Mekanika: Majalah Ilmiah Mekanika

Corrosion Rate Analysis and Prediction of the Remaining Life of the Research Vessel to Improve Ship Safety Aspects

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Abstract

Corrosion is a major concern in the marine industry, compromising the safety and integrity of ships. This paper presents a corrosion rate analysis and prediction of the remaining life of the Baruna Jaya IV research vessel using Non-Destructive Testing (NDT) ultrasonic testing to improve ship safety aspects. The NDT ultrasonic testing was conducted on the ship's hull to evaluate the thickness and detect any hidden corrosion. The results were used to develop a corrosion rate model and predict the remaining life of the ship using a probabilistic model. The study found that the corrosion rate of the ship was high, and the remaining life of the ship was estimated to be less than five years. The study's findings can be used to develop a maintenance and repair strategy to reduce corrosion and improve the safety of the Baruna Jaya IV research vessel.

1 Introduction

The Baruna Jaya IV research vessel is an important asset to the marine research community. This vessel was built in 1992 and is owned by the Directorate of Research Vessel Management, National Research and Innovation Agency (BRIN). It has served for over three decades. Consequently, its age categorization falls within the high range. According to Jurisic et al. [1], this aging factor contributes to observable consequences such as heightened stress levels and the deterioration of ship structure strength. Over this extended period of service, the vessel has been subjected to harsh marine conditions, leading to significant corrosion. Corrosion's adverse effects include material loss, structural vulnerabilities, and potential failure. Numerous studies, such as those represented by [2-6], have been conducted to evaluate corrosion waste and its impact on ship ultimate strength. Therefore, it becomes imperative to actively monitor corrosion rates and predict the remaining operational life of the vessel to ensure its continued safety. In the realm of ship construction, inherent imperfections resulting from the production process are virtually unavoidable, particularly in instances when ship contractors disregard welding procedure specifications.

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Classification societies mandate partial inspections, given the impracticality of achieving 100% inspection coverage, to safeguard production quality. These assessments focus on scrutinizing welding quality, prioritizing critical joint areas to ensure production excellence, and determining the overall percentage of observed defects on a single vessel [7]. Non-Destructive Testing (NDT) techniques, exemplified by ultrasonic testing, hold a pivotal role in assessing thickness and revealing concealed corrosion within the ship's hull. These methods are especially pertinent for inspecting weld joints made from low-carbon steel, common in the construction of mild steel vessels. Deepak et al. [8] emphasize NDT's significance in evaluating the corrosion resistance attributes of low–carbon steel, particularly when subjected to environmental or weather-related deterioration. Tscheliesnig et al. [9] recommends acoustic emission testing for real-time monitoring and the identification of cracks and corrosion. Nevertheless, this approach faces challenges due to elevated background noise levels, necessitating intricate data analysis to differentiate genuine indications from background noise. The efficacy of this strategy hinges on a substantial database of monitoring tests conducted on actual structures under service conditions or conditions akin to them. Corrosion poses considerable safety risks, causing issues such as thickness penetration, fatigue cracks, brittle fractures, and unstable failures. According to Soares et al. [10], depending on the ship type, these failures can lead to human casualties and environmental contamination. To address these concerns, Soares et al. [11] introduced an equation intended to guide ship owners and classification societies in monitoring variables that enable more accurate predictions of corrosion wastage within ship tanks. Melchers et al. [12] asserts that developing a precise model for the probability of marine corrosion is required to accurately assess a ship's remaining lifespan. Given the nonlinearity of corrosion events, a log–normal probability distribution model for corrosion depth has emerged as consistent with available data. Liu et al. [13] propose the utilization of Benefit–Cost Ratio (BCR) and Net Present Value (NPV) methods to optimize the extension of service life. These methodologies, which are based on the fatigue-critical limit state, offer a decision-making framework for extending service life extension. Prior research has examined the significance of construction inspection using various measuring devices; however, these studies have yet to expand on the procedural utilization of inspection outcomes for predicting remaining life.

