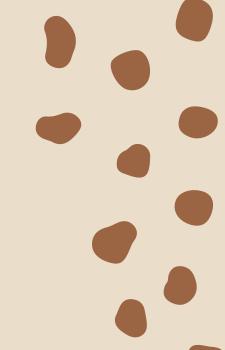
CASE STUDY ON CORROSION OF MARINE STRUCTURES **MADE BY YASH KUMAR** (B22MT047)





Corrosion is a natural process that occurs when metals react with their environment, leading to deterioration and a gradual breakdown of the material. This electrochemical reaction results in the formation of oxides or other compounds on the metal surface, compromising its integrity over time.



Causes and Factors Leading to Corrosion in Marine Environments

- 1. <u>Salinity</u>: High salt content in marine environments accelerates corrosion. Saltwater acts as an electrolyte, facilitating the flow of electric current between metal surfaces.
- 2. <u>Dissolved Oxygen</u>: Oxygen dissolved in seawater is a key contributor to corrosion. It reacts with metals, leading to the formation of metal oxides and accelerating the corrosion process.
- 3. <u>Microbial Influences</u>: Microorganisms present in marine environments can promote corrosion by producing corrosive byproducts or creating conditions that favor the growth of corrosive bacteria.
- 4. <u>Temperature Fluctuations:</u> Extreme temperature variations, especially in marine environments, can contribute to the expansion and contraction of metals, creating stress and facilitating corrosion.

Brief Overview of Different Types of Corrosion

- 1. <u>Uniform Corrosion</u>: A common and widespread form of corrosion, uniform corrosion occurs evenly across the entire metal surface, leading to a gradual loss of material.
- 2. <u>Pitting Corrosion</u>: Localized corrosion characterized by the formation of small pits or craters on the metal surface. Pitting corrosion can be particularly detrimental as it can penetrate deep into the material.
 - 3. <u>Galvanic Corrosion</u>: Caused by the electrochemical interaction between two dissimilar metals in contact with each other in the presence of an electrolyte, such as seawater.
 - 4. Stress Corrosion Cracking: Occurs due to the combined influence of tensile stress and a corrosive environment, leading to the development of cracks in the metal.

Corrosion Mechanisms in Marine Structures

1. Electrochemical Processes in Seawater

Electrochemical processes in seawater play a pivotal role in both natural phenomena and technological applications. Seawater, with its high conductivity, serves as an electrolyte, facilitating corrosion of metals in marine environments. This corrosion is a significant concern for structures like ships and offshore platforms.

2.Influence of Salinity, Temperature, and Oxygen Content

- High salinity increases ion mobility, promoting efficient electron transfer.
- Desalination processes leverage salinity differences for effective ion separation.
- Temperature impacts reaction rates and ion transport.
- Electrochemical technologies like seawater batteries are sensitive to temperature variations.
- Corrosion rates vary with oxygen availability.
- Oxygen plays a role in both protective and detrimental aspects of electrochemical reactions.

3. Galvanic Corrosion and Microbial Influences

- Occurs when dissimilar metals are in direct contact in the presence of an electrolyte (seawater).
- The more reactive metal (anode) corrodes faster, while the less reactive metal (cathode) is protected.





- Microorganisms in the marine environment can contribute to corrosion.
- Biofilm formation, metabolic activities, and secretion of corrosive substances by microbes influence corrosion rates.

Common Corrosion-Prone Materials

Steel:

- 1. Overview: Widely used in marine structures for its strength, steel is susceptible to corrosion, particularly in saltwater environments.
- 2. Identification: Carbon steel and low-alloy steel are common in marine applications.
- 3. Examples: Rusting and pitting corrosion can compromise material integrity.





Aluminum:

- Overview: Lightweight with good corrosion resistance, aluminum can corrode in marine settings due to saltwater exposure.
- Identification: Aluminum alloys, like 5xxx and 6xxx series, are common in marine applications.
- Examples: Galvanic corrosion and localized issues like pitting can occur, especially when in contact with other metals.



Copper and Brass:

Overview: Used in marine applications for corrosion resistance, copper and brass alloys (e.g., Cu-Ni, brass) are susceptible to specific corrosion types.

Identification: Copper-nickel alloys and brass alloys are common. Examples: Dezincification in brass and galvanic corrosion with dissimilar metals are concerns.

