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Salinity, an important factor in the corrosion of the ship's metal structures. Review

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Abstract. Corrosion is the degradation of metal materials under the action of external factors. In the maritime domain, this is a major problem affecting ship hulls and most metal structures. Salinity is one of the most important factors acting on metal bodies.
This article aims to analyze the influence of salinity concentration on the ship's metal structures and the mechanisms involved.
For an efficient and modern naval industry, proper corrosion prevention is necessary to ensure the safety of maritime operations and the optimization of equipment maintenance costs.
Keywords: corrosion, salinity, naval industry.

1. Introduction

Corrosion represents one of the most significant dangers in the maritime domain, because it can seriously affect metal compounds of the ships body.

This article intends to study the impact the salts contained in seawater have on the metal structures of ships, and the necessary measures to avoid and counterbalance the effects of corrosion. Salinity represents the number of dissolved salts present in water. The average salinity of seawater is approximately 35 g/L. The seawater salts enhance its conductivity and stimulate chemical processes. [Morcillo et al, 2000]

The deterioration of metals and alloys as a result of interaction with the seawater leads to corrosion, specifically to the creation of an electrochemical reaction between the salts in seawater and oxygen. This reaction is the main cause for the occurrence of rust (iron oxides) that acts on the ship's structural integrity and can cause serious damage and failures.

The activity of seagoing ships takes place in an excessively aggressive environment, where regular exposure to salt water, oxygen, temperature variations, and other conditions substantially contributes to the degradation of metallic structures. Corrosion in marine environment is both a technical and an economic issue, affecting operational efficiency and demanding important maintenance and repair costs.

2. Categories of Corrosion Found on Ships

A ship's hull, which is made basically of steel or metallic alloys, is exposed to a vast range of corrosive processes, especially in the marine environment, where such processes are accelerated by the presence of salt water, oxygen, and other environmental agents. Below are the most common types of corrosion that can affect the metal ship structures.

2.1. Uniform Corrosion

Is the most frequent form of corrosion and acts as a uniform loss of material across the entire exposed surface. It appears when the metal surface is exposed to the environment and has a consistent rate of progression. Even if uniform corrosion is relatively foreseeable and controllable, it can provoke erosion of ship’s hull and, over time, to a reduction in mechanical strength. [Li & Wang, 2017]

Example: The ship's hull in permanent contact with seawater.

2.2. Galvanic Corrosion

Takes place when two distinct metals, being in electrical contact, are immersed in an electrolytic medium (such as salt water). The metal with the lower electrochemical potential (less noble) behaves as the anode and its corrosion is faster, while the more noble metal is somewhat protected. [Qian et al, 2023]

Influencing factors:

- Difference in electrochemical potential of the metals;
- Surface area of the two metals (a smaller anodic surface corrodes faster);
- Environmental conductivity.

Example: Linking a brass (noble) element to a steel body (less noble) without proper insulation.

2.3. Pitting Corrosion

Is a heavy type of corrosion that occurs in specific spots or confined areas of the metal surface, especially where there are imperfections in the protective layer or deposits. [Zhu, et al, 2022] It is hard to detect it in the early stages and has the capacity to rapidly lead to perforations in the metal. [Xu, et al, 2020]

Example: Corrosion existing beneath biological debris or accumulated sediments on the hull.

2.4. Stress Corrosion Cracking

Is a dangerous type of corrosion implying the interaction between a corrosive environment and mechanical stresses (internal or external) applied to the material. It is a main cause for the formation of cracks that may extend fast and unpredictably without visible warning signs. [Tian, et al 2022]

Example: Welded ship components being under stress during service and exposed to the marine environment.

2.5. Erosion-Corrosion

Appears during the simultaneous exposure of a metal surface to corrosive action and mechanical forces due to rapid fluid flow (seawater). The protective oxide layer can be removed by high water velocity or abrasive particles, accelerating corrosion.

Example: Ship’s propellers, keel, water intakes and discharge zones.

2.6. Intergranular Corrosion

Occurs along the limits of metal crystals, particularly in stainless steels exposed to high temperatures (e.g., during welding) without a proper post-treatment. It can provoke weakening of structural integrity, even though the surface may appear intact.

Example: Welded pipes or elements exposed to high temperature variations.

2.7. Microbiologically Influenced Corrosion

Is a type of corrosion caused or accelerated by the metabolic activity of certain microorganisms, such as sulfate-reducing bacteria, responsible for creating a localized aggressive chemical environment that lead to rapid metal degradation. [Yin, et al, 2023]

Example: Ballast tanks or stagnant hull zones where bacterial colonies usually develop.

This classification emphasizes the variety of corrosion mechanisms that can affect a ship. In practice, these corrosion types often occur simultaneously, overlapping and complicating both diagnosis and effective treatment. [Zhang, et al, 2021]

3. Environmental Factors Influencing Corrosion

In addition to materials used, structural corrosion of ships is also determined by the specific conditions of the marine environment in which they operate. The marine environment, especially saline, is a natural electrolytic complex that facilitates oxidation reactions. [Cai,et al 2018; Soares et al 2009] The main environmental factors that accelerate or alter corrosion mechanisms in ships are presented below.

3.1. Water Salinity

Seawater has a high salt content, especially chlorides (NaCl), which increase conductivity and facilitate ions transfer between the anode and cathode. Chloride ions destabilize passive oxide layers on metal surfaces, promoting pitting and galvanic corrosion.

Higher salinity equals faster corrosion.

3.2. Water and Air Temperatures

Temperature is a factor that considerably influence the rate of electrochemical reactions. Generally, high temperature accelerates corrosive processes by:

- Strengthening salt solubility and ion mobility;
- Intensifying reaction speed between oxygen and metal;
- Potential deterioration of protective layers.