This paper addresses this gap by accentuating the role of construction inspection in enhancing ship longevity. It accomplishes this by providing detailed procedural guidelines and meticulous examination steps for harnessing inspection results to forecast ships' remaining operational lives. Ship operators can refine their maintenance strategies and improve decision-making processes associated with ship longevity by integrating non-destructive testing techniques, accounting for environmental variables, and employing probabilistic models. The insights presented in this paper are valuable resources for similar vessels seeking to extend the longevity of their maritime assets.

2 Research Methods

The research was conducted by inspecting the ship construction, specifically the plate thickness inspection. Measurements were taken on the ship using an NDT method to determine the existing plate thickness, followed by calculating the minimum allowable plate thickness, corrosion rate, and remaining lifespan of the ship according to the Ship Classification standard regulations (see Table 1 and Figure 1).

Table 1. Practical use of NDT technique and limitation

NDT inspection	Practical use	Limitations
Visual inspection	Visible surface defect inspection	Small defect is difficult to detect
Ultrasonic	Surface and interior defects	Testing material must be a conductor of sound
Magnetic particle	Surface and layer defect	Suitable for magnetic material
Acoustic emission sensors	Real time inspection for fatigue and structural strength	Need application of logical filtering and data treatment.
Radiography	Internal defects inspection	Ability is limited to detect fine cracks
Liquid penetrates	Surface defects inspection	Not suitable for porous material

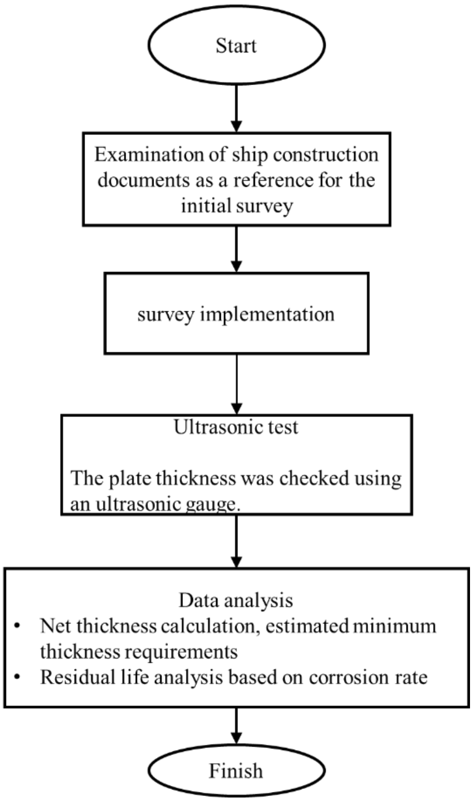

Figure 1. Ultrasonic thickness gauge

2.1 Determining plate thickness

Measurements were taken on the ship using a Non-Destructive Testing (NDT) method to determine the existing plate thickness. The specification ultrasonic testing and determined points on the ship are shown in Figure 2-8. To determine points on the ship, first examine ship plans and structural drawings to understand the ship's layout and identify critical areas susceptible to corrosion, which require inspection. Second, divide the ship into sections or zones based on its structural layout and the inspection objectives. In this study, the ship was divided into five zones: top deck, navigation deck, forecastle deck, main deck, and hull. The number of Ultrasonic Thickness (UT) inspection locations refer to maritime regulations and classification society guidelines that dictate inspection requirements.

Ultrasonic thickness gauge BENETECH version: GM 100-EN-05 Shenzhen city, China.
Specification:
- Measuring range: 1.2~220 mm (Steel)
- Accuracy: (1%H+0.1) mm
- Resolution: 0.1 mm
- Sound velocity range: 1000~9999 m/s
- Working frequency: 5 MHz
- Minimum limit for tube measuring: 20*3 mm (Steel)
- Power supply: 3 x 1.5 V AAA batteries
- Weight: 210 g
- Size: 70 x 145 x 28 mm