Stainless Steel:

Overview: Stainless steel, known for corrosion resistance, can still corrode in specific marine conditions.

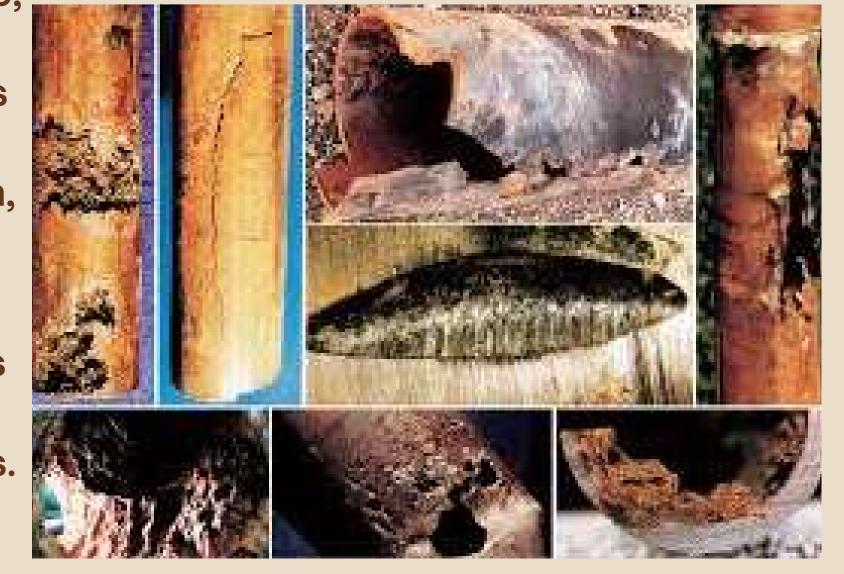
Identification: Austenitic stainless steel (e.g., 304, 316) is widely used.

Examples: Chloride-induced corrosion, crevice corrosion, and stress corrosion cracking may occur.

Cast Iron:

Overview: Used in some marine components, cast iron is prone to corrosion, especially in saltwater.

Identification: Gray iron and white iron are common types. Examples: General corrosion and pitting corrosion can affect cast iron in marine environments.



MONITORING AND INSPECTION TECHNIQUES:

Monitoring and inspection are crucial aspects of maintaining the integrity and safety of various structures and systems.

This is particularly important in industries such as manufacturing, construction, aerospace, and oil and gas, where the consequences of equipment failure or structural damage can be severe.

Importance of Regular Inspection:

- Safety Assurance
- Asset Integrity
- Reliability

- Compliance
- Cost Reduction



Common Techniques for Detecting Corrosion

Utilizing a combination of these techniques provides a comprehensive approach to detect corrosion.

Each method has its strengths, contributing to the overall effectiveness of corrosion monitoring and maintenance

Visual Inspection

Ultrasonic Testing (UT)

Electromagnetic Testing

Acoustic Emission Testing

Radiographic Testing (RT)







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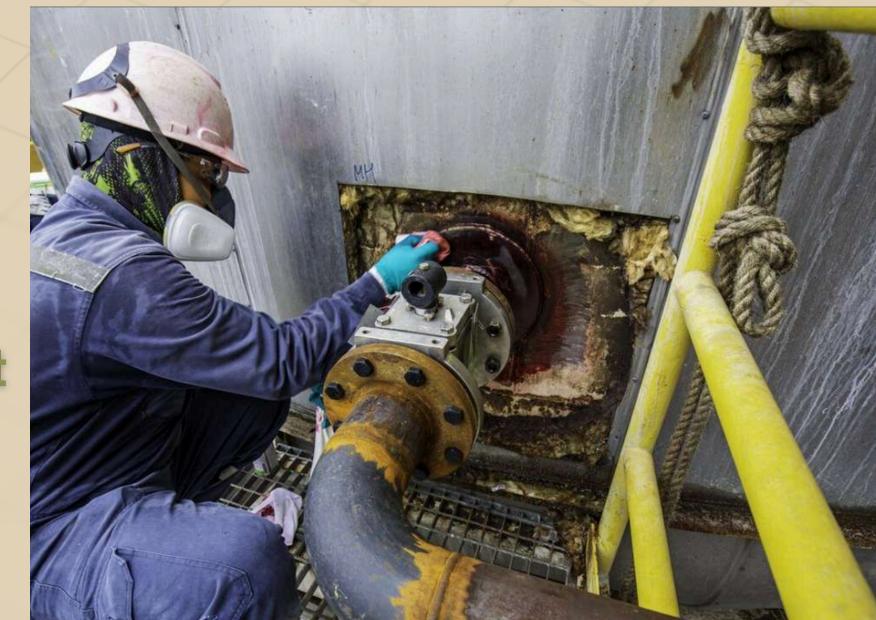
Role of Non-Destructive Testing (NDT) Methods

