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Contents

Preface

Corrosion is a complex degradation process in which a chemical or electrochemical reaction occurs between a metallic material and its environment, leading to the deterioration of the material's structural integrity. It is one of the primary challenges threatening the safe and reliable operation of various engineering systems and materials. The corrosion behavior of iron and steel is influenced not only by environmental factors but also by numerous metallurgical characteristics inherent to the materials themselves. A comprehensive understanding of the corrosion mechanisms of steel, along with the key factors influencing these processes, is essential for enhancing the corrosion resistance of steel and developing more durable materials for industrial applications.

As human activities extend into increasingly harsh environmental conditions, the demand for corrosion-resistant steel materials in critical infrastructure – such as offshore platforms, bridges, buildings, docks, and ships – has grown significantly. The smelting and casting processes of iron and steel introduce a range of metallurgical factors, including alloying element composition, elemental segregation, inclusions, precipitated phases, dislocations, microstructural variations, and shrinkage defects. These factors, which arise from differences in alloying elements and manufacturing processes, are closely tied to the corrosion behavior of steel materials. Understanding the corrosion mechanisms induced by these factors and evaluating their impact on corrosion resistance is critical for advancing the development of high-performance, corrosion-resistant steel alloys.

In recent decades, substantial advancements in production technologies have resulted in significant improvements in the properties of iron and steel materials, particularly low-alloy steels. However, earlier research and development efforts predominantly focused on mechanical properties as the primary performance metrics, often at the expense of corrosion resistance. This oversight has contributed to several catastrophic incidents, such as the 2018 collapse of the Italian sea-crossing bridge, the 2020 collapse of the Miami condominium, and the gas pipeline explosion in Hubei, China, all of which were attributed to the failure of steel materials due to corrosion.

This book offers an in-depth exploration of the latest research on modulating metallurgical factors in various types of steel materials to enhance their corrosion resistance. It covers a diverse range of materials, including low-alloy steels, stainless steels, ductile iron, rebar, and titanium-steel composite plates. Additionally, the book highlights cutting-edge research on the development of corrosion-resistant steels, leveraging advanced corrosion big data technologies. The objective of this work is to elucidate the mechanisms and modulation techniques for metallurgical factors that influence the corrosion resistance of steel materials, while also identifying emerging trends in the future development of corrosion-resistant alloys.

Chapter 1 of this book discusses the common types of corrosion in steel materials, providing readers with a foundational understanding of the material degradation process. Chapter 2 primarily introduces the initiation mechanisms of corrosion induced by inclusions in stainless steel, along with studies on the effect of alloying elements on the modification and regulation of inclusions, and how these changes impact the material's pitting corrosion resistance. Chapter 3 focuses on the role of rare earth (RE) elements as alloying elements for controlling inclusions in steel, and their influence on the chemical and electrochemical mechanisms that govern the initiation of localized corrosion induced by inclusions. Chapter 4 discusses the effects of multicomponent inclusion-controlling elements in 690 MPa-grade calcium-treated marine engineering steel on inclusions and their impact on the initiation mechanism of localized corrosion, ultimately proposing three chemical-electrochemical mechanisms for the initiation of localized corrosion induced by inclusions. Chapter 5 examines the effect of microstructural coarsening on the corrosion resistance of materials. Chapter 6 delves into the coupled mechanisms between microstructural features and inclusions during the initiation and development of corrosion. Chapter 7 analyzes the mechanisms by which alloying elements influence the corrosion resistance of low-alloy, high-strength steels, with a focus on the effect of alloying elements on rust layer formation. Chapter 8 investigates the impact and mechanisms of copper (Cu) on the microbiologically influenced corrosion resistance of low-alloy steels. Chapter 9 introduces the evolution of stress corrosion sensitivity in pipeline steels under soil environments and damaged coatings. Chapter 10 analyzes the influence and mechanisms of inclusions, as typical metallurgical factors, on the hydrogen-induced stress corrosion cracking resistance of pipeline steel materials. Chapter 11 investigates the effects of RE elements and chromium modulation on the corrosion resistance of HRB400 rebar in concrete environments, discussing the mechanisms of corrosion under different chloride concentrations and pH-reduced conditions due to concrete carbonation. Chapter 12 discusses the impact and mechanisms of metallurgical defects such as shrinkage and porosity on the corrosion resistance of ductile iron pipes. The combination of these technologies allows for the efficient identification of key microalloying elements and their contributions to improving the corrosion resistance of steel, thus enhancing the efficiency of research and development efforts in corrosion-resistant steel alloys.

