

CORROSION: BRIDGING SCIENCE AND SOCIETY

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Abstract: "Corrosion: Bridging Science and Society" delivers a groundbreaking perspective on corrosion science while directly addressing multiple Sustainable Development Goals (SDGs). This book systematically explores corrosion fundamentals—from basic definitions and electrochemical principles to advanced measurement techniques like electrochemical impedance spectroscopy and salt spray testing. It details various corrosion types, including uniform, galvanic, pitting, and stress corrosion cracking, while analysing critical influencing factors such as material properties, environmental conditions, and industrial processes. The work presents practical prevention methods ranging from protective coatings to cathodic protection systems, emphasizing sustainable solutions. Particularly valuable are the discussions connecting corrosion science to real-world challenges in infrastructure, transportation, energy, and environmental protection, including economic analyses and public awareness strategies. Written for both technical and non-technical audiences, this volume serves as an indispensable reference for materials scientists, engineers, industry professionals, and policymakers seeking to understand and mitigate corrosion's multifaceted consequences. The book's unique integration of scientific rigor with societal applications makes it an essential resource for advancing corrosion education and developing industrial practices.

Keywords: Corrosion science, electrochemical impedance spectroscopy (EIS), corrosion prevention, stress corrosion cracking

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ABBREVIATIONS

ω	angular frequency
°C	degree Celsius
°F	degree Fahrenheit
Ag	Silver
Al	Aluminium
Al ₂ O ₃	aluminium oxide
AMPP	Association for Materials Protection and Performance
ASTM	American Society for Testing and Materials
Au	Gold
BCC	Body-centred cubic
Be	Beryllium
C	Capacitor
Ca	Calcium
CA	corrosion allowance
Cd	Cadmium
Co	Cobalt
CPE	Constant Phase Elements
Cr	Chromium
Cr ₂ O ₃	Chromium (III) oxide
Cu	Copper
E	Electrochemical potential
e	electron
E_{corr}	corrosion potential
EIS	Electrochemical Impedance Spectroscopy
EMF	electromotive force
FCC	Face-centred cubic
Fe	Iron
Fe ²⁺	ferric ions
Ga	Gallium
GDP	Gross domestic product (GDP)
H ⁺	hydrogen ions
H ₂	hydrogen
H ₂ O	water
H ₂ S	hydrogen sulphide
H ₂ SO ₄	sulfuric acid
HAZ	Heat-affected Zone
HCL	hydrochloric acid
HCP	hexagonal close packed
Hf	Hafnium

Hg	Mercury
HVLP	High Volume Low Pressure
i_{corr}	corrosion current density
In	Indium
ISO	International Organisation for Standardisation
K	Potassium
L	Inductance
Li	Lithium
Mg	Magnesium
MgO	magnesium oxide
MIC	microbiologically influenced corrosion
mm	millimetre
Mn	Manganese
MnO ₄	permanganate
MnS	Manganese(II) sulphide
mpy	mils per year
N	Nitrogen
Na	Sodium
NACE	National Association of Corrosion Engineers
NaCl	sodium chloride
NaOH	sodium hydroxide
NDT	Non-destructive Testing
Ni	Nickel
O ₂	oxygen
OH ⁻	hydroxide ions
Pb	Lead
PCB	printed circuit board
Pd	Palladium
PTC	power tool cleaning
PVC	Polyvinyl chloride
R	Resistor
S ²⁻	sulphide ions
SCC	stress corrosion cracking
SDG	Sustainable Development Goals
SHE	Standard Hydrogen Electrode
Sn	Tin
SO ₄ ²⁻	sulphate ions
SRB	sulphate-reducing bacteria
SST	Salt Spray Test
Ti	Titanium
Tl	Thallium
U	Uranium

UTM	Ultrasonic Thickness Measurement
UV	Ultraviolet
VOCs	Volatile Organic Compounds
<i>W</i>	Warburg elements
<i>Z</i>	Impedance
Zn	Zinc
ZnCl ₂	zinc chloride
Zr	Zirconium

PREFACE

Corrosion is an ever-present challenge that silently erodes our infrastructure, impacts economies, and poses risks to public safety and the environment. From rusting bridges to deteriorating pipelines, the consequences of corrosion extend far beyond mere material degradation. Corrosion affects the very fabric of modern society. *Corrosion: Bridging Science and Society* seeks to explore this unescapable issue by connecting the scientific principles of corrosion with its real-world implications.

