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MAINTENANCE ANALYSIS OF ANCHOR CHAIN AGAINST CORROSION RATE BY PAINTING METHOD

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ABSTRACT

One of the damages to the anchor and its chain is caused by being exposed to various environmental loads from the sea every time the anchor is lowered or when the anchor is raised, so that it will gradually experience fatigue due to dynamic loads that occur repeatedly in a long period of time. However, there has not been an analysis that combines anchor chain maintenance of the corrosion rate with the painting method and a comparison between before painting and after painting. Therefore, the researchers proposed a study, "Analysis of Anchor Chain Maintenance of Corrosion Rates Using the Painting Method". This study aims to carry out an analysis to reduce the corrosion factor on the anchor chain by using marine coatings or painting processes so that the operability and capability of the system can be maintained. The research design is based on an experimental method that seeks to posit and solve the problem of the condition of a ship's anchor chain made of steel or metal. based on both visual data and literacy. The existing data is then analyzed and interpreted, which is comparative. The interval for each coat of paint depends on the drying power. What can you do with the next coat of paint if the previous paint layer is dry, it should not exceed the specified paint allowance, because it will give poor adhesion. From the analysis of the anchor chain structure, the resulting stress is 168.73 MPa. If it is estimated with a period of 3 years from the anchor chain structure, the stress result is 192.75 MPa, and if it occurs at this time in 2022 with a period of 5 years, the stress result is 213.95 MPa.

Keywords: Anchor chain, corrosion, marine coating, maintenance, analysis.

Introduction

An anchor is one component of ship equipment that plays a very important role in the marine transportation system. Ship anchors are used so that the ship does not move due to gusts of wind, currents, or waves. The anchor is designed in such a way and connected with a chain made of cast iron so that it can withstand the movement of the ship [4]. The anchor chain is equipment that is useful for connecting the ship's anchor to the ship so that it is not released if the anchor is lowered from the ship [3].

One of the damages to the anchor and its chain is caused by being exposed to various environmental loads from the sea every time the anchor is lowered or when the anchor is raised, so it will eventually experience fatigue due to dynamic loads that occur repeatedly over a long period of time. The risk of breaking the anchor chain is due to wear on the anchor chain material. Wear basically has several mechanisms, namely abrasion, erosion, adhesive, fatigue, and corrosion. Damage to the anchor and its chain is caused by environmental loads from the sea when the anchor is lowered or when it is raised, so that over time it will cause deformation in the anchor structure and its chain [4].

Based on previous research from Andarum Septianto, it has been stated that the absence of a good anchor chain maintenance role in its implementation can have several impacts that can become a problem on the ship, such as corrosion, depletion of wildcat serrations, influence on the anchor feeding process, the heavy up anchor process is disrupted and from several impacts that can occur resulting in hampering ship operations [1].

In a study conducted by Mardawiah, it was shown that the stress result was 168.73 MPa when estimated with a period of 3 years from the installation of the chain line installation, the stress result was 192.75 MPa, and if it occurs at this time in 2022 with a period of 5 years, the stress result is 213.95 MPa. The strength of the chain line structure when receiving loads that work on safe criteria and do not exceed the maximum Yeild Strength according to the DNV OS E301 standard reference of 265.5 MPa, as well as the deformation results of 0.35101 mm, when estimated with a time period of 3 years from the installation of the chain line installation, the deformation results are 0.65605 mm. The results of the deformation value obtained do not exceed the maximum limit of deformation according to the DNV OS E301 standard reference of 0.8 mm [2].

Based on research, it can be concluded that the largest Von Mises stress value is found in the area between joints, which is 242.71 MPa under maximum loading conditions. The stress value is still below the yield strength value of the material used, which is 680 MPa, and the largest deformation value in the end shackle structure due to environmental loads is 0.103 mm. Based on this, it can be said that the end shackle structure used to withstand loads from anchors and environmental loads is in a safe condition for use and does not exceed the allowable stress set by the Indonesian Classification Bureau, which is 400 MPa [4].

Government and international organizations have been spurred by this to make significant pledges to decrease marine debris in many nations. Plans for regional and national garbage management have been created in numerous nations [5]. This has encouraged the emergence of various innovations and technologies for cleaning marine debris, one of which is a catamaran-type garbage collection ship and which uses conveyors with several conveyor wing variations [6].