Figure 2. Ultrasonic thickness gauge

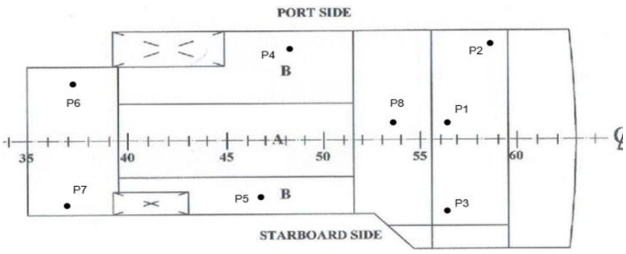

Figure 3. UT inspection location on Baruna Jaya IV Top Deck

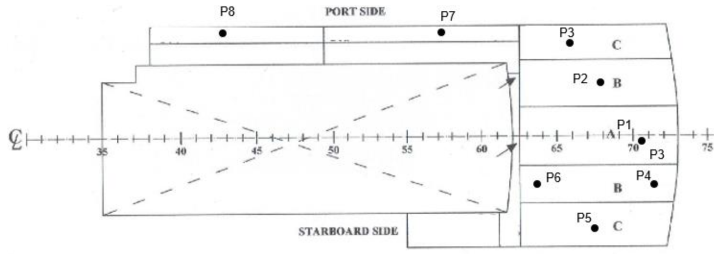

Figure 4. UT inspection location on Baruna Jaya IV Navigation Deck

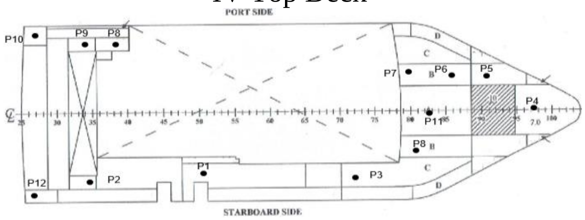

Figure 5. UT inspection location on Baruna Jaya IV Fore Castle Deck

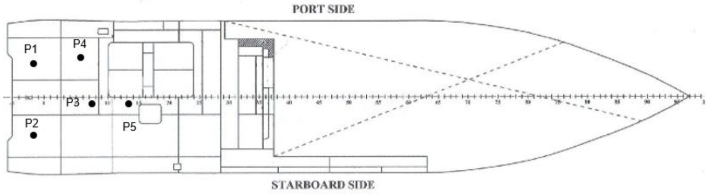

Figure 6. UT inspection location on Baruna Jaya IV Main Deck

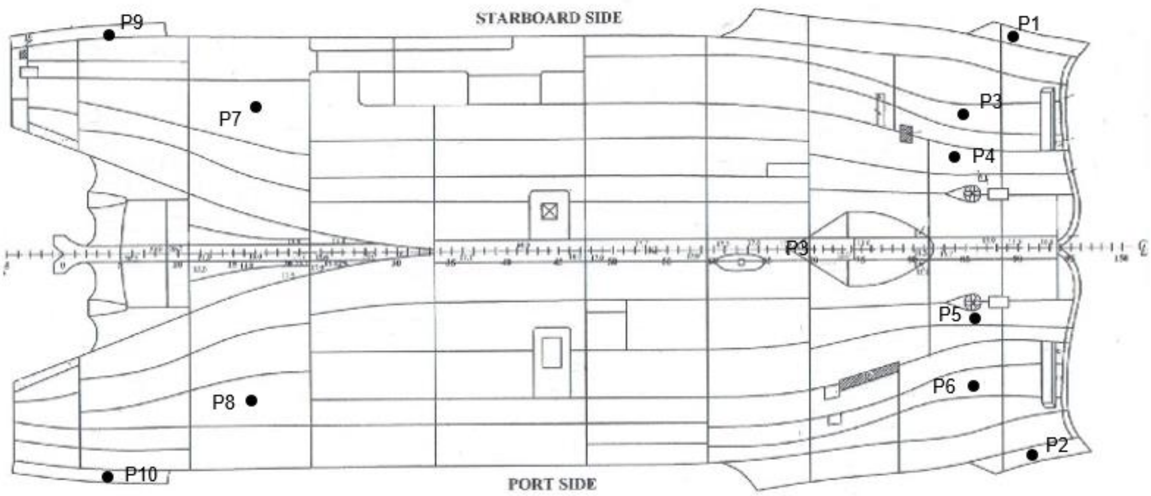

Figure 7. UT inspection location on Baruna Jaya IV Hull

Figure 8. UT inspection on Baruna Jaya IV Vessel

2.2 Determining the minimum plate thickness

To determine the minimum plate thickness allowed for ships, refer to the regulations of the Indonesian Classification Society Volume II rule for Hull 2022 [14] as shown in in Equations 1-2