This book is designed to serve as a comprehensive, yet accessible guide for beginners, such as students and postgraduates in engineering, materials science, and related fields. This book is also suitable for professionals, policymakers, and anyone interested in understanding corrosion from both technical and societal perspectives. It begins with the fundamentals of corrosion, explaining the electrochemical processes that drive material degradation in a clear and approachable manner. Next, it delves into the various types of corrosion, highlighting their mechanisms and real-life manifestations with practical examples.

Beyond theory, this book emphasises on preventive measures, showcasing cutting-edge techniques and best practices to mitigate corrosion in industries and everyday life. Most importantly, it examines the broader impact of corrosion on society, including its economic costs, threats to critical infrastructure, and environmental consequences. A dedicated discussion on public awareness highlights the need for education and proactive policies to combat this silent menace.

Whether you are a student encountering corrosion studies for the first time, a postgraduate researcher deepening your knowledge, or a professional seeking practical insight, this book provides a balanced blend of foundational science and real-world relevance. The goal of *Corrosion: Bridging Science and Society* is not only to inform, but also to inspire action—whether through better engineering solutions, smarter regulations, or increased community engagement.

We invite readers to explore this intersection of science and society, where knowledge transforms into meaningful change.

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We would like to express our appreciation to the broader scientific and societal communities for their engagement with corrosion science which is a field critical to infrastructure, sustainability, and technological progress. It is our hope that this book serves as a meaningful bridge between research and real-world applications.

Finally, we would also like to acknowledge the contributions of our colleagues, industries, education community and families whose insights and expertise enriched the content of this book. Special thanks go to the editors, and publishing team for their dedication and meticulous efforts in ensuring the quality of this publication.

INTRODUCTION

Corrosion is an omnipresent challenge that affects nearly every aspect of modern life; from infrastructure and transportation to healthcare and energy systems. *Corrosion: Bridging Science and Society* explores this critical phenomenon, offering a comprehensive examination of its scientific principles, economic consequences, and societal implications.

This book begins with an Introduction to Corrosion (Chapter 1), defining corrosion and highlighting its significance across industries, including infrastructure, transportation, healthcare, and the environment. It establishes corrosion as a process that reverses metallurgical gains, emphasising its far-reaching economic and societal impacts. Chapter 2 (Terminology in Corrosion Science) provides essential definitions and electrochemical concepts, laying the foundation for understanding corrosion mechanisms.

Meanwhile, Chapter 3 (The Measurement of Corrosion Rate) discusses key techniques for assessing corrosion, from weight loss methods to advanced electrochemical analyses. Chapter 4 (Types of Corrosion) categorises different corrosion forms—uniform, galvanic, pitting, stress corrosion cracking, and microbiologically influenced corrosion.

Chapter 5 (Factors Affecting Corrosion) examines material properties and environmental influences. Chapter 6 (Corrosion Prevention Techniques) explores mitigation strategies, including coatings, cathodic protection, and alloying. Finally, Chapter 7 (Interconnections of Corrosion and Society) highlights the need for public awareness, education, and sustainable industrial practices to combat corrosion effectively.

By integrating scientific principles with real-world applications, this book serves as a vital resource for engineers, scientists, policymakers, and educators, fostering a deeper understanding of corrosion's role in shaping a sustainable future.

CHAPTER 1

INTRODUCTION TO CORROSION



- ✓ Understand the fundamental principles of corrosion and the concept of “metallurgy in reverse”.
- ✓ Explore the societal and economic impacts of corrosion.
- ✓ Discover the importance of learning corrosion.

1.0 Definition of Corrosion

Corrosion is a natural process that occurs when materials, particularly metals, deteriorate due to chemical or electrochemical reactions with their environment. It is most commonly associated with the rusting of iron or steel, where the metal reacts with oxygen and water to form iron oxide. The chemical equation for the reaction can be written as follows:

Overall Reaction



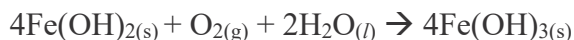
Step 1: Oxidation of Iron

Iron reacts with oxygen in the presence of water to form iron (II) hydroxide ($\text{Fe}(\text{OH})_2$):



Step 2: Further Oxidation

Iron (II) hydroxide is then further oxidised by oxygen to form iron (III) hydroxide ($\text{Fe}(\text{OH})_3$), which is the hydrated form of iron oxide (rust):

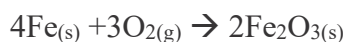


Step 3: Dehydration

Over time, iron (III) hydroxide can lose water molecules to form iron (III) oxide (Fe_2O_3), the anhydrous form of rust:



The reddish-brown rust, commonly seen on iron surfaces, is primarily iron (III) oxide (Fe_2O_3) or its hydrated forms (e.g., $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$). For simplicity, the overall reaction can be written as:



This equation represents the formation of anhydrous iron (III) oxide, which is the primary component of rust.

