Corrosion of Brass Fishing Vessel Propeller in Artificial Seawater

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A B S T R A C T S

The propeller was an important component in the fishing vessels marine propulsion system. Brass was widely used as a fishing vessel propeller. Brass was chosen because it has good mechanical properties and good corrosion resistance. The content of seawater in Indonesia has levels of 3% – 3.5% NaCl. In addition to the level of Ion Cl-, environmental factors can affect corrosion rate of material or metal. The environmental factors that affect the corrosion rate are the level of salinity, pH, DO, temperature and TDS. The objective of the present work was to explain the corrosion rate of brass in artificial seawater in Indonesia with exposure time. The material used for research is fishing vessel propeller commercial in Indonesia market. Measurement of the corrosion rate of brass used the principle of weight loss according to ASTM G31-72 (2004). During the corrosion test, the artificial seawater solution was tested for its pH and salinity quality over time of immersion. The result of immersion brass in the artificial seawater shows that the corrosion rate decreases in 1-to-10-days exposure time due to the increase in salinity levels above 30‰. While the results of exposure time immersion above 15 days tends to increase the corrosion rate due to a decrease in pH level. pH level of seawater depends on the environmental conditions and tends not to change significantly.

INTRODUCTION

Fishing vessels were one of the fishing tools used for traditional fishing operations at sea. The fishing vessel propulsion system uses propeller that fishing vessel move forward due to the thrust force produced [1]. The propeller was one component of the vessel propulsion system that had a function to transmit power by converting rotational motion into a thrust force and then the vessel can move [2]. The thrust of the propeller operating in seawater requires that the material selection of the propeller must have good mechanical properties and corrosion resistance [3]. Brass (copper alloy) and aluminium alloy were widely used as propeller fishing vessel materials. Both materials were used because they have advantages in the working environment i.e., corrosion resistance in seawater. Brass had greater

strength than aluminium so that brass was widely used as a material for fishing vessel propellers.

Brass is a copper alloy made of copper (Cu) and zinc (Zn) with levels of 60-90% Cu and 10-40% Zn and with the addition of other elements such as Mn, Si, and Pb [4], [5]. The use of Brass as a fishing vessel propeller because Brass has good tensile strength properties, easy to shape [6], and has resistant to seawater corrosion [7] due to the formation of a passive shield (oxide) or a thin layer of non-conductive corrosion products on its surface [8]. Corrosion on the surface of the propeller has a negative effect on the construction performance of the material so that it can reduce efficiency during use [9].

Corrosion was the degradation of materials due to environmental influences [10], [11]. The corrosion rate of copper (brass) alloys had been investigated. The brass corrosion rate observed in the artificial seawater environment has a value of 0.1133 mm/year [12]. On the other hand, the corrosion rate of brass in the analytical NaCl environment is 0.138747 mm/year [7]. In addition, the effect of exposure time on immersion artificial seawater media can change the value of the corrosion rate [13]. Seawater was a corrosive solution for some materials, one example was seawater from Nansha [14]. The characteristics of copper and copper alloys (including brass) that were immersed in various environments, namely 35 g/L NaCl, wastewater, and clean water had a thin layer that can inhibit the corrosion rate [15], [16]. However, some do not know the corrosion behaviour of brass due to changes in environmental factors in the seawater.

The influence of environmental factors on corrosive solutions causes the corrosion rate of the material to change. A simple example was that an increase in temperature can cause an increase in the rate of diffusion and accelerate the corrosion process. However, in the open marine environment, the corrosion rate can increase with temperature changes and can decrease due to changes in oxygen from seawater [17]. Other hand temperature, salinity has the same effect on the corrosion rate and its effect on dissolved oxygen was even greater [18]. Changes in pH at seawater due to pollution cause the corrosion rate to change faster [19], [20]. Therefore, environmental factors greatly affect the corrosion rate of a material. The present research on the corrosion rate of brass which was influenced by environmental aspects (salinity and pH) needs to be done because it was very relevant to the characteristics of seawater in Indonesia which had different conditions.

