengan mempertimbangkan nilai kadar kakisan dan nilai kecekapan perencat.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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In the Name of *Allah*, the Most Gracious, the Most Merciful

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Last but not least I'd like to express my appreciation to my parents, Mazuraini Binti Sulaiman and Ahmad Kamarul Helmy Bin Ahmad Zaki also my friends, who have shown incredible tolerance as I've worked hard on my studies. They have always encouraged me and showered me with love and support, which has pushed me to achieve my goals. In addition, I'd want to express my gratitude to all of my loved ones who have provided me with invaluable emotional and spiritual support throughout my time of study.

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

اونيۆرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

UTeM
اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيۏرسيتي تيکنيکل مليسيا ملاک
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF SYMBOLS AND ABBREVIATIONS

SEM - Scanning Electron Microscopy
EDX - Energy Dispersive X-Ray
W_o - Weight absence of inhibitor
W_i - Weight presence of inhibitor
I.E(%) - Percent inhibitor efficiency
mm/yr - Millimeter per year
HCl - Hydrochloric acid
NaCl - Sodium chloride
ATR-FTIR - Attenuated total reflectance-Fourier transform infrared spectroscopy
g - Gram
L - Litre
mL - mililitre
gL - gram per litre
M - Mol/L

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF APPENDICES

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Carbon steel is a type of steel that contains varying amounts of carbon, typically between 0.05% and 2.0% carbon content. It is one of the most used materials in manufacturing due to its strength, durability, and affordability. Carbon steel is classified into three main categories based on its carbon content: low carbon steel, medium carbon steel, and high carbon steel. Low carbon steel, also known as mild steel, has a carbon content of up to 0.30%. It is used in a variety of applications such as construction, machinery parts, and automobile components. Medium carbon steel has a carbon content between 0.30% and 0.60%, and is used for gears, axles, and other mechanical parts. High carbon steel has a carbon content between 0.60% and 2.0% and is used for cutting tools, knives, and springs. Carbon steel has a variety of properties that make it desirable for use in manufacturing. It is strong, durable, and can be easily machined and welded (Maurice Stewart, 2021).

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Additionally, it has good heat resistance and can withstand high temperatures without losing its strength. The disadvantage of carbon steel is that it is prone to rusting and corrosion. To prevent this, carbon steel is often coated with protective materials or surface treatments. Another disadvantage is that high carbon steel can be brittle and less ductile than other types of steel, making it more prone to cracking under stress (Maurice Stewart, 2021).

Corrosion is a natural process that occurs when metals and alloys degrade due to chemical reactions with their environment. It is a complex electrochemical process that involves the transfer of electrons between a metal and an electrolyte solution. The effects of corrosion can range from minor aesthetic damage to severe structural damage, leading to the failure of machinery, infrastructure, and other systems. Corrosion can occur in various environments including atmospheric, aqueous, and underground environments (R. G. Kelly, 2006). Atmospheric corrosion occurs when metals are exposed to air and moisture, while aqueous corrosion occurs when metals are in contact with water or other liquids. Underground corrosion can occur when metals are buried in soil, and the surrounding environment can create an electrolyte solution (Roberge and Pierre R. 2000).

Corrosion inhibitors are chemical compounds that can be added to a corrosive environment to reduce or prevent corrosion of metals and alloys. Corrosion inhibitors work by interfering with the electrochemical reactions that cause corrosion, either by forming a protective layer on the metal surface or by modifying the chemistry of the environment. This chemical substance inhibits corrosion without affecting corrosive agent concentration if its in the right concentration (Tamalmani and Husin, 2020). This does not include oxygen and hydrogen Sulphide Scavengers, which prevent corrosion by modifying solution pH. Anodic, Cathodic, and mixed corrosion inhibitors can delay cathodic or anodic reactions. The inhibited metal's corrosion potential shifts cathodically (negatively) or anodically (positively). Anodic or cathodic corrosion reactions can be slowed by reducing a metal's active surface area or shifting its oxidation or reduction activation energy. Combining cathodic and anodic corrosion inhibitors provides better protection at lower doses (Pradna D. Desai, 2022).

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

In recent years, there has been increasing interest in the development of eco-friendly corrosion inhibitors, which are non-toxic, biodegradable, and sustainable. The study of corrosion inhibitors is important for various industries, including oil and gas, chemical processing, and transportation, where materials and structures are exposed to harsh environments that can cause corrosion (Sharma et al., 2009). Corrosion inhibitors can help to protect equipment and structures, reduce maintenance costs, and improve safety and reliability. That’s mean the corrosion inhibitors are an important tool in the fight against corrosion, and ongoing research is needed to develop new and more effective inhibitors that are sustainable and environmentally friendly (Chetan B. Pawar, 2022).

In this study, low carbon steel was used as the substrate and was simulated in an acidic environment, namely a 5M HCl solution. Other than that, we also simulated the low carbon steel in the lake water and 3.5% NaCl medium. We also employed piper sarmentosum leaves as an extract. The leaves were totally disintegrated in tjose 3 types of 4medium. The piper sarmentosum leaf extracts should form a homogeneous protective shield on the low carbon steel surface, isolating the corrosive media from the reactive regions towards the low carbon steel. A variety of research methodologies, including mechanical testing, visual inspection, weight loss measurement, corrosion rate, and inhibitor efficiency, was used to gain insight into the anti-corrosive mechanism of the barrier layer formed on the low carbon surface by Piper sarmentosum leaves.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.2 Problem Statement of Study

Corrosion is a pervasive problem that affects various metallic structures and equipment in different industries, leading to significant economic losses, safety hazards, and environmental concerns. The use of synthetic corrosion inhibitors has been effective in mitigating the corrosion process. However, their toxicity and potential environmental impact have raised concerns about their sustainability. Thus, there is a growing interest in exploring natural sources of corrosion inhibitors that are environmentally friendly, cost-effective, and readily available. Every attempt has been made to minimize large losses caused by metal corrosion of alternative materials and material selection. Therefore, it is necessary to design and produce green inhibitors from trees, leaves, and other natural materials that are both inexpensive and environmentally safe and capable of effectively retarding corrosion.

1.3 Objective of Study

The objective of this study is to evaluate Piper sarmentosum leaf extract as an environmentally friendly corrosion inhibitor for low carbon steel in a 5M HCl medium, lake water and 3.5 wt.% NaCl medium. Specifically, the following are the study's objectives:

i. To investigate the influence of the immersion period on the inhibition efficiency of the green inhibitors.

ii. To evaluate the effectiveness of green inhibitors derived from natural sources which is Piper Sarmentosum extract in preventing corrosion of metal surfaces in three different mediums.

iii. To compare the inhibition efficiency of Piper Sarmentosum leaves as plant-based green inhibitors of low carbon steel in three different mediums.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.4 Scope of Study

The scope of this study are as follows:

i. To determine the optimum amount of green inhibitor to act as anti-corrosion overall performance of inhibitor on a low carbon steel substrate for use in the oil and gas industries.

ii. Selection of suitable plants which are Piper sarmentosum leaves to be extractedas green organic inhibitors

iii. Preparation of plant-based green organic inhibitors for extraction.

iv. Using Bandsaw cutting machines to cut the substrate material to the diameter of a 25 mm cylinder and a thickness of 10 mm.

v. Use a hardness test and an optical microscope to perform mechanical testing on the substrate.

vi. Conduct a corrosion test on the base metallic that was protected through the Piper Sarmentosum leaf corrosion inhibitor.

vii. To study corrosion behaviour via an immersion test in Lake water, 3.5wt.% NaCl medium and 5M HCl medium.

viii. Divide the sample into two groups with 18 samples in each group. Group one is the samples that have the presents of Piper Sarmentosum extract and group two is the samples that not have the presents of Piper Sarmentosum extract. Six samples from group one was immerse in Lake water, another six samples in 3.5wt.% NaCl and the last six samples from group one is in 5M HCl. For the group two also was the same, the only different is this group was test without Piper Sarmentosum extract.

ix. All the samples will immerse in Lake water, 3.5wt.% NaCl medium and 5M HCl medium for a period of 7, 14, 21, 28, and 35 days.

x. Utilize a Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX) to study the corrosion behaviour on the substrate after a test.

1.5 Significant of Study

As an outcome of the study, it offers information on the study’s significance. This further explains the significance of the study and its potential benefits. The aim of this study is to evaluate Piper sarmentosum leaves extract as an environmentally friendly corrosion

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inhibitor for carbon steel in three different environments which is acidic, lake water and 3.5 wt.% NaCl solution. Furthermore, these studies had been conducted using specific methods and equipment for the treatment of substrates corrosion as an important eco-friendly corrosion. Therefore, the usable material that Piper sarmentosum leaves extract represents was analyzed through the process of using the specific machine and apparatus to run the test inhibition. With added chemicals such as green inhibitors so the goal is to assist industrial oil and gas companies in mitigating corrosion of closed systems such as pipelines, pressure vessels, and tanks. In addition, the green inhibitor that would be used is also non-toxic, safe, cheap and biodegradable.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Carbon Steel

Steel is a kind of alloy that is made up of mainly iron as its major constituent. Carbon steel, also known as plain carbon steel, contains iron and carbon as its major components, alongside with other residual components such as Manganese (Mn). Other residual components may be put in in accordance to its particular usage. As defined by American Iron and Steel Institute (AISI), plain carbon steel is the type of alloy with its given major components are made of iron and carbon and contains specific amount of Mn not more than 1.65 wt%, Silicon (Si) not more than 0.6 wt%, and Copper (Cu) not more than 0.6 wt%. Other than that, it may also contain not more than 0.05 wt% of both Phosphorus (P) and Sulphur (S) (Totten, G.E., 2006)

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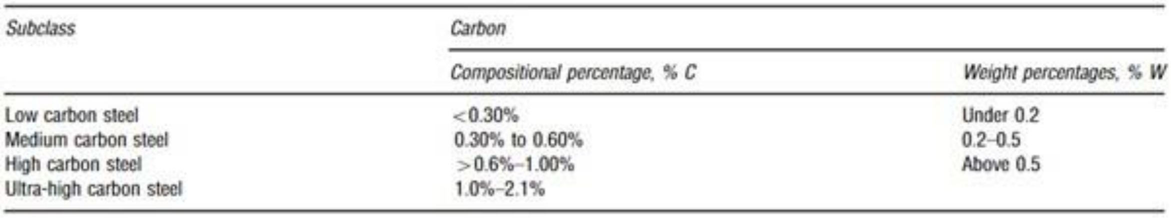
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.1.1 Type of Carbon Steel

Carbon steels are usually classified based on many characteristics including its composition, the manufacturing and finishing methods, the product form and deoxidation practice, the microstructure as well as its required strength level. Other than that, the chemical composition system has been extensively use in categorizing carbon steels, where steels are basically categorized based on its components and constituents (Islam & Rashed, 2019). The addition of different alloying elements to the iron allows it to possess specific and distinctive qualities. These variations are made possible through different production methods, deoxidation practices, and advancements in steelmaking processes. When the composition of the steel changes, it imparts certain characteristics and properties to the material. The mechanical properties, such as hardness and strength, can be adjusted by altering the carbon content. Increasing the carbon content typically results in higher hardness and strength, which can be seen in Table 2.1 (Islam & Rashed, 2019). According to Islam & Rashed, there are four major group of plain carbon steel. They are low, medium, high and ultra-high carbon steel, as shown in Figure 2.1



Subclass	*Carbon*	
	Compositional percentage, % C	*Weight percentages, % W*
Low carbon steel	$<0.30\%$	Under 0.2
Medium carbon steel	0.30% to 0.60%	0.2–0.5
High carbon steel	$>0.6\%$–1.00%	Above 0.5
Ultra-high carbon steel	1.0%–2.1%	

Figure 2.1 The four prime group of plain carbon steel (Singh, R., 2015; Bramfitt and Benscoater, 2001)

The chemical properties, microstructure, and characteristics of low, medium and high carbon steel are indicated in Table 2.1.

Table 2.1 The chemical properties, microstructure, and characteristics of low, medium and high carbon steel

Category of steel	**Carbon content (wt.%)**	**Characteristics**	**Microstructure**
Low carbon steel	$0.04 \leq \text{Carbon} < 0.25$ Sulphur - 0.055% Phosphorus - 0.055%	Low hardness and cost. High ductility, toughness, machinability and weldability.	Ferrite and pearlite
Medium carbon steel	$0.25 \leq \text{Carbon} < 0.60$	Low hardenability, medium strength, ductility and toughness.	Martensite
High carbon steel	$0.60 \leq \text{Carbon} < 2.0$	High hardness, strength, low ductility	Pearlite

2.1.2 Low Carbon Steel

Low carbon steel is a widely used form of carbon steel with a low carbon content ranging from 0.04% to 0.25%. It also commonly contains approximately 0.055% of Phosphorus and 0.055% of Sulphur, as shown in Table 2.1. The majority of the steels used

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

these days are made from this class of carbon steel. They are generally produced as flat-rolled items like sheets or strips, usually after undergoing a process of cold rolling and annealing. When it comes to rolled steel structural plates and sections, the carbon content is frequently raised to around 0.30%, while the manganese content is elevated to 1.5%. These materials are utilized in various applications such as stampings, forgings, seamless tubes, and boiler plates (Singh, 2020).

As shown in Figure 2.2 which is the Classification of steels (Totten, G.E., 2006), low carbon steel is unresponsive towards heat treatment, while its microstructures are made up of ferrite and pearlite elements, as shown in Figure 2.2. These characteristics cause the low carbon steel to have no martensite formation. It also causes low carbon steel to be somewhat soft and not very strong, but they have the remarkable ability to stretch and withstand impacts without breaking easily. As a result, they can be easily welded, are machinable and mostly cheaper than the other type of steels. (Totten, G.E., 2006; Singh, R., 2015; Westwood, A., 1996). Figure 2.3 shows example of low carbon steel (Azom., 2012).

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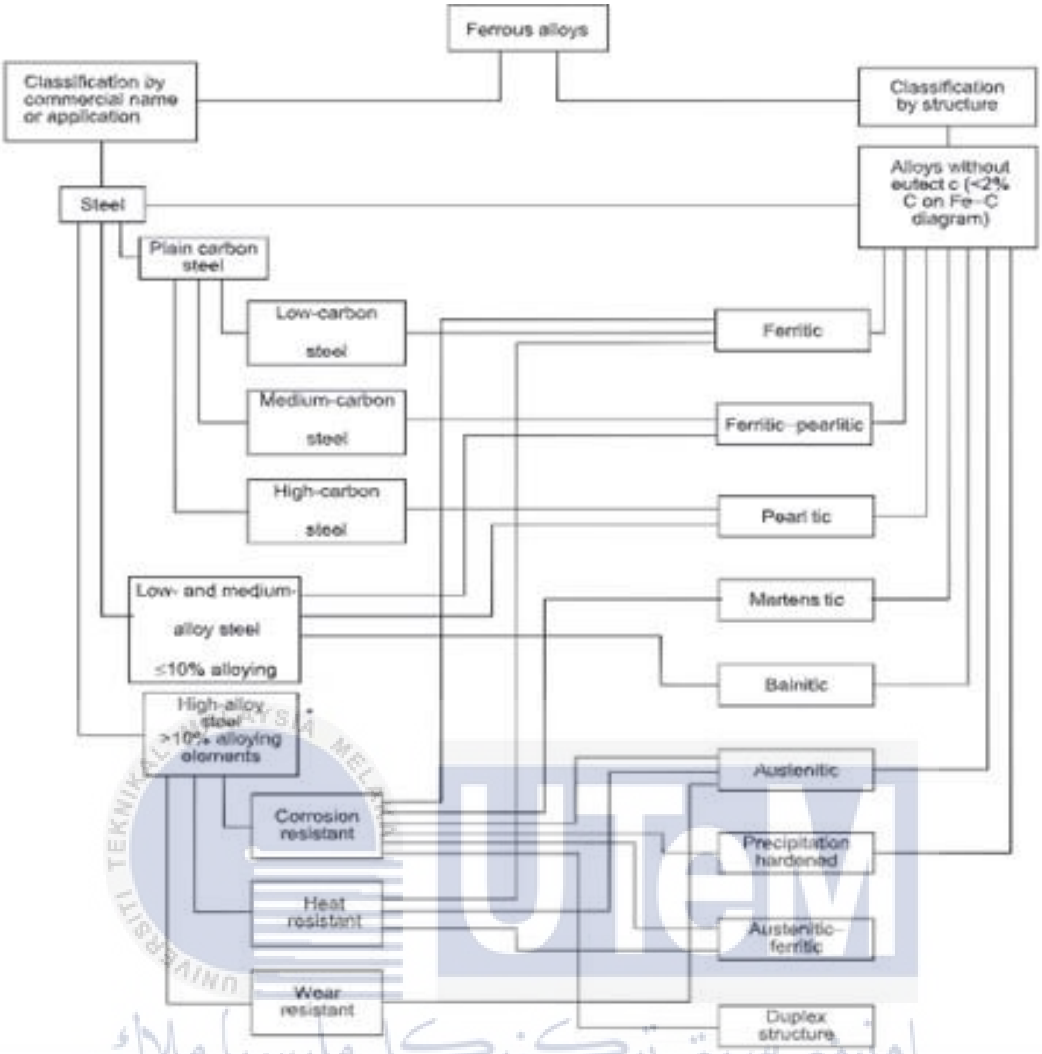

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Figure 2.2 Classification of steels (Totten, G.E., 2006)

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Figure 2.3 Low carbon steel (Azom., 2012)

2.1.3 Application of Low Carbon Steel

From automotive spare parts such as car doors and truck bed flooring to home appliances, low carbon steels serve many functions in our daily life. Due to its microstructure, low carbon steels can be bended and easily. In automobile field, low carbon steels are utilized for making parts that need only need mild bending and gentle shaping. The parts include rear truck cab panels, tailgate opening covers, floorboards as well as truck bed bottoms its also have been used in oil & gas industries as shown in figure 2.4 (Jay Leone., 2023).

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Figure 2.4 Low Carbon Steel in Oil & gas (Jay Leone., 2023).

In terms of machinability, low carbon steels maintain its championship as the type of carbon steels that are easily malleable. The element ductility relates with the amount of carbon in the steel. The higher the number of carbons in the steel, the lesser then ductility of the steel (Jay Leone., 2023).

Low carbon 1010 steel, also referred to as AISI 1010 steel, is characterized by its low strength and a carbon content of 0.10 percent. Its relatively low carbon content makes it a malleable and ductile steel. While it may not possess the high strength, properties found in other steel grades, its weldability and malleability make it suitable for specific applications (Jay Leone., 2023).

To enhance its strength, low carbon 1010 steels can undergo different tempering processes. Tempering involves heating the steel to a specific temperature and subsequently cooling it, resulting in improved hardness and toughness. The exact tempering process and parameters depend on the desired properties and the specific application requirements (Jay Leone., 2023).

Low carbon 1020 steels on the other hand typically contains a carbon content of approximately 0.2 percent. It is commonly utilized in the production of bolts and fasteners. The combination of strength and ductility makes this steel highly suitable for various applications. Additionally, it can be subjected to hardening processes to expand its potential uses. In comparison to 1010 steel, 1020 steel exhibits greater tensile strength and hardness values (Jay Leone., 2023).

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Another well-known type of low carbon steel is 1018 steel. AISI 1018 steel contains a slightly higher carbon content than 1010 steel, typically around 0.18 percent. This increased carbon content contributes to enhanced strength and hardness compared to 1010 steel. Additionally, 1018 steel is recognized for its machinability, formability, and weldability, making it a versatile choice for various manufacturing processes (Jay Leone., 2023).

Sprocket assemblies, commonly employed in mechanical systems to transmit motion or power, are frequently constructed using 1018 steel. This choice is favoured due to the favourable combination of strength, machinability, and weldability offered by 1018 steel. The specific design and dimensions of sprockets can vary depending on the intended application and load requirements (Jay Leone., 2023).

To conclude, low carbon steels like 1010, 1018 and 1020 steel are absolutely the most efficient to be used where high strength is not the primary concern, but machinability, formability, and weldability are desired. These steels provide cost-effective solutions across a wide range of industries and applications (Jay Leone., 2023).

2.2 Overview of Corrosion

Corrosion is a natural process of deterioration that occurs when metals and alloys react with their environment, leading to the degradation of the material. It is primarily an electrochemical process involving the transfer of electrons between the metal and its surroundings. When a metal is exposed to a corrosive environment, such as air, water, or chemicals, it undergoes chemical reactions that result in the breakdown of the metal's atomic structure (Revie and Uhlig, 2008). The most common form of corrosion is known as oxidation, where metals react with oxygen in the presence of moisture to form metal oxides. The essential characteristics used to characterise the environment are as follows: physical state (gas, liquid, or solid), chemical structure of components or solution, and temperature. Other factors may be important in certain situations. In other words, the relative velocity of a solution as a result of flow or agitation and mechanical stresses on the material, as well as residual tension inside the material that represents these causes (Up, 2019).

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Furthermore, according to (Cai *et al.*, 2021) many environmental factors with different routes impact the atmospheric corrosion process at the same time. Furthermore, relative humidity, temperature, and air pollution all have a substantial impact, as demonstrated by several studies. As a result, iron and steel share the ability to react with available chemical components, allowing them to revert to their lowest strength levels. Iron and steel react with natural gas and water to form hydrous iron oxides, which are rust and chemically identical to the initial ore (Up, 2019). Figure 2.5 show the flowchart of corrosion classification.

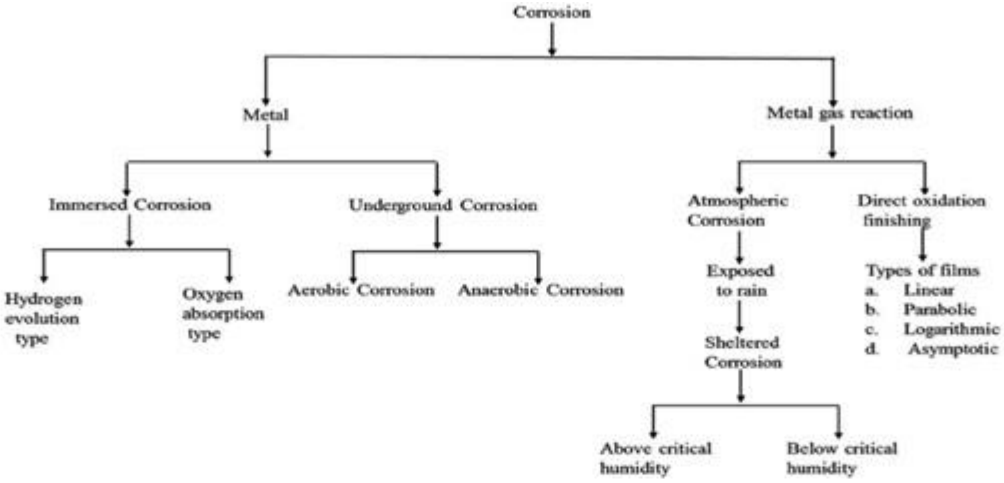

Figure 2.5 Flowchart of corrosion classification (Hussain et al., 2020).