CHAPTER 2

TERMINOLOGY IN CORROSION SCIENCE



- ✓ Understand the terminology related to corrosion.
- ✓ Able to elaborate the electrochemical cell and its working principles.
- ✓ Able to discuss the relationship between electromotive force (EMF) and the inherent reactivity of metals.
- ✓ Proficient in determining the standard cell potential of a galvanic cell

2.0 Understanding the Terminology

Understanding the terminology used in corrosion science is essential for grasping its fundamental concepts and mechanisms. This section provides a detailed explanation of key terms, units, and symbols commonly used in the field.

2.1 Key Terms and Definitions

2.1.1 Corrosion

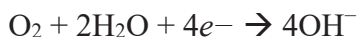
As discussed in Chapter 1, corrosion is defined as the gradual degradation or destruction of materials, usually metals, due to chemical or electrochemical reactions with their environment. It is a natural process that occurs when metals are exposed to elements such as oxygen, moisture, and pollutants, leading to the formation of oxides, hydroxides, or other compounds. The rusting of iron is one of the most common examples of corrosion. When iron is exposed to oxygen and moisture, it reacts to form iron oxide (rust). The reddish-brown rust weakens the iron structure over time, leading to material failure.

2.1.2 Oxidation

Oxidation is a chemical reaction in which a material loses electrons. In the context of corrosion, oxidation occurs at the anode, where the metal atoms lose electrons and dissolve into the surrounding environment as ions. For example, the oxidation of iron, in the presence of water and oxygen, produces iron ions i.e., $\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^-$. This reaction is the first step of the rusting process and is a key component of electrochemical corrosion.

2.1.3 Reduction

Reduction is a chemical reaction in which a material gains electrons. In corrosion, reduction occurs at the cathode, where electrons released during oxidation are consumed. The cathode is typically protected from corrosion. In neutral or alkaline environments, oxygen is reduced in the presence of water to form hydroxide ions:



CHAPTER 3

THE MEASUREMENT OF CORROSION RATE



- ✓ Able to differentiate the corrosion rate measurement methods.
- ✓ Able to interpret the Tafel polarisation plots and electrochemical impedance spectroscopy (EIS) analysis.
- ✓ Able to determine the corrosion allowance.

3.0 Corrosion Rate Measurements

Corrosion rate is defined as the speed at which a material corrodes, typically expressed as a loss of thickness per unit time. The common units for corrosion rate are:

- i) mm/yr (millimetres per year). Widely used in engineering to measure the penetration depth of corrosion.
- ii) mpy (mils per year): 1 mil = 0.001 inch. Commonly used in the United States.
- iii) g/m²/yr (grams per square meter per year). Used to measure weight loss due to corrosion.

For example, a corrosion rate of 0.1 mm/yr means that the material loses 0.1 mm of thickness annually. Hence, it is a critical parameter in materials science and corrosion engineering, as it helps predict the lifespan of structures and components exposed to corrosive environments. Several methods are used to measure corrosion rates, depending on the application and environment (Usman, A. D., & Okoro, L. N. (2015)).

3.1 Weight Loss Method

There are a few critical steps to measure the corrosion rate using weight loss method. First, the metal sample is cleaned to ensure no deposits or contaminants on its surface. Then, the metal sample is exposed to a corrosive environment for a specific period i.e., 24 hours. The sample is then cleaned again to remove corrosion products, and its weight loss is measured. Finally, the corrosion rate is calculated using the formula:

$$\text{Corrosion rate} = \frac{K \cdot W}{A \cdot T \cdot D}$$

Where:

K = Constant (depends on units).

W = Weight loss (g).

A = Surface area of the sample (cm²).

T = Exposure time (hours).

D = Density of the metal (g/cm³).