In comparison with polar waters, corrosion is much more aggressive in tropical zones, due to high water temperature.

3.3. Dissolved Oxygen Concentration

Oxygen is an essential oxidizing agent in electrochemical corrosion. The presence of dissolved oxygen in water accelerates the formation of differential aeration cells, leading to localized corrosion in poorly aerated zones (e.g., under deposits or in cracks).

The areas that are hard to access (tanks, ballast compartments) are more prone to anaerobic or microbiological corrosion.

3.4. Water Movement (currents, waves, cavitation)

Water circulation around the ship's hull can have a considerable impact:

- Causes mechanical erosion that destroys protective films;
- Washes away corrosion products, constantly exposing fresh metal;
- Encourages cavitation corrosion, especially around the propeller and intake/discharge parts.

Erosion-corrosion is intensified by turbulent water movement.

3.5. Presence of Biological and Chemical Contaminants

Marine microorganisms (bacteria, fungi, algae) usually adhere to metal surfaces, forming biofilms, which locally alter the pH and chemical composition, contributing to microbiological corrosion. Additionally, industrial pollutants (ammonia, acids, sulfides) can accelerate degradation through aggressive chemical corrosion.

3.6. Environmental pH

The pH value influences the type of oxidation reactions occurring. An acidic environment (low pH) significantly increases corrosion of ferrous metals. Even if the seawater's pH is slightly alkaline (7.5–8.5), pollution or biological processes may alter this balance locally.

3.7. Contact with Other Materials

Except the environment, interactions with other materials (metals, polymer, paints) can alter the electrochemical potential of the structure. For example, improper use of certain alloys in proximity can provoke galvanic corrosion.

These factors often act simultaneously, making precise prediction of corrosive behavior difficult without experimental studies. [Xu et al, 2022; Congcong et al, 2024] However, understanding each factor's influence is important for an adequate material selection, protective treatments, and preventive maintenance planning.

4. Materials Used in Shipbuilding and Their Corrosion Behavior

The most commonly used materials in shipbuilding are carbon steels, stainless steels, aluminum, and copper alloys. [Pradhan et al, 2018] The choice of material directly influences corrosion resistance. For example:

- Carbon steel is cheap and easy to work with, but requires corrosion protection;
- Stainless steel is more expensive, but offers better resistance;
- Aluminum is lightweight and resistant to galvanic corrosion, but prone to stress corrosion.

5. Corrosion Protection Measures

Preventing and controlling corrosion on ships is necessary for maintaining structural integrity, ensuring operational safety, reducing maintenance costs, and increasing vessel lifespan. Due to large variety of corrosive mechanisms, the protection must combine both active and passive measures. The most common methods are presented below.

5.1. Coating Protection (Paints and Barrier Layers)

One of the most widespread prevention methods consists in applying protective coatings to metal surfaces. These coatings represent a physical barrier against water, oxygen, and corrosive ions.

Types of coatings:

- Epoxy paints that are highly resistant to abrasion and seawater action;
- Zinc-rich primers that offer local cathodic protection;
- Antifouling coatings that contain biocides to prevent marine organism accumulation.

Proper application and maintenance of protective coatings are essential, especially in exposed areas: hull, keel, propeller, ballast tanks.

5.2. Cathodic Protection

This method implies an electrochemical potential modification of the metal structure so that it can act as a cathode (inert). Two types are used:

- Sacrificial anode protection: More active metals (zinc, aluminum, magnesium) are attached to corrode instead of the main structure;
- Impressed current protection: An external power source applies a controlled current to maintain a stable cathodic potential.

This method is frequently used on ship hulls, ballast tanks, offshore platforms, and underwater pipelines.

5.3. Proper Material Selection

Material selection is essential in preventing galvanic reactions and accelerated corrosion, and the following considerations have to be taken into account:

- Natural corrosion resistance (stainless steel, copper-nickel alloys);
- Galvanic compatibility of alloys used together;
- Adequate heat treatment of welded components.

5.4. Periodic Maintenance and Visual Inspections

A planned maintenance activity allows early identification of corrosion-affected areas and prevents major degradation. [Dalmora et al, 2025] Such activity includes:

- Mechanical or hydro jet cleaning;
- Inspection and replacement of sacrificial anodes;
- Reapplication of protective coatings;
- Monitoring electrochemical potential in active cathodic protection systems.

5.5. Control of Contaminants and Microorganisms

The prevention of microbiological corrosion includes:

- Complete drainage of ballast tanks when not in use;
- Use of biocides and controlled chemical treatments;
- Periodic washing of surfaces exposed to biological accumulations. [Luo,et al, 2023]

5.6. Monitoring Environmental Conditions

Can be accomplished by installing sensors for pH, temperature, dissolved oxygen and electrochemical potential.

6. Conclusions

Ship corrosion is a complex phenomenon, influenced simultaneously by different types of chemicals, physical, and biological interactions. In the marine environment, factors such as salinity, temperature, and the presence of microorganisms intensify these processes, the maintenance and protection of metal structures requiring a constant attention.

Proper identification of the type of corrosion is very important for selecting the appropriate control method. For example, cathodic protection is effective against galvanic corrosion, while special coatings are more suitable for preventing uniform and pitting corrosion.

Prevention is the most effective measure and less costly than repairs. Active measures (applying coatings, regular inspections, and using sacrificial anodes) can substantially extend the vessel's lifespan and reduce structural risks.

Materials specialists, naval engineers, and maritime operators have to collaborate closely to develop monitoring and maintenance strategies and adapt them to each ship type and operating regime. Ongoing research in corrosion protection can also result in discovering more durable and eco-friendly technologies in the future.

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