2.2.1 Form of Corrosion

Corrosion, an electrochemical process that leads to the degradation of materials, particularly metals, manifests in various forms (Revie and Uhlig, 2008). One such form is uniform corrosion, also known as general corrosion, which occurs uniformly across the entire metal surface due to its reaction with the surrounding environment (NACE International, 2016). Another type is galvanic corrosion, which arises when dissimilar metals are in contact within an electrolyte, resulting in accelerated corrosion at the anodic metal and relative protection of the cathodic metal (Babu *et al.*, 2006). Additionally, pitting corrosion is a localized form characterized by the formation of small, deep pits on the metal surface when protective films or oxide layers break down Understanding these different forms of corrosion is essential in developing effective corrosion prevention and control strategies (Tait, 2012). Figure 2.6 show the example various type of corrosion.

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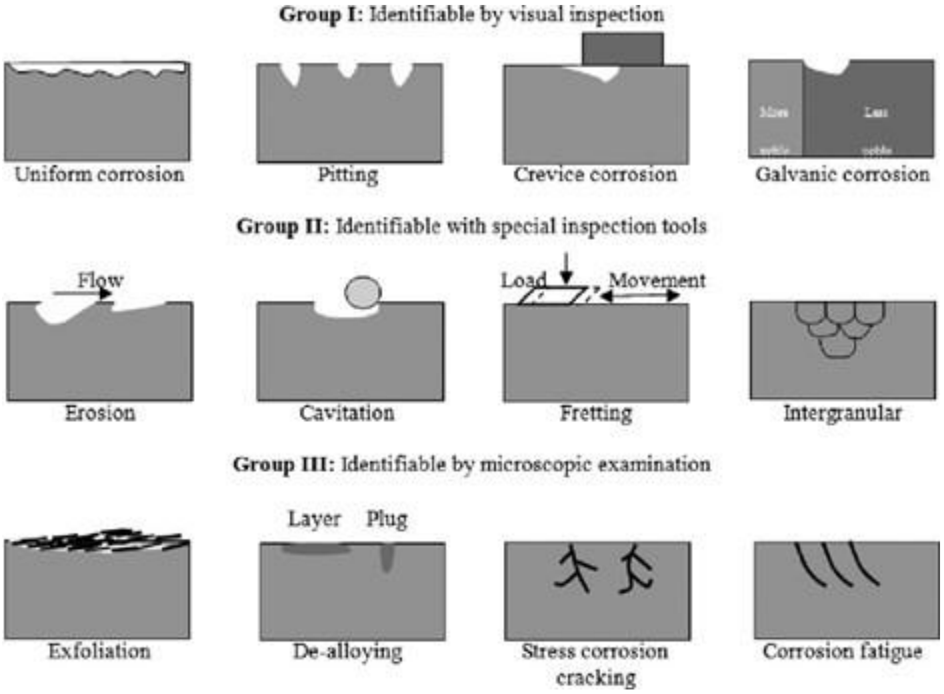

Figure 2.6 The various types of corrosion (Popoola, Olorunniwo and Ige, 2014).

The corroded metals are classified into eight types of wet (or aqueous) corrosion which is uniform or general corrosion, pitting corrosion, crevice corrosion, as well as corrosion beneath tubercles or deposits, thready corrosion and poultice corrosion, galvanic corrosion, erosion-corrosion, as well as stress corrosion cracking and environmental cracking, intergranular corrosion. Table 2.2, is the example of classifies of corrosion with their own characteristics.

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Table 2.2 Classification of Corrosion (Tait, 2012)

Corrosion Type	Description
Uniform corrosion	Occurs when metal is uniformly attacked across its entire surface. It results in a gradual thinning of the material and loss of its original shape.
Galvanic corrosion	Arises when two dissimilar metals are in contact with each other in the presence of an electrolyte. It leads to the accelerated corrosion of the less noble metal.

Pitting corrosion	Characterized by the formation of small pits or cavities on the metal's surface. It can be localized and penetrates deep into the material, leading to structural damage
Crevice corrosion	Takes place in confined spaces or crevices where the access to oxygen or other corrosion inhibitors is limited. It can cause severe localized corrosion.
Intergranular corrosion	Occurs along the grain boundaries of a metal, typically due to the presence of impurities or sensitization. It can lead to the weakening and failure of the material.
Stress corrosion cracking	Caused by the combined effect of tensile stress and a corrosive environment. It leads to the formation and growth of cracks, potentially resulting in catastrophic failure.
Filiform corrosion	Typically observed on coated metal surfaces, where thread-like filaments develop under the coating, causing localized corrosion.
Environmental cracking	Includes corrosion types such as hydrogen-induced cracking, sulfide stress cracking, and corrosion fatigue, which occur due to the interaction of specific environments with the metal.

Corrosion that spreads evenly throughout most of a piece of chemical processing equipment is called "general" or "uniform" corrosion. The piece of low carbon steel shown in Figure 2.7 is corroded in a typical fashion. Aqueous solutions passed through the valve, causing widespread uniform corrosion. The carbon steel's thickness was also diminished due to the corrosion. General corrosion is frequently mislabeled as uniform corrosion since the corrosion depth varies over the metal's surface.

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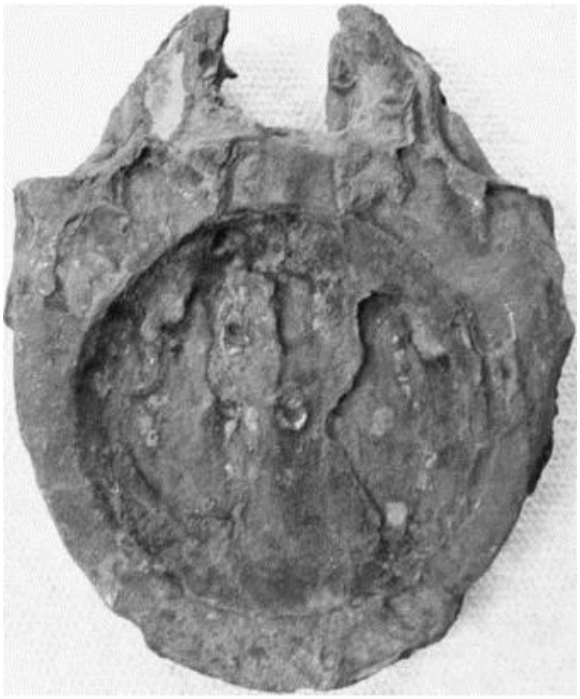

Figure 2.7 Uniform orrosion on a low carbon steel (Tait, 2012).

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2.2.2 Behaviour of Corrosion Toward Low Carbon Steel

Low carbon steel, also known as mild steel, is widely used in various industries due to its desirable mechanical properties and cost-effectiveness. However, its susceptibility to corrosion poses a significant challenge in terms of durability and performance. the corrosion of low carbon steel is influenced by factors such as the presence of corrosive agents, environmental conditions, and the steel's microstructure. Corrosive agents commonly encountered include moisture, oxygen, and various pollutants in the surrounding atmosphere or aqueous environments (G. P. Sahoo *et al.*, 2017)

Besides, Various studies have investigated the impact of environmental conditions on the corrosion behavior of low carbon steel. higher temperatures and humidity levels increase the corrosion rate of low carbon steel. Similarly, the presence of aggressive ions, such as chloride ions (Cl^-), can significantly accelerate the corrosion process, leading to pitting corrosion and localized damage. To mitigate the corrosion of low carbon steel, several protective measures can be employed. These include the application of protective coatings, such as paints or metallic coatings, to act as a barrier between the steel and the corrosive environment. Additionally, the use of corrosion inhibitors, which can be organic or inorganic compounds, has been proven effective in slowing down the corrosion rate of low carbon steel (S. R. Bakhtiar *et al.*, 2019)

2.3 Corrosion Protection Method

Corrosion protection methods are crucial in preserving the integrity and durability of various materials, especially metals, in corrosive environments. Several strategies and techniques can be developed to mitigate or prevent corrosion. Figue 2.8 shows some corrosion protection method. One widely used method of corrosion protection is the application of protective coatings on the surface of the material. These coatings act as a physical barrier, preventing direct contact between the corrosive environment and the substrate. Examples of protective coatings include organic coatings, such as paints, and inorganic coatings, such as metal or ceramic coatings. The application of protective coatings can effectively reduce the corrosion rate of metals. The coatings provide a barrier that limits the diffusion of corrosive species, such as moisture and oxygen, thereby inhibiting the corrosion process (A. R. Yilmaz *et al.*, 2018).

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Cathodic protection is also other technique commonly used to protect metal structures from corrosion. It involves making the structure the cathode of an electrochemical cell, which shifts the corrosion reaction from the metal surface to another sacrificial metal or an impressed current system. By providing a more easily corroded material, the corrosion of the protected metal is significantly reduced. Cathodic protection can be a highly efficient method, especially for buried or submerged structures, by maintaining the metal at a cathodic potential (E. O. Abdullah *et al.*, 2020).

Other than that, Corrosion inhibitors are chemical compounds that can be added to the corrosive environment to reduce the corrosion rate of metals. These inhibitors work by adsorbing onto the metal surface and forming a protective film that inhibits the electrochemical reactions responsible for corrosion. The use of corrosion inhibitors has shown significant effectiveness in reducing the corrosion rate of metals. The study investigated the performance of various organic and inorganic inhibitors and highlighted their potential as an economical and environmentally friendly corrosion protection method (S. S. Abdel-Rehim *et al.*, 2019). corrosion protection methods play a crucial role in preventing or minimizing the deterioration of materials in corrosive environments. Protective coatings, cathodic protection, corrosion inhibitors, and alloying/surface modification are some effective strategies that have been widely studied and applied. By employing these methods, the integrity and lifespan of materials, particularly metals, can be significantly enhanced.

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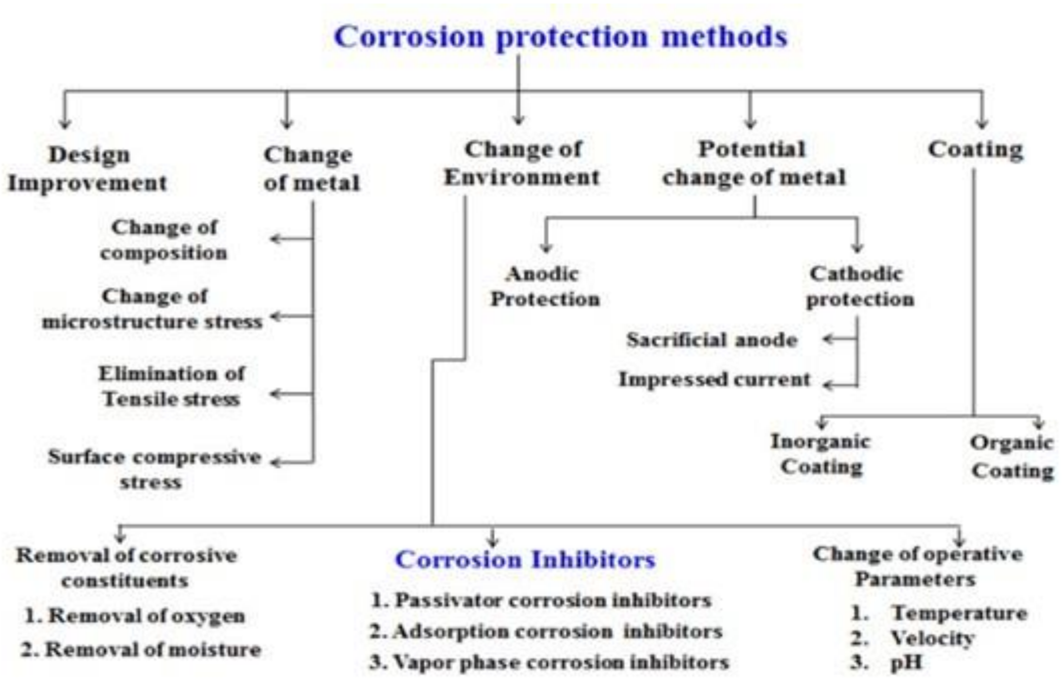

Figure 2.8 Corrosion protection method (Eno Robenso *et al.*, 2018)

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2.3.1 Corrosion Inhibitor

Corrosion inhibitors are chemical compounds used to mitigate corrosion by reducing the corrosion rate of metals and alloys in corrosive environments. These inhibitors function by adsorbing onto the metal surface, forming a protective film or altering the electrochemical reactions responsible for corrosion. These corrosion inhibitors can be classified into two categories which is inorganic and organic inhibitors.

Inorganic inhibitors are typically inorganic compounds that provide corrosion protection through different mechanisms. Examples of inorganic inhibitors include chromates, molybdates, phosphates, and silicates. These inhibitors can either form a passive film on the metal surface or react with the corrosive species to suppress corrosion. A study by L. Wang *et al.*, (2019) investigated the effectiveness of inorganic corrosion inhibitors in various corrosive environments. The research emphasized the importance of pH, concentration, and exposure time in achieving optimum inhibition performance. Additionally, the study highlighted the potential environmental concerns associated with certain inorganic inhibitors, such as chromates, which have been gradually phased out due to their toxicity.

While Organic inhibitors are often organic compounds containing nitrogen, sulfur, or phosphorus atoms. These compounds possess functional groups that facilitate their adsorption onto the metal surface. Organic inhibitors form a protective film that acts as a barrier, hindering the electrochemical reactions and reducing the corrosion rate. A comprehensive review by E. A. Noor and S. S. Abdulkareem (2020) explored the effectiveness of various organic corrosion inhibitors. The study discussed different mechanisms of adsorption and inhibition, such as chemisorption, physical adsorption, and film formation, and highlighted the importance of molecular structure in determining the inhibition efficiency. Figure 2.9 shows the classification of corrosion inhibitors.

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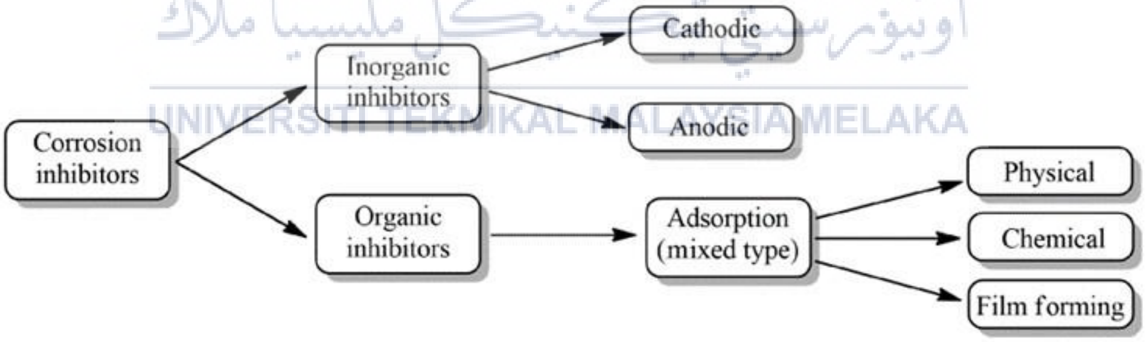

Figure 2.9 Classification of corrosion inhibitors.

2.3.1.1 Inorganic Inhibitors

Inorganic inhibitors are chemical compounds that provide corrosion protection by forming a protective film or reacting with corrosive species to suppress corrosion. They are typically inorganic compounds containing elements such as chromates, molybdates, phosphates, and silicates. Inorganic inhibitors offer advantages such as good stability, wide applicability, and cost-effectiveness. However, it is important to consider the environmental impact and regulations associated with certain inorganic inhibitors, such as chromates.

1. Chromates: Chromate-based inhibitors, such as sodium chromate (Na_2CrO_4) and potassium chromate (K_2CrO_4), have been widely used in corrosion protection. They form a passive film on the metal surface, which acts as a barrier against corrosive species. The formation of a stable chromate film is attributed to the self-passivation ability of chromates on metals like aluminum and zinc.

A study by (F. Mansfeld and G. S. Jackson., 2016) investigated the corrosion inhibition mechanism of chromates. The research revealed that chromates function by forming a protective film on the metal surface, hindering the electrochemical reactions responsible for corrosion.

However, it is important to note that chromates are facing increasing restrictions due to their environmental toxicity, and alternative environmentally friendly corrosion inhibitors are being sought.

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2. Molybdates: Molybdate-based inhibitors, such as sodium molybdate (Na_2MoO_4), have been extensively studied for their corrosion protection properties. Molybdates can form a passive film on the metal surface, which acts as a barrier against corrosive species. They exhibit excellent inhibition efficiency against various metals, including carbon steel and aluminum.

A research study by (R. Naderi *et al.*, 2018) investigated the corrosion inhibition performance of molybdate-based inhibitors. The study highlighted the role of molybdate ions in the formation of a protective film, which reduced the corrosion rate of the metal.

3. Phosphates: Phosphate-based inhibitors, such as zinc phosphate ($Zn_3(PO_4)_2$), are commonly employed for corrosion protection, particularly in metal coatings and primers. Phosphates react with metal ions and corrosive species to form insoluble precipitates or protective films that act as barriers against corrosion.

A study by (A. Rahmat *et al.*, 2019) examined the corrosion inhibition properties of phosphate-based inhibitors. The research demonstrated that phosphate compounds interact with metal surfaces, leading to the formation of a protective layer that impedes the corrosion process.

4. Silicates: Silicate-based inhibitors, such as sodium silicate (Na_2SiO_3), are utilized as corrosion inhibitors in various applications. Silicates form a protective film on the metal surface by reacting with metal ions and oxygen. The formed silicate film acts as a barrier against corrosive species, preventing direct contact with the metal.

A research article by (X. Li *et al.*, 2017) investigated the inhibition effect of silicate-based inhibitors on steel corrosion. The study revealed that silicates can effectively reduce the corrosion rate of steel by forming a protective film and altering the metal's electrochemical behavior.

2.3.1.2 Organic Inhibitors

Organic inhibitors are chemical compounds that provide corrosion protection by adsorbing onto the metal surface and forming a protective film. They are typically organic compounds containing functional groups that facilitate their adsorption onto the metal surface. Organic inhibitors offer advantages such as ease of use, wide applicability, and compatibility with different metals. Their efficiency depends on factors such as concentration, temperature, and the nature of the corrosive environment.

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1. Amines: Amines, such as aliphatic amines (e.g., ethanolamine) and aromatic amines (e.g., benzotriazole), are commonly used as organic corrosion inhibitors. Amines function by adsorbing onto the metal surface and forming a protective film. The film inhibits the electrochemical reactions responsible for corrosion, thereby reducing the corrosion rate.

A research study by (E. A. Noor *et al.*, 2018) investigated the corrosion inhibition mechanism of ethanolamine. The study revealed that ethanolamine adsorbs onto the metal surface through chemisorption, forming a protective film that hinders the corrosion process.

2. Imidazolines: Imidazolines, such as octadecylamine and dodecylamine, are organic compounds widely used as corrosion inhibitors, particularly in oil and gas industries. Imidazolines possess long hydrocarbon chains that facilitate their adsorption onto the metal surface. They form a protective film that hampers the corrosion process by blocking the access of corrosive species to the metal.

A study by (M. A. Quraishi *et al.*, 2017) explored the corrosion inhibition properties of imidazolines. The research demonstrated that imidazolines adsorb onto the metal surface and form a protective film, leading to a significant reduction in the corrosion rate.

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3. Triazoles: Triazoles, such as benzotriazole and tolyltriazole, are widely used organic inhibitors due to their excellent corrosion inhibition properties. Triazoles form a protective film on the metal surface, which acts as a barrier against corrosive species. The film prevents direct contact between the metal and the corrosive environment, thereby reducing the corrosion rate.

A comprehensive review by (R. K. Singh Raman and S. S. Mahobia, 2018) discussed the corrosion inhibition mechanism of benzotriazole. The review highlighted that benzotriazole adsorbs onto the metal surface and forms a protective film, which inhibits the corrosion process by blocking the electrochemical reactions.

4. Organic Acids: Organic acids, such as acetic acid and citric acid, can act as corrosion inhibitors. These acids function by acidifying the environment, which reduces the rate of electrochemical reactions responsible for corrosion. Additionally, the acidic environment can promote the formation of a passivating film on the metal surface.

A study by (M. T. El-Awady *et al.*, 2018) investigated the corrosion inhibition properties of acetic acid. The research demonstrated that acetic acid can significantly reduce the corrosion rate by promoting the formation of a protective film on the metal surface.

2.4 Green Inhibitors

The rise in eco-consciousness and the new restrictions that limit the use of traditional corrosion inhibitors due to their toxicity have piqued interest in green corrosion inhibitors. Corrosion inhibitors that are safe for the environment can be found in a wide variety of natural products; those with high concentrations of active organic compound elements like oxygen, carbon, nitrogen, and sulfur are particularly useful. Steel reinforcement incorporated into concrete is just one example of the many natural materials covered here and how they are used in various processes. Novel synthetic methods for ionic liquids, considered new corrosion green inhibitors, are made possible by the advancement of green chemistry and green chemical technologies; the adsorption mechanism of these inhibitors, as well as their actions in various media and protective roles for various metals and alloys, are discussed. At last, the mechanics and commercial uses of vapor-phase inhibitors are discussed. (Omnia S. Shehata., 2017)

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When introduced to a corrosive environment, green inhibitors can cure the surfaces of metals and alloys. When introduced to various industrial systems, plant extracts have been found to reduce corrosion through the adsorption of effective species on metal surfaces.

i. Accelerating or slowing down the anodic and/or cathodic reactions
ii. Interacting with metallic structures and slowing the diffusion rate of aggressive ions;
iii. Coating a metal surface with a coating makes it more electrically insulating.

The cathodic process, which occurs when a metal ion moves into a solution from an active location (the anode), requires the presence of an electron acceptor such as oxygen, oxidizing agents, or hydrogen ions. Slowing or stopping the anodic or cathodic reactions, or both, can greatly reduce corrosion. Adsorbed inhibitors establish a barrier across the metal's surface and interact with anodic and/or cathodic reaction sites, reducing the rate of these corrosive reactions.