CHAPTER 4

TYPES OF CORROSION



- ✓ Able to identify and classify different forms of corrosion.
- ✓ Able to explain the key characteristics and visual appearances of each form.
- ✓ Can relate material properties to susceptibility to certain corrosion types.

4.0 Various types of corrosion

Understanding the different types of corrosion is crucial for designing effective prevention and mitigation strategies. This chapter discusses the main types of corrosion and its mechanism.

4.1 Uniform Corrosion

Uniform corrosion occurs evenly over the entire surface of the metal. It is relatively straightforward to measure and predict, which helps prevent catastrophic failures and makes them exceptional. Often, the primary concern with uniform corrosion is its impact on appearance rather than structural integrity. The mechanism of uniform corrosion relies on the anodic and cathodic sites which are uniformly distributed i.e., rusting of iron in a humid environment.

Since this type of corrosion spreads evenly across the entire surface of a metal component, it can be effectively managed through cathodic protection, by applying coatings or paints, or incorporating a corrosion allowance in design. Interestingly, in some cases, uniform corrosion can enhance the aesthetic appeal of a surface. Notable examples include the distinctive patina that forms on naturally tarnishing copper roofs and the attractive rust tones developed on weathering steels.

4.2 Galvanic Corrosion

Galvanic corrosion, also known as *dissimilar metal corrosion* is the accelerated corrosion damage that occurs when two different metals or materials are electrically connected in the presence of a corrosive electrolyte. This phenomenon arises when two or more dissimilar metals come into contact while being submerged in or exposed to an electrolyte, such as water. In such a galvanic couple, one metal acts as the *anode* and undergoes faster corrosion than it would in isolation, while the other metal acts as the *cathode* and experiences slower corrosion compared to its standalone behaviour.

Specifically, each metal in the pair may or may not corrode on its own under normal conditions. However, when these dissimilar metals are brought into contact, their individual corrosion behaviours change significantly. The mechanism of galvanic corrosion can be simplified as the more active metal

CHAPTER 5

FACTORS AFFECTING CORROSION



- ✓ Able to recognise the metal and environmental factors.
- ✓ Able to specify each of the factors that affect corrosion rates.
- ✓ Able to relate the factors and significant effects to metals and corrosion behaviour.

5.0 Introduction

Corrosion is a complex electrochemical process influenced by a wide range of factors. Understanding these factors is essential for predicting, preventing, and controlling corrosion in various environments.

5.1 Material Factors

The properties of the material itself play a significant role in its corrosion behaviour i.e., the composition of alloys and impurities (Gusieva, K et al., 2015). Alloying elements are intentionally added to a base metal to improve its properties, including corrosion resistance. For example, chromium (Cr) and molybdenum (Mo) in stainless steel. When added to steel, Cr forms a thin, adherent, and self-repairing oxide layer (Cr_2O_3) on the surface, which acts as a barrier against further oxidation and corrosion. Meanwhile, Mo often added to stainless steels to make it highly resistant to rust and corrosion in many environments. Other elements like copper (Cu), titanium (Ti), and nitrogen (N) can also be added to improve specific corrosion-resistant properties. It is proven that titanium stabilises stainless steel against intergranular corrosion.

In some cases, during manufacturing of metals or alloys, impurities may be introduced. Impurities are unintended elements or compounds present in the material, and significantly degrade corrosion resistance. For instance, Sulphur (S) and Phosphorus (P) are common impurities in steel. Sulphur can form sulphides (e.g., MnS), which act as initiation sites for pitting corrosion. Meanwhile, Phosphorus can segregate at grain boundaries, making the material more susceptible to intergranular corrosion.

In addition, non-metallic inclusions, such as oxides, sulphides, or silicates can create localised stress points or discontinuities in the material. These sites are prone to corrosion initiation because they disrupt the protective oxide layer and can act as galvanic cells, accelerating corrosion. Figure 5.1 illustrates examples of inclusion in metals that can initiate corrosion. Besides inclusion, the presence of precipitates, containing minor alloying elements and impurities, can create several issues as well. The formation of phases with significantly different electrochemical properties can lead to localised variations in corrosion resistance. While alloying elements are often added to enhance corrosion resistance, they can also increase susceptibility to localised corrosion mechanisms, such as pitting or intergranular corrosion.

CHAPTER 6

CORROSION PREVENTION TECHNIQUES



- ✓ Able to recognise the metal and environmental factors.
- ✓ Able to differentiate between cathodic protection (sacrificial anodes vs. impressed current) and anodic protection.
- ✓ Able to relate the factors and significant effects to metals and corrosion behaviour.