Various studies on garbage collection vessels using catamaran vessels have been conducted. Research on the numerical investigation of the effect of conveyor wing type on marine garbage collection behavior has been conducted. This study discusses the effect of wing shape on garbage collection in calm waters. The three wing shape variations used in the numerical simulation are solid wing shape, square hollow wing shape, and circular hollow wing shape. As a result, from the simulation results, the circular hollow wing is faster in collecting marine debris, followed by the square hollow wing and the solid wing. From the flow pattern analysis, the circular hollow wing model is easier to get the marine debris closer to the winged conveyor than the square wing and solid wing models [7].

Other research is an experiment on the hollow wing technique to improve conveyor performance in marine debris collection [8]. Debris collection ratio than other models. A study on the effect of placing a portable conveyor on a garbage collection vessel on marine garbage collection behavior has been conducted [9].

According to research conducted by Alfafa and Zuan Syafa, the results of the calculation of the corrosion rate with the obtained factors, causing the diameter of the chain to decrease, namely corrosion and maintenance factors. The result of the reduction in the diameter of the anchor chain of the right X container ship is 0.549 mm, the corrosion rate is 0.198 mm/y, the left is 0.970 mm, and the corrosion rate is 0.232 mm/y. The right Y container ship is 0.054 mm, corrosion rate is 0.018 mm/y, the left is 1.392 mm, corrosion rate is 0.464 mm/y, and the right Z container ship is 1.088 mm, corrosion rate is 0.363 mm/y, the left is 2.267 mm, corrosion rate is 0.882 mm/y [10].

However, no analysis has been found that combines the maintenance of the anchor chain against the corrosion rate with the painting method and the comparison between before being subjected to painting and after painting. Therefore, the researcher proposed the research "Analysis of Anchor Chain Maintenance on Corrosion Rate by Painting Method". This research aims to conduct an analysis to reduce the corrosion factor of the anchor chain with the use of marine coating or painting processes, so that the operability and capability of the system can be maintained.

Methodology

Corrosion

Corrosion is the deterioration of metals due to electrochemical reactions with their environment. NACE (National Association of Corrosion

Engineers) defines corrosion as a decrease in the quality of a material (usually steel) or its properties caused by a reaction with its environment [11-12]. Meanwhile, Trethewey (1988) provides a definition of corrosion as a decrease in the quality of steel due to electrochemical reactions with the environment [1]. Furthermore, the ASM Materials Engineering Dictionary states corrosion as a chemical or electrochemical reaction between the anode and cathode of steel with an electrolyte environment that results in a decrease in material quality and chemical properties [13].

In many cases, corrosion attacks cannot be avoided, but they can be controlled so that the steel structure or component has a longer service life. Every structure or component generally goes through a three-stage process: design, manufacture, and use. Corrosion control plays an important role in each of these stages. Failure in any of the corrosion control stages can lead to premature failure of the component. In principle, corrosion control can be done in various ways, including: [14]

- Component design modification.
- Environment modification.
- Material selection.
- Cathodic and anodic protection.
- Application of protective coatings.

Protective or barrier coatings applied to steel surfaces aim to separate the steel from its environment or to control the microenvironment at the steel surface. There are many coating methods used for this purpose, including paints, organic coatings, varnishes, steel coatings, and enamels. However, by far, the most common and widely used method is paint [15].

The research design is based on an experimental method that tries to suggest and solve problems from the condition of the ship's anchor chain, made of steel or metal. based on data, both visual and literary. The existing data is then analyzed and interpreted, which is comparative in nature. This study uses research materials, including:

Research materials

The materials needed for research are as follows:

1. Anchor chains

An anchor chain is a critical component in a ship's mooring system that serves to connect the anchor to the ship. It has several special characteristics, such as high tensile strength, corrosion resistance, and flexibility, which allow the anchor to hold the vessel securely in place despite ocean currents, wind, and waves. Anchor chain materials are usually made of high-quality steel coated with anti-corrosion materials to increase durability against harsh marine environments. The anchor chain is shown in Figure 1.