METHODS

The test specimen used in this study was a fishing vessel propeller commercial in the Indonesian market shown **Figure 1**. The propeller was cut used a grinder to serve as a coupon test for corrosion tested. The size of the specimen (coupon test) to corrosion test was 20mm × 40mm with a thickness of 3 mm. The chemical composition (wt.%) of the brass propeller specimens were 57.65Cu, 0.92Sn, 1.94Pb, 38.50Zn, 0.25Ni, 0.66Fe, 0.10Si, 0.02Mn, 0.02Cd. Before being tested, the brass was cleaned mechanically used #500 coarse sandpaper. The use of coarse sandpaper was expected that the specimen was close to the actual workpiece roughness. After that, the specimens were washed with water and dried with a tissue. corrosion test preparation was carried out according to ASTM G1-03 (2017).
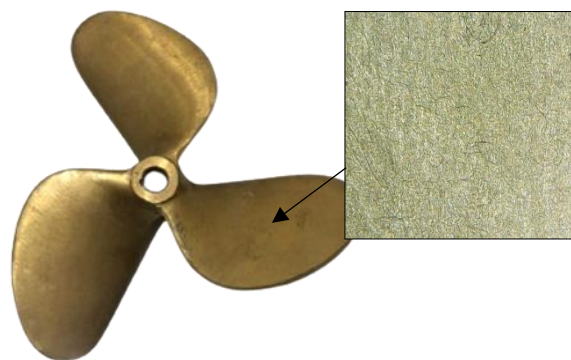

Figure 1. Fishing vessel propeller commercial.

The media of corrosion test was artificial seawater, specifically NaCl 3.5%. The NaCl solution was prepared used Sodium Chloride powder (p.a Merck). The artificial seawater was prepared by dissolved 35 gr NaCl in 1 l of water. Weight loss measurement for corrosion tested on brass coupon tested was carried out according to ASTM G31-72. The test was carried out in a weight loss immersed container or chamber containing 1 litre of artificial seawater. Then measure the initial mass with a 4-digit accuracy scale and the surface area of the test object with a caliper (Mitutoyo). The specimens were simultaneously immersed in the corrosive solution for 1, 3, 6, 10, 15 20, 25 30, 35, and 40 days. Furthermore, the specimen was cleaned with water and dried in the air then specimen was measured by weight. Measurement of corrosion rate, in general, can use **Equation 1**.

$$\text{Corrosion Rate} = \frac{K \times W}{A \times T \times D} \qquad (1)$$

Where K was a constant (According ASTM G31-72; K = 8.76 x10^4 mm/y), T was a time of exposure in hours to the nearest 0.01 h, A was an area in cm^2, W was a mass loss in gr, and D was density (8.4 gr/cm^3). During corrosion test, artificial seawater solution was also tested for its pH and salinity quality over time of immersion. The pH test uses a pH meter while the salinity test uses a refractometer with the help of sunlight when taken the value. The results of the immersion test were observed on a macro basis on the surface morphology after the corrosion tested process. Macro-morphological photo tested used a macro camera.

RESULTS AND DISCUSSION
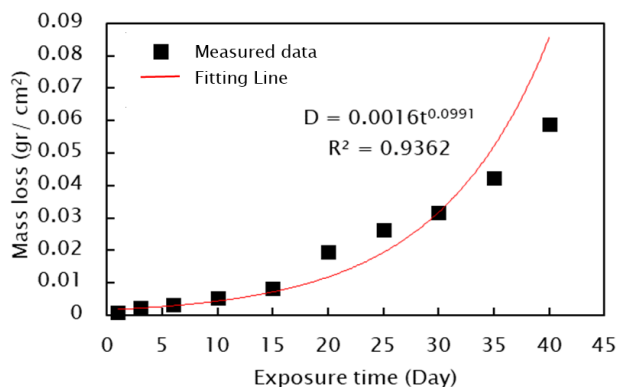
Figure 2. Weight loss in ship propeller brass material in artificial seawater.