NDT methods play a vital role in maintaining the integrity and efficiency of structures and systems.

Their non-destructive nature, early detection capabilities, and comprehensive assessments make them essential for ensuring safety and reliability.



- Efficiency
- Quality Control
- Comprehensive Assessment
- Preservation of Integrity





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In examining corrosion failures, several real-world examples underscore the destructive impact of this phenomenon on marine structures. One notable case involves the corrosion of structural steel supports in a coastal bridge, leading to a partial collapse. Another instance involves the corrosion of offshore oil rig components, compromising their structural integrity. These cases emphasize the urgent need for effective corrosion management to prevent catastrophic failures in critical infrastructure.



SILVER BRIDGE COLLAPSE (1967)





In 1967, the Silver Bridge over the Ohio River collapsed during rush hour, causing 46 fatalities. The failure was attributed to the corrosion-induced metal fatigue of a single eyebar in the suspension chain. This incident underscored the pivotal role of corrosion in infrastructure failures, prompting advancements in inspection, maintenance practices, and the implementation of updated bridge design standards. The lessons learned have influenced global regulations and engineering practices, enhancing corrosion resistance and overall safety in infrastructure.

IMPACTS ON STRUCTURES, ENVIRONMENT, AND ECONOMY

The consequences of corrosion extend beyond structural damage. Corrosion-induced failures pose risks to human safety, environmental ecosystems, and the economy. Structural failures can result in disruptions to transportation networks, environmental contamination from leaked materials, and economic losses from repair and downtime. Understanding the broader impacts highlights the importance of proactive corrosion prevention measures for safeguarding both infrastructure and the surrounding environment.

LESSONS LEARNED FROM PAST INCIDENTS

Analyzing past corrosion incidents provides valuable lessons for future prevention. Common themes include the importance of regular inspections, the necessity of using corrosion-resistant materials, and the role of proactive maintenance strategies. Collaboration between engineers, regulators, and industry stakeholders is crucial for implementing effective corrosion management practices. By learning from these incidents, we can develop robust strategies to mitigate the impact of corrosion on marine structures and enhance overall resilience.



PREVENTIVE MEASURES AND MAINTENANCE STRATEGIES

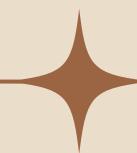
Importance:

In the battle against corrosion, being proactive is the key to success. Let's explore why.

- Being proactive means staying ahead of corrosion challenges before they become problems.
- Proactivity is crucial for minimizing costs and ensuring the longevity of structures.
- Emphasize the financial impact of corrosion-related damages.
- Preventive measures are a cost-effective way to avoid the expenses of reactive repairs.



PROTECTION TECHNIQUES



CATHODIC PROTECTION SYSTEMS (CPS)

- CP is a widely adopted method for steel structures in marine environments, including ships and infrastructure.
- Aims to counteract corrosion caused by seawater by transforming the metallic structure into a cathode within an electrochemical cell.
- Achieved through two methods: Impressed Current Cathodic Protection (ICCP) and Sacrificial Anodes Cathodic Protection (SACP).

COATING SYSTEMS (CS)

- Protective barrier against corrosion by isolating the steel surface from seawater.
- Metallic coatings, often comprising zinc or aluminum alloys, exhibit higher corrosion resistance than carbon steels.
- Coatings offer three main protective mechanisms: by creating a barrier effect, inhibiting corrosion, and supplying a galvanic effect.

CORROSION ALLOWANCE (CA)

- CA involves using thicker steel in construction as a precaution against corrosion.
- It serves as a backup solution if conventional protection systems fail or coating damage occurs.