Figure 1. Anchor chain

2. Anti-corrosive (AC)

Anti-corrosion paint is a type of paint specifically designed to protect metal surfaces from corrosion or rust. These paints contain chemicals that create a protective layer on the metal surface, preventing reactions between the metal and corrosive elements such as oxygen, water, salt, and other chemicals. The use of anti-corrosion paints is very common in the maritime industry, construction, automotive, and other sectors where metal protection from rust is essential. These include epoxy paints and zinc-rich primers. The function of epoxy is anti-corrosion protection, strong adhesion, mechanical strength, and abrasion resistance. The function of the zinc-rich primer is Cathodic Protection, good adhesion, Barrier Protection, and coating repair. The combination of epoxy, zinc-rich primer is very influential because, by using zinc-rich primer as the base coat and epoxy as the final protective layer, this combination provides very effective corrosion protection. Zinc-rich primer provides cathodic protection while epoxy protects against mechanical damage and corrosive elements, ensuring the anchor chain remains in optimal condition for a longer period of time. It is then painted with a protective marine anti-corrosion coating.

3. Salt Solution (NaCl)

Salt solution (NaCl) is a solution formed when table salt (sodium chloride) is dissolved in water as shown in Figure 2. Table salt consists of sodium ions (Na^+) and chloride ions (Cl-), which dissociate in water to form an electrolyte solution. Salt solutions are very important in various fields due to their distinctive electrolyte properties and their ability to simulate corrosive environments. NaCl is used to create environmental conditions that accelerate the corrosion process of metals. NaCl helps in checking how well protective coatings or paints protect metals from corrosion. And comparing the corrosion resistance of different types of metals or coatings under controlled conditions. NaCl is therefore very useful for simulating corrosive environments, for example, to test the corrosion resistance of materials and coatings.

Figure 2. Salt solution

Test equipment

The equipment needed for research is as follows:

1. Spray gun

A spray gun is a device used to spray liquids, such as paint, varnish, or other coatings, onto the surface of an object, as shown in Figure 3. It works by using air pressure to atomize the liquid into small particles, which are then sprayed in the form of a fine mist. Spray guns are essential tools in a variety of painting and coating applications, providing professional and efficient results.

Figure 2. Spray gun

2. Air compressor

An air compressor is a device used to increase air pressure by compressing the air entering the system, as shown in Figure 4. This pressurized air is then stored in a tank and can be used for a variety of industrial, repair, and maintenance applications, including as a power source for pneumatic tools such as spray guns, air drills, and lifting equipment. The compressor was used to assist with the painting process of the anchor chain.

Figure 4. Air compressor

3. Sandblasting tools

Sandblasting is the process of cleaning or smoothing the surface of a material by firing abrasive particles using high air pressure. Sandblasting tools are devices used to apply this technique. Sandblasting is usually used to clean ship hulls and steel structures from rust and dirt. The advantages of using sandblasting are high efficiency because it can clean surfaces quickly and effectively, accurate results because it provides smooth and uniform cleaning results, and flexibility because it can be used on various materials such as metal, wood, glass, and concrete. Therefore, by using sandblasting tools, the cleaning and surface preparation process becomes faster and more efficient, and provides a high-quality finish.

4. Micrometer for measuring paint thickness

A micrometer is a precision measuring device used to measure thickness or small dimensions with high accuracy. To measure the thickness of a paint layer, a special micrometer known as a coating thickness gauge is used. Micrometers are also commonly used to control the thickness of paint layers on various products to ensure quality and durability. The advantages of micrometers are high accuracy, ease of use, and flexibility. Therefore, by using a special micrometer to measure paint thickness, quality control becomes more efficient, and production or maintenance results are more reliable.

5. Corrosion rate measuring instrument

A corrosion rate meter is a device used to measure the degree of degradation or damage caused by corrosion to a particular material. It is generally designed to provide information about the speed of corrosion under various environmental conditions. Corrosion rate meters have the ability to control environmental conditions (such as temperature, humidity, and pH), make accurate and consistent measurements, and the ability to record data and analyze it for further evaluation. The use of corrosion rate meters is important in various industries such as manufacturing, construction, and metal treatment industries to identify and reduce the impact of corrosion on material reliability and service life.

6. Digital scales

Digital scales are measuring devices used to determine the weight of material samples before and after exposure to corrosive conditions. This weight difference helps calculate the corrosion rate or the rate of material loss due to corrosion. The digital scales are shown in Figure 5. Digital scales are measuring devices used to determine the weight of material samples before and after exposure to corrosive conditions. This weight difference helps calculate the corrosion rate or the rate of material loss due to corrosion. The digital scales are shown in Figure 5.