This book aims to provide theoretical guidance for corrosion-resistant steel smelting technologies (e.g., inclusions regulation, alloy modulation, rolling processes) by investigating the laws and mechanisms underlying the influence of various metallurgical factors on the corrosion resistance of steel. The findings are intended to be applied directly to the steel production process. By utilizing state-of-the-art research methodologies, this book contributes to advancing our understanding of corrosion in stainless steels, low-alloy steels, ductile iron, and rebar and offers innovative perspectives for the future development of corrosion-resistant steels.

This work presents the latest advancements in the study of corrosion mechanisms and the modulation of corrosion-resistant steels, making it an invaluable resource for scientists, researchers, and students across various disciplines. It underscores the critical role of metallurgical factors in influencing the corrosion behavior of steel. The authors encourage readers to consult the references cited throughout the text to gain a deeper understanding of the research discussed in this book.

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Although the cover lists two authors, this book represents the collective achievements of the research team at the National Materials Corrosion and Protection Data Center. at the University of Science and Technology Beijing in the field of corrosion-resistant steel research. It encapsulates the collective wisdom of dozens of dedicated researchers.

December 2024 *Chao Liu*
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1

Corrosive Environments and Types of Steel

1.1 Introduction

Corrosion is defined as the process by which metallic materials when interacting in a specific environment undergo a chemical or electrochemical reaction that degrades their properties. Any material, especially metal material, has its specific use in environment. Use in an unsuitable environment may lead to premature corrosion damage to the material and induce corrosion accidents, which will not only cause economic losses but even cause casualties and environmental pollution [1].

According to statistics, more than half of the steel is in service in the natural environment (atmosphere, soil, and water), another part is used in industrial acids, alkalis, salts, or high-temperature and high-pressure environment, and a very small part is used in extreme harsh environments, such as high-temperature, high-humidity, and high-salt spray extreme marine atmospheric environments, deep-sea environments below 300 m, and dry and hot desert environments. Therefore, the service environment of steel is extremely complex, the study also shows that the type of corrosion of steel in specific environments is also diversified, which leads to the complexity of steel varieties. Correct and comprehensive understanding of the corrosion environment and corrosion type of steel in the development of high-quality steel is the first major issue.

1.2 Natural Corrosive Environments

1.2.1 Atmospheric Corrosive Environments

Atmospheric corrosion environment accounts for more than half of the total corrosion environment. According to the humidity of the surface, it can be divided into three categories: (i) dry atmospheric corrosion: when there is a discontinuous liquid film layer on the surface, a very thin invisible oxide film is formed on the surface of the metal whose free energy of reaction is negative, for example, the thickness of the oxide film of iron is about 30 Å. (ii) Damp atmospheric corrosion: corrosion that occurs when there is a thin liquid film layer on the surface of the metal that is

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First Edition. Chao Liu and Xiaogang Li.

invisible to the naked eye, such as for example, rusting of iron when there is no rain or snow. (iii) Wet atmosphere corrosion: corrosion that occurs when the humidity of the air is close to 100%, or when moisture in the form of rain, snow, foam, etc., falls on the metal surface, and there is a film layer of condensed water visible to the naked eye on the surface of the metal. According to regional conditions and atmospheric characteristics, this can be divided into rural atmosphere, marine atmosphere, suburban atmosphere, industrial atmosphere, etc.

The main environmental factors that impact atmospheric corrosion are: (i) Humidity: the greater the humidity, the easier the metal surface condensation, the longer the electrolyte film exists, and the more the corrosion rate increases. There exists a critical humidity for metallic materials, and the corrosion rate of the material increases dramatically when the humidity is greater than the critical humidity level. For iron and steel, copper, nickel, zinc, and other metals, the critical humidity is about 50–70% between. (ii) Temperature: in other conditions are the same, areas with high average temperatures have higher atmospheric corrosion rates. (iii) Rainfall: rainwater may damage and wash away the rust layer on the material surface, accelerating corrosion. However, in some cases, rain can slow down corrosion to some extent by washing away dust, salt particles, or water-soluble corrosion products from the rust layer on the metal surface. (iv) Atmospheric composition: outside the basic composition of the atmosphere, atmospheric pollutants, such as sulfides, nitrides, CO, and CO_2, salt particles, and sand, can accelerate atmospheric corrosion to some extent. (v) The impact of abnormal climatic conditions: for example, acid rain can reduce the corrosion resistance of Fe, Zn, Cu, Pb, and other metal greatly. Due to the complexity of atmospheric factors, the corrosion behavior and rate of materials under specific atmospheric conditions can be determined through long-term field testing. The usual corrosive classification of the atmospheric environment is shown in Table 1.1.