The weight loss or degradation quality of the exposure (immersion) specimen was evaluated every cycle by taking the specimen and measuring the weight loss of the tested sample by repeated measuring mass. The results of the calculation of weight loss can be used as a reference in the empirical prediction of the corrosion rate of materials [14]. The results of the weight loss shown in **Figure 2**. The value of weight loss from exposure time of 1 day to 30 days had a magnitude of 0.000846 gr/cm^2 to 0.058972 gr/cm^2. The rate of weight loss in brass will always increase along with exposure time longer. The rise in weight loss will be increased gradually along with exposure time increase. The increase in the value of the relative weight loss was not significantly linear [18]. This phenomenon was indicated by the presence of corrosion kinetics of metals exposure in the artificial seawater. Corrosion kinetics can be described by empirical equations as in **Equation 2** [14], [21], [22].

$$D = At^n \tag{2}$$

$$D = 0.0016t^{0.0991} \tag{3}$$

Where D was a representation of the weight loss after immersion in the corrosive solution (gr/cm^2); t was the exposure time of the coupon test (a); A was the prediction of the initial corrosion rate in units of time or $g\ cm^{-2}\ a^{-1}$, which reflects the corrosion properties of the metal in its environment. While n was a constant coefficient that reflects the natural protection of the corrosion product layer. Based on **Figure 2** it can be shown that the predictive value of weight loss was shown in **Equation 3**. The value of R^2 must be greater than 0.9. If it was assumed that the corrosion process reaches a stable state when the change in corrosion rate was less than 10% [23]. Determination of the corrosion process with predictions can reach a stable state at 4.9 years according to the equation fittings that had been used [24]. The value of n generated in **Equation 3** was less than 1, then the mode of the corrosion rate of the

material was in deceleration mode [21]. The brass fishing vessel propeller had a coefficient of less than 1 so it was predicted by the weight-loss equation so that it belongs to the deceleration mode [14].
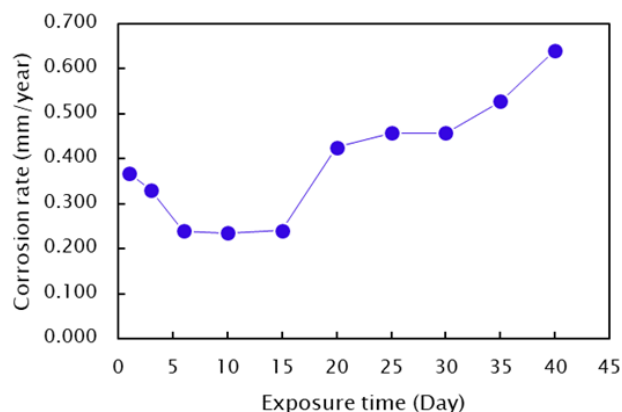
Figure 3. Corrosion rate on the brass propeller in artificial seawater.

The results of the calculation of the corrosion rate of brass used ASTM G31-72 can be shown in **Figure 3**. Based on weight loss brass, the corrosion rate according to the ASTM G31-72 weight loss was in the range of 0.235 mm/year to 0.641 mm/year. The corrosion rate was included in the corrosion rate range that had been carried out in previous studies [7], [13]. On the other hand, the corrosion rate at exposure time 1 day to 10 days decreased the corrosion rate with a value of 0.368 mm/year to 0.235 mm/year. Meanwhile, the exposure time of 15 days to 40 days increased with a value of 0.241 mm/year to 0.641 mm/year. This phenomenon can occur because at the exposure time of 1 day to 10 days it was indicated that the brass surface had a thin layer that makes the corrosion media unable to contact the surface to form oxide compounds [12], [25]. The phenomenon of the decreased corrosion rate of brass was similar to studies that had been carried out with other copper alloys [17]. Corrosion products that make a thin layer of brass may be in the form of Cu_2O which was a compound that was harmful to the environment [26]. The resistance of the copper passive layer to corrosion attack is influenced by the concentration of Cl in seawater. The longer the immersion the concentration of Cl attacks can make the passive layer saturated so that the passive layer becomes rust. In this case, the resistance of the passive layer of the material used is estimated at 10 days of immersion. The formation of a thin layer of Cu_2O is:

1. Cu ions lose electrons and form Cu^+, Cu → Cu^++e
2. Cu^+ reaches the metal surface and reacts with the corrosion medium Cl^- in NaCl to Cu^++Cl^- → CuCl
3. Increasing CuCl and decreasing Cl^-, then CuCl tends to hydrolyze into, 2CuCl + H_2O → Cu_2O + 2HCl, Cu_2O was more thermodynamically stable and adheres to metal surfaces
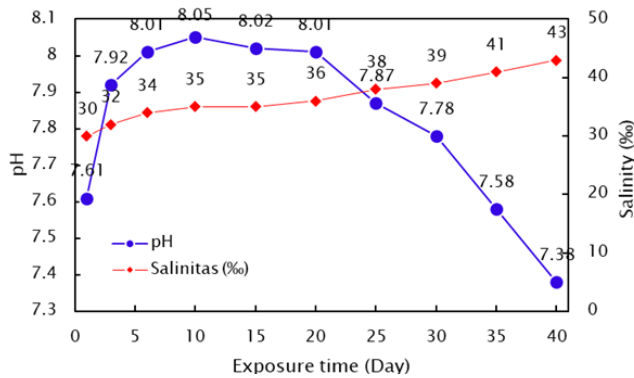
Figure 4. The results of pH and Salinity measurements on artificial seawater against exposure times.

As the result of the corrosion rate from the immersion of the brass specimen in this study, it can be classified as very high. During the process conditions, the specimen was exposed to an artificial seawater solution for 40 days, many possibilities occurred to both the test specimen and the corrosive solution. The corrosion rate change depending on several parameters of the chemical composition of the material and the environment. The environmental aspect of the media can be included temperature, dissolved oxygen content, total dissolved solids, and most importantly pH and salinity of the solution [27]. **Figure 4** shows that the results of pH and salinity measurements on artificial seawater solution for 40 days of exposure. Based on the measurement of artificial seawater solution for 40 days the pH value had a range between 7.38 to 8.05. A corrosive solution that had a pH value range of 5.8 to 8.5 was categorized as still in freshwater [28]. On the other hand, the pH value increased up to 10 days of time exposure. The increase in pH greatly affects the formation of a thin protective layer on the surface of the brass specimen so that the corrosion medium did not come into direct contact with the metal surface [20]. The pH solution will be decreased after 15 days to 40 days of exposure time. The decrease in value after an increase in pH measurements had the same results as previous studies. However, lowering the pH of the solution can make the solution more acidic so that the solution will become more than corrosive [29], [30] Effect of pH on the solubility of corrosion products during the corrosion process. The pH of the solution was often the key to determining the concentration of metals in the aqueous environment [31].

In addition to pH, the parameter that can affect the metal corrosion rate was the parameter of the amount of chloride content in the corrosion media solution. The chloride content in water can also be defined by salinity [29]. The correlation of salinity with Cl- ion content can be formulated by the empirical equation in **Equation 4** [32]. The content of Cl- ions in seawater was a combination of the content of Cl- in NaCl, MgCl$_2$, and KCl [30], [33].