MAINTENANCE STRATEGIES



In the context of marine structures, the following three maintenance strategies are often considered crucial:

Preventive Maintenance (PM):

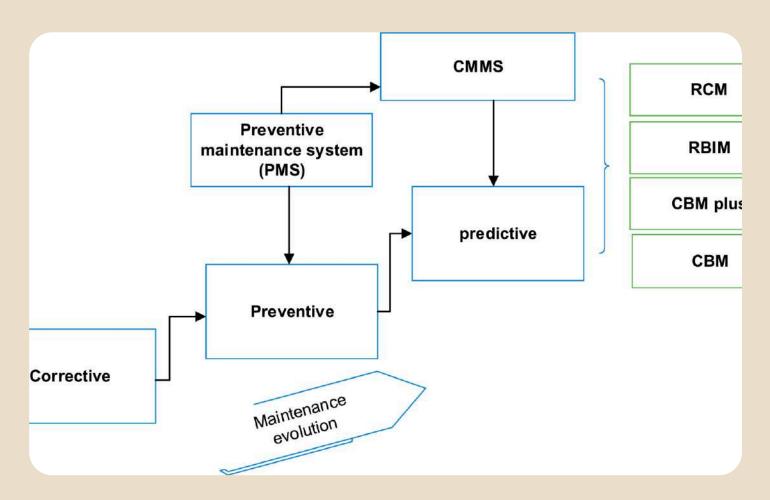
- Interval-based maintenance to avoid potential failures and degradation.
- Higher system availability, reduced failure rates, longer lifespan, and lower costs compared to corrective maintenance.

Reliability-Centered Maintenance (RCM):

- Planned maintenance program to retain essential functions while improving reliability, maintainability, and availability.
- Reported to reduce maintenance effort by 40%–70% compared to other strategies.

Condition-Based Maintenance (CBM):

- Uses modern CM methods to diagnose faults and predict future working conditions.
- More effective than time-based PM; can extend maintenance cycles and save costs.



REGULATORY COMPLIANCE

Regulatory compliance in the context of corrosion of marine structures refers to the adherence and fulfillment of rules, standards, and guidelines established by national and international regulatory bodies, as well as classification societies and industry organizations, to ensure the prevention, monitoring, and mitigation of corrosion in marine structures. The aim is to promote the safety, environmental sustainability, and structural integrity of marine installations.

Key aspects of regulatory compliance in this context include:

- Material and Coating Standards
- Corrosion Prevention Plans
- Monitoring and Reporting
- Environmental and Safety Compliance





RELEVANT REGULATIONS AND STANDARDS

International Maritime Organization (IMO) Standards:

- International Maritime Organization (IMO): The IMO sets global standards for the safety, security, and environmental performance of international shipping. Relevant conventions include:
 - International Maritime Solid Bulk Cargoes Code (IMSBC Code)
 - International Maritime Dangerous Goods (IMDG) Code
 - International Maritime Organization's Antifouling Systems Convention (AFS)

ISO Standards:

• **ISO 12944:** This standard provides guidelines for corrosion protection of steel structures by protective paint systems. It classifies environments based on corrosivity and recommends appropriate coating systems.

DNV GL (Det Norske Veritas Germanischer Lloyd):

 DNV GL provides classification services and issues guidelines related to the design, construction, and maintenance of maritime structures, including those addressing corrosion prevention.







• ASTM G28:

ASTM G28 is a series a test methods designed to detect susceptibility to intergranular corrosion in wrought, nickel-rich, chromium bearing alloys, including but not limited to alloys such as N06625 and N08800. It can also be effective in evaluating the impacts of heat treatment processes on a materials corrosion resistance.

• ASTM A262:

ASTM A262 is a set of practices designed to detect susceptibility to intergranular attack of austenitic stainless steels. The various practices included in ASTM A262 cover a range of reduction potentials, allowing this test to be applied to a wide variety of stainless steels. It can be used to compare different alloys via the corrosion rate determined during testing, as well as ensuring that the corrosion rate of a given piece of material meets the requirements of its end use environment.