6.0 Corrosion prevention

Corrosion is a natural process that deteriorates metals due to chemical or electrochemical reactions with their surroundings, such as oxygen, moisture, and salts. Corrosion can lead to catastrophic structural failures, financial losses, and safety hazards. For instance, rusted pipelines may burst, bridges may weaken, and industrial equipment may malfunction, leading to costly repairs, downtime, and even environmental damage. Additionally, corrosion affects aesthetics, reducing the lifespan and value of vehicles, buildings, and machinery. Given these risks, implementing effective corrosion protection is crucial in industries like construction, automotive, marine, and oil and gas.

Several methods are employed to combat corrosion, each suited to different environments and materials. Barrier protection is one of the most common approaches, where coatings like paint, epoxy, or powder coatings are applied to shield the metal from corrosive elements. Galvanisation, which involves coating steel with zinc, provides both a physical barrier and sacrificial protection. Cathodic protection is another key technique, where a more reactive metal (like zinc or magnesium) is used as a sacrificial anode, corroding in place of the protected structure. Alternatively, an impressed current system can be used, where an external electrical current prevents oxidation. Material selection also plays a vital role—stainless steel, aluminium, and titanium are inherently corrosion-resistant due to their passive oxide layers, while non-metallic materials like plastics and composites are used in highly corrosive environments. Environmental controls, such as dehumidification and corrosion inhibitors in coolants or coatings, help slow down degradation. Finally, smart design practices, such as avoiding moisture traps, using compatible metals, and ensuring proper drainage, can significantly reduce corrosion risks.

By combining these methods, industries can enhance durability, reduce maintenance costs, and ensure the safety and reliability of critical infrastructure and equipment. The choice of protection depends on factors like exposure conditions, material type, and economic feasibility, making corrosion management a vital aspect of engineering and maintenance. The next sections elaborate on each of the stated methods, providing deeper insights into their mechanisms, applications, and advantages.

CHAPTER 7

INTERCONNECTIONS OF CORROSION AND SOCIETY



- ✓ Able to reflect on the importance of public education and policy in corrosion management.
- ✓ Able to explain the related programmes conducted by the government or agencies for corrosion mitigation.
- ✓ Able to relate the implications of corrosion with society and the Sustainable Development Goals (SDGs).

7.0 Introduction

Corrosion is an everyday issue of significant concern in the industrial, infrastructural, and environmental domains (Chilkoor, G. et al., 2018). Corrosion is estimated to incur losses of over £2.5 trillion per year, accounting for around 3.4% of the world's GDP (Sharafudeen, R., 2020). This is one of the many consequences of corrosion, which is very serious, yet, remains fairly unknown. Education and outreach programmes can be implemented to offer support by encouraging proactive solutions and offering guidance on effective corrosion management strategies (Kordas, G., 2022). These programmes mitigate the consequences and assist policymakers, industry stakeholders, and ordinary citizens to comprehend the criticality of corrosion control and prevention.

7.1 Public Awareness and Education in Corrosion Prevention

Awareness campaigns can promote proactive measures to counter the detrimental impacts corrosion has on an economic, safety, environmental, and technological level sustainability. It goes without saying that corrosion has severe consequences which leads to decreased financial earnings because of costly repairs, maintenance, and replacements. This in return will cause a considerable impact on the economy (Al-Amiery et al. 2024). Government and industries have spent considerable amounts to prevent corrosion, yet small businesses and individual sellers are often unaware of the costs associated with corrosion damage (Huang, L. et al., 2024). If people were more educated, a campaign, encouraging people to adopt proactive maintenance measures, would pave way for reduced corrosion costs while maximising durability.

Furthermore, corrosion can be a hazard to safety. Corrosion-induced structural failures can give rise to terrible accidents, including loss of life and damage to nature. These catastrophic events may include a pipe bursting and the breakdown of a bridge, which need improved control measures (Mungwari, C. P. et al., 2024). Helping people understand the dangers that correlate with corrosion is important so that they can obey rules and ensure safety and, in turn, lower the chances of dangerous failures taking place, enhancing public safety.

In addition to safety and economic problems, corrosion also affects the environment significantly. The breakdown of infrastructure, like oil and chemical works, oil pipelines, and even water treatment facilities, can lead to

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