Analysis of the Effect of Temperature Inhibitors on Corrosion Rate and Surface Structure Changes in Metal 2024-T3

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ABSTRACT
In seaplane design, the float is a component used for take off and landing in water that allows corrosion, in seaplane 172 skyhawk the float material is made of Aluminum 2024-T3. Corrosion is an event that changes the shape of the chemical structure of the metal which is a problem in the aviation industry because it can reduce the strength of the aluminum. The method used is weight loss according to ASTM G31-72 with inhibitor temperatures of 24℃, 28℃, and 32℃ with treatment without rinsing and rinsing every 120 hours, 240 hours, 360 hours, 480 hours and with seawater media that has a NaCl content of 3.5%. The results of this study obtained the corrosion rate of aluminum without rinsing at 24 ℃ has a corrosion rate of 2.294 mpy, while at 28 ℃ has a corrosion rate of 2.753 mpy, and at 32 ℃ has a corrosion rate of 3.212 mpy. Aluminum with rinsing at 24 ℃ has a corrosion rate of 1.376 mpy, while at 28 ℃ it has a corrosion rate of 1.835 mpy, and at 32 ℃ it has a corrosion rate of 2.294 mpy. The rinsing process reduced the corrosion rate by 66%. In seaplane maintenance with an average seawater temperature of 28 ℃ such as in the Banyuwangi sea, it is better to wash the seaplane float that has been submerged in the sea for a maximum of 120 hours once so that the corrosion rate does not increase, because based on the results of the study that Aluminum placed at 28 ℃ with treatment rinsed every 120 hours did not increase the corrosion rate.

Keywords: *Aluminium 2024-T3, corrosion rate, seawater salinity*

1. INTRODUCTION

In the continuity of today's industrial technology, it is necessary to improve the properties of a material. Aluminum metal is widely used for machine elements, automotive components, building construction, aircraft components, office equipment, and others. Aluminum has the advantage of being lightweight, easy to shape and resistant to corrosion. Aluminum is a material that is widely used for construction because it has strong and lightweight properties. (Junipitoyo et al, 2020). In general, aluminum is mixed with other metals to form aluminum alloys.

Aluminum has the characteristics of corrosion resistance, good electrical conductivity, and different metal properties. To improve mechanical properties, aluminum is compounded with additional Mg, Cu, Mn, Si, Zn and Fe, Si and Mg to increase corrosion resistance. Fe as a shrinkage preventer, Cu as a strength enhancer, and Mn as a formability enhancer. Aluminum alloy 2024 is commonly used by aircraft manufacturers for materials in the manufacture of structures on aircraft. Aluminum alloy 2024 has high strength for use in low corrosion resistance weight ratio. Therefore, aircraft manufacturers cover aluminum alloy 2024 and a handful of pure aluminum which is corrosion resistant on surfaces with a thickness of 30mm - 50mm. (Miftakh and Jamaludin, 2018).

The type of aluminum used in the Cessna type Skyhawk Seaplane float at the Indonesian Aviation Academy (API) Banyuwangi is type 2024-T3 aluminum referring to the service manual for the wipline model 2100/2350 amphibious and seaplane floats. Aluminum 2024-T3 series is a combination of Al-Cu metal and copper around 3.8% - 4.9%. Meanwhile, T3 means the physical state of the material and indicates the processing of an aluminum alloy. Treatment in the T3 condition includes solution treatment which means heating to a single phase temperature (±500˚C), quenching means cooling rapidly (dipped) to room temperature, and cold work in the form of strain hardening (cold roll). (Rochman et al., 2010).

In general, corrosion (rust) is known to many people, but many do not observe it. Many dangerous incidents such as ruptured oil pipelines, jammed guns, exploding boilers, cracked wings and many others, prove that corrosion requires more attention. The disadvantages of corrosion are seen from the considerable cost expenditures including maintenance costs, replacement costs, mechanic costs, reduced company profits (if production stops), obstructed production handling time. Corrosion must be addressed before severe damage occurs. It can be overcome by preventive control to inhibit corrosion attack. This method is better than suppression repair, which is much more expensive. (Suzanna, 2020).