IMPORTANCE OF COMPLIANCE IN MINIMIZING CORROSION RISKS

Reasons why compliance is important in minimizing corrosion risks

1. Structural Integrity and Safety:

- Adherence to Standards: Compliance with international and national standards ensures that marine structures are designed, constructed, and maintained to specific criteria, contributing to their overall structural integrity.
- Safety of Personnel: Complying with regulations helps ensure the safety of individuals working on or around marine structures, as corrosion-related failures can lead to accidents and injuries.

2. Environmental Protection:

- **Pollution Prevention:** Compliance with environmental regulations helps prevent the release of harmful substances into marine environments, reducing the environmental impact of corrosion-related incidents.
- Sustainable Practices: Following standards contributes to sustainable practices by promoting responsible corrosion management and minimizing the ecological footprint of marine structures.

3. Operational Reliability:

- **Reduced Downtime:** Regular inspections and maintenance, as required by regulations, contribute to the early detection and prevention of corrosion. This, in turn, reduces the risk of unexpected failures and operational downtime.
- Extended Service Life: Compliance with corrosion prevention measures outlined in standards contributes to the longevity of marine structures, reducing the need for premature replacements and associated costs.



4. Financial Implications:

- Cost Avoidance: Regulatory compliance helps avoid costs associated with corrosion-related failures, such as repairs, replacements, and environmental remediation. It is often more cost-effective to invest in prevention and compliance upfront.
- o Insurance and Liability: Compliance may impact insurance coverage and liability considerations. Meeting industry standards can positively influence insurers and reduce potential liabilities in case of incidents.

5. International Trade and Shipping:

• Global Acceptance: Compliance with international regulations, especially those set by organizations like the IMO, enhances the global acceptance of marine structures. It facilitates international trade by ensuring vessels meet recognized safety and environmental standards.

6. Public and Stakeholder Trust:

• **Reputation Management:** Demonstrating commitment to regulatory compliance builds trust among stakeholders, including the public, investors, and regulatory authorities. It enhances the reputation of organizations operating and managing marine structures.



CASE STUDY EXAMPLES OF SUCCESSFUL REGULATORY IMPLEMENTATION

1.) PIPELINE CORROSION PREVENTION

Pipeline corrosion prevention involves applying protective coatings, utilizing cathodic protection systems, and implementing corrosion inhibitors. Coatings shield the pipeline from external elements, cathodic protection involves sacrificial anodes or impressed currents to counteract corrosion, and inhibitors form protective layers in transported fluids. Regular inspections, smart pigging, and real-time monitoring are critical for early detection. Material selection, proper design, and compliance with industry standards contribute to robust corrosion prevention, ensuring pipeline integrity, reliability, and environmental safety.

2.) BALLAST WATER MANAGEMENT

Ballast water management is a maritime practice aimed at preventing the spread of invasive species through ships' ballast water. Ships take in ballast water to maintain stability, but if not managed properly, it can transfer harmful aquatic organisms across ecosystems. International regulations, like the International Maritime Organization's Ballast Water Management Convention, require ships to adopt treatment systems or exchange methods to remove or neutralize these organisms before discharge. This helps safeguard marine environments, biodiversity, and ecosystems, promoting responsible environmental practices in the shipping industry.

Future Trends in Corrosion Prevention

- Corrosion prevention is a persistent challenge in various industries.
- Explore upcoming trends shaping the future of corrosion prevention.

- Nanotechnology Coatings: Researchers are exploring nanomaterials to develop coatings with enhanced protective properties. Nanoparticles can provide better adhesion and coverage, forming more effective barriers against corrosive elements.
 - 2.Self-Healing Materials: The development of smart materials capable of self-repair is gaining traction. These materials can automatically mend small defects, reducing the need for manual intervention and extending the lifespan of structures or equipment.
- 3. Smart Corrosion Sensors: Integration of sensors and Internet of Things technology allows real-time monitoring of corrosion conditions. This data-driven approach enables proactive maintenance, helping to identify and address potential corrosion issues before they escalate.

4.Predictive Analytics: Data analytics and machine learning are being applied to corrosion data to predict future corrosion events. By analyzing patterns and trends, industries can implement targeted maintenance strategies, optimizing resources and minimizing downtime. using data and machine learning.

5.Environmentally Friendly Solutions: The industry is moving towards eco-friendly corrosion prevention methods. This includes the use of sustainable coatings, green inhibitors, and processes that have minimal environmental impact.