- for side shell:

$$t_{min} = \sqrt{L.k} \text{ (mm)} \tag{1}$$

- for deck:

$$t_{min} = (4.5 + 0.05.L).\sqrt{k}\ (mm) \tag{2}$$

2.3 Determining the corrosion rate

To determine the corrosion rate on the ship plate can be done using the formula in Equation 3.

$$Cr = \frac{t_0 - t_1}{\Delta T} \tag{3}$$

where:
t_0 = Plate thickness at last docking (mm)
t_1 = Existing thickness (mm)
ΔT = Time interval (year)
Cr = Corrosion rate (mm/year)

2.4 Determining the remaining life of a plate

To determine the remaining life of the plate can be obtained by using the formula in Equation 4.

$$RL = \frac{t_1 - t_{(min)}}{CR} \tag{4}$$

where:
RL = Remaining life
$t_{(min)}$ = Minimum thickness (mm)
t_1 = Existing thickness (mm)
CR = Corrosion rate (mm/year)

The Equations 3 and 4 are adopted from expert judgment in the engineering area, such as corroded subsea pipelines [15].

2.5 Determining the probabilistic ship structural degradation

Komariyah et al. [16] determined and obtained the number of plate thickness diminution by using a probability model. This diminution could illustrate the actual value of plate thickness reduction of the Oil Tanker that has voyage in the Indonesian waterway. The results are used as corrosion margins as summarized in Table 2.

Table 2. Thickness diminution for ship structural member in mm (Komariyah et al. [16])

Structural member	Max.	Mean	Deviation	Cumulative Probability				
				80 %	85 %	90 %	95 %	98 %
Deck plate	4.36	0.51	0.42	1.89	1.93	2.01	2.07	2.38
Side plate	2.7	0.24	0.34	1.56	1.68	1.87	2.06	2.05
Bottom plate	2.5	0.51	0.38	1.26	1.39	1.54	1.81	2.26
Inner bottom plate	2.4	0.38	0.28	0.97	1.08	1.26	1.53	1.87

3 Results and Discussion

The NDT ultrasonic testing revealed that the thickness of the ship's plate was significantly reduced, and hidden corrosion was detected. In Table 3, the corrosion rate model predicted the highest corrosion rate is 0.6 mm/year, which is high compared to other ships of similar age and type. The calculation also predicted that the remaining life of the ship was less than five years, indicating that immediate action is required to improve the ship's safety aspects, such as re-plating.

Table 3. Prediction on remaining life based on thickness measurement Baruna Jaya IV Vessel

Inspection Area/Part	Thickness (mm)			Corrosion rate (mm/year)	Remaining life prediction (year)	Recommendation
	t_1	t_0	t_{min}			
Top Deck						
P1	4.8	5	3.5	0.10	13.00	-
P2	4.9	5	3.5	0.05	28.00	-
P3	4.8	5	3.5	0.10	13.00	-
P4	4.9	5	3.5	0.05	28.00	-
P5	4	5	3.5	0.50	1.00	Re-plating
P6	4.7	5	3.5	0.15	8.00	-
P7	4.6	5	3.5	0.20	5.50	-
P8	4.8	5	3.5	0.10	13.00	-
Navigation Deck						-
P1	4.8	6	4.5	0.60	0.50	Re-plating
P2	5.4	6	4.5	0.30	3.00	-
P3	5.3	6	4.5	0.35	2.29	-
P4	5.4	6	4.5	0.30	3.00	-
P5	5.4	6	4.5	0.30	3.00	-
P6	10.1	11	9.5	0.45	1.33	Re-plating
P7	5.4	6	4.5	0.30	3.00	
P8	5.2	6	4.5	0.40	1.75	Re-plating
Forecastle deck						-
P1	6.1	7	5.5	0.45	1.33	Re-plating
P2	6	7	5.5	0.50	1.00	Re-plating
P3	7.7	8	6.5	0.15	8.00	-
P4	6.1	7	5.5	0.45	1.33	Re-plating
P5	6.3	7	5.5	0.35	2.29	
P6	6.1	7	5.5	0.45	1.33	Re-plating
P7	6.3	7	5.5	0.35	2.29	
P8	8.3	9	7.5	0.35	2.29	
P9	6.1	7	5.5	0.45	1.33	Re-plating
P10	19.8	20	18.5	0.10	13.00	
P11	6.5	7	5.5	0.25	4.00	