Corrosion occurs due to the reaction of metals with the surrounding environment. Corrosion is an electrochemical reaction of a natural nature and continues spontaneously. Corrosion is very common in household and industrial objects. Corrosion can react with air and water, to form new compounds. The new compounds are red-brown solids that are brittle and porous. Corrosion is detrimental and shortens the life of metal objects with high corrosion rates. The corrosion process requires the help of oxygen and water (Sari, 2017). Temperature is the degree of cold heat of an environment or object. While the tool used to calculate the temperature is a thermometer. In everyday life, people often tend to measure temperature by touch, but as technology develops, a thermometer was born to measure temperature. (Indarwati et al., 2019).

In his research, Royani, A (2020) stated that the use of carbon steel for infrastructure construction in marine and offshore areas is very sensitive to corrosion. To investigate the effect of temperature on the corrosion rate of carbon steel, a corrosion study was conducted using the Tafel linear polarization electrochemical method in a marine environment. Extrapolation of the array was done at different temperatures by varying the electrode potential automatically. The resulting corrosion rates of low carbon steel in seawater at room temperature, 37℃ and 50℃ are 5.54 mpy, respectively; 11.91mpy and 14.53mpy. An increase in temperature will increase the reaction rate and will increase the corrosion rate. In addition to solution temperature, dissolved oxygen content, salinity, pH and total dissolved solids also affect corrosion in seawater.

Wibowo and Ilman (2011), stated in their research, potassium chromate (K2CrO4) as an inhibitor was added into seawater with different concentrations of 0.1%; 0.3%; and 0.5%. In addition, the corrosion rate was calculated by three-electrode potential cytometry with saturated calomel (Hg2Cl2) as the reference electrode while platinum (Pt) was used as an additional electrode. In support of the data, component testing, microstructure testing, Vickers hardness testing and tensile testing were conducted. As a result, the corrosion rate of Al 2024-T3 in marine environment without inhibitor is 0.0216 mm/year. The addition of potassium chromate (K2CrO4) inhibitor tends to reduce the corrosion rate and the optimum concentration is reached at 0.5% K2CrO4, which is characterized by a minimum corrosion rate of 0.0134 mm/year, i.e. the corrosion rate is reduced by 38%. The form of corrosion that occurs is pitting corrosion due to damage to the passive film. In this case, the inhibitor with passive film closure function is damaged so that it can inhibit the corrosion rate.

Nugroho and Ilman (2012) stated that Aluminum 2024-T3 is susceptible to corrosion if exposed to corrosive media such as sea water, one way to improve its corrosion resistance is through anodizing, anodizing is a way to improve its corrosion resistance. The anodizing process uses a 10° sulfuric acid solution with a current density ranging from 0.75 A/dm3 to 3 A/dm3 with immersion times of 30, 40, 50 and 60 minutes. In addition, the corrosion rate was measured by three-electrode potential cytometry using saturated calomel (Hg2Cl2) as reference electrode and platinum (Pt) as auxiliary electrode. In support of the data, component testing, microstructure testing, Vickers hardness testing and tensile testing were conducted. The results showed that the corrosion rate of Al 2024-T3 in unanodized seawater was 0.03043 mm/year. The anodizing process tends to reduce the corrosion rate and at a current density of 2.25 A/dm3 for 30 minutes provides optimum results with a corrosion rate of 0.00795 mm/year. The corrosion that occurs on Al 2024-T3 is pitting corrosion due to the failure of the passivation film. Anodizing can increase the thickness of the aluminum oxide layer thereby reducing the corrosion rate.