Economics Of Corrosion

Corrosion costs the maritime industry between \$50 and \$80 billion annually not including indirect costs.

Some facts may explain why corrosion is so costly:

- 5 metric tons of steel disintegrate every second worldwide.
- 40% of all produced steel is used to replace corroded steel.
- 60% of the world offshore fleet is past its theoretical design age of 20 years, including 6,000 stationary platforms that cannot be moved.
- Offshore maintenance is 15 20 times more costly than performing work at a yard.
- Corrosion can account for 60% of offshore maintenance costs.
- At least a portion of the cost can be attributed to coating failure.



The Cost

Cost of marine paint: - 485/L

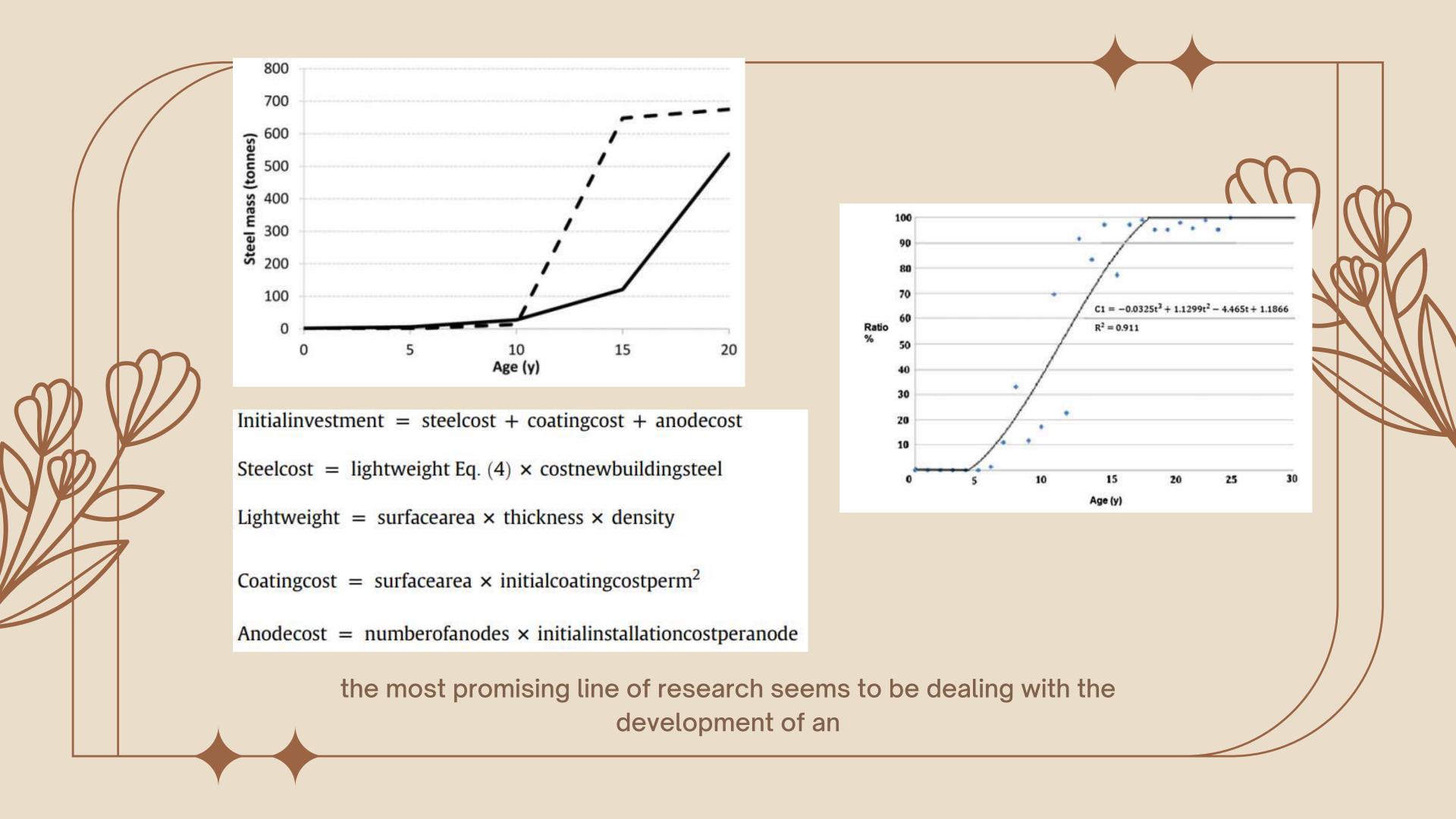
The cathodic protection part of the ICCP projects averages \$14.08/ft2 (\$151.47/m2), while zinc anode installation costs an average of \$7.13/ft2 (\$76.67/m2).

