Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

A review of nanocomposite coatings for marine applications

G. Nagarajan
gnaga@niot.res.in
Scientific Officer, Ministry of Earth Sciences, National Institute of Ocean Technology, Chennai, Tamil Nadu, India

Abstract: This paper reviews the performance and material characterization of nanocomposite coatings on the hydraulic pipelines of Ship A-Frame, which were corroded due to seawater exposure. Hydraulic pipe lines made of carbon steel face severe corrosion due to the highly corrosive nature of seawater with high salinity and microorganisms. The shipping industry utilizes organic and inorganic coatings to safeguard the hydraulic and seawater pipe lines of deck machines from marine pollution. High hydraulic pressures cause corrosion of A-Frame and scientific winches, potentially reducing the service life of corroded hydraulic pipe lines. Various environmentally friendly coating techniques, including epoxy resin, FBE (fusion-bonded epoxy), AE (asphalt enamel), neoprene, and multilayer PE (polyethylene), PP (polypropylene), and PU (polyurethane), are widely used for pipeline coating. Nanocomposite coatings can be created using a diverse range of matrices and reinforcement materials. The corrosion control of nanocomposite coatings relies on the preparation and use of various matrices as their main component. Marine applications such as tidal power plants, coastal factories, and desalination plants require high resistance to wear due to seawater contact. Nanocomposites offer high strength, light weight; corrosion resistance, design flexibility, and durability due to their small size range of 1 to 100 nm and can act as reinforcement materials. NPs have been successfully utilized in the creation of advanced composite coatings by incorporating them into various matrices. Nanocomposite coatings provide superior protection against marine corrosion. The study of new technologies in this field is crucial and may justify additional investments in the research and development of smart coatings. The experimental analysis presented in this paper highlights advancements in nanocomposite coatings for pipelines, aiming to provide environmentally friendly materials with improved properties and longer lifetimes, reducing ship dry dock and maintenance costs, and effectively utilizing research ships for scientific communities.

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

Keywords: Ship A-Frame, Nanocomposite coatings, Pipelines, Saltwater, Wear, Corrosion, Matrices, Hydaulic

---

1. Introduction

Sea water and hydraulic pipe line systems are crucial for cooling marine disel engines, scientific winches, and ship material handling systems, including on-board deck and engine machinery, on ships. Carbon steel is crucial for corrosion protection in seawater and marine environments due to its low initial cost, low availability, and compliance with welding procedures, making it an attractive option for seawater pipeline applications. The corrosion rate of carbon steel in seawater is rapidly increasing due to factors such as the flow rate, oxygen content, and temperature increase [1].

Common protection methods include organic, metallic, cathode protection, and chemical treatment for sea water inhibition, which involves oxygen removal. Seawater pipe lines utilizing low-carbon steel metal pipes are at risk of corrosion due to the highly corrosive nature of seawater, which can cause issues in coolers, engines, and deck equipment pipelines. Eighty-five percent of the corroded pipe lines on the engine and deck sides of the ship were identified during routine inspection and preventive maintenance. Sea water is richer in dissolved ions than fresh water. The sea water corrosion rates are greater in the metallic and deck machinery areas of pipeline systems in contact with sea water environments. The composition of seawater varies across different regions due to variations in seawater salinity. Table 1 displays the typical chemical composition of salt water [2].

Protective coatings are crucial for enhancing the corrosion resistance of hydraulic and seawater pipeline systems. The quality and performance of pipeline system coatings depend on the surface preparation and coating procedures. Ships use different colors for identifying pipe lines, such as blue for fresh water, brown for fuel, green for sea water, and gray for nonflammable gases.

Table 1: The text provides a detailed analysis of the chemical composition of saltwater, as per Pinit's 1996 research.