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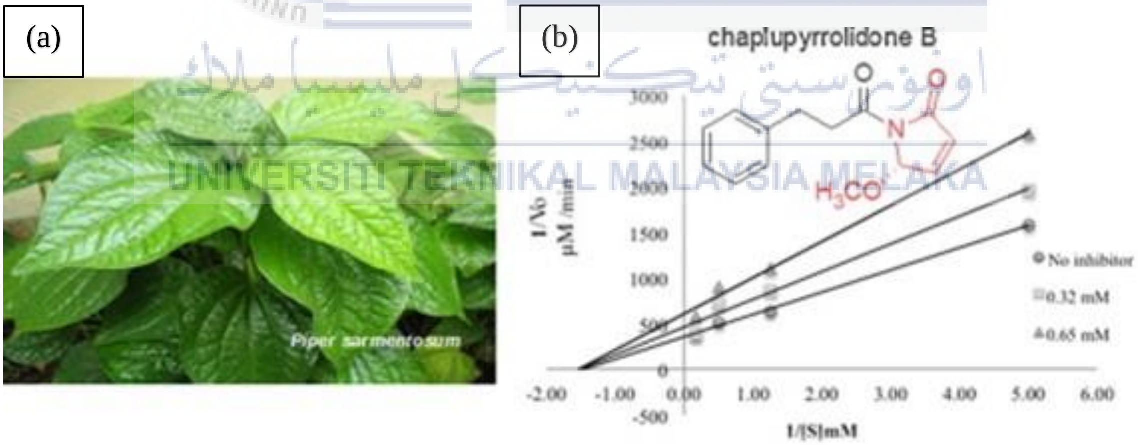

Figure 2.10 Piper Sarmentosum Reaction (Thanakorn Damsud,2013)

2.4.1 Plant Extraction

The plant extraction process is a solid/liquid separation procedure that consists of soaking the plant in an appropriate solvent. The approach taken by most researchers to obtain plant-based inhibitors involves washing, drying and crushing plant roots, barks, leaves or peel to a powder form. It is possible to use commercially available extract powder as well as to prepare inhibitor stock solutions. This study presented a compilation of studies from other researchers on other plants such as Salvia Officinalis, C. Papaya, Ligularia Fischeri, Musa paradisiaca and Molasses that uses as green inhibitor, as well as study of their perfomance (%) againts chemical constituents of the extraction as shown in Table 2.3.

Table 2.3 Other plant that tested as extraction of inhibitor corrosion

Author name (Year)	**Plant Name**	**Chemical Constituent**	**Substrate**	**% Efficiency**	**Findings**
(Soltani, Tavakkoli, Khayatkashani, Jalali, & Mosavizade, 2012)	Salvia Officinalis Leaf	1 M HCl	Stainless Steel	96%	the corrosion-inhibiting efficacy of S. Officinalis extract results fromadsorption of the extract organic matter on the corroding metal surface.
(kumar, 2014)	C. Papaya	HCl	Mild Steel	91%	By using the weight loss technique, papaya leaf extract had an inhibitory effectiveness (IE) of 91% at Zn^{2+} (50 ppm). Synergism parameters were developedto assess the synergistic impact that exists between C.
(Prabakaran *et al.*, 2016)	Ligularia fischeri	1 M HCl	Mild Steel	92%	A methyl alcohol extract

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					of *Ligularia fischeri* was tested for its ability to prevent low-carbon steel corrosion in an exceedingly 1 M acid media
(Ji *et al.*,2015)	Musa paradisiaca	1 M HCl	Mild Steel	92%	The inhibitory and adsorption effects of *Musa paradisica* (Banana) peel aqueous extracts on mildsteel corrosion in 1 M HCl.
(Slepski *et al.*, 2014)	Molasses	1 M HCl	Low Carbon Steel	90%	Volumetric and electrochemical measurements were used to study the influence of molasses on thecorrosion of low carbon steel in 1M hydrochloric acid solution.

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2.4.2 Piper Sarmentosum Leaves Extraction

Southeast Asian countries use Piper sarmentosum leaves for both medicinal and culinary purposes, with the plant's aerial parts eaten as a vegetable in a variety of preparations and the whole plant or parts used as folk remedies, either on their own or in combination with other herbs, for a wide range of conditions (Hussain et al., 2012). Piper sarmentosum, or “kaduk”, as it is commonly known in its native Malaysia and Indonesia, is a plant that has been used medicinally for centuries. These tender leaves are eaten raw in Malaysia, where they have proven useful in treating malaria and cough (Sun et al., 2020). Figure 2.11 shows the example Piper Sarmentosum leaves.

Figure 2.11 Piper Sarmentosum Leaves (Iplantz., 2023)

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There are a number of ways for extracting the active components from Piper sarmentosum leaves, including as solvent extraction, maceration, and steam distillation. The bioactive components of the leaves are often extracted using solvents such ethanol, methanol, or water (Hussain *et al.*, 2008). An abundance of amides, alkaloids, flavonoids, tannins, saponins, glycosides, terpenoids, and phenolic chemicals can be found in Piper sarmentosum. (Mgbeahuruike *et al.*, 2017). Table 2.4 shows the taxonomic classification of piper sarmentosum.

Table 2.4 taxonomic classification of piper sarmentosum (Azahar et al., 2022)

Kingdom	**Plantae**
Division	Magnoliphyta
Class	Magnolipsida
Family	Piperaceae
Genus	Piper
Species	Betle
Binomial name	Piper betle
Order	Piperales

As shown in Table 2.5, this study offered a collection of other researchers' investigations on Piper sarmentosum leaves for use as inhibitors, and also a review of their performance (%) against chemical elements of the extraction.

Table 2.5 Piper sarmentosum leaves extract as inhibitor

Author Name	**Chemical Constituent**	**Substrate**	**%Efficiency**	**Finding**
(Rozuli, Hamidon, & Hussin, 2019)	0.5M HCL	Mild Steel	92.18	Mild steel's corroding nature was investigated at 303–333 K temperature range to acquire the influence of temperature on corrosion. . In view of SEM analysis, mild steel panel treated with PSE showed a significantly improved surface condition, i.e., a much smoother surface morphology.
(Mohamed *et al.*, 2018)	1M HCl	Carbon steel	93	the results showed that the extract exhibited significant inhibitory properties, reducing the corrosion rate and increasing the polarization resistance of the metal.
(Rajendran *et al.*, 2019)	1M HCl	Copper	90	the active compounds present in the extract acted as adsorption inhibitors, forming a

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				protective layer on the metal surface and impeding the corrosion reaction.
(Abdul Rahim *et al.*, 2019)	Saline solution	Aluminium alloy	91	The findings revealed a considerable decrease in the corrosion rate, demonstrating the potential of Piper sarmentosum as an eco-friendly corrosion inhibitor for aluminum alloys.

Table 2.6 Piper sarmentosum leaves extraction method

Author name (Year)	**Method**
(Rozuli et al., 2019)	1. Piper sarmentosum leaves were obtained and cleaned. 2. Exposed to sunlight for 2 days. 3. The dried leaves were ground into the powdered using laboratory blender. 4. The extraction process was done by adding 1.0 g of powdered dried leaves in 100 ml of ethanol. 5. the mixture was shaken at 130 rpm for 24 h at ambient room temperature before proceeding with the filtration process. 6. The filtrate was continued to evaporate using a Heidolph Laborota 4011 digital rotary evaporator and eventually was subjected to oven dry at 50°C overnight.
(Mohamed *et al.,* 2018)	1. Piper sarmentosum leaves were obtained and cleaned with tap water. 2. Dry the leaves at 50°C for 12 hours. 3. Grounding to powder by the blender, and then sieving size of 125 µm. 4. After that, filter with filter paper and steam until all of the methanol evaporates and the oil settle.
(Rajendran *et al.,* 2019)	1. 10 grams of CPL were pulverized with 2 liters of double-distilled water to create an aqueous extract. 2. filtering was used to get rid of the solid pollutants. One hundred milliliters of the extract were concentrated.

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(Abdul Rahim *et al.*, 2019)	1. After carefully washing with ultrapure water, we dried the leaves of piper sarmentosum for 24 hours in an oven set to 333 K. 2. The leaves were then pulverized into a powder once they were completely dry. 3. In a 2 liter beaker, 100 grams of powdered piper sarmentosum leaf were weighed using an electronic analytical balance. 4. After adding 1 L of ultrapure water to the beaker, we boiled it until the liquid had evaporated to 200 mL, at which point we filtered out the remaining piper sarmentosum leaf residue via a fine gauze. The purified PLE was concentrated by heating it. 5. When the extract was taken off the heat, it had a total volume of about 50 mL. The PLE extract was placed in a small beaker and placed in the refrigerator for 10 hours. 6. After 24 hours in a freeze-drying box (FD-1), the PLE turned out to be a tan color and weighed 5.23 grams. When it came time to actually use the PLE, it was dehydrated in a desiccator.

2.5 Summary of Literature Review

Low carbon steel has a carbon content of 0.05% to 0.25% and contains up to 0.4% manganese. The substrate for this research was made of low carbon steel. Furthermore, ferrite and pearlite make up the microstructures. We also talk about corrosion's definition as the breakdown of metals and alloys due to chemical or electrochemical exposure to their surroundings. Wet or aqueous corrosion is used to categorize corrosive metals into eight different groups.

There was also a discussion in this chapter on the plants that are used the most often in this industry. It was possible for these plants to provide protection against corrosion for a wide variety of metals and other materials because of the distinctive chemical compositions that they had. As a consequence of this, the technique for avoiding corrosion on the surface of carbon steel was also discussed in this chapter. In the course of this investigation, green

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inhibitors were used in the form of piper sarmentosum leaves and an extract of the chemical makeup of the leaves. An immersion test was performed on the substrate, and it was collected after being subjected to 5M HCl, lake water, and 3.5 wt.% NaCl.

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CHAPTER 3

REASERCH METHODOLOGY

3.1 Introduction

In this chapter, we will go over the methods of the research in great detail, beginning with the materials and moving on to preparation stage, production processes, and testing procedures. The process flow chart that highlighted the steps necessary to finish this research can be found in Figure 3.1. These phases include both the input and the output. As a result, the extraction was performed using Piper sarmentosum leaves, and the substrate was cylindrical low-carbon steel specimens with dimensions of 25 millimetres in diameter and 10 millimetres in thickness. After the Piper sarmentosum leaves have been extracted into a solution, the solution was filtered repeatedly until the required amount of the plant has been collected. In addition, the plant extract is first boiled using a magnetic stirrer, after which it is crushed and blended in order to remove the waste content.

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In order to obtain the extraction, the raw material was first boiled and then filtered in order to eliminate the fibre as well as any other compositions, such as the water composition. At some point, when the temperature is just right, the extract was baked in the oven for a few days to ensure that the amount of water in the final product is minimised. As a direct consequence of this, the extracted substance will have the consistency of jelly when it is removed from the oven. As a consequence of this, once the extraction has been obtained, it was mixed with 5M HCl, lake water, and a medium containing 3.5 wt.% NaCl, and then it was poured into three different containers containing the specimen that was immersed for observation within the number of days necessary to determine which extraction is the best inhibitor for low carbon steel. Calculating the weight loss, corrosion rate, and inhibitor efficiency that occur on the substrates, as well as using SEM and EDX to determine the extraction's inhibition efficiency against low-carbon steel surfaces, was done in order to determine the effectiveness of the inhibitor.

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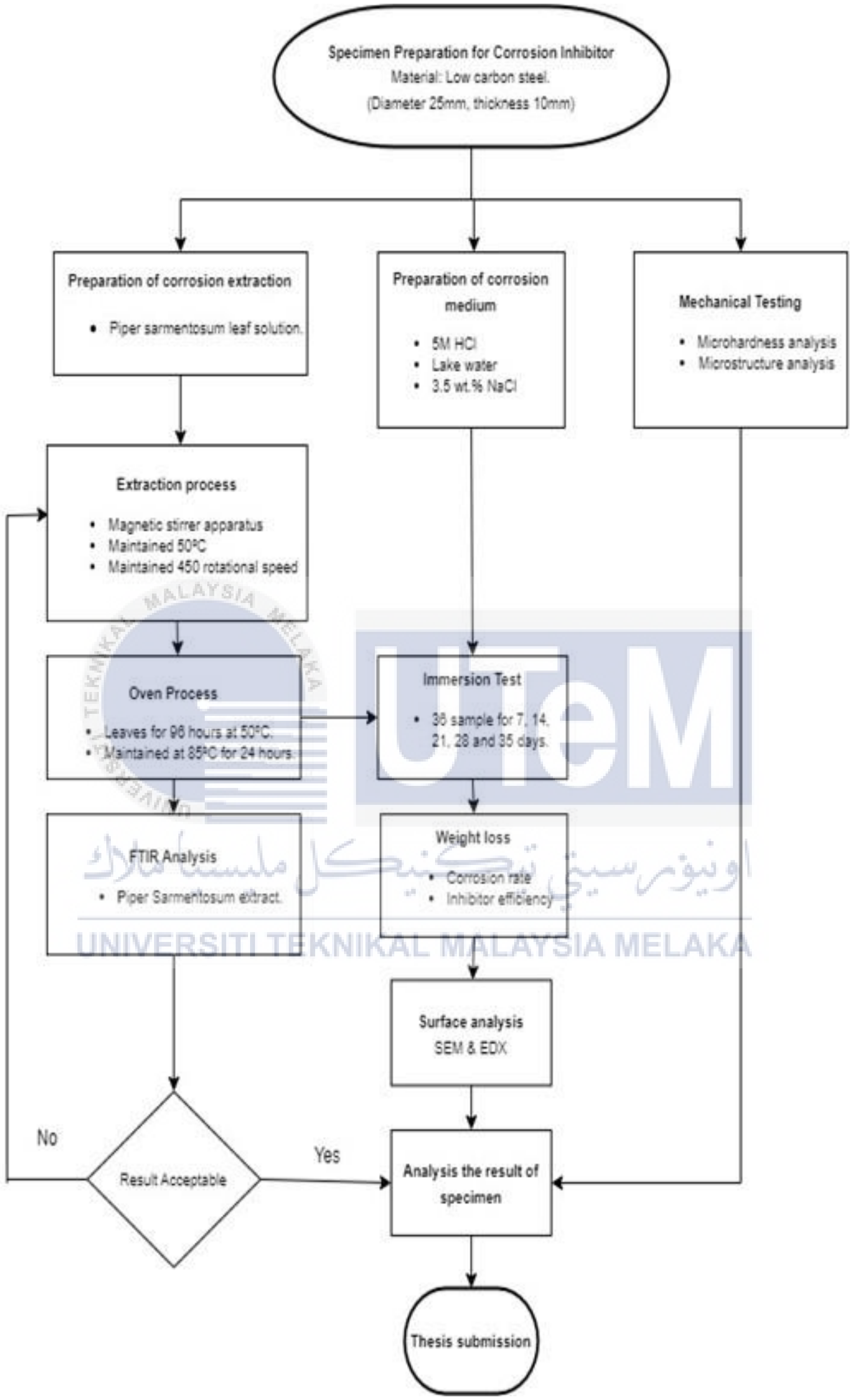

Figure 3.1 Process flow chart for this study

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3.2 Sample Preparation

The substrates which is low carbon steel has been prepared by using Bandsaw Cutting machine at FTKMP laboratory as shown in Figure 3.2 bandsaw cutting machine.

Figure 3.2 Bandsaw cutting machine.

In addition, the measurements of this specimen suggest that it is roughly in the shape of a coin, with a diameter of approximately 25 millimetres and a thickness of approximately 10 millimetres, as demonstrated by the vernier callipers in Figure 3.3.

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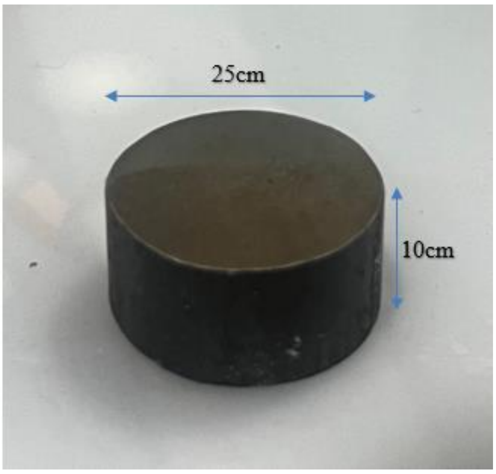

Figure 3.3 specimen shape.

Before mounting in the mounting press machine, the specimen was first chainsaw-cut into four smaller pieces so that it could be more easily handled. In the Material Science Laboratory, mounting presses and other apparatus are used to enclose specimens of metal, ceramic, or other materials, particularly one small specimen, with a mounting compound that contains appropriate mounting resin, enabling grinding, polishing, and other operations. Polishing, in addition to other types of sample preparation, in order to examine samples using microscopes, hardness testers, or spectrometers. The machine used for mounting metallography samples is depicted in figure 3.4 which is Kemet mounting metallography press machine.

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Figure 3.4 Kemet Mounting Metallography Press.

For the purpose of producing a smooth surface, the specimen was pulverized using abrasive paper with grits of 60, 150, 360, 600, 800, and 1200. In addition, as can be seen in Figure 3.5, every piece of abrasive paper was given a few minutes in a grinding machine to have it broken up into smaller pieces. In the meantime, the specimen has been meticulously cleaned with sterile water before being transferred to a different quality of paper. This was done to prevent contamination from the coarse grit that was found on the surface of the specimen.

Figure 3.5 Mecapol Metallographic Polishing machine

3.3 Inhibitors Extraction

The raw ingredients, such as the leaves of Piper sarmentosum, was converted from their solid state to their liquid condition before the extraction process was finished. In addition, in order to manufacture the extracts, the raw material had to go through a few stages of processing, which called for the utilisation of specific pieces of machinery.

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3.3.1 Piper Sarmentosum Leaves Extraction

To obtain the best extraction yield, 40 g of dry Piper Sarmentosum leaves was blended with 500 mL of deionized water. After that, the blended ingredients were poured into the beaker and 1000 mL of deionized water was added. Then, boiled it for 1 hour at 50˚C using a magnetic stirrer until the extraction concentrated. Moreover, the filtrate of the Piper Sarmentosum leaves extraction had been separated from the residue using filter paper. Later, the extracted juice was put on the aluminium foil and a hole was made. Additionally, the extraction juice was ready to be inserted into the oven. The juice was put into the laboratory oven at 50˚C for 96hours and kept constant at 85˚C for 24 hours. Figure 3.6 shows how the piper sarmentosum processed.

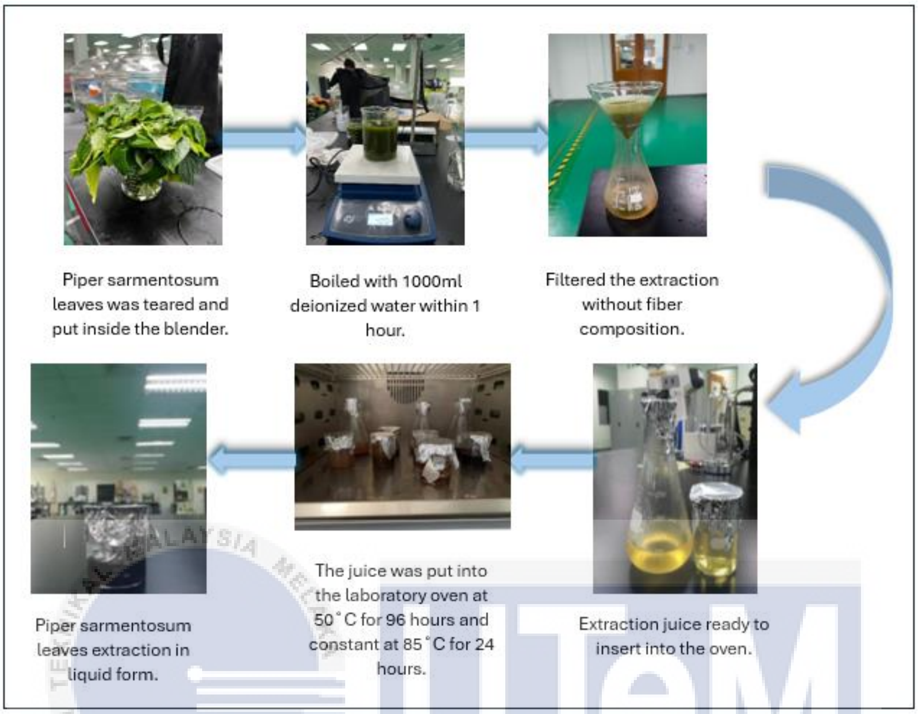

Figure 3.6 Piper sarmentosum extraction process.

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3.3.2 Attenuated total reflectance - Fourier-transform infrared spectroscopy (ATR-FTIR)

ATR-FTIR spectroscopy is among the most efficient tools for identifying functional groups in membranes and also some possible molecular interactions between membrane chemical compounds (Mohamed *et al.*, 2017). The ATR-FTIR instrument sends infrared radiation of about 10,000 to 100 cm^{-1} through a sample, with some radiation absorbed and some passed through. The absorbed radiation is converted into rotational or vibrational energy by the sample molecules. Any interaction between the medication and the polymer matrix can be detected using ATR-FTIR spectroscopy at room temperature in the region of 450-4000 cm-1. Hydrogen bonds between the drug's amino groups and the polymer's ether or alcoholic groups are the most commonly predicted interaction between these components (Ibrahim A. *et al.*, 2016). Figure 3.7 shows the Jasco ATR-FTIR machine.

Figure 3.7 Jasco FT/IR-6100 machine

3.4 Mechanical Testing

When a material is subjected to external forces, its mechanical qualities become apparent. Mechanical testing is used to determine the hardness and microstructure of low carbon steel in this study. Carbon steel corrodes uncontrollably in acidic environments. In order to better see the microstructure or macrostructure, etching is often used to increase contrast on surfaces. Substrates with low carbon steel shape, composition, and hardness were also studied, as were their material properties.

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3.4.1 Microstructure Testing

Microstructure analysis is a technique that is used in a wide range of sectors to determine the characteristics of a substance at a range of different phases of testing. As a consequence of this, the purpose of this study is to investigate the relationship between microstructure, surface condition, and the effectiveness of inhibitors in relation to corrosion. As a result of this research, we now understand that it is challenging to determine the yield strength, as well as the ultimate tensile or compressive strength of a material because of its high hardness and low ductility. As a result, the efficiency of an inhibitor is reduced by pre-corrosion; however, the effect varies depending on the microstructure. Figure 3.8 shows the Axio upright light microscope that will help this study to investigate the microstructure of low carbon steel substrates. Additionally, low carbon steels are produced in substantially bigger amounts than other alloys.

Figure 3.8 Axio Upright Light Microscope.

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3.4.2 Hardness Testing

When testing on highly solid or very soft surfaces or on very small portions of composite, hardness measurement is a tool for assessing the strength or durability of penetration. Surface properties of materials with multi-phase, non-homogeneous, or crack-resistant microstructures may be characterised with high accuracy and reliability using this method. In order to determine the hardness, a cylindrical probe was employed and guided to the surface while the weights were applied. The duration of an abusive relationship is usually limited. In conventional mechanical investigations, measuring the length or depth of a cylinder probe was used to establish hardness. There are two scales for measuring aggression: macrohardness and microhardness. Vickers and Knoop hardness examinations are two common microhardness procedures (Wang *et al.*, 2019). Therefore, the indenter-type ball in this study has a measured depth of 1.588 mm, a total force of 294.2 N, and an HRB hardness symbol. Microhardness testing apparatus, as shown in Figure 3.9. shows the Mitutoyo Automated Rockwell Hardness Testing Machine.

Figure 3.9 Mitutoyo Automated Rockwell Hardness Testing Machine

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3.5 Corrosion Test

The purpose of corrosion testing is to evaluate a material's durability in a variety of corrosive situations. Many types of corrosion tests are performed on aluminium alloys, and low carbon steel was used in this study's investigation. On the other hand, these need to be tailored to the particular forms of corrosion they'll be employed against; otherwise, it was impossible to tell, for example, pitting corrosion from intergranular corrosion or exfoliating corrosion from a surface attack. Corrosion can cause long-term damage to things including materials, machinery, buildings, and pipes. This loss is not only financially costly to restore, but also causes the machinery to deteriorate, leading to production downtime (Kadhim *et al.*, 2021).