2. METHODS

This study has the aim of analyzing the effect of seawater on the corrosion rate of aluminum 2024-T3 with temperature inhibitors, analyzing the comparison of the corrosion rate of metal 2024-T3 with washed and unwashed treatment, and analyzing the effect of corrosion on the surface structure of metal 2024-T3. The existence of these objectives requires a case study to answer the research objectives, namely by making Aluminum Alloy 2024-T3 specimens used for corrosion rate testing and analyzing structural changes. Aluminum alloy 2024-T3 specimens are made with dimensions of 20mm x 10mm x 3mm and weigh 1,600 grams. Structural tests were carried out using a dino eye with the aim of observing changes in microstructure and material in the aluminum. The next step is to make a NaCl solution to soak the specimen. Immersion testing of specimens was carried out without rinsing and rinsing by rubbing by hand and then weighed every 120 hours to 480 hours, with the temperature of each specimen being 24 ℃, 28 ℃, and 32 ℃. Testing the corrosion rate is done by weight loss method, weight loss can be calculated by Equation (1).

$$CR = \frac{(K \times W)}{A \times T \times D} \quad (1)$$

3. RESULTS AND DISCUSSION

3.1 Treatment Of Unrinsed Alumuminum 2024

Test aluminum 2024-T3 with an initial weight of 1.600 grams with a tolerance of 0.005 in NaCl solution at 24 ℃ , 28 ℃ , and 32 ℃ without rinsing obtained weight loss data, with the following results:

1. Aluminum with treatment without rinsing at 120 hours of immersion with inhibitor temperature of 24 ℃ does not have an impact on weight loss, but at inhibitor temperatures of 28 ℃ and 32 ℃ it has an impact on weight loss, namely 0.001 grams because the crystallization process quickly occurs at a temperature inhibitor that supports the temperature starting at 28 ℃ and above.
2. The increase in weight loss at 24 ℃, 28 ℃, and 32 ℃ has a similar pattern of losing 0.002 grams / 120 hours, but at 24 ℃ it starts from 240 hours of immersion, the same as at 28 ℃ and at 32 ℃ it starts at 120 hours.

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 24 ℃ temperature without rinsing, the following corrosion rate data were obtained:

1. No corrosion rate occurs, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process to occur takes a long time.
2. The increase in corrosion rate every 120 hours decreased which has an impact on the longer the aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 0.000 mpy then in the second 120 hours the corrosion rate increased by 0.917 mpy, then the third 120 hours the corrosion rate remained at 0.917 mpy (1.835 mpy - 0.917 mpy), and the fourth 120 hours the corrosion rate decreased by 0.459 mpy (2.294 mpy - 1.835mpy).

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 28 ℃ temperature without rinsing, the following corrosion rate data were obtained:

1. No corrosion rate occurs, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process to occur takes a long time.
2. The increase in corrosion rate every 120 hours decreased which has an impact on the longer the aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 1.835 mpy then in the second 120 hours the corrosion rate remained at 1.835 mpy, then the third 120 hours the corrosion rate increased by 0.612 mpy (2.447 mpy - 1.835 mpy), and the fourth 120 hours the corrosion rate decreased by 0.306 mpy (2.753 mpy - 2.447 mpy).

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 32 ℃ temperature without rinsing obtained the following corrosion rate data:

1. At 120 hours immersion, Aluminum 2024-T3 against NaCl solution at 32 ℃ inhibitor without rinsing does not occur corrosion rate, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process takes a long time.
2. The increase in corrosion rate every 120 hours decreases which has an impact on the longer the aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 1.835 mpy then in the second 120 hours the corrosion rate increased by 0.918 mpy (2.753 mpy - 1.835 mpy), then the third 120 hours the corrosion rate decreased by 0.306 mpy (3.059 mpy - 2.753 mpy), and the fourth 120 hours the corrosion rate decreased by 0.153 mpy (3.212 mpy - 3.059 mpy).