Figure 5. Digital scales

Marine Coating Methods with Epoxy Paint is one of the most popular marine coating options due to its strength and resistance to corrosion and abrasion. Epoxy can be applied to metal, concrete, and wood surfaces and provides long-lasting protection. Several studies have shown that epoxy paints are very effective in protecting ship surfaces from corrosion and the effects of the marine environment [16].

Marine Coating Method with Fluorinated Polymer is a marine coating material that is resistant to corrosion and highly resistant to the effects of harsh marine environments. It is often used for the protection of tankers and marine platforms due to its UV resistance and long-lasting performance [17].

Polyurethane Marine Coating Method is a marine coating material that is highly resistant to the effects of the marine environment, including corrosion and UV light. This material is resistant to abrasion and is easily applied to ship surfaces. Several studies have shown that polyurethane provides excellent protection and can increase the longevity of ships and marine structures [18].

Research Procedure

a. Sample preparation

1. Site Identification and Initial Preparation

In the site identification and preliminary preparation phase of corrosion testing, steps include selecting a representative and relevant test site, such as a maritime area with aggressive seawater conditions or a corrosion-prone industrial environment. In addition, the initial preparation includes collecting anchor chain samples from the site, as well as cleaning and smoothing the surface of the samples to remove any dirt, rust, or previous corrosion layers, to ensure consistent initial conditions ready for further treatment in the test. Proper site selection and preparation are critical to obtaining accurate and reliable test results.

2. Painting Method Selection

In the painting method selection stage of corrosion testing, different types of paints and coatings are considered based on the environmental conditions and material properties of the anchor chain. Considerations include paint resistance to seawater, adhesion ability, and durability under extreme operational conditions. Application methods such as brushing, spraying, or immersion were also evaluated to determine the most effective technique for providing maximum protection against corrosion. The selection of an appropriate painting method aims to ensure an optimal protective coating, so as to minimize the corrosion rate and extend the service life of the anchor chain.

3. Surface Preparation

The surface preparation stage in corrosion testing involves cleaning and smoothing the surface of the anchor chain to remove dirt, rust, and remnants of previous corrosion. This process includes the use of mechanical methods such as sandblasting, as well as chemical cleaning to ensure the surface is free of contaminants. Optimal surface preparation is essential to ensure strong adhesion of the paint protection layer, thereby increasing the effectiveness of corrosion protection and providing accurate and consistent test results.

4. Anchor Chain Painting

The process of painting the anchor chain in corrosion testing involves first applying an anti-corrosion primer coat, such as using an epoxy, zinc-rich primer to provide basic protection and improve the adhesion of the main paint. Thereafter, the main marine paint coating is applied by the chosen method, such as spraying or immersion, to ensure uniform coverage and appropriate thickness. Each coat of paint is given sufficient drying time to achieve optimum hardness and durability. Afterward, measure the thickness of the paint layer using a micrometer to ensure uniform thickness. Careful painting aims to form an effective barrier against corrosive elements, thereby reducing the corrosion rate and extending the service life of the anchor chain in aggressive environments.

5. Observation and Monitoring:

The observation and monitoring stage of corrosion testing involves regular visual inspections and detailed measurements of the condition of the painted anchor chain. Observations are made to detect surface changes, such as the appearance of cracks, peeling paint, or early signs of corrosion. In addition, paint thickness measurements and microstructure analysis using an electron microscope are conducted periodically to obtain quantitative data on corrosion rates. Careful and continuous monitoring is essential to assess the effectiveness of the painting method in protecting the anchor chain from corrosion, as well as to identify areas that require further repair or adjustment while recording visual changes and corrosion rate-related measurements.

methodology can be divided into one or more parts according to the research requirements.

b. Corrosion testing

Test Environment Setup:

1. Prepare a container containing a 3.5% NaCl solution to simulate a marine environment.
2. Place the sample in the container and keep it under controlled conditions (temperature and humidity) for 30 days.

Corrosion Rate Measurement:

1. Take samples at regular intervals (e.g., every 7 days) to measure weight changes using a digital balance.
2. Use a corrater to measure the corrosion rate directly.

c. Data analysis

Data Processing:

1. Calculate the corrosion rate based on the weight change of the sample and the data from the crater.
2. Compare the corrosion rate between painted and unpainted samples.