3.5.1 Immersion Test

Immersion testing is the most commonly used technique for monitoring metal corrosion in aqueous solutions and the process of corrosion degradation caused by the length of time exposed to a corrosive atmosphere, as well as other factors that may contribute to the corrosion period. The detail of ASTM G1 and G31 are shown in Appendix A and Appendix B. Moreover, immersion tests are used in industries that are prone to immersion conditions and they provide uniform results for corrosion of alloys. These factors also include the solution's composition, temperature, oxygenation, volume, velocity, and the impact of the sea surface, specimen material selection, specimen immersion method, test time, and specimen cleaning procedure. Figure 3.10 shows how the setup for immersion test.

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Figure 3.10 Immersion Test Setup

3.5.1.1 Visual Inspection

There has been a lot of focus on the many different parts of the inspection process, but the findings reveal that the factors affecting inspection efficiency are complex and hard to govern. Most manufacturers' reliance on visual inspection methods implies that this is not commonly known or understood and that some people have a fundamentally flawed conviction in the efficacy of SVI alone. Therefore, we have created Group A and Group B from our sample. Piper Sarmentosum extract was used in Group A, whereas no extract was used in Group B. The investigation will involve three distinct environments for each group: 5M HCl, lake water, and 3.5 wt.% NaCl. Six pieces of low-carbon steel have been monitored over the course of 7, 14, 21, 28, and 35 days, respectively, as shown in Table 3.1. The specimen was removed on the predetermined day, and the confirmed results verified the calculated weight loss and corrosion rate.

Table 3.1 Sample of Immersion Test

Group A (with piper sarmentosum extraction)					
Type of medium	**Number of samples taken out from container to measure corrosion rate**				
	Day 7	**Day 14**	**Day 21**	**Day 28**	**Day 35**
5 M HCl	1	1	1	1	1
Lake water	1	1	1	1	1
3.5 wt.% NaCl	1	1	1	1	1
Group B (without piper sarmentosum extraction)					
Type of medium	**Number of samples taken out from container to measure corrosion rate**				
	Day 7	**Day 14**	**Day 21**	**Day 28**	**Day 35**
5 M HCl	1	1	1	1	1
Lake water	1	1	1	1	1

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3.5 wt.% NaCl	1	1	1	1	1

3.5.1.2 Weight Loss Measurement

Substrates have been immersed in three different medium which is 5M HCl, Lake water and 3.5 wt.% NaCl with and without inhibitors to conduct weight loss tests at a range of concentrations. After 7, 14, 21, 28, and 35 days, the samples were taken out, rinsed with acetone, cleaned, and analysed using a microbalance. In addition, quantitative measurements and analyses were derived from a standardised set of rules. In addition, the research was repeated multiple times, and the average results are presented below. Weight-per-million (ppm) concentrations of inhibitors were utilised in the study of weight reduction. Using the equations mentioned below, the weight loss or surface coverage (θ) was calculated.

$$\text{Weight loss } (\theta) = \frac{W_o - W_i}{W_o} \text{ ---------------------- } (1)$$

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Where, W_o represents weight loss without the inhibitor and W_i denotes weight loss with the inhibitor.

3.5.1.3 Corrosion Rate

The corrosion rate is the pace at which a specific metal deteriorates under particularly specific conditions. Because of the composition and condition of the steel, environmental circumstances limit the rate. Furthermore, corrosion rates in the United States are often calculated in mils per year. To put it another way, the corrosion rate is defined by the number of millimeters (thousandths of an inch) that are pierced per year. In this study, the corrosion rate was estimated using the following equation:

$$\text{Corrosion rate (mm/year)} = \frac{KW}{ATD} \text{ -------------------- (2)}$$

Where:

K = Constant, 8.76 mm/y (mils(10^4)per
year)W = Mass loss (gram)
A = Exposed area
(A=$\pi r^2+\pi r^2$)T =
Immersion time (hours)
D = Density in g/cm^3 (7.87 g/cm^3)

3.5.1.4 Inhibitor Efficiency

When the inhibitor concentration, immersion duration, and temperature are increased and the inhibition efficiency increases. In order to investigate the inhibitor efficiency over substrate corrosion, the inhibitor efficiency (I.E%) was evaluated by the subsequent formula:

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$$\text{I.E\%} = \frac{W_o - W_i}{W_o} \times 100 \text{ --------------------(3)}$$

Where, I.E is inhibition efficiency, Wo = weight loss without inhibitor, Wi = weight loss with an inhibitor

3.6 Surface Study by Scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDX)

Understanding the surface layer composition enables analysis of the shield's characteristics in a solvent suitable for the energetic component and at high temperatures, both of which have a significant impact on the re-agent adsorption and dispersion conditions. Surface morphology and chemical composition can also be studied using scanning electron microscopy (SEM) equipped with the appropriate accessories (Stepanova *et al.*, 2018). This study looked into how inhibitors and corrosion affected the outside of low carbon steel. Therefore, the SEM creates a variety of signals on the surface of a solid object by using a concentrated stream of highly energy electrons.

In addition, this study explored how inhibitors and corrosion affected the low carbon steel's exterior. Therefore, using a concentrated beam of highly intense electrons, the SEM creates a variety of signals on the solid's surface. The shape, structure, colour, scale, and pattern of a material can all be gleaned from the SEM results. The imaging time with a scanning electron microscope (SEM) is between 0.1 and 1 minute, and the material must be conductive. Figure 3.11 shows the Zeiss SEM machine.

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Figure 3.11 Zeiss SEM machine analysis

In Energy-dispersive X-ray spectroscopy (EDX) is a different kind of spectrum analysis in which an X-ray hits a specimen, causing an electron in an inner shell to become excited, causing the electron to emit, and thus causing an electron hole to form in the element's electronic structure. In addition, the gap is filled by an electron from a higher energy shell, and the resulting release of energy in the form of X-rays is detected by the detector. Because of this, the total quantity of energy remains the same for all constituents, and their detection might reveal crucial data regarding the presence of specific components (Polini and Yang, 2017). Figure 3.12 shows the EDX machine.

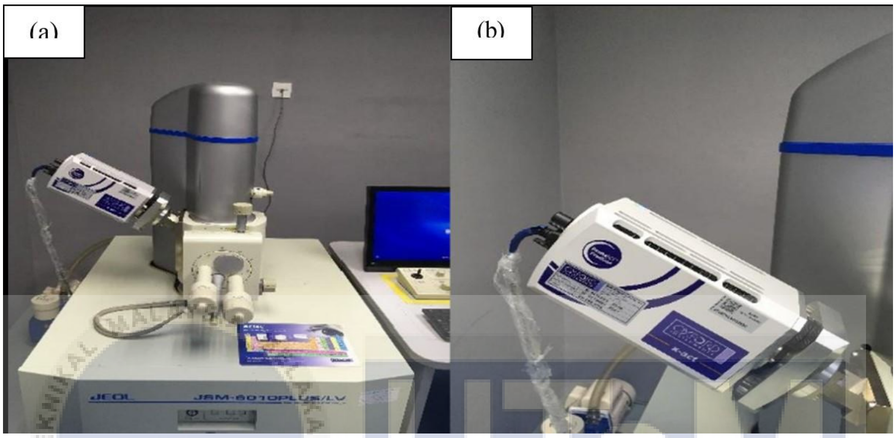

Figure 3.12 JSM-6010PLUS/LV EDX machine analysis

3.7 Summary of Research Methodollogy

This chapter concludes by outlining the strategy advocated for creating a novel corrosion inhibitor formula. The primary objective of the methodological approach under investigation is to provide less cumbersome, more precise, and ultimately faster calculations. In any case, the method's end goal is achievement. Several more examples are offered in the following chapter to validate and expand upon the methods discussed here. Importantly, an immersion test was used to assess the inhibitor's corrosion performance, and six low-carbon steel specimens were included in each sample and monitored within the specified number of days. The specimen was removed during the designated week, and the rate of corrosion and weight loss were computed from there. The efficiency of the inhibitor on low-carbon steel substrates was also evaluated by inspecting

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their microstructure and microhardness. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) were utilised to investigate the structure and chemical composition of the surface layer. Corrosion efficiency and corrosion incidence against low-carbon steel substrates would consequently be greatly improved as a result of this corrosion inhibition.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the findings obtained through the methodologies stated in previous chapter. The main objectives is to identify the significant changes in weight and microstructure of the sample post treatment with the Piper Sarmentosum leaves extract after being exposed in all three distinct medium. Other than that, visual testing will also reveal the potential of this plant as a green inhibitor. These findings are crucial in measuring the efficacy as well as potential of Piper Sarmentosum leaves extract as an eco-friendly inhibitors against corrosion. Other than that, this chapter will also allows the exploration on the kind of medium that has the greater influence on inducing corrosion on carbon steel, as well as the rate of adsorption of the inhibitors on the steel.

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In addition, we will identify the most effective inhibitor for the extraction by implementing measures to prevent corrosion on the specimen and visually inspecting it to determine its corrosion level; if necessary, we will calculate the corrosion rate based on the weight loss measurement. In addition, morphological characterisation and immersion test studies can be conducted using imaging techniques such Fourier transform infrared (FTIR), energy dispersive X-ray spectroscopy (EDX), and scanning electron microscopy (SEM). The specimen's corroded surface was examined using SEM, and the extraction that supported the inhibitor was analysed using EDX to determine the most abundant component. Apart from that, morphological analysis using SEM and EDX confirmed the same results, and this extract has high inhibitory efficacy throughout a broad temperature range.

4.2 Sample Composition

As shown in Appendix C, we utilised Glow Discharge Spectrometry (GDS) as the detailed composition proof to support the claim that the material is low carbon steel. The purpose of this analytical approach is to directly determine the elementary composition of a material. The elemental composition of low carbon steel is detailed in Table 4.1.

Table 4.1 Glow Discharge Spectrometry (GDS) table.

Element	Composition (wt%)
Iron (Fe)	98.4
Carbon (C)	0.174
Manganese (Mn)	0.620
Phosphorus (P)	0.0277
Sulfur (S)	0.0212
Silicon (Si)	0.176
Copper (Cu)	0.280
Nickel (Ni)	0.0777
Chromium (Cr)	0.135

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4.3 Mechanical Testing

For the purposes of this investigation, mechanical testing was carried out at the Material Science Laboratory in order to ascertain the microstructure that was present in the specimen. Additionally, hardness testing was carried out in order to evaluate the strength of low carbon steel.

4.3.1 Microstructure Testing

To conduct this study, the low carbon steel was first subjected to a series of surface treatments, including polishing and etching, using the appropriate chemical reagents. Then, the surface of the low carbon steel was examined under an optical microscope equipped with different lenses to observe its microstructure. One of the most crucial uses of microscopic research is determining the degree to which a substance retains its properties throughout time. Furthermore, in order to demonstrate the importance of low carbon steel's chemical composition, the microstructure test is an absolute necessit (Abdul Rahim *et al.*, 2019).

The microstructure of ferrite and pearlite on low carbon steel can be seen slowly under a high magnification, as shown in Figure 4.1 (a) 50μm and Figure 4.1 (b) 100μm. In addition, a little specimen, about the size of a quarter of a circle of low carbon steel, is required for this study, and the best results would be obtained by focusing on the most typical regions. In order to incorporate both a basic and an advanced observation, the specimen should be taken from a part of the object being studied.

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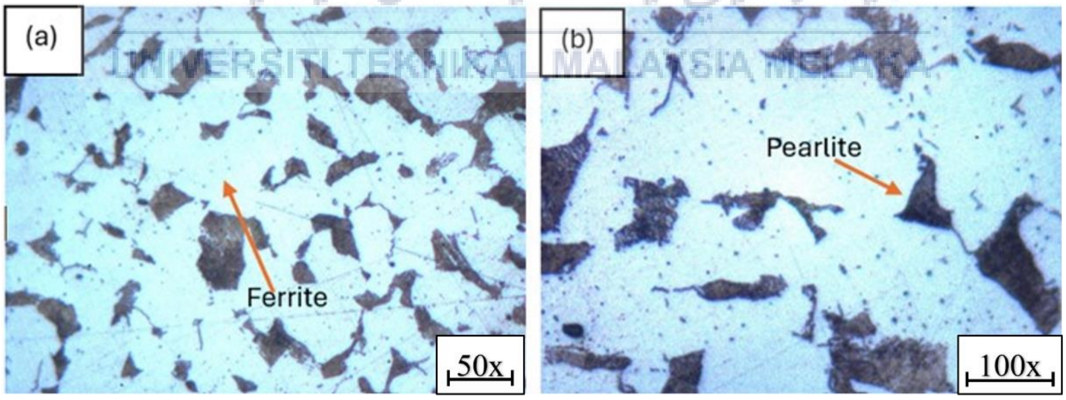

Figure 4.1 Microstructure Analysis at Magnification (a) 50μm and (b)100μm

4.3.2 Hardness Testing

The hardness test measures how well a metal resists plastic deformation under various conditions, including cutting, indentation, scratching, and abrasion. The Rockwell Material Science Laboratory conducted the tests to prove that low-carbon steel could withstand the stress. Hardness Substrate indentation hardness is the determining factor in testing. Another aspect of the Rockwell test is the comparison between the indenter's penetration depth under a preload (minor load) and a heavy force (major load). A single letter denotes the load or indenter used by each scale. Beyond that, for different total test forces, the result is a dimensionless number from HRA to HRV (Riggio and Piazza, 2010). Figure 4.2 demonstrates the substrate that has done hardness testing.

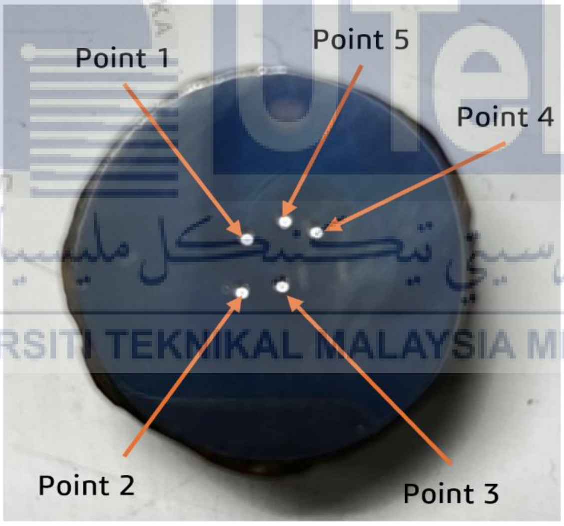

Figure 4.2 Substrate after undergo hardness testing

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The results of the Rockwell hardness test, which uses a five-point scale, are shown in Table 4.2, along with the best overall reading. Hardness rockwell testing is also shown in Figure 4.3 bar chart graph.

Table 4.2 Hardness Test Result

Hardness Rockwell Ball	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
Reading (HRB)	73.8	74.3	76.4	76.8	76.5
Average	76.56				

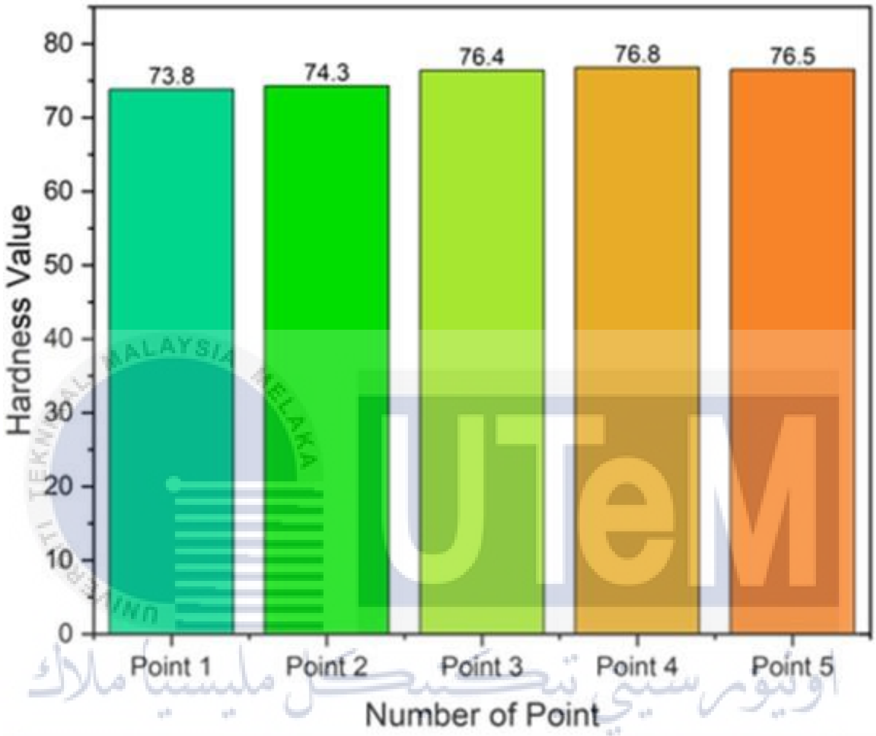

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Figure 4.3 Bar Chart of Hardness Rockwell Test

4.4 Fourier-transform infrared spectroscopy (ATR-FTIR)

In this research, we used Fourier-transform infrared spectroscopy (ATR-FTIR) to obtain the infrared spectrum of absorption or emission of a solid, liquid, or gas. It's an analytical method primarily used for identifying materials and understanding their chemical composition (Ganzoury *et al.*, 2015). In addition to collecting data across a wide range of frequencies, an ATR-FTIR spectrometer may also produce spectra with a high degree of resolution. In addition, Table 4.3 displays the functional groups and wavelengths of the peaks that were employed.

Table 4.3 Wavelength of peaks used for ATR-FTIR analysis and corresponding functional groups (Nugroho *et al.*, 2018).

Wavelength Area (cm^{-1})	**Functional Groups**
675 – 995	C-H
1000 – 1300	C-O
1340 – 1470	C-H
1550 – 1640	N-H
2850 – 2970	C-H
3200 – 3600	O-H

4.4.1 Piper Sarmentosum Leaves ATR-FTIR Analysis

The chemical components found in piper sarmentosum leaves can have their functional groups of information easily recognised using ATR-FTIR. You can see the infrared spectrum of piper sarmentosum leaves in Figure 4.4. The ATR-FTIR spectrum analysis reveals distinct peaks that correspond to various functional groups in the sample. A sharp peak at 3617 cm^{-1} indicates O-H stretch from non-hydrogen-bonded hydroxyl groups, while a broader peak at 3343 cm^{-1} suggests hydrogen-bonded O-H groups. Absorption bands at 2603 cm^{-1} and 2329 cm^{-1} are likely due to overtone or combination modes. The peak at 2057 cm^{-1} may represent a triple bond, and the significant peak at 1629 cm^{-1} could be attributed to a C=C stretch in alkenes or a C=O stretch in conjugated systems. The 1384 cm^{-1} peak is characteristic of C-H bending in CH_3 groups. Peaks at 1168 cm^{-1} and 956 cm^{-1} are consistent with C-O stretching vibrations. Finally, distinct peaks in the fingerprint region at

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709 cm⁻¹ and 543 cm⁻¹ require reference spectra for precise identification due to their specificity to the sample's molecular structure (Rajendran *et al.*, 2019).

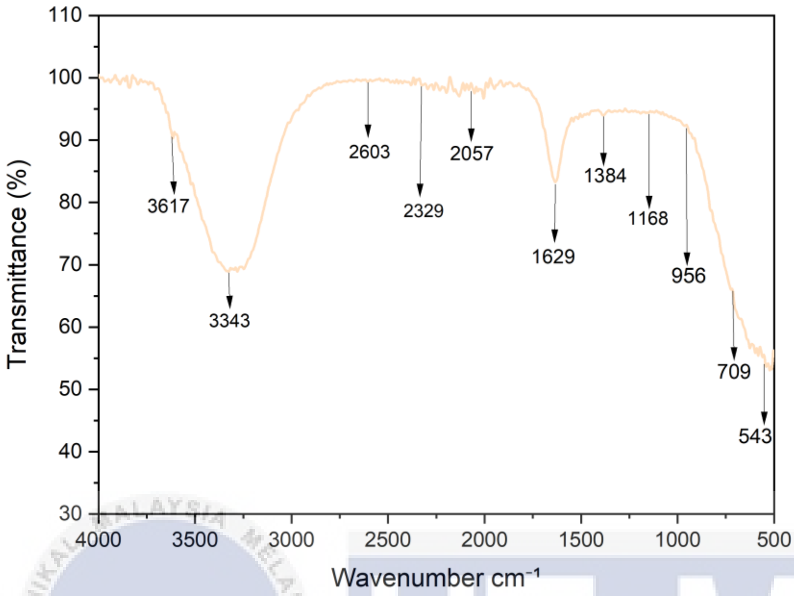

Figure 4.4 ATR-FTIR spectroscopy of piper sarmentosum leaves extract graph

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4.5 Corrosion Test

When determining the resistance of corrosion materials to environmental factors including temperature, humidity, and salt water, corrosion testing is utilised as a method of determining this resistance. In order to investigate the dissolving of oxide materials that do not require an oxidation phase prior to dissolution, such as glasses, numerous corrosion test procedures have been devised (Soltani et al., 2012).

4.5.1 Visual Inspection

The results of the visual inspection are shown in Table 4.4, which displays the results both before and after the specimen was submerged in the three different types of solutions, which are 5M of HCl, lake water, and a solution containing 3.5 wt.% NaCl. Additionally, the specimen that had been corroded and had a diameter of around 25 mm and a thickness of roughly 10 mm was taken out from the immersion test. The specimen that was exposed to 5M hydrochloric acid exhibited a greater degree of corrosion as compared to the other specimen that was exposed to the other solution, which exhibited the least amount of corrosion on the surface of the specimen (Deepak *et al.*, 2021). This was determined by the observation that was carried out during the required number of days. Despite this, the specimen was observed to have corrosion with the use of plain vision. The corrosion can still be seen in both the lake water and the 3.5 wt.% NaCl solutions. However, it is not significantly worse than the specimen that was in the 5M hydrochloric acid solution. Each of the two solutions is more effective than the other when it comes to acting as inhibitors in this corrosion test. Based on the information presented in Table 4.4, we can observe that the surface of low carbon steel both before and after cleaning. Additionally, the colour that was obtained on the surface, which was described as having a reddish brown hue, is a consequence of corrosion. As the number of days spent immersed in water increases, the corrosion products that are evident on the surface of low carbon steel become more apparent. For example, the surface of the specimen on day 35 of exposure is poorer than the surface on day 7 of exposure. The result before and after of the immersion test without inhibitor shows in Table 4.5.