For the U.S. marine shipping industry, the annual corrosion-related costs are estimated at \$ 2.7 billion.

Statistics for ship hulls show that 90% of ship failures are attributed to corrosion

Effective ship maintenance can only be carried out during dry docks. A ship has to visit the dry dock two times every five years, during one of which steel and coating repair jobs are performed.

 $Dry\ dock\ cost\ =\ [Dry\ dock\ time\ \times (Time\ Charter\ Equivalent\ +\ cost\ of\ dry\ dock\ per\ day)]$



Environmental Consequences of Corrosion

Water and Soil Contamination: Corrosion releases toxic metals into water bodies, threatening aquatic life and soil quality.

Health Risks: Metal pollutants pose health threats through contaminated water and seafood consumption, impacting both humans and ecosystems.

Infrastructure Damage and Economic Costs: Corrosion-induced damage leads to economic losses, disrupting services and requiring extensive repairs.

Energy Consumption and Carbon Emissions: Frequent maintenance and replacement contribute to increased energy use and carbon footprint.

Habitat Disturbance: Corroded structures alter natural habitats, impacting biodiversity and ecosystem stability.

Reduced Structural Integrity: Corrosion weakens structures, posing risks of catastrophic failures in critical infrastructure.

Aesthetic and Recreational Impact: Corrosion diminishes visual appeal, affecting recreational value and tourism in affected areas.

Conclusion: Implementing preventive measures and sustainable practices is crucial to mitigate the environmental impact of corrosion and ensure long-term environmental and economic sustainability.

Environmental Consequences of Corrosion in Marine Ecosystems:

- 1. Chemical Pollution: Corrosion of metal structures, especially those containing toxic elements such as lead, mercury, and cadmium, can release these substances into the marine environment. These pollutants can accumulate in the water, sediments, and marine organisms, leading to adverse effects on the health of aquatic life.
- 2. Habitat Modification: Corroded structures, such as shipwrecks and abandoned platforms, can alter the physical structure of marine habitats. This may affect the distribution and abundance of marine species, potentially leading to the displacement of native organisms or the creation of artificial habitats.
- 3. Release of Corrosion Inhibitors: Some corrosion protection methods involve the use of inhibitors to slow down the corrosion process. However, these inhibitors may contain chemicals that, if released into the marine environment, can have harmful effects on marine life and disrupt ecosystems.
- 4. **Economic Impact:** Corrosion-related damage to marine infrastructure, such as bridges, piers, and offshore platforms, can result in significant economic losses. The need for frequent repairs and maintenance increases the risk of environmental exposure to corrosive materials and chemicals.

Strategies for Environmentally Friendly Corrosion Solutions:

Protective Coatings: Non-toxic coatings for long-lasting corrosion resistance.

Cathodic Protection: Sacrificial anodes or impressed current systems to prevent corrosion.

Material Selection: Use corrosion-resistant materials like stainless steel and aluminum.

Biodegradable Inhibitors: Develop and use eco-friendly corrosion inhibitors.

Regular Inspection and Maintenance: Timely actions to identify and address corrosion issues.

Green Corrosion Technologies: Research sustainable methods for corrosion prevention.

In summary, addressing the environmental consequences of corrosion in marine ecosystems requires a holistic approach that combines the use of environmentally friendly corrosion solutions, proper material selection, and regular maintenance practices. Implementing these strategies can help minimize the impact of corrosion on the environment while ensuring the integrity and longevity of marine structures.