Effectiveness Evaluation:

1. Analyze the effectiveness of the protective paint in reducing the corrosion rate.
2. Use statistical analysis to determine the significance of the difference between the painted and unpainted samples.

d. Flow chart

The flowchart of the corrosion testing steps illustrates the stages of the process systematically from site identification and initial preparation, selection of painting method, and surface preparation, to painting application. Thereafter, steps include periodic observation and monitoring of the anchor chain condition, as well as analysis of test data. This diagram helps visualize a structured workflow, ensures each stage is properly executed, and facilitates the identification of critical points that affect the effectiveness of corrosion protection of the anchor chain. The research steps are shown in the flow chart of Figure 6.

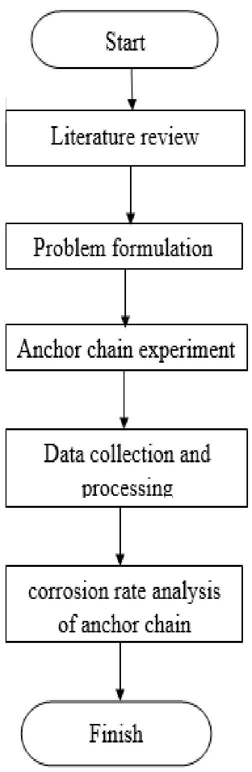

Figure 6. Research flow chart

The selection of ship equipment, such as anchors, anchor chains, and other mooring tools, depends on the equipment items regulated by several classifications [19]. According to BKI 2014 Volume II Section 18 B.1

$$Z= D^{\frac{2}{3}} + 2hB + \frac{A}{10} \quad (1)$$

Where:
Z = modulus (m^3),
D = displacement (ton),
B = ship width (m),
h = sum of freeboard to superstructure height (m)
A = lateral plane area of the body and building (m^2).

Corrosion can be said to be a decrease in the quality of metal. Corrosion can occur due to electrochemical reactions between metals and the environment. One of the environmental conditions that often causes corrosion of iron is seawater. Seawater contains a variety of salts, with the largest percentage of salt being NaCl [20].

The corrosion rate can generally be measured using two methods, namely: the weight loss method or immersion test, and the electrochemical method. The weight loss method is to calculate the weight loss that occurs after some immersion time. In this study, the weight loss method was used, where the difference between the initial weight and the final weight was calculated.

Unit of corrosion rate:

1. Weight reduction = g or mg
2. Weight/unit of metal surface area = mg/mm^2
3. Weight expansion per time = mg/dm^2 day (mdd), g/dm^2. day, g/cm^2.hour, g/m^2 .h, $moles/cm^2$ .h
4. In penetration per time: inch/year, inch/month, mm/year, miles/year (mpy), 1 milli = 0,001 inch

The corrosion rate by immersion test is based on weight loss. The weight loss method is carried out by calculating the difference between the initial weight and the final weight that occurs after some immersion time [21].

$$CR=(87{,}6\times W)/(D\times A\times T) \quad (2)$$

Where:
CR = corrosion rate (mmpy)
W = lost weight (gram)
D = density of corrosion test piece ($gram/cm^3$)
A = surface area (in^2)
T = time (hour).

Corrosion rate according to Faraday's Law, which relates the corrosion rate to the amount of charge involved in the electrochemical reaction [22].

$$I = (m) / (nFt) \quad (3)$$

Where:
I = Corrosion rate (g/yr atau mm/yr)
m = Mass of corroded metal (g)
n = The number of electrons involved in an electrochemical reaction
F = Faraday Constant (96.485 C/mol)
t = Time (s)

Result and Discussion

Results

1. Surface Preparation
- Sandblasting Process:
  The surface of the anchor chain is cleaned of rust, old paint, and other contaminants using sandblasting. This process ensures a clean and rough surface, which is essential for good paint adhesion.
- Visual Inspection:
  After sandblasting, the surface of the anchor chain is visually inspected to ensure that no rust or contaminants remain. This rough and clean surface is ready for primer application.

2. Application of Zinc-Based Primer
- Primer Application:
  A zinc-based primer is applied to the cleaned anchor chain. This primer provides a sacrificial coating that protects the steel from corrosion.
- Coating Consistency:
  The thickness of the primer layer is checked using a micrometer, ensuring consistent thickness according to predetermined specifications.

3. Application of Epoxy Coating
- Epoxy Application:
  An epoxy coating is applied over the zinc-based primer. This coating provides additional protection by offering excellent adhesion and chemical resistance.
- Coating Inspection:
  The thickness and consistency of the epoxy coating are checked to ensure complete coverage and optimal protection.