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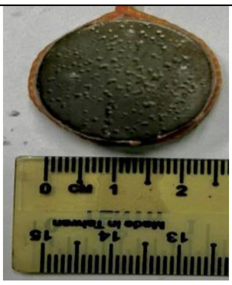
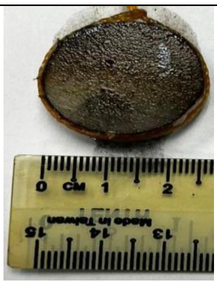
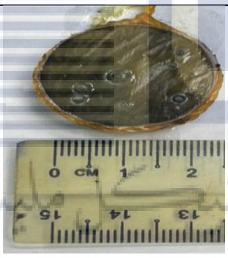
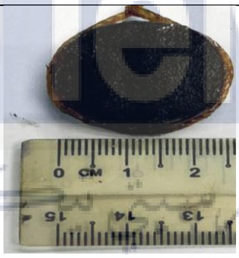
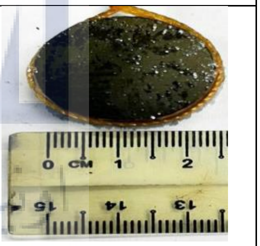
Table 4.4 Result before and after of the immersion test with inhibitor

Days	**Immersion effects before and after clean with acetone**	**5M HCl**	**3.5 wt.% NaCl**	**Lake Water**
7	Before clean			
	After clean			
14	Before clean			
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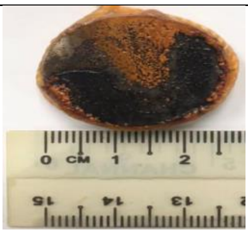
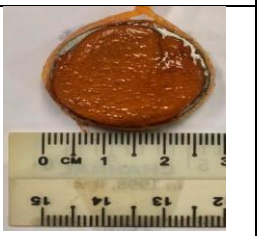
21	Before clean			

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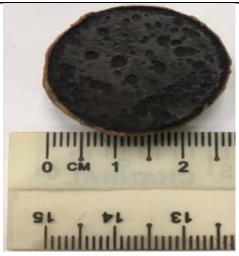
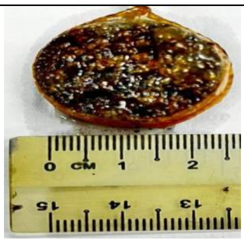
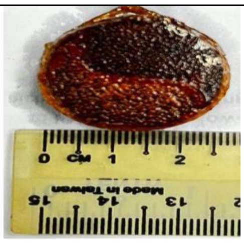
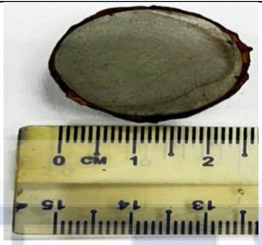
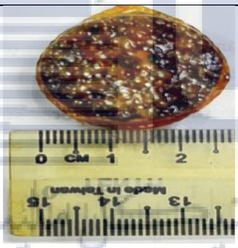
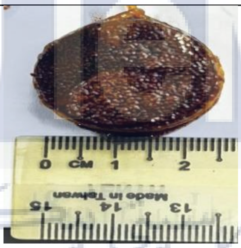
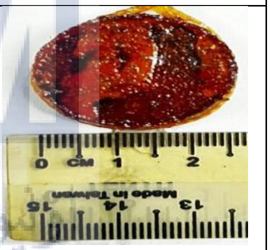
	After clean			
28	Before clean			
	After clean			
35	Before clean			
	After clean			

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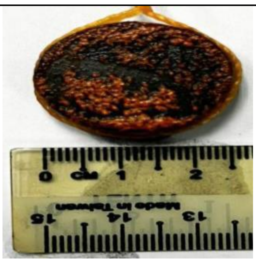
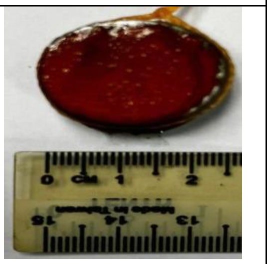
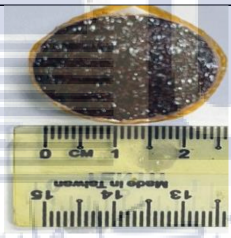
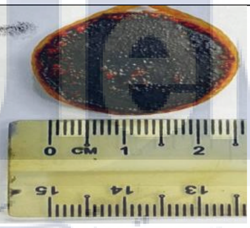
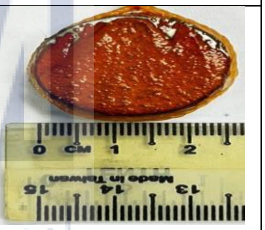
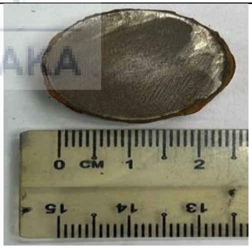
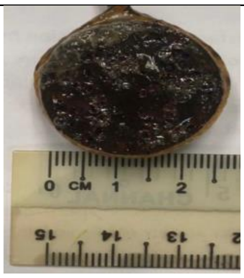
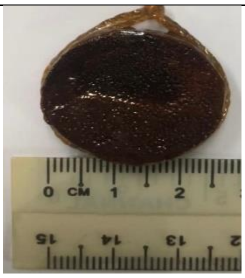
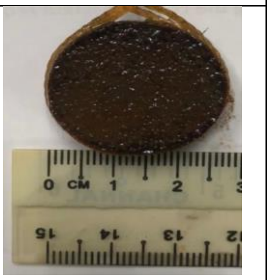
Table 4.5 Result before and after of the immersion test without inhibitor

Days	**Immersion effects before and after clean with acetone**	**5M HCl**	**3.5 wt.% NaCl**	**Lake Water**
7	Before clean			
	After clean			
14	Before clean			
	After clean			
21	Before clean			

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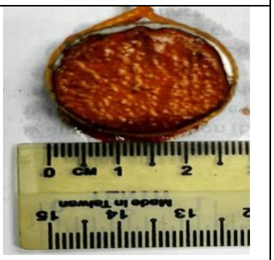
	After clean			
28	Before clean			
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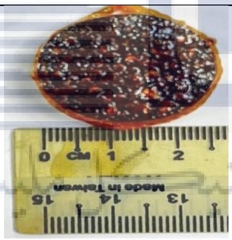
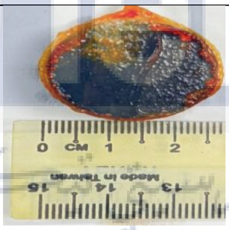
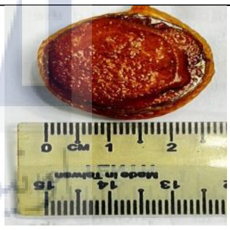
35	Before clean			
	After clean			

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4.5.2 Weight Loss Measurement

In order to determine if there is an increase or decrease in weight loss towards the specimen before and after immersion, weight loss measurement is performed. The specimens made of low carbon steel were tested for weight loss. For example, when the specimen gets closer and equation (1) is used, Table 4.6 shows both a growing and a decreasing weight loss. In any case, samples taken under those conditions showed an increase in mass due to surface corrosion. In order to determine if the specimen lost more or less weight before and after immersion, we will track its weight loss over time.

The graph as Figure 4.5 shows the weight loss between three types of solution such as 5M HCl, 3.5 wt.% NaCl and Lake water. As stated by the exposure periods of 7, 14, 21, 28, and 35 days, the weight loss of the specimen is different from the three solutions and increases accordingly. On day 7, the total weight loss of the specimen in 5M HCl is higher than the other two solutions, which is 0.659 gram, and the 3.5 wt.% NaCl solution is 0.019 gram, follow with the lake water which is 0.018 gram. Table 4.5 shows an increment of weight loss according to the rising exposure time due to the corrosion process.

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Table 4.6 Weight loss of specimen with presence of inhibitor

Days	**Weight loss before and after (g)**	**5M HCl**	**3.5 wt.% NaCl**	**Lake Water**
7	Before	38.134	39.518	33.643
	After	37.475	39.499	33.625
	Total weight loss (g)	**0.659**	**0.019**	**0.018**
14	Before	36.448	35.582	38.225
	After	34.141	35.557	38.214
	Total weight loss (g)	**2.307**	**0.025**	**0.011**
21	Before	34.454	35.567	37.580
	After	32.665	35.513	37.539
	Total weight loss (g)	**1.789**	**0.054**	**0.041**
28	Before	37.021	36.736	38.020
	After	35.092	36.660	37.937
	Total weight loss (g)	**1.929**	**0.076**	**0.083**
35	Before	33.875	38.820	34.947
	After	31.557	38.792	34.928
	Total weight loss (g)	**2.318**	**0.028**	**0.019**

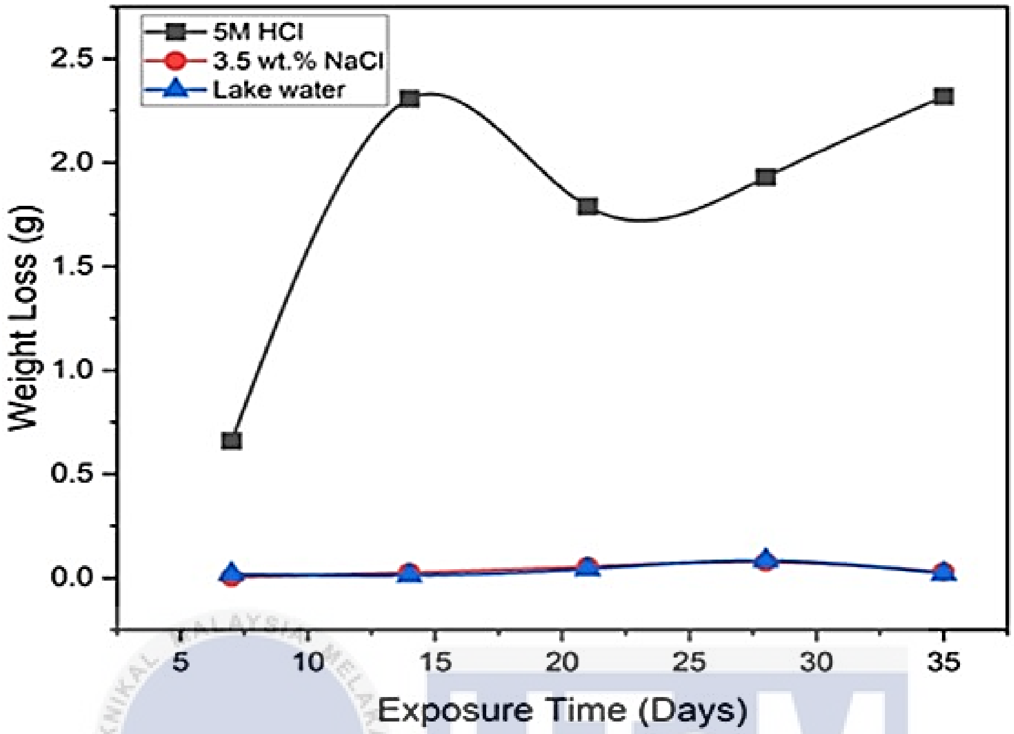

Figure 4.5 Weight Loss Measurement in 35 days for different solution with presence of inhibitor

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Table 4.7 Weight loss of specimen with presence of inhibitor

Days	Weight loss before and after (g)	5M HCl	3.5 wt.% NaCl	Lake Water
7	Before	36.701	38.289	38.295
	After	35.591	38.263	38.270
	Total weight loss (g)	**1.11**	**0.026**	**0.025**
14	Before	40.872	39.501	39.997
	After	38.559	39.448	39.953
	Total weight loss (g)	**2.313**	**0.053**	**0.044**
21	Before	41.150	34.379	38.087
	After	39.204	34.314	38.007
	Total weight loss (g)	**2.306**	**0.065**	**0.080**
28	Before	41.129	39.366	39.139
	After	38.765	39.280	38.955
	Total weight loss (g)	**2.364**	**0.086**	**0.184**
35	Before	36.588	38.792	34.641

	After	34.259	38.707	34.586
	Total weight loss (g)	**2.329**	**0.085**	**0.055**

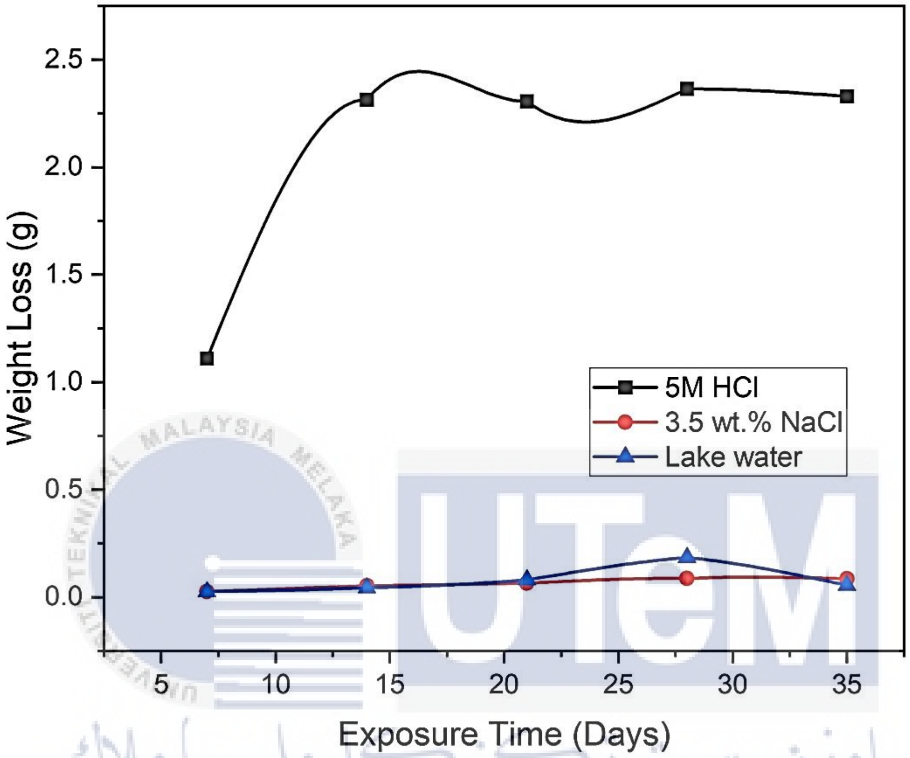

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Figure 4.6 Weight Loss Measurement in 35 days for different solution without inhibitor

4.5.3 Corrosion Rate

The speed that a metal deteriorates under very particular conditions is called its rate of corrosion. Because of the metal's composition and state, environmental circumstances determine the rate of corrosion Table 4.8. The annual amount of corrosion loss in thickness is one way to express it. In addition, the graph in Figure 4.8 displays the link between the three solutions, thus we can make out that the corrosion rate is graph dependent. In this computation, the outcome is validated using Equation (2). On day 35, the comparison between the different types of solutions with inhibitor (Rozuli et al., 2019), 5M HCl had a slight decrease, which the value is 0.0312 mm/year in accordance with the increasing exposure time compared to 3.5 wt.% NaCl, which is 0.0003 mm/year and lake water, which is 0.0003 mm/year as represented in Figure 4.7. While the comparison for corrosion rate of specimen without inhibitor

Table 4.8 Corrosion Rate of Specimen with inhibitor

Days	Types of Solution	K	W(g)	A	T	D	Corrosion Rate
7	5M HCl	$8.76 \times 10^4\ mm/y$	0.659	312.5π	168	$7.87\ g/cm^3$	0.0445
	3.5wt.% NaCl		0.019			$7.87\ g/cm^3$	0.0013
	Lake water		0.018			$7.87\ g/cm^3$	0.0012
14	5M HCl	$8.76 \times 10^4\ mm/y$	2.307	312.5π	336	$7.87\ g/cm^3$	0.0778
	3.5wt.% NaCl		0.025			$7.87\ g/cm^3$	0.0008
	Lake water		0.011			$7.87\ g/cm^3$	0.0003
21	5M HCl	$8.76 \times 10^4\ mm/y$	1.789	312.5π	504	$7.87\ g/cm^3$	0.0402
	3.5wt.% NaCl		0.054			$7.87\ g/cm^3$	0.0012
	Lake water		0.041			$7.87\ g/cm^3$	0.0009
28	5M HCl	$8.76 \times 10^4\ mm/y$	1.929	312.5π	672	$7.87\ g/cm^3$	0.0325
	3.5wt.% NaCl		0.076			$7.87\ g/cm^3$	0.0040
	Lake water		0.083			$7.87\ g/cm^3$	0.0014
35	5M HCl	$8.76 \times 10^4\ mm/y$	2.318	312.5π	840	$7.87\ g/cm^3$	0.0312
	3.5wt.% NaCl		0.028			$7.87\ g/cm^3$	0.0004
	Lake water		0.019			$7.87\ g/cm^3$	0.0003

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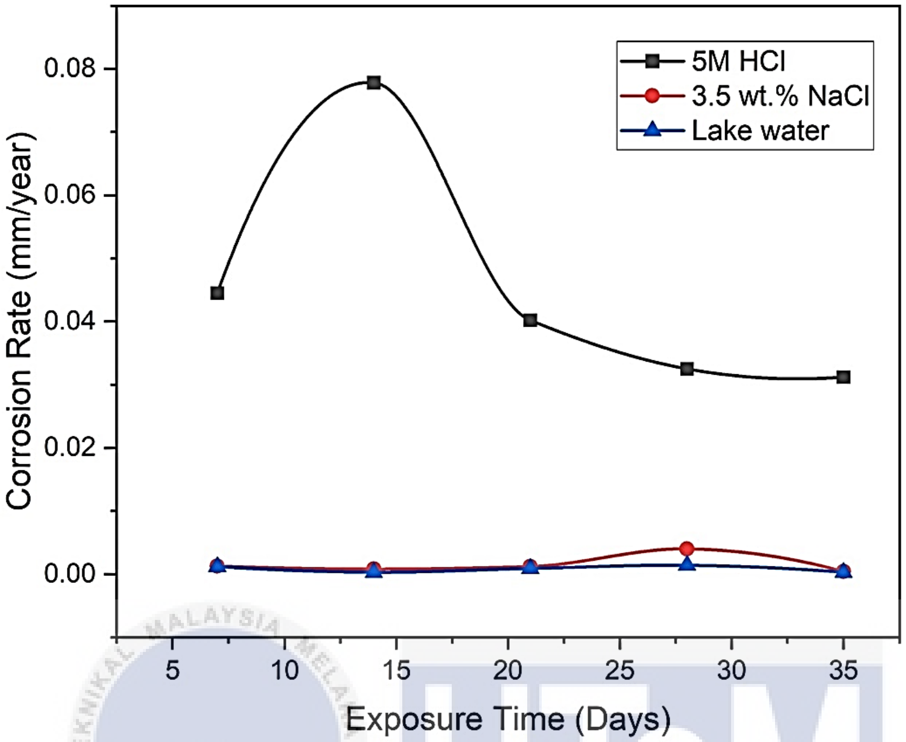

Figure 4.7 Corrosion rate occured toward specimen with presence of inhibitor

Table 4.9 Corrosion Rate of Specimen without inhibitor

Days	Types of Solution	K	W(g)	A	T	D	Corrosion Rate
7	5M HCl	$8.76 \times 10^4\ mm/y$	1.11	312.5π	168	$7.87\ g/cm^3$	0.0751
	3.5wt.% NaCl		0.026			$7.87\ g/cm^3$	0.0018
	Lake water		0.025			$7.87\ g/cm^3$	0.0017
14	5M HCl	$8.76 \times 10^4\ mm/y$	2.313	312.5π	336	$7.87\ g/cm^3$	0.0780
	3.5wt.% NaCl		0.053			$7.87\ g/cm^3$	0.0018
	Lake water		0.044			$7.87\ g/cm^3$	0.0015
21	5M HCl	$8.76 \times 10^4\ mm/y$	2.306	312.5π	504	$7.87\ g/cm^3$	0.0519
	3.5wt.% NaCl		0.065			$7.87\ g/cm^3$	0.0015

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	Lake water		0.080			$7.87\ g/cm^3$	0.0018
28	5M HCl	$8.76 \times 10^4\ mm/y$	2.364	312.5π	672	$7.87\ g/cm^3$	0.0399
	3.5wt.% NaCl		0.086			$7.87\ g/cm^3$	0.0015
	Lake water		0.184			$7.87\ g/cm^3$	0.0031
35	5M HCl	$8.76 \times 10^4\ mm/y$	2.329	312.5π	840	$7.87\ g/cm^3$	0.0314
	3.5wt.% NaCl		0.085			$7.87\ g/cm^3$	0.0011
	Lake water		0.055			$7.87\ g/cm^3$	0.0007

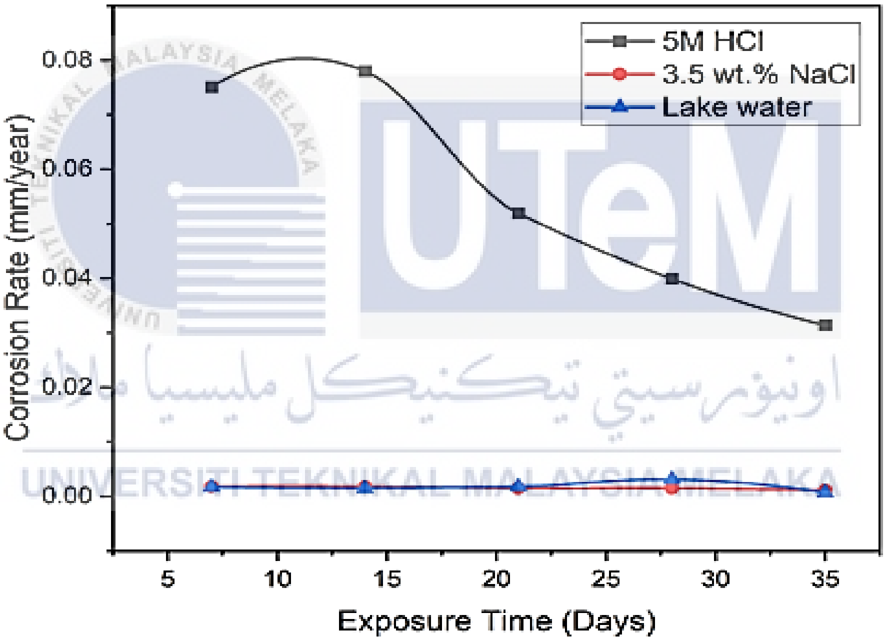

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Figure 4.8 Corrosion rate occured toward specimen without inhibitor

4.5.4 Inhibitor Efficiency

The data needed to determine the inhibitor's efficiency in preventing substrate corrosion in various solutions is shown in Table 4.10 and Figure 4.9, so this study can move further. The adsorption mechanism of inhibitors is greatly affected by their structures. Equation (3) was used to complete the computation. Therefore, as shown in Table 4.10, the proportion of inhibitor efficiency increases with increasing exposure duration (Loto, Loto and Popoola, 2015). The three solutions varied in their inhibitor efficiency percentages; for example, on day 35, the 5M HCl solution had a percentage of 65.45%, the 3.5 wt.% NaCl solution had a percentage of 51.20%, and the lake water solution had 47.23%.