1.2.2 Soil Corrosion Environments

Soil consists of a variety of granular minerals, moisture, gases, microorganisms, and other multiphase compositions, with biological activity, ionic conductivity,

Table 1.1 Classification of environmental corrosivity in terms of corrosion rates of different metals in the first year of exposure.

	Corrosion rate of metals				
Corrosion type	**Unit**	**Carbon steel**	**Zn**	**Cu**	**Al**
C1 (Very low)	g/m^2/a μm/a	<10 <1.3	<0.7 <0.1	<0.9 <0.2	<0.2
C2 (Low)	g/m^2/a μm/a	10–200 1.3–25	0.7–5 0.1–0.7	0.9–5 0.1–0.6	
C3 (Medium)	g/m^2/a μm/a	200–400 25–50	5–15 0.7–2.1	5–12 0.6–1.3	0.6–1.3
C4 (High)	g/m^2/a μm/a	400–650 50–80	15–30 2.1–4.2	12–25 1.3–2.8	
C5 (Very high)	g/m^2/a μm/a	650–1500 80–200	30–60 4.2–8.4	25–50 2.8–5.6	

and capillary colloidal properties. Soil is a special electrolyte, may induce uneven total corrosion of metals and severe localized corrosion [2]. Stray currents and microorganisms also cause soil corrosion.

Soil corrosion and other media electrochemical corrosion processes are due to the metal and the medium of the formation of electrochemical inhomogeneity of the corrosion of the primary battery. At the same time, as the soil medium has multiphase (phases such as soil, water, and air), inhomogeneity and relative stability, and other characteristics, soil environment caused by metal corrosion has its own unique corrosion mechanism and kinetic development process, such as soil macro-uniformity caused by corrosive macrocells; often soil corrosion plays a greater role.

The inhomogeneity of the soil medium is mainly due to the different permeability conditions of the soil. Under different permeability conditions, the rate of oxygen penetration varies greatly, strongly affecting the potential of the metal parts in contact with different areas of the soil, which is the basic factor contributing to the establishment of the oxygen concentration corrosion battery. Soil pH, salt content, and other properties of the change will also cause corrosion macrocells. Long-distance pipelines inevitably have to cross a variety of different conditions of the soil. The formation of long-distance corrosion macrocells is different from other media. Corrosion in the soil plays a role in the following types of macrocells: (i) Long-distance corrosion macrocells: The extended metallic infrastructure buried underground forms a long-distance corrosion macrocell through differential soil compositions and stratified geological structures. (ii) Corrosion macrocells resulting from soil localized heterogeneity: Areas of stone accumulation in the soil are less permeable than soil proper, making it easier for the metal in that area to become the anode of the corrosion macrocell during corrosion, while the metal in the soil-only area becomes the cathode. (iii) Corrosion macrocells caused by different burial depths and edge effects: Due to the different depths of burial and the presence of oxygen diffusion in the soil, an oxygen concentration corrosion cell effect can be formed in areas at different depths. As oxygen more easily reaches the edge of the electrode, the edge of the metal components on the same level becomes the cathode. Compared to the anode area (central part), corrosion of the material edge would be much lighter. (iv) Corrosion macrocells due to differences in metal states: corrosion macrocells formed as a result of dissimilar metal contact, temperature differences, stresses, and different surface states of metals in soil. This in turn induces localized corrosion of the material.