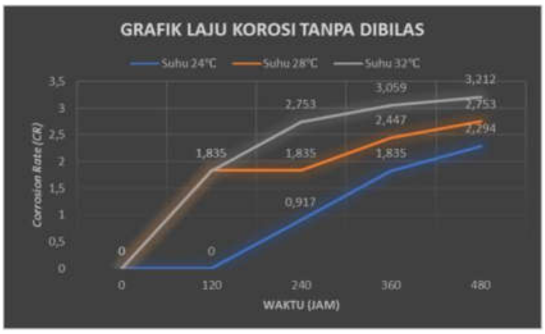

Figure 1. *Comparison of corrosion rate without rinsing*

Aluminum 2024-T3 placed at 28 ℃ and 32 ℃ experienced the same increase in corrosion rate in the first 120 hours, while Aluminum 2024-T3 placed at 24 ℃ experienced no corrosion rate in the first 120 hours. Aluminum 2024-T3 placed at 24 ℃, 28 ℃, and 32 ℃ experienced an increase in corrosion rate that decreased every 120 hours at 360 hours to 480 hours of immersion.

Aluminum microstructure test with *dino eye* camera at 24°C without rinsing, the following results were obtained:

Figure 2. *After soaking for 360 hours*

After immersion placed at 24 ℃ for 360 hours, crystallization began to occur on the metal surface so that the metal surface began to corrode.

Aluminum microstructure test with *dino eye* camera at 28 °C treatment without rinsing, the following results were obtained:

Figure 3. *After soaking for 240 hours*

After immersion, which was placed at 28℃ for 240 hours, crystallization began to occur on the metal surface so that the metal surface began to corrode.

Aluminum microstructure test with *dino eye* camera at 32 °C treatment without rinsing, the following results were obtained:

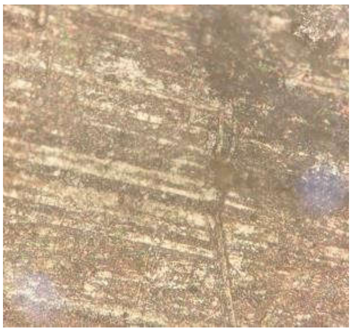

Figure 4. *After soaking for 360 hours*

After immersion placed at 32 ℃ for 360 hours, crystallization began to occur on the metal surface so that the metal surface began to corrode.

3.2 Aluminum 2024 Treatment by Rinsing

Test aluminum 2024-T3 with an initial weight of 1.600 grams with a tolerance of 0.005 in NaCl solution at 24℃, 28℃, and 32℃ with rinsing obtained weight loss data, with the following results:

1. Aluminum with treatment without rinsing at 120 hours of immersion with inhibitor temperature of 24 ℃ does not have an impact on weight loss, but at inhibitor temperatures of 28 ℃ and 32 ℃ it has an impact on weight loss, namely 0.001 grams because the crystallization process quickly occurs at a temperature inhibitor that supports the temperature starting at 28 ℃ and above.

2. The increase in weight loss at 24 ℃, 28 ℃, and 32 ℃ has a similar pattern of losing 0.001 grams / 120 hours, but at 32 ℃ at 360 hours of immersion, the weight loss increased by 0.002 grams / 120 hours.

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 24 ℃ temperature with rinsing, the following corrosion rate data were obtained:

1. No corrosion rate occurs, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process to occur takes a long time.
2. The increase in corrosion rate every 120 hours decreased which has an impact on the longer the aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 0.000 mpy then in the second 120 hours the corrosion rate increased by 0.917 mpy, then the third 120 hours the corrosion rate decreased by 0.306 mpy (1.223 mpy - 0.917 mpy), and the fourth 120 hours the corrosion rate decreased by 0.153 mpy (1.376 mpy - 1.223 mpy).

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 28 ℃ temperature with rinsing, the following corrosion rate data were obtained:

1. No corrosion rate occurs, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process to occur takes a long time.
2. The increase in corrosion rate every 120 hours decreased which has an impact on the longer the

aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 1.835 mpy then in the second, third and fourth 120 hours the corrosion rate remained at 1.835 mpy.