Table 4.10 Inhibitor Efficiency of the speciment with inhibitor

Days	**Specimen**	**Weight loss of sample without inhibitor (g) (W_0)**	**Weight loss of sample with inhibitor (g) (W_1)**	**Inhibitor efficiency (%)**
7	5M HCl	1.11	0.659	42.32
	3.5 wt.% NaCl	0.026	0.019	28.00
	Lake water	0.025	0.018	28.00
14	5M HCl	2.313	2.307	75.00
	3.5 wt.% NaCl	0.053	0.025	41.26
	Lake water	0.044	0.011	25.94
21	5M HCl	2.306	1.789	48.75
	3.5 wt.% NaCl	0.065	0.054	28.61
	Lake water	0.080	0.041	22.42
28	5M HCl	2.364	1.929	54.89
	3.5 wt.% NaCl	0.086	0.076	34.65
	Lake water	0.184	0.083	18.41
35	5M HCl	2.329	2.318	65.45
	3.5 wt.% NaCl	0.085	0.028	51.20
	Lake water	0.055	0.019	47.23

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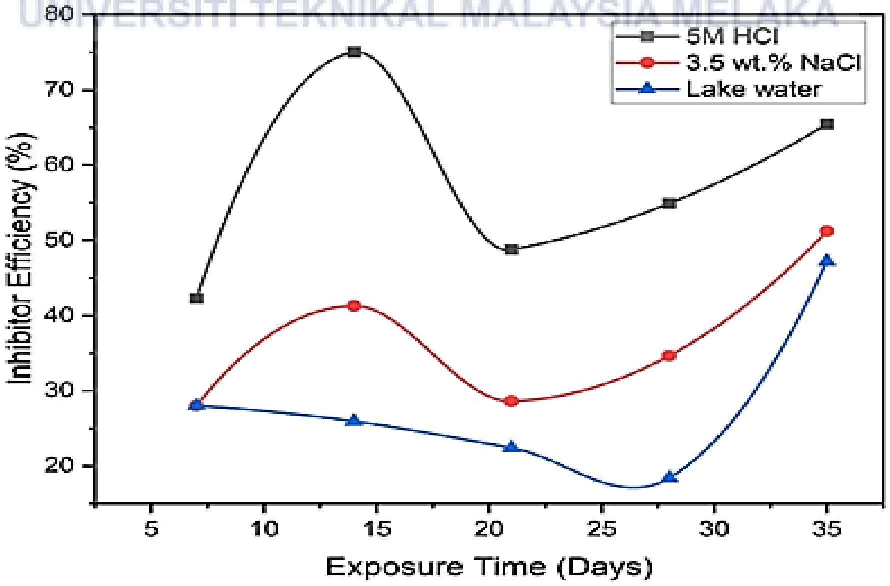

Figure 4.9 Inhibition efficiency of the specimen within days 7 until days 35 in the different solution.

4.6 Surface Study by SEM and EDX

SEM and EDX, which stands for scanning electron microscopy and energy dispersive X-ray spectroscopy, are generally considered to be the most well-known and widely utilised surface examination techniques. Therefore, the scanning electron microscope (SEM) and the electron diffraction (EDX) are utilised in this investigation to validate the surface of the substrates.

4.6.1 Scanning Electron Microscopy (SEM)

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We used scanning electron microscopy (SEM) at varying magnifications to examine the specimen's surface after the immersion test on days 7, 21, and 35, to determine how the inhibitor had responded and whether the inhibitor had increased its efficiency with less corrosion (Alsabagh *et al.*, 2014). The specimens shown in Figures 4.10, 4.11, and 4.12 were immersed for periods of 7, 21, and 35. (a) The surfaces of the specimens in lenses X100 exhibit the least amount of pitting or corrosion when immersed in 5M HCl with inhibitor. At the same magnification, the specimen in the 5M HCl solution (d) without inhibitor showed extensive corrosion on the surfaces of the low carbon steel. Although they were less corroded than the specimen in the 5M HCl solution, the specimens in the 3.5 wt.% NaCl (b) and lake water (c) solutions also displayed mineral extraction on the surfaces of the low carbon steel. There is a direct correlation between the amount of immersion days and the amount of pitting and surface corrosion.

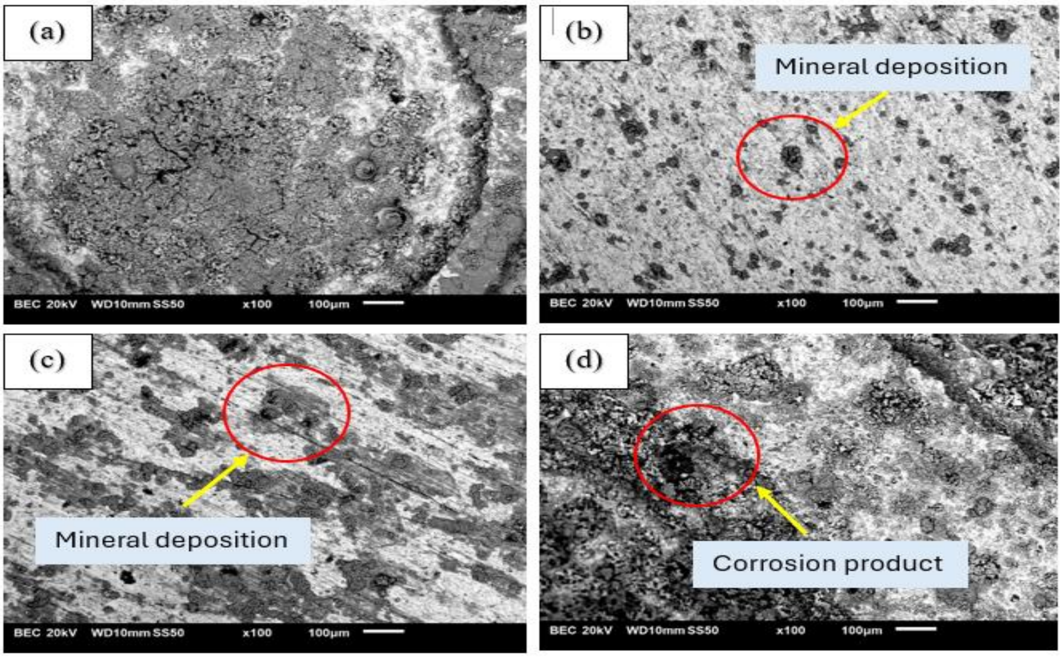

Figure 4.10 SEM morphology after corrosion test days 21 in (a) 5M HCl with inhibitor, (b) 3.5 wt.% NaCl with inhibitor, (c) Lake water with inhibitor and (d) 5M HCl without inhibitor

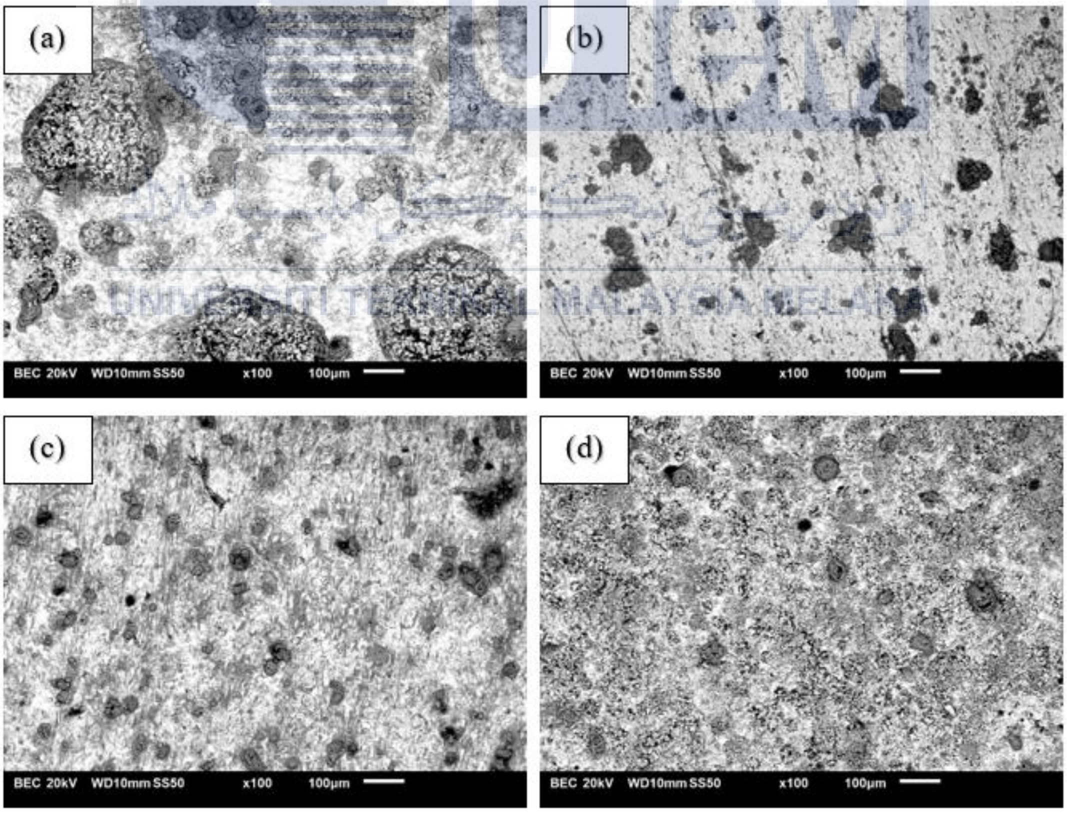

Figure 4.11 SEM morphology after corrosion test days 21 in (a) 5M HCl with inhibitor, (b) 3.5 wt.% NaCl with inhibitor, (c) Lake water with inhibitor and (d) 5M HCl without inhibitor.

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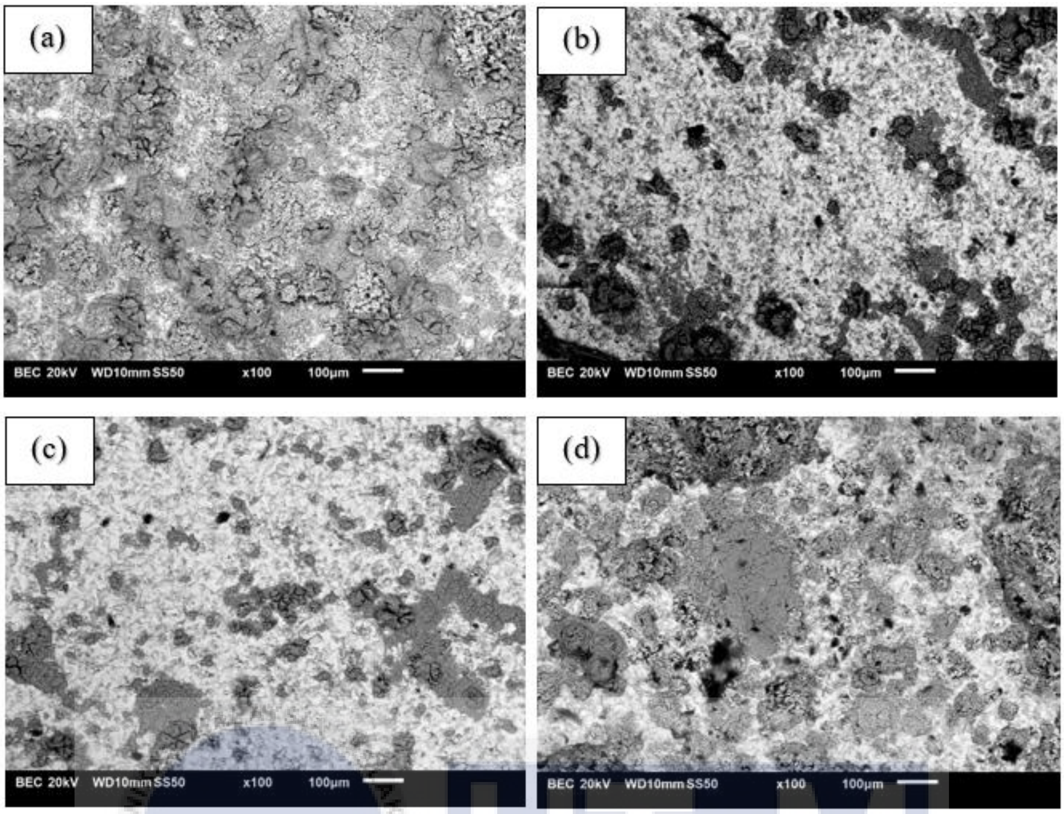

Figure 4.12 SEM morphology after corrosion test days 35 in (a) 5M HCl with inhibitor, (b) 3.5 wt.% NaCl with inhibitor, (c) Lake water with inhibitor and (d) 5M HCl without inhibitor

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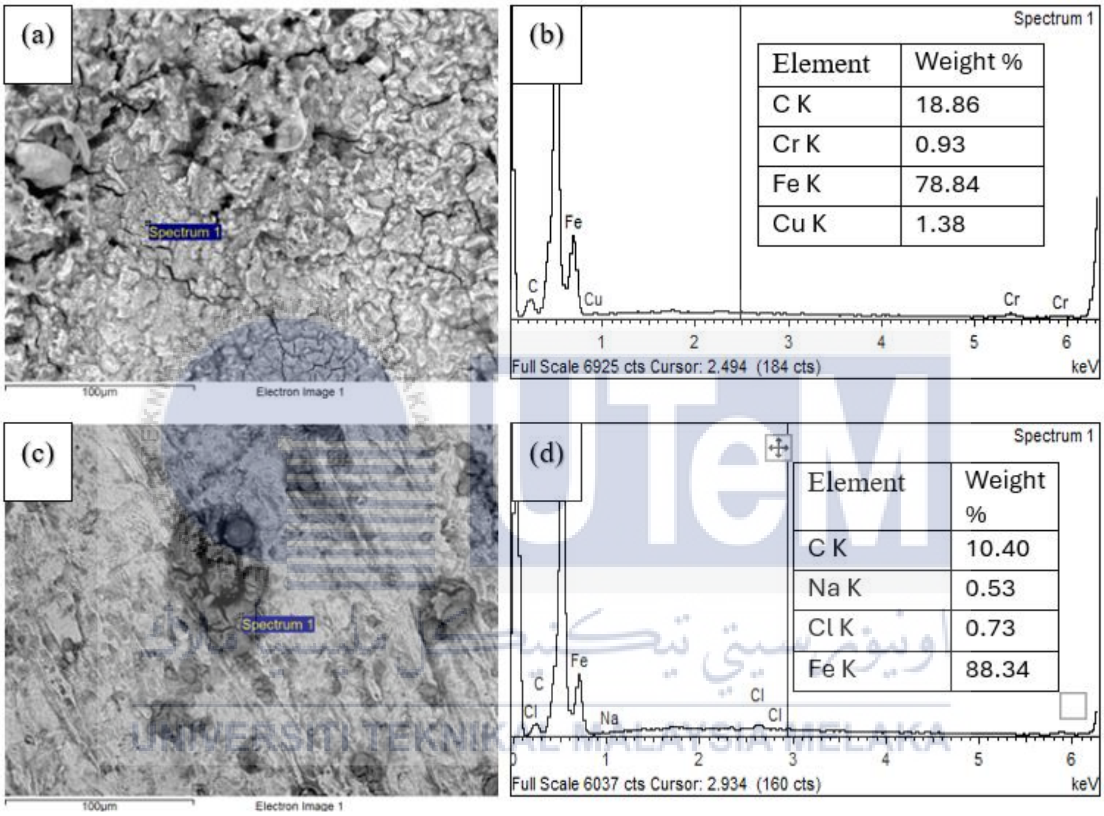
4.6.2 Energy Dispersive X-Ray (EDX)

First and foremost, the Energy Dispersive X-Ray (EDX) machine was utilised in this study to evaluate the element composition of the inhibitor that supported the adsorption that took place on the low carbon steel during the immersion test. This was done in order to avoid the speciment from corroding (Scimeca *et al.*, 2018). Additionally, similar observation was made between the days of 7 and 21, as well as 35.

The morphology of low carbon steel in different solutions was exhibited in Figure 4.13 using scanning electron microscopy and graph EDX. Further evidence of corrosion and pitting on the specimen surface can be seen in Figures (a) and (b) of the SEM morphology specimen in a 5M HCl solution, as well as in the graph of the EDX morphology specimen in the same solution. The pitting on the low carbon steel specimen is caused by the highest weight of ferrum (Fe), at 78.84%, but it is still lower than (g) and (h), at 86.62%, due to the presence of the inhibitor. Figure (d) shows that the ferrum (Fe) weight on substrates is greater in the 3.5 wt.% NaCl solution than in Figure (h), whereas Figure (f) shows that it is somewhat lower in the lake water solution than in Figure (h).



Element	Weight %
C K	18.86
Cr K	0.93
Fe K	78.84
Cu K	1.38

Element	Weight %
C K	10.40
Na K	0.53
Cl K	0.73
Fe K	88.34

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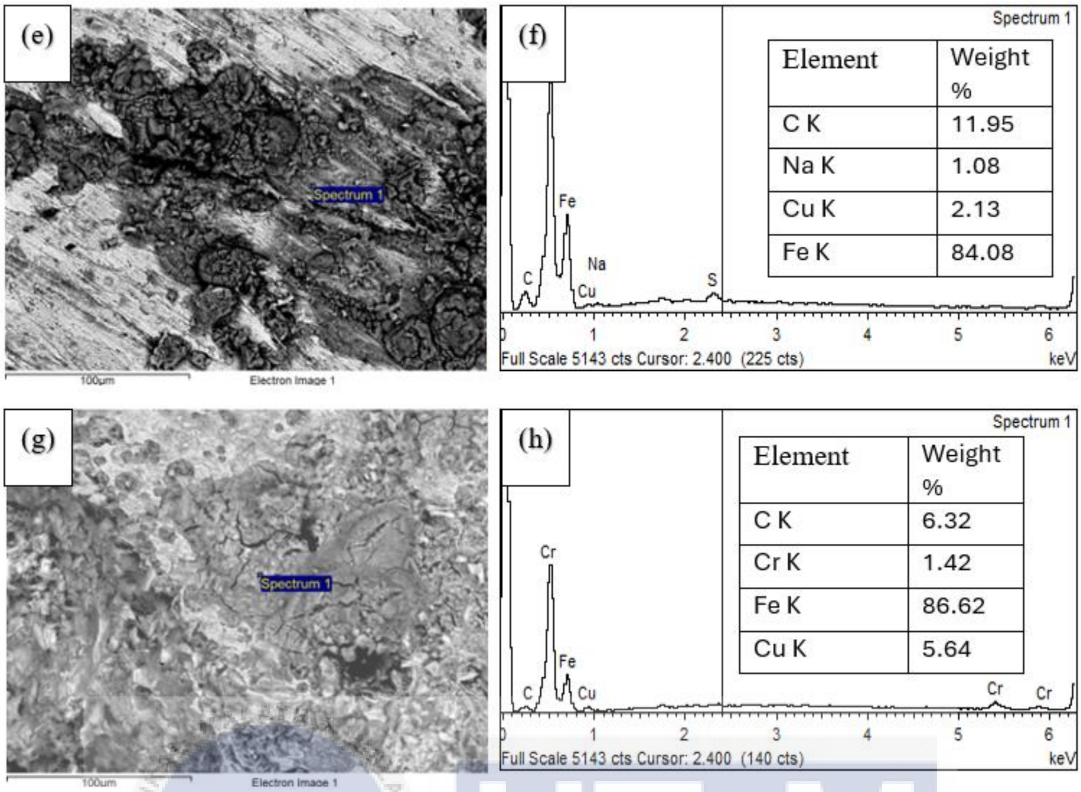
Figure 4.13 EDX analysis of the specimen (a) 5M HCl with inhibitor, (c) 3.5 wt.% NaCl with inhibitor, (e) Lake water with inhibitor and (g) 5M HCl without inhibitor in 7 days.



Element	Weight %
C K	11.95
Na K	1.08
Cu K	2.13
Fe K	84.08

Element	Weight %
C K	6.32
Cr K	1.42
Fe K	86.62
Cu K	5.64

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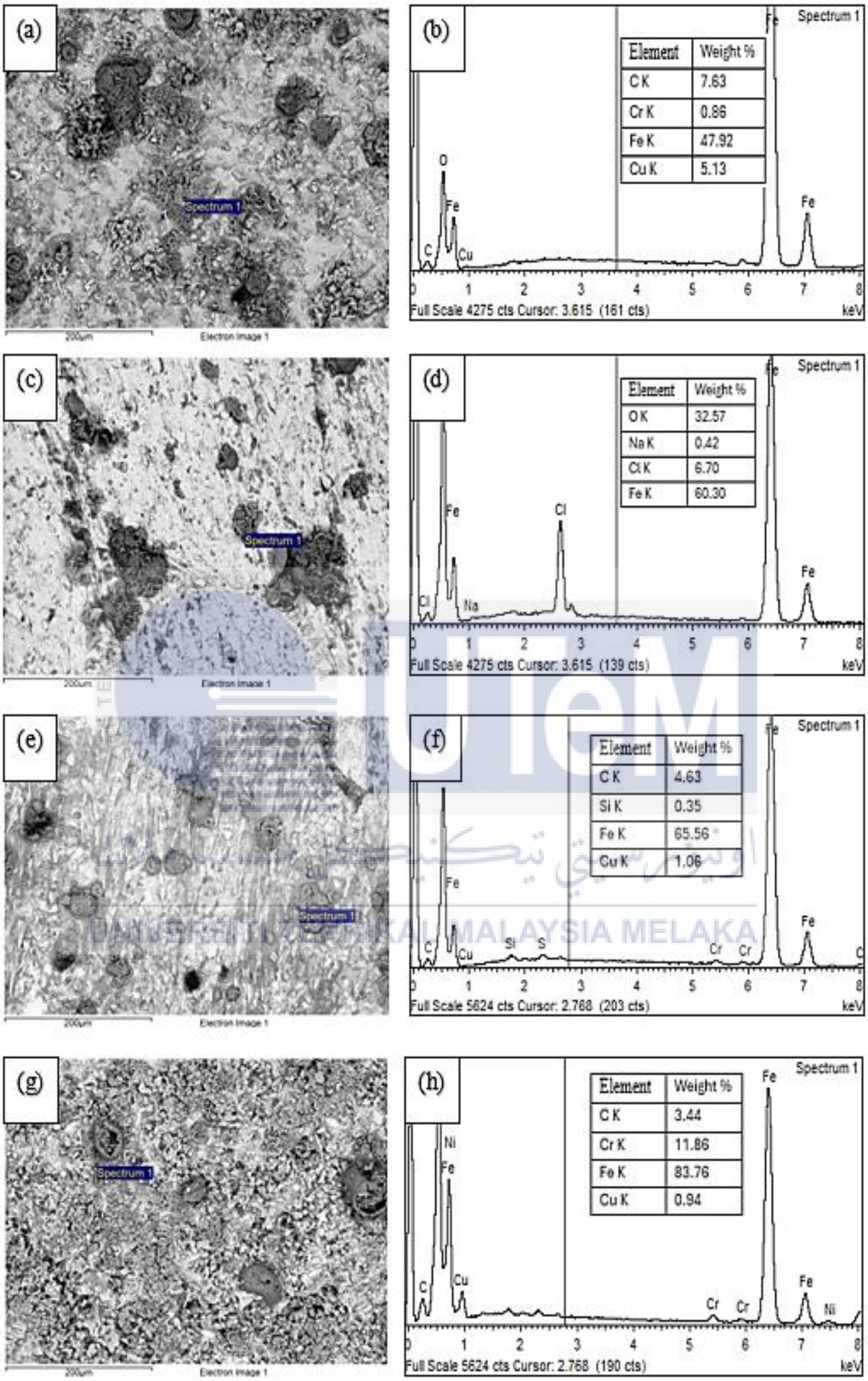
SEM and EDX morphology within 21 days of immersion in various solutions are shown in Figure 4.15, which is EDX spectrum for (b), EDX spectrum for (d) , and EDX specturm for (f) also EDX spectrum for (h). As a result, pitting on the low carbon steel occurred. Figures (a), (c), (e), and (g) show SEM morphology specimens with corroded and pitted surfaces. Furthermore, the specimen in the 5M HCl with inhibitor solution shows 47.92% of Ferum (Fe). The specimen in 3.5 wt.% NaCl with inhibitor solution show 60.30% of Ferum (Fe) and the lake water with inhibitor solution shows 65.56% of Ferum (Fe). The specimen in 5M HCl without inhibitor solution shows the highest corroded and pitted surface with 83.76 % of Ferum (Fe) respectively (Qi *et al.*, 2003).