Environmental factors affecting soil corrosion mainly include: (i) Porosity (permeability): larger porosity is conducive to oxygen penetration and water transmission, and this is the initial occurrence of corrosion promotion factors. Good permeability accelerates the corrosion process of microcells. With poor permeability, the presence of anaerobic microorganisms in the soil leads to microbial corrosion. (ii) Soil temperature: the higher the temperature, the greater the corrosion rate. (iii) Soil water content: when the soil water content is very high (water saturation >80%), the diffusion of oxygen is hindered, and corrosion is reduced. With the reduction of water content, the depolarization of oxygen becomes easier, and the corrosion rate is increased. When the water content falls below 10%, the anodic polarization and the soil resistivity are increased, and the corrosion rate is reduced sharply. (iv) pH value: as soil acidity increases, soil corrosion increases. When the soil contains a large number of organic acids, its pH value is close to neutral, but its corrosiveness is still very strong. (v) Resistivity: generally, the smaller the soil resistivity, the more serious the soil corrosion. Soil resistivity can be used as a parameter for evaluating soil corrosivity. (vi) Soluble ions (salt): soil generally contains sulfates, nitrates, chlorides, and other inorganic salts. In the soil, the electrolyte cations are generally potassium, sodium, calcium, magnesium, and other ions; anions are carbonates, chlorides, and sulfate ions. A large salt content in the soil increases its electrical conductivity and the corrosiveness of the soil. (vii) Soil redox potential: soil redox potential and soil resistivity can also be used as a major indicator of soil corrosivity. Soil corrosivity is generally believed to be −200 mV (vs. SHE) below the anaerobic conditions if corrosion is intense and is susceptible to the role of sulfate-reducing bacteria. (viii) Microorganisms: microbiologically induced corrosion (MIC) is corrosion due to the presence and activity of microorganisms and/or the action of their metabolites. Bacteria, fungi, and other microorganisms play an important role in soil corrosion and the corrosion mechanism is complex. It has been found that there are large corrosion rates in soil due to the action of microorganisms. (ix) Stray current: stray current refers to the current flowing into other places from the leakage of the intended normal circuit, such as electrified railways, electrolysis and electroplating tanks, welding machines, electrochemical protection devices, and disturbances in the large geomagnetic fields. In many cases, stray currents flowing through underground metallic facilities result in severe corrosion damage.

The role of various soil environmental factors on corrosion is intricate and complex. The corrosion behavior and mechanism of metallic materials in specific soil environmental conditions need to be determined through long-term field tests. Usual soil environment corrosion contains uniform corrosion and pitting corrosion simultaneously, hence, grading must be evaluated simultaneously using both uniform and pitting corrosion factors, as shown in Table 1.2.

1.2.3 Natural Water-Corrosive Environment

Corrosion in the water environment generally includes freshwater corrosion, salt lake water corrosion, and seawater corrosion, of which freshwater generally refers to river water, lake water, groundwater, and other natural water with low salt content. Compared with seawater, freshwater has low salinity and variable water quality conditions, and freshwater corrosion is greatly affected by environmental factors of

Table 1.2 Carbon steel soil corrosion classification criteria.

Corrosion class	I (Excellent)	II (Good)	III (Moderate)	IV (OK)	V (Poor)
Corrosion rate/(g/dm^2/a)	<1	1–3	3–5	5–7	>7
Maximum corrosion depth/(mm/a)	<0.1	0.1–0.3	0.3–0.6	0.6–0.9	>0.9

water quality. Usually the salinity of lake water ≥50 g/l brine lake or those lakes with self-dissolving salt deposits are defined as salt lake.

Around 70.9% of the Earth's surface is the ocean. Corrosion of metallic materials in the ocean is quite serious. Marine corrosion losses account for about one-third of the total corrosion losses. In recent years, with the vigorous development of the marine economy, the problem of corrosion in various types of marine equipment has become increasingly prominent [3]. Seawater is a very complex composition of natural electrolytes. Surface seawater (1–10 m) is saturated with oxygen and carbon dioxide, with a pH value of 8.2 or so, and is a corrosive electrolyte solution at room temperature with a certain flow rate. It has high salt content, electrical conductivity, corrosivity, and biological activity. Seawater contains a large number of sodium chloride-based salts and is often approximated as a 3.5% NaCl solution. The temperature of seawater varies between 0 and 35 °C with geographic location, ocean depth, day and night conditions, seasons, and so on. Oxygen content in seawater is the main factor in seawater corrosion, and the surface layer of seawater is saturated with air under normal conditions at the sea surface. The pH in seawater is usually 8.1–8.3, but it varies greatly in local areas.

The marine environment is the world's most complex natural environmental corrosion system, which can be categorized into marine atmospheric zones, splash zones, tidal zones, fully immersed zones, and sea mud zones. According to the different depths of seawater, the fully immersed area can be divided into shallow water, continental shelf, and deep sea area. Marine atmospheric area refers to the sea surface splash zone above the atmospheric area and coastal atmospheric area, carbon steel and low-alloy steel used in this environment would be corroded seriously. Splash zone refers to the zone above the average high tide line where the waves splash and wet. Due to the full contact of seawater and air here, the oxygen content reaches the maximum degree, coupled with the impact of the waves, making the splash zone the most corrosive area. Tidal zone is the area between the average high tide level and the average low tide level, and its corrosion rate is slightly higher than the full immersion zone. However, for long-sized steel strip specimens, the corrosion rate in the tidal zone is lower than that in the total immersion zone. The mean low tide line below the part up to the bottom of the region is known as the total immersion zone. The marine mud area consists mainly of seafloor sediments. Unlike land soil, the sea mud zone has high salinity, low resistivity, and is more corrosive. Compared with the fully immersed zone, the oxygen concentration in the marine mud zone is low, and the corrosion rate of steel in the marine mud zone is usually lower than that in the fully immersed zone. The corrosion behavior of materials in the deep sea is as follows: with the increase in depth, the uniform corrosion is weakened, the local corrosion increases.