$$1.80655 \; x \; [Cl^-] \tag{4}$$

The results of the salinity test in the artificial seawater solution can be shown in **Figure 4**. The salinity of the artificial seawater solution shows a gradual increase with increasing the immersion time of the specimen. The salinity value during the dyeing process ranges from 30‰ to 43‰. Exposure time in 10 days salinity level was in the range of 30‰ to 35‰ resulting in a relatively decreased corrosion rate [30]. This was due to the release of oxygen from seawater when salinity increases. The solubility of oxygen in an artificial seawater solution was inversely proportional to the salinity resulted in a polynomial equation [17], [34]. Salinity affects favourable solution conductivity yields and adverse DO solubility results [30], [35]. High salinity causes the release of oxygen so that the solubility of oxygen decreases [32], [33]. The decreased oxygen solubility of brass will not form oxidation so that the corrosion rate tends to decrease. The corrosion rate after an exposure time of 10 increases was no longer influenced by salinity but the presence of damage to the protective layer due to a long exposure time. This damage causes the corrosion medium to be in direct contact with the immersed/tested material. This phenomenon was supported by **Figure 5** which shows macro photos of specimens immersed for 0 days, 10 days, 30 days and 40 days. The indication was that after 10 days of immersion the brass metal will experience a decrease in quality if it was in extreme parameter conditions or decreases in pH. However, brass will re-form a thin layer as a corrosion protector with increasing time [12], [25] The exposure time of the return of the thin layer on the brass was estimated after 40 days even though it was mixed with corrosion products.
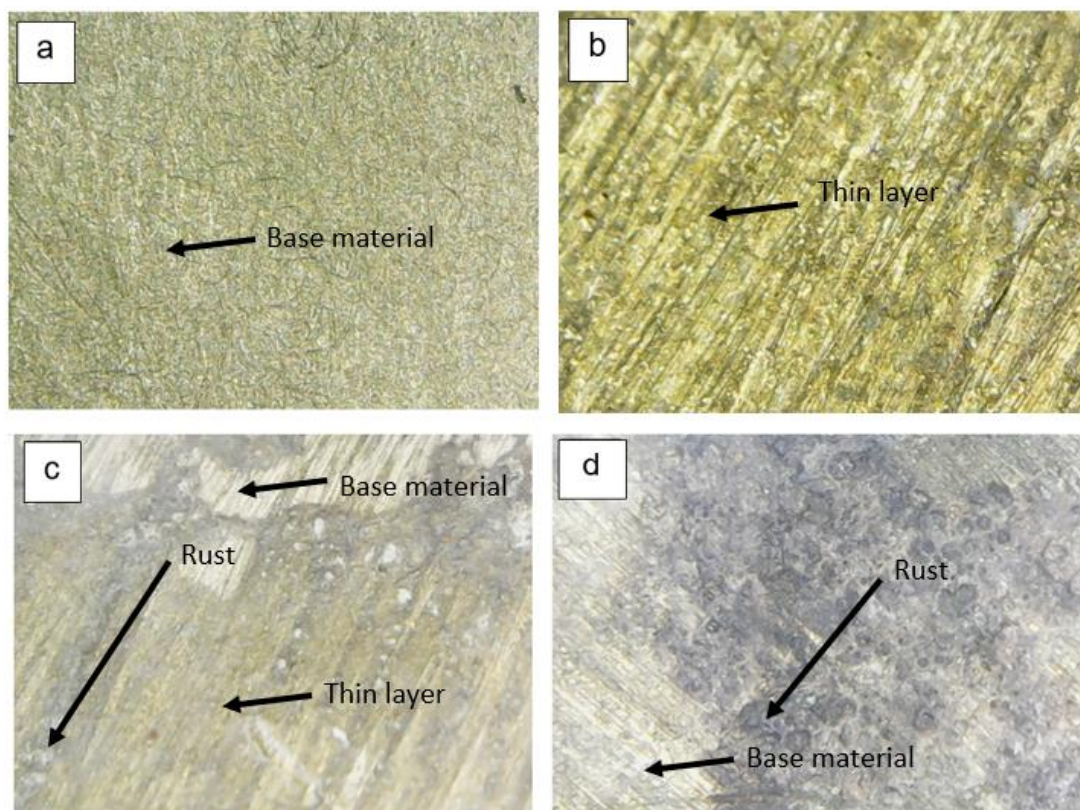
Figure 5. Macro photo of brass specimens with an exposure time of a) 0 days, b) 10 days, c) 30 days and d) 40 days.

CONCLUSION

Based on the test results on brass specimens and artificial seawater solution, the results showed that brass metal had a relatively decreased corrosion rate (by 0.368 mm/year to 0.235 mm/year) from 1 to 10 days exposure time due to an increase in salinity of artificial seawater solution causes oxygen levels to decrease and the formation of a thin protective layer. While the exposure time after 15 days, the corrosion rate of brass tends to increase (by 0.241 mm/year to 0.641 mm/year) as the pH solution of the artificial seawater decreases. In the reality case, pH level of seawater depends on the environmental conditions. Based on several cases in the research environment, the pH level of seawater tends not to change significantly.

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