Symbol	Element	Percentage
O	Oxygen	85.84
H	Hydrogen	10.82
CL	Chloride	1.82

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

Na	Sodium	1.08
Mg	Magnesium	0.1292
S	Sulphur	0.091
Ca	Calcium	0.04
Ka	Potassium	0.04
Br	Bromide	0.0062
C	Carbon	0.0028
V	Vanadium	1.5×10^{-11} to 3.3×10^{-11}

The safety of ship navigation is significantly impacted by the large amount of seawater that will enter scientific cabins. Seawater pipeline design has been continuously studied and implemented to prevent corrosion. The study of corrosion in pipeline systems due to seawater environments is crucial for the shipping industry to ensure increased pipeline system lifetime and reliable ship operation by utilizing advanced corrosion protection methods and nanocoating material characterization.

2. Materials and Methods

2. 1 Surface preparation and coating methods

The pipe line coating surface should be free of dust, oil, and grease and the adhered particles should be thoroughly cleaned with a wire brush and silicon carbide sandpaper following the composite coating procedure.

- The surfaces to be coated with pipe lines must be clean and free from all rust particles.
- A cleaning agent was applied to the surface of the corroded metal pipe lines.
- The adhesive paste and curing agent are mixed in a paste container for 20 minutes until the color becomes uniform.
- A thoroughly mixed material was applied to the surface of the hydraulic pipe lines, and then a glass-fiber mat was applied over the surface area.
- The resin and curing agent were thoroughly mixed in the provided container.
- The glass fiber was wetted using a brush, and mixed resin was applied.
- A thin fiber mat is applied over the glass fiber using a brush to achieve a polished surface finish.
- The coating process requires 8 hours of curing and drying.

The experiment utilized rapid-curing paste materials consisting of epoxy resin (A) and a hardener (B) as the materials. Figure 1 depicts a side A-frame pipe line with a corrosion identified area, and Figure 2 shows that the engine room pipe line has been identified as a potential area for corrosion.

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

Figure 1: Side A-Frame Pipe Line (Corrosion Identified Area)

Figure 2: Engine room Pipe Line (Corrosion Identified Area)

The pipe patch repair kit (NANO A-450) included a 100:10 mixture of the nanocomposite material. Table 2 displays the technical data of the rapid curing epoxy paste. The NANO A-450 pipe patch repair kit comprises the following components:

1. Adhesive Paste-450 g
2. Resin-450 g
3. Curing agent: 50 g
4. Cleaning Agent, 100 g
5. Glass fiber, 500x500 mm
6. Brush
7. Hand Gloves
8. Mixing container
9. Mixing Sticks
10. Putty Blade

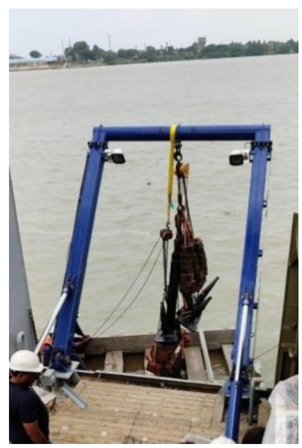

Table 2 Rapid Curing Epoxy Paste Technical data

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

S. No.	Property	Results
1	Composition	Epoxy resin and hardener
2	Mixing Ratio	A:B = 100:10
3	Working Time	20 Minutes
4	Application Temperature	Ambient temperature
5	Curing time for full strength	24 hours (conditions: 25 °C, 50% RH)
6	Tensile Strength	470 MPa
7	Tensile Modulus	13900 MPa
8	Compressive Strength	196 MPa
9	Compressive Modulus	4152 MPa
10	Lap Shear	11.13 MPa
11	Glass Transition Temperature	62°C
12	Coefficient of Thermal Expansion	$1x10^{-5}$
13	Shore Hardness	93

The experiments involved samples from a Stern A-Frame hydraulic pipeline system, as depicted in Figure 3. The pipe line, with a 1 in. external diameter and 0.133 in. wall thickness, has been polished to 1200 grit using silicon carbide sandpaper (SiC).