(b)

Element	Weight %
C K	7.63
Cr K	0.86
Fe K	47.92
Cu K	5.13

(d)

Element	Weight %
O K	32.57
Na K	0.42
Cl K	6.70
Fe K	60.30

(f)

Element	Weight %
C K	4.63
Si K	0.35
Fe K	65.56
Cu K	1.06

(h)

Element	Weight %
C K	3.44
Cr K	11.86
Fe K	83.76
Cu K	0.94

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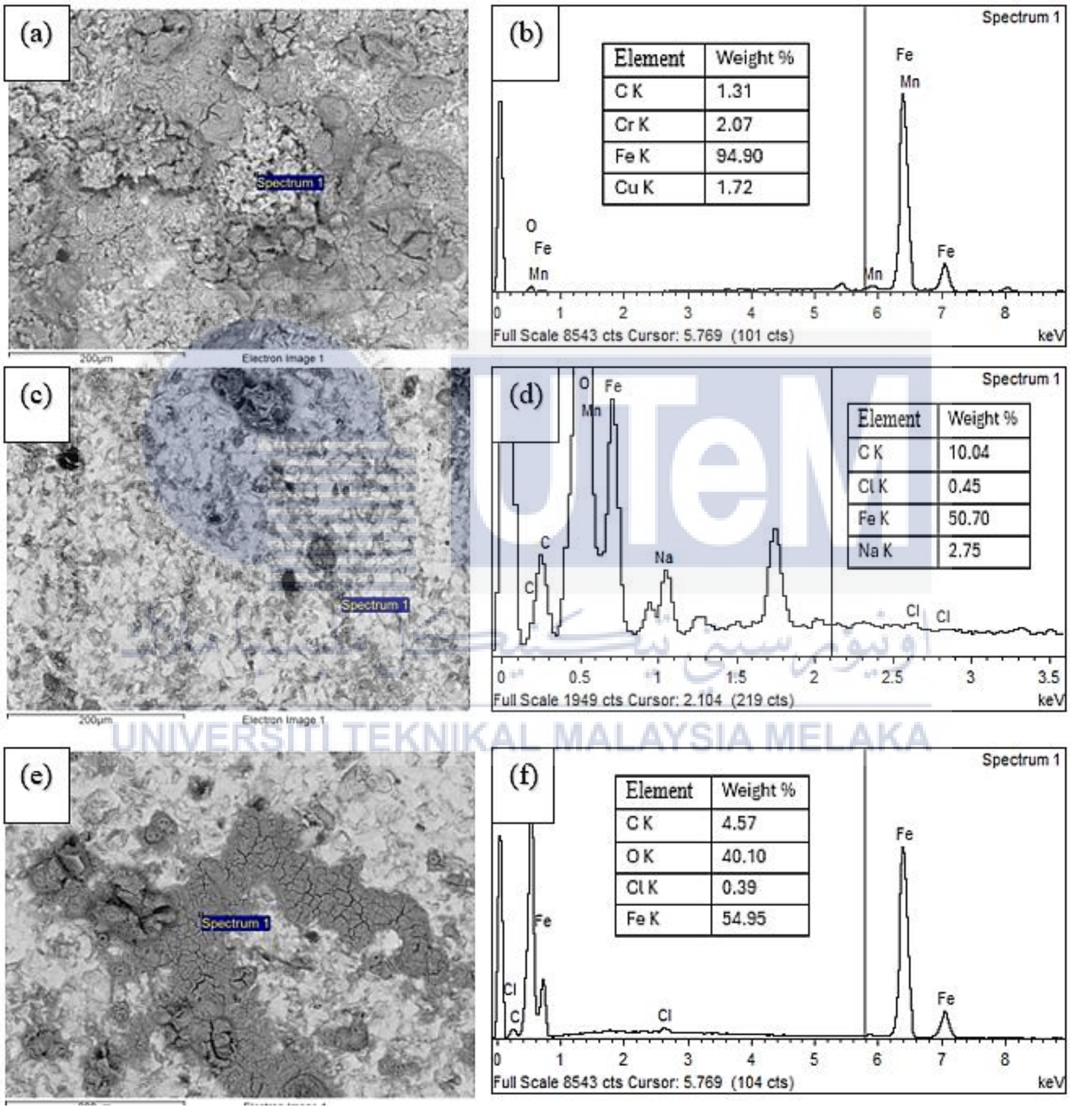
Figure 4.14 EDX analysis of the specimen in the (a) 5M HCl with inhibitor, (c) 3.5 wt.% NaCl with inhibitor, (e) Lake water with inhibitor and (g) 5M HCl without inhibitor in 21

Figure 4.16 shows the SEM and EDX morphology on days 35 of immersion in different solutions, as illustrated in (b), (d), and (f). Consequently, the low carbon steel developed pits. Surface microscopy images of corroded and pitted specimens are shown in Figures (a), (c), and (e). In comparison to other solutions, such as (c) at 50.70% and (e) at 54.95%, the amount of ferrum (Fe) on low carbon steel in (a) is 94.90%.



Element	Weight %
C K	1.31
Cr K	2.07
Fe K	94.90
Cu K	1.72

Element	Weight %
C K	10.04
Cl K	0.45
Fe K	50.70
Na K	2.75

Element	Weight %
C K	4.57
O K	40.10
Cl K	0.39
Fe K	54.95

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Figure 4.15 EDX analysis of the specimen in the (a) 5M HCl with inhibitor, (c) 3.5 wt.% NaCl with inhibitor, (e) Lake water with inhibitor in 35 days

4.6.3 Green Inhibitor Mechanism

Green inhibitors represent an environmentally friendly approach to corrosion inhibition, offering a sustainable alternative to traditional inhibitors that often contain harmful chemicals. Adsorption is the main mechanism by which these inhibitors, which originate from natural sources such as plant extracts, work. This is when organic molecules that are rich in heteroatoms, such as sulfur, nitrogen, and oxygen, attach to the surface of metals. This layer of protection builds on the metal, greatly limiting its exposure to corrosive substances, and it can be achieved by physical or chemical adsorption. Figure 4.17 shows an example of how the green inhibitor mechanism works. Its same with the specimen that has been immersed with piper sarmentosum exract, the Low carbon steel will be successfully blocked by the inhibitor's durable barrier layer.

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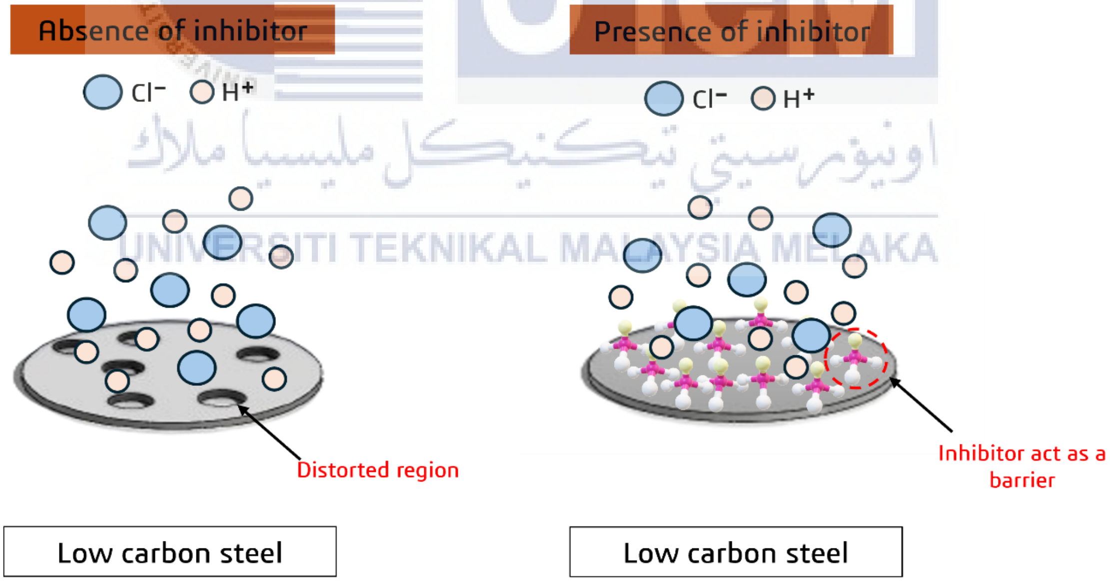
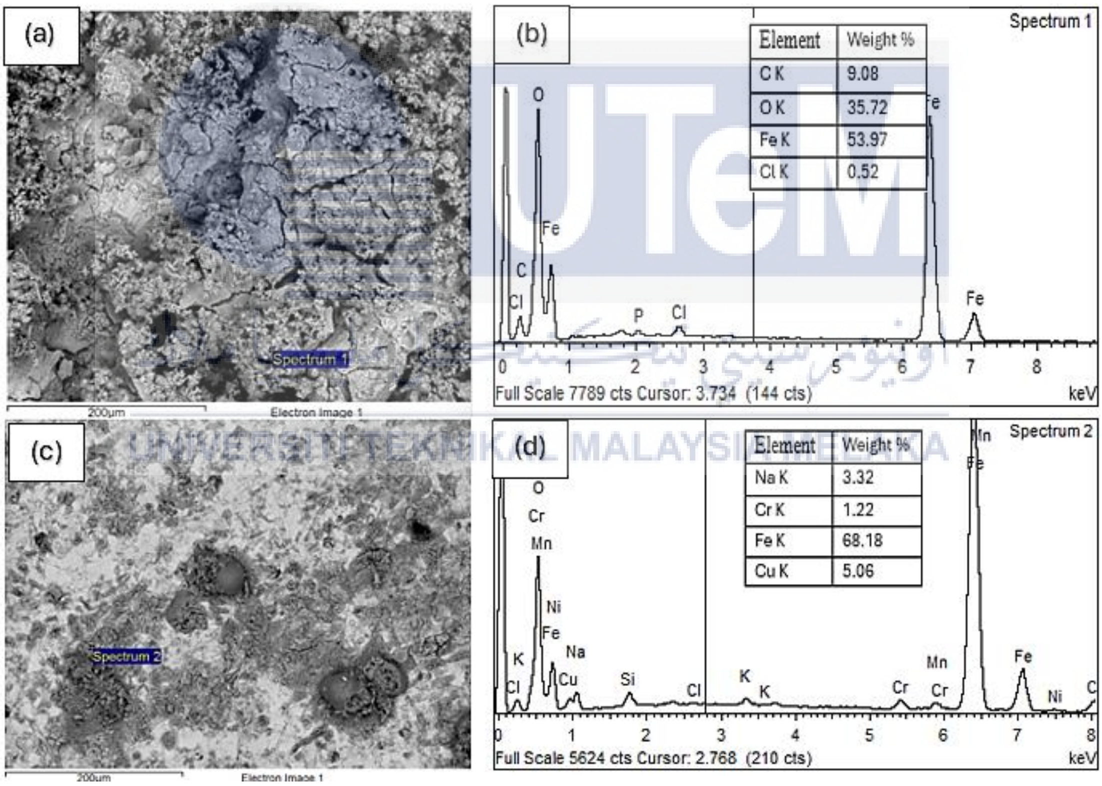


Figure 4.16 Green Inhibitor Mechanism

Energy-Dispersive X-ray Spectroscopy (EDX) is a sophisticated analytical technique used predominantly for elemental analysis or chemical characterization of materials. It is commonly integrated with scanning electron microscopy (SEM). The fundamental principle of EDX involves the interaction of an electron beam with the sample being analyzed. In this study, we examined the chemical composition of piper sarmentosum extract layers on low-carbon steel. In particular, Figure 4.18 shows the morphology of SEM and EDX for specimens in 5M HCl with inhibitor, 3.5 wt.% NaCl with inhibitor, lake water with inhibitor, and 3.5 wt.% NaCl without inhibitor. Moreover, the amount of Ferum (Fe) in 5M HCl solution with inhibitor is the lowest which is 53.97% than the 3.5 wt.% NaCl solution with inhibitor and lake water solution with inhibitor which are 68.18% and 73.44% individually. The specimens in 3.5 wt.% NaCl solution without inhibitor is the highest amount of Ferum (Fe) which is 94.23%.



Element	Weight %
C K	9.08
O K	35.72
Fe K	53.97
Cl K	0.52

Element	Weight %
Na K	3.32
Cr K	1.22
Fe K	68.18
Cu K	5.06

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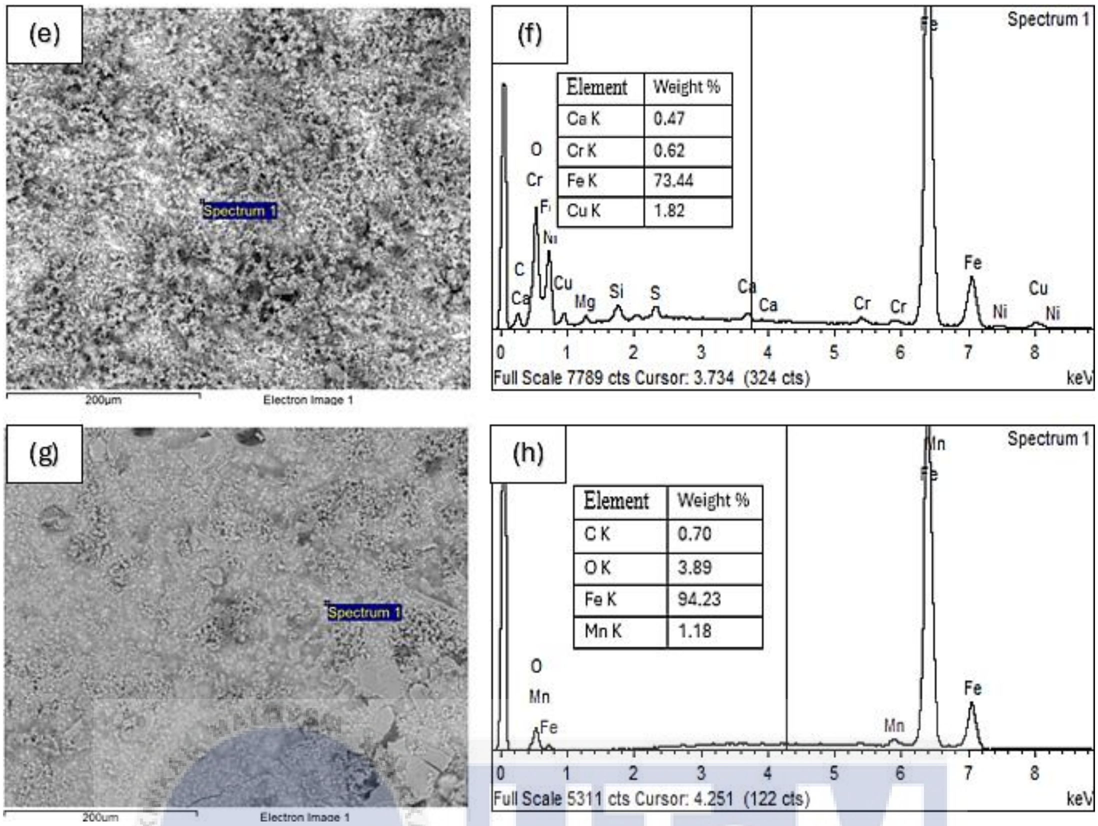

Figure 4.17 EDX analysis of the specimen (a) immersed in 5M HCl with inhibitor, (c) immersed in 3.5 wt.% Nacl with inhibitor, (e) immersed in lake water with inhibitor and (g) immersed in 3.5 wt.% NaCl without inhibitor.

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The differences in the percentage of ferum (Fe) that are present in each of the four mechanisms are displayed in Table 4.10. According to the findings, the specimens consisted of low carbon steel and were submerged in water without piper sarmentosum extract. These specimens had the greatest value compared to the other solutions.

Table 4.11 Fe Weight % value

Mechanism	**Fe Weight %**
5M HCl with inhibitor	53.97
3.5 wt.% NaCl with inhibitor	68.18
Lake water with inhibior	73.44
3.5 wt.% NaCl without inhibitor	94.23

4.7 Summary of Result and Discussion

To summarize, the results of the hardness testing, which include microstructure testing and microhardness testing up until the green inhibitor mechanism, were determined in this chapter. Based on these findings, it is possible to conclude that the amount of efficiency achieved with the inhibitor is more than the amount achieved without the inhibitor. For the weight loss we can conclude that from day 7 to day 35, specimen that have been immersed in 5M HCl has the greatest weight loss compare to others. The corrosion rate and inhibitor effciency also we can conclude that the specimen in 5M HCl has the highest corrosion rate and inhibitor efficiency compared to 3.5 wt.% NaCl and Lake water. Furthermore, it is of equal significance that the morphology of the substrate surfaces as determined by SEM and EDX revealed that the Ferum (Fe) percent was comparatively lower in solutions containing the inhibitor than in solutions lacking the inhibitor. The corrosion inhibitor mechanism of low carbon steel immersed in a lake water medium containing 3.5 wt.% NaCl, 5M HCl, with or without piper sarmentosum as the green inhibitor is represented by the green inhibitor mechanism. The application of piper sarmentosum extraction on low carbon steel provides a protective layer, as evidenced by the Ferum (Fe) percentage. This occurs due to the coordination bond or shape of the leaves of Piper sarmentosum.

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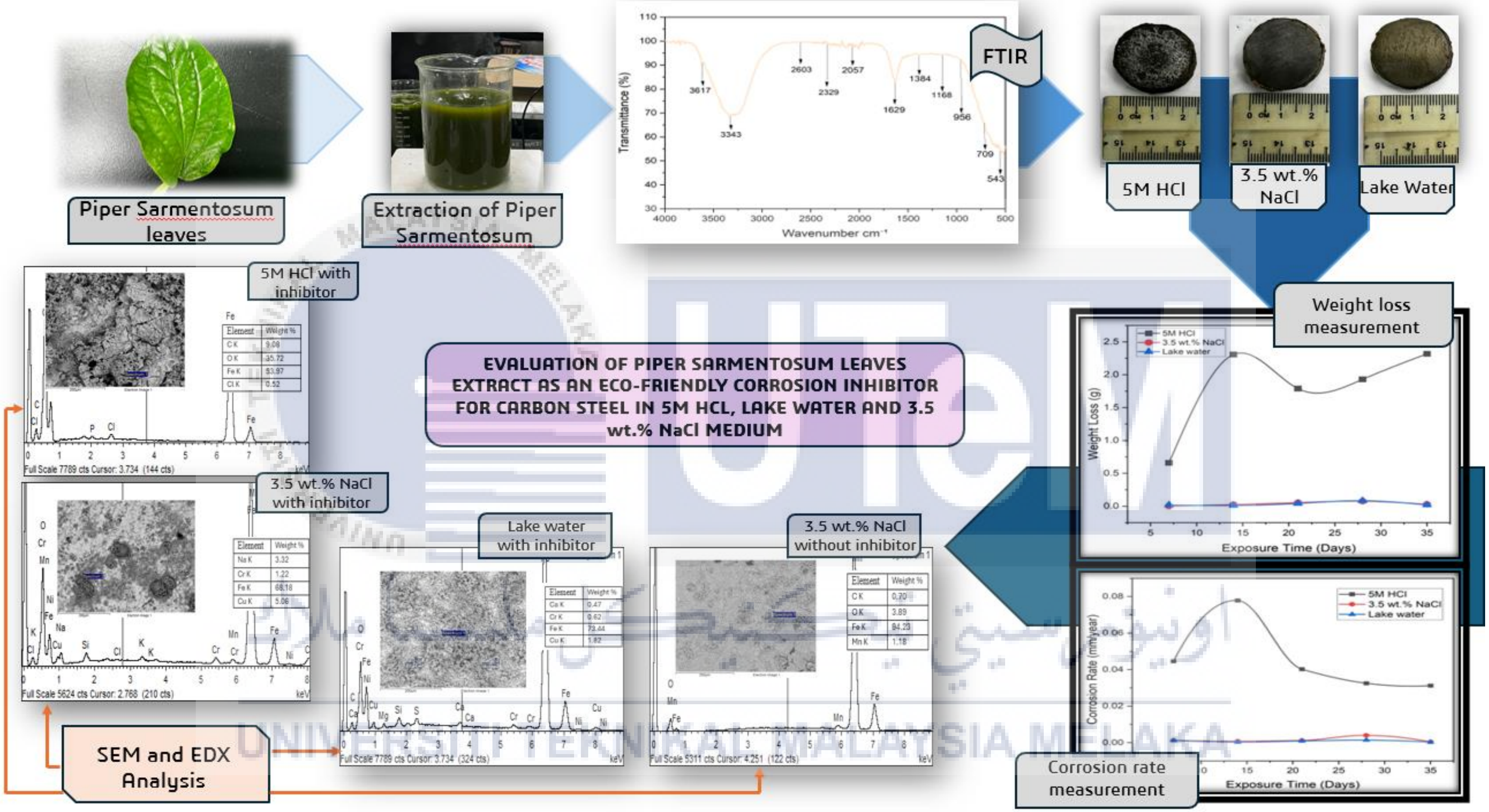

Figure 4.18 Infographic for extraction mechanism

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CHAPTER 5

CONCUSION AND RECOMMENDATIONS

5.1 Conclusion

In a nutshell, from this study we can identify:

1. The ability of Piper Sarmentosum, which is an inhibitor that is friendly to the environment Considering the nature of low carbon steel, it has been demonstrated that leaves have high adsorption capabilities. Furthermore, it has been demonstrated that leaves have the ability to reduce corrosion on low carbon steel.
2. The microstructure test on the low carbon steel revealed that it is composed of pearlite and ferrite, as confirmed by the mechanical tests. Similarly, low carbon steel's strength properties are supported by its hardness tests, which yielded an average value of 76.56 HRB.
3. While doing the immersion test, we were able to visually see the variations in the surfaces of the specimens. Acetone was also used to clean the specimen so it could be clearly seen. Specimen surfaces in the three solutions differ accordingly between the pre- and post-cleaning states. Compared to specimens immersed without an inhibitor, those in the solution have a smoother surface.
4. In addition, the pattern graph of the Fourier transform infrared spectroscopy (FTIR) reveals that both extracts exhibited the same graph pattern, with the same peak pattern over the wavenumber, despite the fact that their transmittance levels were different.
5. It is also possible to verify that the specimen in solution that contains an inhibitor has the least amount of weight loss in comparison to the specimen in solution that does

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not contain an inhibitor. This is the case regardless of whether the inhibitor is present or absent inside the solution.

vi. When compared to the corrosion rate that occurred towards the specimen without the inhibitor, the corrosion rate in the green inhibitor showed slightly better performance.

vii. The piper sarmentosum leaves inhibitor efficiency is 65.45% in 5M HCl solution, 51.20% in 3.5 wt.% NaCl solution and 47.23% in lake water on day 35.

viii. The specimen in the 5M HCl solution had greater pitting or corrosion, as shown by the morphology of SEM and EDX analysis, than in the 3.5 wt.% NaCl and lake water solutions, due to the higher Ferum (Fe) atomic percent and weight percent concentration.

ix. Finally, green inhibitor mechanism and EDX results showed that 5M HCl with inhibitor has a lower Ferum (Fe) weight percent of 53.97% than 3.5 wt.% NaCl (68.18%) and lake water (73.44%). Ferum (Fe) weight percent is maximum at 3.5 wt.% NaCl without inhibitor, 94.23%.