Table 3. *Cont.*

Inspection Area/Part	Thickness (mm)			Corrosion rate (mm/year)	Remaining life prediction (year)	Recommendation
	t_1	t_0	t_{min}			
Main deck						
P1	9.3	10	8.5	0.35	2.29	
P2	9.5	10	8.5	0.25	4.00	
P3	9.6	10	8.5	0.20	5.50	
P4	9.3	10	8.5	0.35	2.29	
P5	8.7	10	8.5	0.65	0.31	Re-plating
Shell						
P1	7.6	8	6.5	0.20	5.50	-
P2	7.7	8	6.5	0.15	8.00	-
P3	7.6	8	6.5	0.20	5.50	-
P4	9.4	10	8.5	0.30	3.00	-
P5	9.7	10	8.5	0.15	8.00	-
P6	7.7	8	6.5	0.15	8.00	-
P7	7.6	8	6.5	0.20	5.50	-
P8	7.8	8	6.5	0.10	13.00	-
P9	8.4	9	7.5	0.30	3.00	-
P10	8.3	9	7.5	0.35	2.29	-

The average corrosion values for each structural member of the ship are obtained to identify which parts of the ship require additional maintenance to address corrosion issues. In Figure 9, it can be observed that the highest average corrosion rate is found in the navigation deck section, with an average value of 0.38 mm per year. In comparison, the lowest average corrosion rate of 0.17 mm per year is recorded in the top deck section.

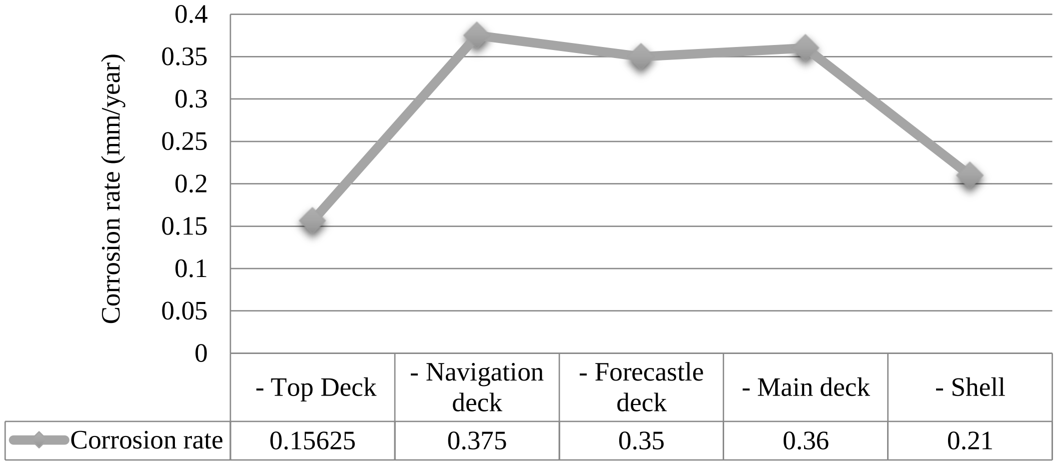

Figure 9. Average corrosion rate of Baruna Jaya IV Vessel

4 Conclusions

The study discovered that the corrosion rate of the ship was high, and the remaining life of the ship was less than five years. The findings of this study can be used to develop a cost-effective maintenance and repair strategy to improve the safety of the ship. Further research is needed to investigate the effectiveness of various corrosion mitigation strategies for ships.

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