The corrosion rate of Aluminum 2024-T3 in NaCl solution with 120 hours immersion and 32 ℃ temperature with rinsing, the following corrosion rate data were obtained:

1. No corrosion rate occurs, which is caused by incomplete crystallization, because the lower the temperature for the crystallization process to occur takes a long time.
2. The increase in corrosion rate every 120 hours decreased which has an impact on the longer the aluminum is immersed, the more stable the corrosion rate will be. In the first 120 hours the corrosion rate amounted to 1.835 mpy then in the second and third 120 hours the corrosion rate remained at 1.835 mpy, while in the fourth 120 hours the corrosion rate decreased by 0.459 mpy (2.294 mpy - 1.835mpy).

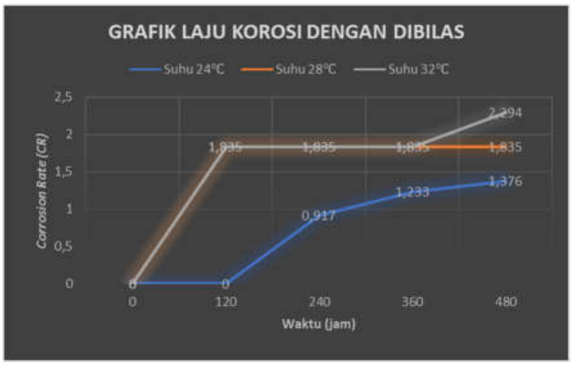

Figure 5. *Comparison of corrosion rate with rinsing*

1. Aluminum 2024-T3 placed at 28°C and 32°C experienced the same increase in corrosion rate until the first 120 hours, then did not experience an increase in corrosion rate until the 360th hour.
2. Aluminum 2024-T3 placed at 24°C did not experience any corrosion rate in the first 120 hours.
3. Aluminum 2024-T3 placed at 24°C experienced an increase in corrosion rate that decreased at 240 hours to 480 hours of immersion, if the longer the immersion, the more stable the corrosion rate of the aluminum.
4. Aluminum 2024-T3 placed at 32°C did not increase in corrosion rate from 120 hours to 360 hours of immersion, then increased at 480 hours.

Aluminum microstructure test with *dino eye* camera at 24 °C treatment with rinsing, the following results were obtained:

Figure 6. *After soaking for 240 hours*

After immersion placed at 24 ℃ for 240 hours, crystallization began to occur on the metal surface so that the metal surface began to corrode.

Aluminum microstructure test with *dino eye* camera at 28 °C treatment with rinsing, the following results were obtained:

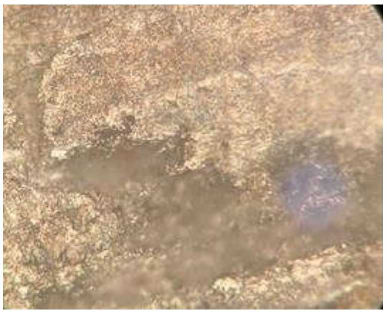

Figure 7. *After soaking for 240 hours*

After immersion placed at 28 ℃ for 240 hours, crystallization began to occur on the metal surface so that the metal surface began to corrode.

Aluminum microstructure test with dino eye camera at 32 °C treatment with rinsing, the following results were obtained:

Figure 8. *After soaking for 120 hours*

At 120 hours, the metal surface looks brownish due to uniform corrosion, but after immersion placed at 32 ℃ for 240 hours, crystallization begins to occur on the metal surface so that the metal surface begins to look corroded.

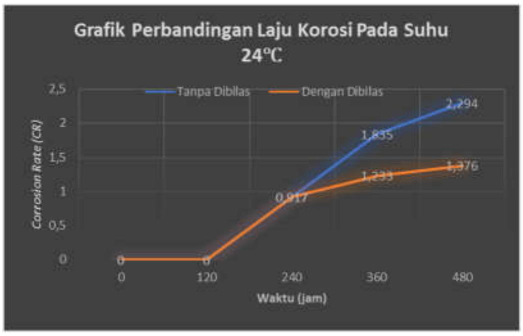

Figure 9. *Comparison chart of 24℃ temperature with rinsing and without rinsing*

In immersion 0-240 hours the corrosion rate is the same, but after 240 hours aluminum with treatment without rinsing an increase in corrosion rate up to 1.835 mpy at 360 hours immersion and 2.294 mpy at 480 hours immersion. Aluminum with rinsed treatment at every 120 hour interval has an increase in corrosion rate that decreases up to 480 hours, i.e. the longer the aluminum is immersed, the more stable the corrosion rate.