The main environmental factors of seawater corrosion are: (i) Salinity: The salinity in seawater is just close to the salt concentration required to maximize the corrosion rate of steel. When the salinity exceeds a certain value, the increase in salinity decreases the solubility of oxygen and the corrosion rate of the material decreases. (ii) pH: as the pH of seawater is generally neutral, the corrosion effect is not significant. In the deep sea, pH is slightly reduced, which is not conducive for the generation of protective carbonate layer on the metal surface. (iii) Carbonate saturation: in the pH conditions of seawater, carbonate saturation, easy to deposit on the metal surface, and the formation of a protective layer. The river water at the estuary dilutes the seawater, making the carbonate solution undersaturated. As a result, it is less likely to precipitate and form a protective layer on the metal surface, leading to an increase in corrosion. (iv) Oxygen content: if the seawater oxygen content increases, it can increase the metal corrosion rate. (v) Temperature: increase in the temperature can usually accelerate the reaction, but with the rise in temperature, the oxygen solubility decreases, and weaken the temperature effects. (vi) Flow rate: as the flow rate increases, the corrosion rate increases. However, for metals that can be passivated in seawater, an appropriate flow rate can promote the passivation and corrosion resistance of titanium, nickel alloys, and high-chromium stainless steel. When the seawater flow rate is very high, metal corrosion increases dramatically, which is the same as in freshwater, due to friction, impact, and other mechanical forces, abrasions, erosion, and cavitation. (vii) The influence of biological factors: the organisms and microorganisms in seawater can attach to the material surface, accelerating the corrosion of the material.

1.3 Industrial Corrosive Environments

Industrial environments involve high temperatures, high pressures, and corrosive media such as various acids, alkalis, salts, and chemical substances, which accelerate the corrosion failure process of materials. Typical industrial corrosive environment of petroleum, chemical, and nuclear power industry is also extremely complex.

1.3.1 Corrosive Environments in the Petroleum Industry

The petroleum industry consists of exploration, drilling, development, oil recovery, gathering, refining, and storage. All aspects of the petroleum industry are closely linked to steel, and most of the steel structures are in service in very harsh environments, leading to severe corrosion of equipment in the petroleum industry.

The corrosion-prone environments in the oil extraction process are mainly in the drilling, oil extraction, and gathering and transportation projects. The corrosive medium in the drilling process mainly comes from the atmosphere, drilling fluid, and formation outputs, usually several components exist at the same time; oil extraction and gathering and transportation projects are mostly CO_2 and H_2S-corrosive environments; oil and gas gathering and transportation projects also have water-doped environments [4].

The main corrosive environment of the oil refining industry contains: (i) $HCI + H_2S + H_2O$ corrosive environment mainly exists in the normal decompression distillation unit, the temperature is lower than 150 °C parts; (ii) sulfide corrosive environment, including: room temperature sulfide stress cracking corrosion and dew-point corrosion and 240 °C higher than the corrosive environment formed by the heavy oil parts of sulfur, sulfide, and hydrogen sulfide; (iii) naphthenic acid corrosive environment exists between 220 and 400 °C; (iv) Hydrogen embrittlement (HE) environment mainly occurs at room temperature, hydrogen corrosion refers to the temperature above 200 °C, hydrogen partial pressure >0.5 MPa caused by corrosion.

Petrochemical equipment corrosion environment for: (i) high-temperature hydrochloric acid corrosion environment; (ii) high-temperature sulfuric acid corrosive environment; (iii) hydrogen fluoride, and hydrofluoric acid corrosive environment.

Petrochemical fiber equipment corrosion environment: (i) acetic acid, maleic acid, and other organic acids corrosion environment, (ii) sulfuric acid corrosion environment, (iii) hydrochloric acid corrosion environment. In addition, chemical fiber equipment also exists in the corrosive environment of adipic acid, terephthalic acid corrosive environment, and sodium hydroxide corrosive environment.