4. Final Coating Application
- Final Coating Application:
  The finish coat is applied as additional protection against environmental factors such as UV radiation and mechanical abrasion.
- Final Result:
  The finish coat is checked to ensure good adhesion and a durable finish, providing long-term protection against corrosion.

5. Testing and Measurements
- Thickness Measurement:
  A micrometer is used to measure the total thickness of the coating system (primer, epoxy, and finish), ensuring that the thickness meets the set standards.
- Corrosion Resistance Testing:
  The coated anchor chain was tested under simulated marine conditions to evaluate its resistance to corrosion. Results showed that the protective coating significantly reduced the corrosion rate compared to the uncoated anchor chain. From the experimental observations of the addition of marine anti-corrosive coatings, compared to before adding marine anti-corrosive coatings to anchor chain materials in seawater fluid, data and corrosion rates on anchor chains with different conditioning.

Discussion

1. Effectiveness of Surface Preparation:
   Thorough surface preparation through sandblasting is critical to the success of the painting method. Without adequate preparation, the paint will not adhere well to the steel surface, reducing the effectiveness of the coating.

2. Importance of Zinc-Based Primer:
   Zinc-based primers provide initial protection against corrosion by acting as a sacrificial layer. This means that the zinc will corrode before the steel, protecting the anchor chain from more severe corrosion damage.

3. Benefits of Epoxy Coatings:
   Epoxy coatings enhance protection by offering excellent adhesion and chemical resistance. Epoxy also acts as an additional barrier, extending the life of the anchor chain.

4. Role of the Finish Coat:
   The finish coat protects against environmental factors such as UV radiation and mechanical

abrasion. This ensures that the coating system remains effective for a longer time, even in harsh marine conditions.

5. Effect of Coating Thickness:

Consistent coating thickness is critical to the effectiveness of the coating system. Precise measurements ensure that each layer is of sufficient thickness to provide the required protection without compromising flexibility or adhesion.

6. Performance under Load Conditions:

Coated anchor chains exhibit improved corrosion resistance during operational use. This improvement translates into longer service intervals and lower maintenance costs, ensuring the anchor chain remains functional and reliable.

painting can prevent corrosion of the anchor chain. The painting methods used include painting with anti-corrosion paint. Painting can increase the resistance of the anchor chain to wear and mechanical damage.

Strength analysis of the anchor chain structure using some of the data has different dimensions. The strength analysis of the anchor chain structure is carried out using a dimensional reduction due to the corrosion rate of the anchor chain material.

The interval of each coat of paint depends on its drying power. The next coat of paint can be applied when the previous coat is dry, but it should not exceed the specified allowance, as it will give poor adhesion. The interval required by each painting is different. Primer paints have a 10-hour allowance and a maximum of 3 months. Anti-corrosive paints allow 50 minutes at the earliest and 8 hours at the latest, while anti-animal and marine plant paints require 24 hours for the next painting.

Conclusion

A painting method consisting of thorough surface preparation, the application of a zinc-based primer, an epoxy coating, and a final coat proved effective in controlling corrosion of the anchor chain. Results show that this coating system significantly increases the service life and reliability of anchor chains, making it a valuable approach to marine equipment maintenance. Regular inspections and strict quality control are essential to ensure the continued effectiveness of the protective coating.

Based on the research that has been done, conclusions can be drawn such as, not implementing the role of good anchor chain maintenance in its implementation can have several impacts that can become a problem on the ship, such as corrosion, exhaustion of wildcat serrations, influence on the anchor feeding process, the process of the heavy up anchor is disrupted and from several impacts that can occur resulting in hampering ship operations.

Anchor chain painting is an effective method to prevent corrosion and improve chain durability. Various painting methods can be used, depending on the type of metal and environmental conditions. By using the right painting method, the anchor chain can remain in good working order and ensure the safety of the ship. The method of painting with zinc-rich primer and epoxy coating proved effective in reducing the corrosion rate of the anchor chain. Regular maintenance and periodic repainting is highly recommended to maintain the stability and service life of the anchor chain under corrosive marine environmental conditions.

It is hoped that research that can be developed in future studies can be in the form of analyzing the maintenance of anchor chains and windlasses against corrosion rates, with other methods that are more effective than the painting method used in this study.

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