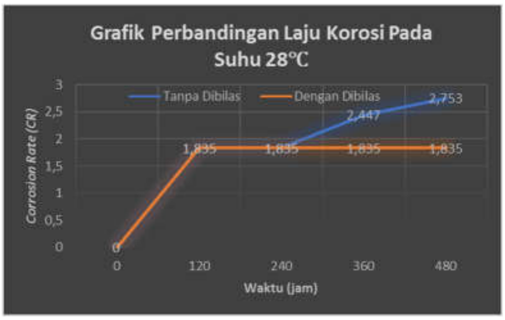

Figure 10. *Comparison chart of 28℃ temperature with rinsing and without rinsing*

Immersion 0-240 hours the corrosion rate is the same, but after 240 hours aluminum with treatment without rinsing there is a very high increase in corrosion rate caused by crystallization that occurs in NaCl solution does not disappear which is inversely proportional to the washed aluminum. Aluminum with treatment rinsed every 120 hours interval did not experience an increase in corrosion rate up to 480 hours.

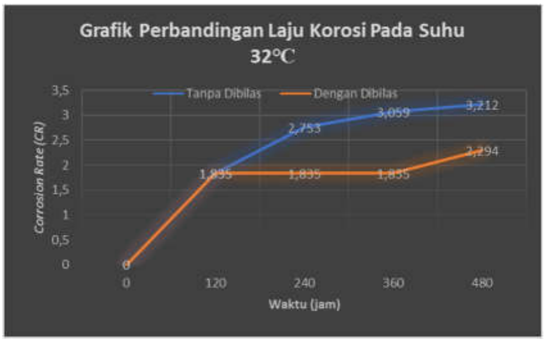

Figure 11. *Comparison chart of 32℃ temperature with rinsing and without rinsing*

Immersion 0-120 hours the corrosion rate is the same, but after 120 hours aluminum with treatment without rinsing there is a high increase in corrosion rate up to 2.753 mpy at 240 hours immersion then 3.059 mpy at 360 hours immersion, and 3.212 mpy at 480 hours immersion. Aluminum treated with rinsing at every 120-hour interval did not experience an increase in corrosion rate until 360 hours, then experienced an increase in corrosion rate up to 2.294 at the 480-hour immersion.

4. CONCLUSION

Based on the research that has been conducted, it can be concluded that:

1. In testing Aluminum 2024-T3 with rinsed and non-rinsed treatments placed at 24℃, 28℃, and 32℃, the results show that the higher the surface temperature of seawater, the faster the corrosion rate of the aluminum. The higher the temperature, the reaction speed and corrosion rate increase.
2. The difference in the test results of Aluminum 2024-T3 washed every 120 hours and without washing is very high, which is presented in figure 4.3, figure 4.4, and figure 4.5. Regardless of the temperature at the seawater surface, the treatment of rinsing every 120 hours will reduce the corrosion rate. This is due to crystallization not forming because the areas where crystallization occurs are rinsed away.
3. NaCl solution causes structural changes that lead to the formation of corrosion on Aluminum 2024-T3. The type of corrosion formed from Aluminum 2024-T3 immersed in NaCl solution experiences uniform corrosion on the metal surface due to chemical reactions due to humid air and low water pH, so that the longer the metal will be thinner.

AUTHORS' CONTRIBUTIONS

1. The authors take full responsibility for the writing of this article.
2. The author has approved the article for publication as per the aviation college Final Project guidelines.

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