Figure 3: Side A-Frame

The experiment utilized a layer-by-layer deposition method for coating nanocomposite materials, which consisted of at least two phases, a nanocrystalline phase and an amorphous phase, resulting in improved properties due to the smaller grain sizes compared to those of conventional materials [3].

Nanocomposite coatings offer cost-effective, superior anticorrosion and adhesive properties, with good mechanical strength, weight reduction, improved barrier properties, and increased heat, wear, and scratch resistance, ensuring longer performance.

2.2 Material Selection and Design

Proper material selection for pipeline applications can reduce corrosion, considering the pipeline's design life and the surrounding environment. The choice of materials for seawater pipeline systems is crucial for ocean-going vessels. Marine materials are designed to withstand corrosion by seawater, marine biofouling, and the external environment under various operating conditions. The application of the onboard Engine & Deck machinery system involved the use of various marine steels.

Seawater pipeline systems commonly use materials such as galvanized steel, copper alloys, carbon steel, stainless

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

steels, titanium, reinforced plastics, and bare carbon steel. The corrosion of water pipelines is primarily caused by three major intermediate events: environmental factors, pipe-related factors, and operational factors. Figure 4 displays the fault tree analysis (FTA) diagram for examining the corrosion factors contributing to the failures of the water system. The structure of FTA is analyzed using primary units such as OR Gate, AND Gate, Basic Event, Intermediate Event, and Transfer to prevent loss**.** [4]

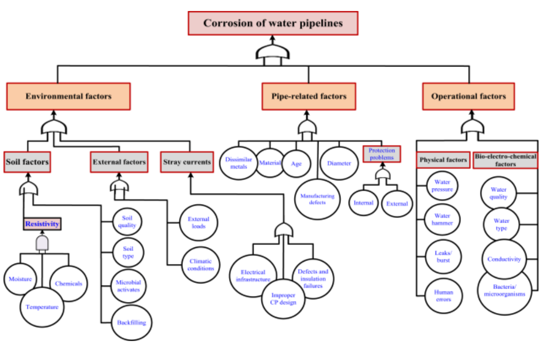

Figure 4: Fault tree diagram of the causes of corrosion for water pipelines

3. Experimental Analysis

3.1 Problem identification

The reduction in pipeline material thickness can result in a significant loss of strength and, in some cases, structural failure or breakdown. [5].During the scientific cruise, corrosion defects in sea water and hydraulic pipe lines were identified at varying pressures and temperatures. Corrosion of the surface of pipes leads to small holes or rough surfaces, reducing their lifetime.

The following problems were identified on board the ship:

1. The seawater environment has caused the corrosion of hydraulic pipe lines.
2. The IRS survey inspection mandated the complete removal of the pipeline from every dry dock.
3. The surface of the pipe line is experiencing pitting corrosion.
4. The pipeline is frequently damaged.
5. Oil leakage during scientific operations is a significant issue.
6. Operating scientific equipment and repairing pipeline damage during harsh weather conditions can be challenging.
7. The scientific cruise is experiencing a delay due to the repair work on the onboard pipeline.

The Coastal research vessel (CRV) conducted an experimental analysis on the composite material coating on the hydraulic pipe line of the A-Frame. The performance of the coating material was evaluated using various characterization techniques available in the onboard laboratory. The ship's engine room and deck sides were inspected for hydraulic and seawater-corroded pipe lines. The pipeline was coated using a rapid-curing epoxy paste composite material [6-8].

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

The Figure 5 depict the NPs Coating Work in Progress

Figure 5. Coating on corroded pipeline

The experimental analysis of pipeline coatings was conducted on three different ships using the collected data.

1. The ship engine log provides information on the LWT and HWT of the engine room pipeline.
2. The ship engine log provides information on the hydraulic oil operating pressure and temperature under various loading conditions.
3. Pipeline materials were utilized in marine applications, as evidenced by material test certificates.
4. The IRS report covers five years of ship dry dock activities.