The common corrosive environments of large nitrogen fertilizer plants are: low-temperature $H_2S—CO_2—H_2O$ environment; high-temperature hydrogen corrosion environment; medium-temperature $CO_2—CO—H_2$ environment; $K_2CO_3—CO_2—H_2O$ environment; high temperature and high-pressure $H_2—N_2—NH_3$ environment; room temperature ammonia environment.

1.3.2 Corrosive Environments in the Chemical Industry

The chemical industry is the most complex man-made corrosive environment of the industrial field. The history of almost every new product and the emergence of new processes are accompanied by the emergence of new corrosive environment; almost all man-made corrosive environment exists in the chemical industry. According to its medium classification, it is mainly divided into acid corrosion environment, salt corrosion environment, and alkali corrosion environment.

Chemical industry acid and alkali corrosion environment include all organic acids, inorganic acid environment, and all alkali. Their corrosion of metal is serious, and corrosion law is also complex. Acid corrosion of metals, depending on whether it is oxidizing or nonoxidizing, is very different.

Chemical industry salt corrosive environment has a variety of categories of forms. According to the acidity and alkalinity, when the salt is dissolved in water, the salt can be divided into acidic, neutral, and alkaline salts and oxidizing and nonoxidizing salt distinction. Table 1.3 lists the classification of some inorganic salts.

1.3.3 Corrosive Environments in the Nuclear Power Industry

The main corrosive media and environments in the nuclear industry are: radiation and irradiation; high-temperature and high-pressure water, high-purity sodium and high-purity lithium; and strongly aggressive media. Vibration corrosion, scouring corrosion, and corrosion fatigue in nuclear reactor operation and oxidation of zirconium alloys in high temperature water vapor are important [5].

Rays and irradiation corrosion environment: the nuclear industry often see rays of α-particles, β-particles, X-rays, γ-rays, neutron flow, etc., in addition to proton flow, deuteron flow, and other charged heavy particle beams. These rays will more or less play a role in the corrosion of the material [6].

Table 1.3 Classification of acidity and alkalinity of some inorganic salts.

	Neutral salt	**Acid salt**	**Alkali salt**
Nonoxidizing	NaCl KCl Na_2SO_4 K_2SO_4 LiCl	NH_4Cl $(NH_4)_2SO_4$ MnO_2 $FeCl_2$ Ni_2SO_4	Na_2S Na_2CO_3 Na_2SiO_3 Na_3PO_4 $Na_2B_2O_7$
Oxidizing	$NaNO_3$ $NaNO_2$ K_2CrO_4 K_2CrO_7 $KMnO_4$	$FeCl_3$ $CuCl_2$ $HgCl_2$ NH_4NO_3	NaClO $Ca(ClO)_2$

High-temperature and high-pressure water, high-purity sodium, high-purity lithium, and high-purity helium corrosive environments: High-temperature and high-pressure water is mainly used in light-water reactors, and the environment of high-temperature and high-pressure water in the nuclear power industry is very strictly controlled. High-purity sodium is mainly used in liquid metal cooling reactors, and high-purity lithium is used in fusion reactors. There are also high-temperature gas-cooled reactors using high-purity helium. The presence of impurities in helium can cause corrosion problems.

Strongly aggressive media corrosive environment: uranium mining in the nuclear industry, the chemical treatment and processing of ores, the refining and enrichment of uranium compounds, the treatment of nuclear fuel elements after nuclear reactions in nuclear reactors, the separation and recycling of fission products, and the treatment process of radioactive waste liquids and wastes require the use of a large number of acids, alkalis, and salt compounds, which are all of different erosive properties. Corrosion problems at welds and wear and tear corrosion from mineral materials are serious. During the separation of uranium isotopes, uranium hexafluoride is chemically exceptionally active, and it reacts with water to form HF, which has an erosive effect.

1.4 Uniform Corrosion and Localized Corrosion

The forms of metal corrosion are generally divided into two major categories: uniform corrosion and localized corrosion. Localized corrosion can be further classified into pitting corrosion, crevice corrosion, galvanic corrosion, intergranular corrosion, selective corrosion, stress corrosion, corrosion fatigue, and erosion–corrosion, commonly referred to as the eight main forms of localized corrosion. Localized corrosion, in contrast to uniform corrosion, is characterized by the occurrence of corrosion limited to or concentrated on a specific part of the metal. When localized