Maintenance Strategies for Off-shore Structures

CHALLENGES FACED IN THE MAINTENANCE OF OFF-SHORE STRUCTURES

- The corrosive effects of saltwater, coupled with the harsh marine environment, can cause accelerated corrosion rates that can compromise the safety and longevity of vessels.
- Delays in addressing corrosion issues can lead to increased repair costs and downtime.
- CUI-Corrosion under insulation, can result in significant damage, especially in areas with fluctuating temperatures.
- Corrosion combined with cyclic loading can accelerate material degradation and increase the risk of structural failure.

INSPECTION AND MONITORING METHODS

- Regular <u>visual inspections</u> of all
 Non-destructive testing (NDT) structures platform
 - and components above and below water to identify corrosion, coating other damage. This can be done by inspectors on the platform, underwater divers, or remotely via cameras/drones.
- Levels of protective electrical monitored are current on submerged or buried platform structures to ensure the cathodic protection system is working to prevent corrosion.
- methods such ultrasonic as thickness gauging, radiography, and eddy current testing to breakdown, metal loss, cracks, or measure loss of metal thickness in structural members, tanks, pipes etc. due to corrosion. This identifies areas needing repair.
 - Testing of fluids, process produced water, and seawater around the platform to monitor for contaminants and chemistry changes that could accelerate corrosion.

 Probes are permanently installed on submerged platform members and give real-time corrosion rate monitoring by measuring electrical resistance changes as metal loss occurs.

CORROSION IN SPANISH BOATS-A CASE STUDY

CAUSES:

- Lack of qualified maintenance personnel on ships and in repair workshops
- lack of rigorous inspections and enforcement of standards by maritime authorities.
- aging fishing fleet and overcapacity for current fishing stocks led to financial pressures, heavier use of older boats, and inability to invest properly in maintenance.
- The supply and service sector was geared more towards recreational boating

PROPOSED SOLUTIONS

- <u>Implementing mandatory national</u> and international standards for inspections, maintenance, and repairs
- Increased training programs to develop skilled maintenance workers and inspectors qualified in corrosion prevention methods.
- More rigorous inspection schedules
- Expanding use of impressed current cathodic protection systems for professional fishing vessels
- <u>Financial programs</u> to help upgrade and renew aging fishing fleets within sustainable fishing limits



Corrosion in ship structures: Challenges and Solutions

Corrosion is a significant concern in ship structures due to the harsh marine environment. It can compromise the safety of vessels, leading to costly repairs and potential accidents. Therefore, understanding the factors contributing to corrosion, implementing preventive measures, and learning from case studies are crucial for mitigating this issue effectively.

Factors Contributing to Corrosion in Ship Structures:

- Saltwater Exposure: Seawater contains chlorides that accelerate the corrosion process.
- **Electrochemical Reactions:** The presence of dissimilar metals coupled with the electrolyte(seawater), leads to galvanic corrosion.
- Temperature and Humidity: Variations in Temperature and humidity levels can exacerbate corrosion rates.

- Microbial Activity: Marine organisms like algae and barnacles can facilitate the localised corrosion.
- <u>Mechanical damage:</u> Impact from waves or floating debris can remove protective coatings, exposing underlying metal to corrosion.

Preventive Measures for Ship Corrosion:

- <u>Cathodic Protection:</u> Installing sacrificial anodes or impressed current systems to protect the ship's hull from galvanic corrosion.
- <u>Protective Coatings:</u> Applying zinc, epoxy, or other corrosion-resistant coating to surfaces vulnerable to corrosion.
- <u>Regular Maintenance:</u> Implementing inspection and maintenance schedules to detect and repair corrosion damage promptly.
- Environmental Controls: Minimising exposure to corrosive environments through proper ventilation, drainage systems, and freshwater rinsing.

Case Studies of Corrosion Issues in Ship Structures:

HMS Warrior: The historic iron-hulled warship experienced severe corrosion due to prolonged exposure to seawater. Restoration efforts included extensive surface preparation and the application of advanced coatings to prevent further deterioration.

Oil Tanker Leaks: Corrosion-induced leaks in oil tanker hulls have led to environmental disasters. Investigations revealed inadequate maintenance and ineffective corrosion protection measures as contributing factors.

Cargo Ship Hatch Covers: Corrosion-related failures of hatch covers on cargo ships have resulted in cargo damage and safety hazards. Enhanced inspection protocols and retrofitting with corrosion-resistant materials have been implemented to address these issues.