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5.2 Recommendations

The recommendation to improve the finak year project are:

i. Firstly, before placing the solution in the oven, it is essential to boil and filter the extract of Piper sarmentosum leaves for the longest period of time to decrease the water content.

ii. More forms of ecologically friendly corrosion inhibitors with high inhibitor performance in acid media are being considered for use as low carbon steel adsorption. These include garlic, turmeric, ginger, tea leaves, rosemary, and alpinia galangal.

iii. In addition to doing the extraction manually using a rotary evaporator, which may occasionally generate incorrect messages regarding the composition included, there are alternative means to acquire the extraction, such as any chemical supplier market.

5.3 Project Potential

This are several of this project potential:

i. This corrosion inhibitor project on low carbon steel might potentially be employed in the oil and gas business due to its suitability for usage in close systems. Additionally, any form of industry that involves a significant amount of steel material that is conductive could potentially benefit from this project.

ii. In general, this environmentally friendly inhibitor may be applied to the underwater pipe system, as well as to the body of offshore structures and metal structures that are exposed to salt water.

iii. This project are highly recommended to be used in industries because our project are designed to be less toxic and more biodegradable than traditional inhibitors, minimizing harm to ecosystems in case of accidental releases or leaks.

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REFERENCES

Abdulsada, S. A., Al-mosawi, A. I. and Hadi, A. A. A. (2017) ‘Studying the Effect of Eco- addition Inhibitors on Corrosion Resistance of Reinforced Concrete’, *Bioprocess Engineering*, 1(3), p. 81. doi: 10.11648/j.be.20170103.14.

Alvarez, P. E., Fiori-Bimbi, M. V., Neske, A., Brandán, S. A., & Gervasi, C. A. (2018). Rollinia occidentalis extract as green corrosion inhibitor for carbon steel in HCl solution. *Journal of Industrial and Engineering Chemistry*, *58*(22345957), 92–99. https://doi.org/10.1016/j.jiec.2017.09.012

Andrade, C. et al. (2004) ‘Test methods for on-site corrosion rate measurement of steel reinforcement in concrete by means of the polarization resistance method’, Materials and Structures/Materiaux et Constructions, 37(273), pp. 623–643. doi: 10.1617/13952.

Azom (2012) ‘AISI 1045 Medium Carbon Steel’, pp. 1–3. Available at: http://www.azom.com/article.aspx?ArticleID=6130.

Cai, Y. *et al.* (2021) ‘Extrapolating short-term corrosion test results to field exposures in different environments’, *Corrosion Science*, 186(March), p. 109455. doi: 10.1016/j.corsci.2021.109455.

Damsud, T., Adisakwattana, S., & Phuwapraisirisan, P. (2013). Three new phenylpropanoyl amides from the leaves of Piper sarmentosum and their α-glucosidase inhibitory activities. *Phytochemistry Letters*, *6*(3), 350–354. https://doi.org/10.1016/j.phytol.2013.04.001

Dwivedi, D., Lepková, K., & Becker, T. (2017). Carbon steel corrosion: a review of key surface properties and characterization methods. *RSC Advances*, *7*(8), 4580–4610. https://doi.org/10.1039/C6RA25094G

Faisal, M., Saeed, A., Shahzad, D., Abbas, N., Fayaz Ali Larik, Pervaiz Ali Channar, … Syeda Aaliya Shehzadi. (2018). General properties and comparison of the corrosion

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

inhibition efficiencies of the triazole derivatives for mild steel. *General Properties and Comparison of the Corrosion Inhibition Efficiencies of the Triazole Derivatives for Mild Steel*, *36*(6), 507–545. https://doi.org/10.1515/corrrev-2018-0006

Gaikwad, S. (2022, December 19). The Many Uses of Low-Carbon Steel. Retrieved June 19, 2023, from Thepipingmart Blog website: https://blog.thepipingmart.com/metals/the-many-uses-of-low-carbon-steel/

Ganzoury, M. A. *et al.* (2015) 'Introduction to Fourier Transform Infrared Spectrometry',*Renewable and Sustainable Energy Reviews*, 50, pp. 1–8. doi: 10.1016/j.rser.2015.05.073.

Guo, W. *et al.* (2020) 'Corrosion inhibition of carbon steel by three kinds of expired cephalosporins in 0.1 M H2SO4', *Journal of Molecular Liquids*, 320, p. 114295. doi: 10.1016/j.molliq.2020.114295.

Hussain, K., Hashmi, F. K., Latif, A., Ismail, Z., & Sadikun, A. (2012). A review of the literature and latest advances in research ofPiper sarmentosum. *Pharmaceutical Biology*, *50*(8), 1045–1052. https://doi.org/10.3109/13880209.2011.654229

Islam, T., & Rashed, H. M. M. A. (2019). Classification and Application of Plain Carbon Steels. *Reference Module in Materials Science and Materials Engineering*. https://doi.org/10.1016/b978-0-12-803581-8.10268-1

Kilo, M., Rahal, H. T., El-Dakdouki, M. H., & Abdel-Gaber, A. M. (2020). Study of the corrosion and inhibition mechanism for carbon steel and zinc alloys by an eco-friendly inhibitor in acidic solution. *Chemical Engineering Communications*, *208*(12), 1676–1685. https://doi.org/10.1080/00986445.2020.1811239

Leone, J. (2023, June 12). What Are the Different Uses of Low Carbon Steel? Retrieved June 7, 2023, from About Mechanics website: https://www.aboutmechanics.com/what-are-the-different-uses-of-low-carbon-steel.htm

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Nurul Adilla Rozuli, Tuan Sherwyn Hamidon, & M. Hazwan Hussin. (2019). Evaluation of *Piper sarmentosum* extract's corrosion inhibitive effects and adsorption characteristics for the corrosion protection of mild steel in 0.5 M HCl. *Evaluation of Piper Sarmentosum Extract's Corrosion Inhibitive Effects and Adsorption Characteristics for the Corrosion Protection of Mild Steel in 0.5 M HCl*, *6*(10), 106524–106524. https://doi.org/10.1088/2053-1591/ab3677

Sadowski, A. J., Rotter, J. M., Reinke, T., & Ummenhofer, T. (2015). Statistical analysis of the material properties of selected structural carbon steels. *Structural Safety*, *53*(01674730), 26–35. https://doi.org/10.1016/j.strusafe.2014.12.002

Shehata, O. S., Korshed, L. A., & Attia, A. (2017). Green Corrosion Inhibitors, Past, Present, and Future. In *www.intechopen.com*. IntechOpen. Retrieved from https://www.intechopen.com/chapters/58797

Singh, R. (2020). Classification of steels. *Applied Welding Engineering*, 53–60. https://doi.org/10.1016/b978-0-12-821348-3.00014-8

Soltani, N., Tavakkoli, N., Khayatkashani, M., Jalali, M. R., & Mosavizade, A. (2012). Green approach to corrosion inhibition of 304 stainless steel in hydrochloric acid solution by the extract of Salvia officinalis leaves. *Corrosion Science*, *62*(0010938X), 122–135. https://doi.org/10.1016/j.corsci.2012.05.003

Sun, X., Chen, W., Dai, W., Xin, H., Rahmand, K., Wang, Y., … Han, T. (2020). Piper sarmentosum Roxb.: A review on its botany, traditional uses, phytochemistry, and pharmacological activities. *Journal of Ethnopharmacology*, *263*(18727573), 112897. https://doi.org/10.1016/j.jep.2020.112897

Tait, W. S. (2012). Corrosion Prevention and Control of Chemical Processing Equipment. *Handbook of Environmental Degradation of Materials*, 863–886. https://doi.org/10.1016/b978-1-4377-3455-3.00028-6

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APPENDICES

APPENDIX A ASTM G1

Designation: G1 – 03

Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens[1]

This standard is issued under the fixed designation G1; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers suggested procedures for preparing bare, solid metal specimens for tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corrosion by mass loss and pitting measurements. (**Warning**—In many cases the corrosion product on the reactive metals titanium and zirconium is a hard and tightly bonded oxide that defies removal by chemical or ordinary mechanical means. In many such cases, corrosion rates are established by mass gain rather than mass loss.)

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see 1 and 7.2.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

D1193 Specification for Reagent Water

D1384 Test Method for Corrosion Test for Engine Coolants in Glassware

D2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)

G15 Terminology Relating to Corrosion and Corrosion Testing

G16 Guide for Applying Statistics to Analysis of Corrosion Data

G31 Practice for Laboratory Immersion Corrosion Testing of Metals

G33 Practice for Recording Data from Atmospheric Corrosion Tests of Metallic-Coated Steel Specimens

G46 Guide for Examination and Evaluation of Pitting Corrosion

G50 Practice for Conducting Atmospheric Corrosion Tests on Metals

G78 Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments

3. Terminology

3.1 See Terminology G15 for terms used in this practice.

4. Significance and Use

4.1 The procedures given are designed to remove corrosion products without significant removal of base metal. This allows an accurate determination of the mass loss of the metal or alloy that occurred during exposure to the corrosive environment.

4.2 These procedures, in some cases, may apply to metal coatings. However, possible effects from the substrate must be considered.

5. Reagents and Materials

5.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[3] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type IV of Specification D1193.

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[1] This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

Current edition approved October 1, 2003. Published October 2003. Originally approved in 1967. Last previous edition approved in 1999 as G1 – 90 (1999)$^{\varepsilon 1}$. DOI: 10.1520/G0001-03.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

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APPENDIX B ASTM G31

Designation: NACE TM0169/G31 – 12a

Standard Guide for
Laboratory Immersion Corrosion Testing of Metals[1]

This standard is issued under the fixed designation NACE TM0169/G31; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers and describes the factors that influence laboratory immersion corrosion tests, particularly mass loss tests. These factors include apparatus, sampling, test specimen, test conditions (test solution composition, temperature, gas sparging, fluid motion, solution volume, method of supporting test specimens, duration of test), methods of cleaning test specimens, interpretation of results, and calculation of corrosion rates. This guide also emphasizes the importance of recording all pertinent data and provides a checklist for reporting test data.

1.2 The specific evaluation of localized attack, environmentally assisted cracking, and effects of solution flow are not within the scope of this guide.

1.3 This guide is intended to be used by those designing laboratory immersion tests who may not be familiar with all of the variables to consider and the pitfalls that could be encountered when designing and conducting this kind of testing. It should be used as a reference to ensure that the test will allow generation of data relevant to the application with the minimum of interferences.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
D1193 Specification for Reagent Water
E8 Test Methods for Tension Testing of Metallic Materials
E300 Practice for Sampling Industrial Chemicals
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G28 Test Methods for Detecting Susceptibility to Intergranular Corrosion in Wrought, Nickel-Rich, Chromium-Bearing Alloys
G34 Test Method for Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys (EXCO Test)
G46 Guide for Examination and Evaluation of Pitting Corrosion
G48 Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
G66 Test Method for Visual Assessment of Exfoliation Corrosion Susceptibility of 5XXX Series Aluminum Alloys (ASSET Test)
G67 Test Method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloys by Mass Loss After Exposure to Nitric Acid (NAMLT Test)
G71 Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes
G78 Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments
G82 Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance
G107 Guide for Formats for Collection and Compilation of Corrosion Data for Metals for Computerized Database Input
G108 Test Method for Electrochemical Reactivation (EPR) for Detecting Sensitization of AISI Type 304 and 304L Stainless Steels

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[1] This guide is under the jurisdiction of NACE/ASTM Committee J01, Joint Committee on Corrosion, and is the direct responsibility of Subcommittee J01.01, Working Group on Laboratory Immersion Tests.

Current edition approved July 1, 2012. Published October 2012. Originally approved in 1972. Last previous ASTM edition approved in 2012 as G31–12. NACE edition originally approved in 1969. Last previous NACE edition approved in 2000 as TM0169-2000. DOI: 10.1520/G0031-12A.

[2] For referenced ASTM standards, visit the ASTM Web site, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM Web site. For NACE standards, visit the NACE Web site, www.nace.org, or contact NACE *FirstService* at firstservice@nace.org.

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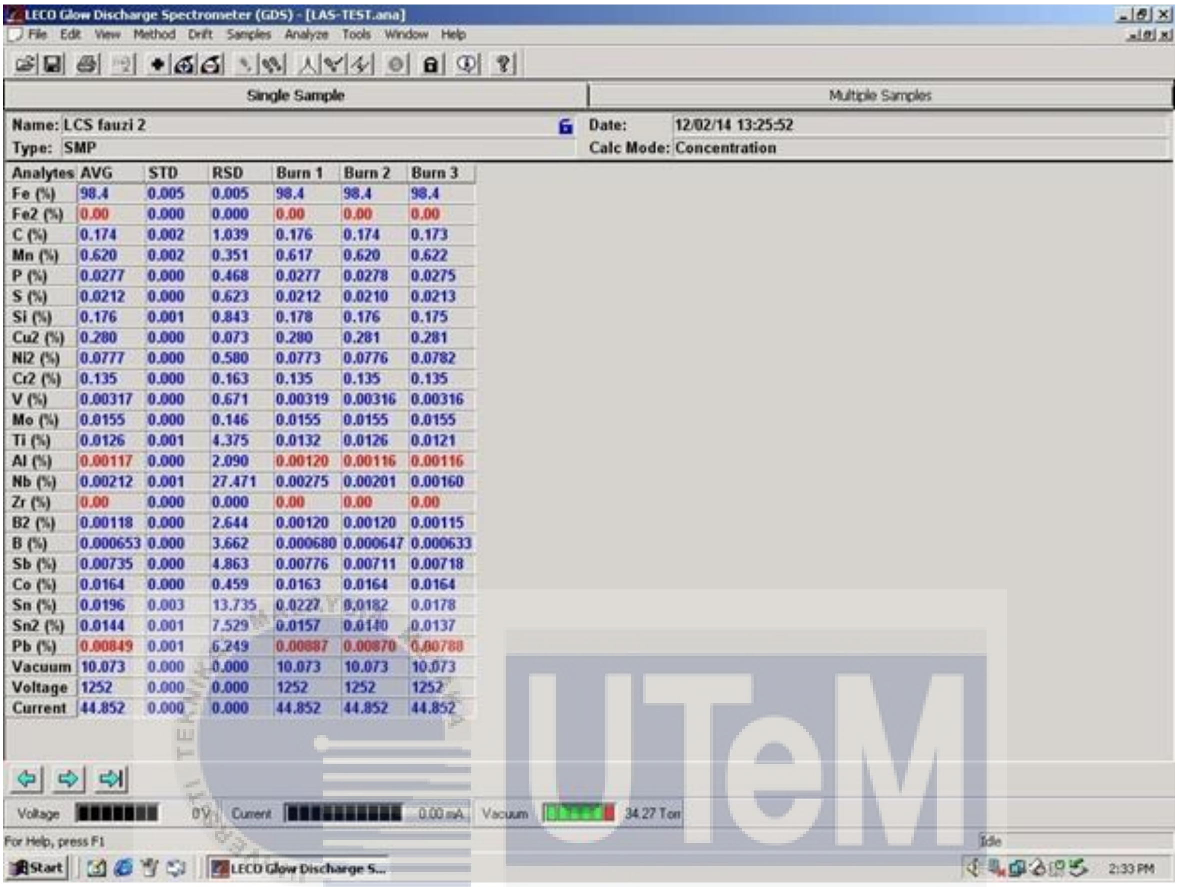
APPENDIX C GDS Result



Name: LCS fauzi 2
Type: SMP
Date: 12/02/14 13:25:52
Calc Mode: Concentration

Analytes	AVG	STD	RSD	Burn 1	Burn 2	Burn 3
Fe (%)	98.4	0.005	0.005	98.4	98.4	98.4
Fe2 (%)	0.00	0.000	0.000	0.00	0.00	0.00
C (%)	0.174	0.002	1.039	0.176	0.174	0.173
Mn (%)	0.620	0.002	0.351	0.617	0.620	0.622
P (%)	0.0277	0.000	0.468	0.0277	0.0278	0.0275
S (%)	0.0212	0.000	0.623	0.0212	0.0210	0.0213
Si (%)	0.176	0.001	0.843	0.178	0.176	0.175
Cu2 (%)	0.280	0.000	0.073	0.280	0.281	0.281
Ni2 (%)	0.0777	0.000	0.580	0.0773	0.0776	0.0782
Cr2 (%)	0.135	0.000	0.163	0.135	0.135	0.135
V (%)	0.00317	0.000	0.671	0.00319	0.00316	0.00316
Mo (%)	0.0155	0.000	0.146	0.0155	0.0155	0.0155
Ti (%)	0.0126	0.001	4.375	0.0132	0.0126	0.0121
Al (%)	0.00117	0.000	2.090	0.00120	0.00116	0.00116
Nb (%)	0.00212	0.001	27.471	0.00275	0.00201	0.00160
Zr (%)	0.00	0.000	0.000	0.00	0.00	0.00
B2 (%)	0.00118	0.000	2.644	0.00120	0.00120	0.00115
B (%)	0.000653	0.000	3.662	0.000680	0.000647	0.000633
Sb (%)	0.00735	0.000	4.863	0.00776	0.00711	0.00718
Co (%)	0.0164	0.000	0.459	0.0163	0.0164	0.0164
Sn (%)	0.0196	0.003	13.735	0.0227	0.0182	0.0178
Sn2 (%)	0.0144	0.001	7.529	0.0157	0.0140	0.0137
Pb (%)	0.00849	0.001	6.249	0.00887	0.00870	0.00788
Vacuum	10.073	0.000	0.000	10.073	10.073	10.073
Voltage	1252	0.000	0.000	1252	1252	1252
Current	44.852	0.000	0.000	44.852	44.852	44.852

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APPENDIX D Gantt Chart of Study for PSM 1

ACTIVITIES	STATUS	WEEK															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SUPERVISOR SELECTION AND REGISTERED TITLE	PLAN	🟩	🟩														
	ACTUAL	🟩															
BRIEF AND PROJECT EXPLANATION BY SUPERVISOR	PLAN		🟩	🟩	🟩	🟩											
	ACTUAL		🟩	🟩	🟩	🟩	🟩	🟩									
MODULE #1 RESEARCH DESIGN AND PLANNING	PLAN		🟩														
	ACTUAL		🟩														
DISCUSS PROBLEM STATEMENT AND OBJECTIVE FOR CHAPTER 1	PLAN				🟩	🟩	🟩	🟩									
	ACTUAL				🟩	🟩	🟩	🟩									
MODULE #2 FINAL YEAR PROJECT LITERATURE REVIEW	PLAN			🟩													
	ACTUAL			🟩													
DRAFTING LITERATURE REVIEW AND WRITING UP CHAPTER 2	PLAN		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
	ACTUAL	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
DRAFTING SUBMISSION OF CHAPTER 2	PLAN						🟩	🟩	🟩	🟩	🟩						
	ACTUAL					🟩	🟩	🟩	🟩	🟩							
MODULE #3 RESEARCH METHODOLOGY	PLAN				🟩												
	ACTUAL				🟩												
RESEARCH ON METHODOLOGY AND WRITING UP CHAPTER 3	PLAN								🟩	🟩	🟩	🟩					
	ACTUAL									🟩	🟩						
WRITING UP PRELIMINARY RESULT	PLAN			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
	ACTUAL			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
SUBMISSION OF FIRST DRAFT PSM 1	PLAN										🟩	🟩	🟩				
	ACTUAL											🟩	🟩				
SUBMISSION OF SECOND DRAFT PSM 1	PLAN														🟩	🟩	🟩
	ACTUAL														🟩		
PREPARATION AND PRESENTATION PSM 1	PLAN														🟩		
	ACTUAL														🟩	🟩	🟩

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APPENDIX E Gantt Chart of Study For PSM 2

ACTIVITIES	**STATUS**	**WEEK**															
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
MEETING AND DISCUSSION	PLAN	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	ACTUAL	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
CUT THE MATERIAL	PLAN		🟩	🟩													
	ACTUAL		🟩	🟩													
CONDUCTING THE EXPERIMENT	PLAN		🟩	🟩	🟩	🟩	🟩	🟩									
	ACTUAL		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
COLLECT DATA AND MAKE ANALYSIS ON SAMPLE	PLAN		🟩	🟩	🟩	🟩											
	ACTUAL						🟩	🟩	🟩	🟩	🟩						
DISCUSS ON RESULT EXPERIMENT	PLAN					🟩	🟩	🟩	🟩								
	ACTUAL					🟩	🟩	🟩	🟩	🟩	🟩	🟩					
START DRAFT REPORT AND WRITING UP CHAPTER 4	PLAN						🟩	🟩	🟩								
	ACTUAL				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
START DRAFT REPORT AND WRITING UP CHAPTER 5	PLAN					🟩	🟩	🟩	🟩	🟩							
	ACTUAL										🟩	🟩	🟩				
SUBMISSION OF FIRST DRAFT PSM 2	PLAN									🟩	🟩	🟩					
	ACTUAL												🟩				
RECHECK FIRST DRAFT	PLAN											🟩	🟩				
	ACTUAL												🟩	🟩			
WRITING UP CONCLUSION FOR THIS STUDY	PLAN												🟩	🟩			
	ACTUAL											🟩	🟩				
SUBMISSION OF FULL REPORT	PLAN													🟩	🟩		
	ACTUAL														🟩	🟩	
FINALIZE THE CORRECTION OF FULL REPORT	PLAN													🟩	🟩		
	ACTUAL														🟩	🟩	
PREPARATION AND PRESENTATION OF PSM 2	PLAN														🟩	🟩	🟩
	ACTUAL															🟩	🟩

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