The ship operated within the EEZ area, with the ship stern A-frame frequently used for scientific operation and the hydraulic power pack (HPP) system maintaining a maximum hydraulic oil working pressure of 250 bars. The seawater environment severely impacts hydraulic pipe lines, making it challenging to protect them from marine environments despite the use of marine-grade paint. The side A-frame of the hydraulic pipe lines is coated with rapid curing paste material, as depicted in Figure 6[9-10].

Figure 6: Rapid curing paste

4. Results and Discussion

An experimental analysis of pipeline coatings on board a pipe was successfully conducted Implementing this approach on all research ships can significantly decrease dry dock repair and maintenance costs. The hydraulic pipe lines' side A-frame is coated with rapid curing paste material before and after the coating, as shown in Figures 6 and 7.

Journal of Offshore Structure and Technology
Research paper
Vol 11, issue 1,2024
Receiving date:20-5-2024
Acceptance- 29-05-2024
Publication 30-05-2024

Figure 5: Before coating

Figure 6: After coating)

This technology is versatile and can be utilized in various sectors, such as gas oil pipelines, petroleum, petrochemicals, and the natural gas industry.

5. Conclusion

The successful experimental analysis of the nanocomposite coatings was conducted. The study revealed that nanocomposite coatings effectively reduce the corrosion of pipeline systems in on-board deck machines, with the coating providing the most protection and reducing the corrosion rate. The corrosion protection method enhances the life and efficiency of hydraulic and seawater pipeline systems. Composite coatings are known for their superior performance in protecting pipes of small and large diameters at moderate operating temperatures. Composite coatings enhance the lifespan of hydraulic and seawater pipeline systems, thereby reducing ship maintenance and repair costs. It is the most cost-effective protection for pipeline repair technology. Nanocomposite coatings are high-performance materials that exhibit unique properties.

References

1. Mardare L, Benea L. Development of Anticorrosive Polymer Nanocomposite Coating for Corrosion Protection in Marine Environment. IOP Conf Ser Mater Sci Eng. 2017;209:012056. doi:10.1088/1757-899X/209/1/012056.
2. Senna CM, Santos D, Geraldi TS. Coatings for Saltwater Pipelines. Int J Adv Eng Res Sci. 2018 Sep;5(9). ISSN: 2349-6495(P) | 2456-1908(O).
3. Muresan LM. Nanocomposites Coatings for Anti-Corrosion Properties of Metallic Substrates. 2023 Jul 19.
4. Farh HMH, Ben Seghier MEA, Taiwo R, Zayed T. Analysis and ranking of corrosion causes for water pipelines: a critical review. npj Clean Water. 2023;6:65.
5. AL Buhri SA, Keloth Kaithari D, Rasu E. Development of Corrosion Resistance Coatings for Sea Water Pipeline. Int J Sci Res Technol Manag. 2016;4(2):24-29. doi:10.18510/ijsrtm.2016.421.
6. Zhang G, Wu H, Dong C, et al. Recent advances in the development of anti-corrosion coatings for

marine applications. J Mater Sci Technol. 2020;45:190-201. doi:10.1016/j.jmst.2019.09.028.

7. Montemor MF. Functional and smart coatings for corrosion protection: A review of recent advances. Surf Coat Technol. 2014;258:17-37. doi:10.1016/j.surfcoat.2014.06.031.

8. Ramezanzadeh B, Attar MM. Electrochemical and mechanical properties of epoxy-based nanocomposite coatings containing various combinations of clay and nanoparticulate zirconia. Prog Org Coat. 2011;72(3):293-300. doi:10.1016/j.porgcoat.2011.05.010.

9. Li X, Liu Q, Li Z, et al. A comprehensive review on smart anti-corrosion coatings: Modeling, design, and applications. J Mater Sci Technol. 2021;75:41-57. doi:10.1016/j.jmst.2020.08.070.

10. Fu Y, Li L, Zhang Y, et al. Advances in anti-corrosion coatings for mild steel: A comprehensive review. Surf Coat Technol. 2020;385:125391. doi:10.1016/j.surfcoat.2020.125391.