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GALVANIZED CORROSION PATTERNS ON SACRIFICIAL ANODE OF AZ91D MAGNESIUM ALLOY ON SHIP AND UNDERWATER STRUCTURES

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ABSTRACT

This study attempts to evaluate the possible application of magnesium as a sacrificial anode on ships and underwater structures obtained from the summary of previous studies. In this study the performance assessment of the two alloys will be carried out which includes protection potential and the resulting galvanic current, capacity, efficiency, consumption rate, induction time, and its corrosion pattern. Environmental and design factors, such as concentrations of dissolved salts and wide protected variations, have also been studied for their effects on the performance of the alloy. The results show that magnesium alloy AZ91D, can be applied in ship and underwater structures due to higher resistance to galvanized corrosion. The AZ91D magnesium alloy has a longer time resistance in marine or saline (NaCl) environmental conditions, with a lower mass loss rate. To improve magnesium resistance on ships and underwater structures, AZ91D specimens are better coated with aluminum metal to increase corrosion resistance and are harder than non-coated specimens

Keywords: AZ91D magnesium alloy, galvanic corrosion, sacrificial anode, ships, underwater structures.

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1. INTRODUCTION

Indonesia which is mostly in the form of oceans has many structures or constructions of metal materials, especially carbon steel. The construction is always related to sea water which is a corrosive electrolyte. This has the consequence of the occurrence of corrosion attacks on these structures, which can cause a large loss both in technical and economic terms. In a related

context, the study of ship building and consideration of various problems that is possible to obtain considerable attention. Windyandari et al. (2018) examined the comparative studies on buckling strength between the swedge-stiffened and the ring-stiffened of the midget type submarine pressure hull. Chrismianto et al. (2015) examined the development of cubic Bezier curve and curve-plane intersection method for parametric submarine hull form design to optimize hull resistance using CFD. Zakki et al. (2016) analyze the development of new type free-fall lifeboat using fluid structure interaction analysis. By using under ice-grounding scenario models, Prabowo et al. (2017) examine the structural analysis for estimating damage behavior of double hull. With other method of finite element analysis, Zakki et al. (2017) analyze the structure design and characteristic analysis of buckling strength on swedge frame pressure hull. Similarly, Yudo et al. (2017) focused on the numerical investigation of the buckling strength behavior of ring stiffened submarine pressure hull. In terms of corrosion, various methods for preventing corrosion in seawater environments continue to be developed. One of them is the use of sacrificial anodes that work based on the principle of cathodic protection. The surface of metal structures in seawater is converted into cathodic by giving a current coming from the sacrificial anode. The sacrificial anode type that is suitable for use in seawater environments is the AZ91D magnesium alloy sacrificial anode. The availability of these two types of alloys provides the choice for users to determine the type of alloy that suits their needs. The basis of this election should be based on the best performance. In this study the performance assessment of the two alloys will be carried out which includes protection potential and the resulting galvanic current, capacity, efficiency, consumption rate, induction time, and its corrosion pattern. Environmental and design factors, such as concentrations of dissolved salts and wide protected variations, have also been studied for their effects on the performance of the alloy.

Cathodic protection is an electrochemical corrosion protection method in which the oxidation reaction in the galvanic cell is concentrated on the anode and removes corrosion on the cathode. The structure that will be protected electrically is made negative so that it acts as a cathode. The other electrodes are electrically made positive and act as an anode to create a closed-circuit electric current system as well as only when a piece of metal is corroded. This system requires the anode, cathode, electrical flow between the two and the presence of electrolytes. This study attempts to evaluate the possible application of magnesium as a sacrificial anode on ships and underwater structures obtained from the summary of previous studies. Magnesium applications as sacrificial anodes are increasing in the automotive and aircraft industries. This is due to its light weight, its relative strength, adequate mechanical properties and affordable costs (Liu & Schlesinger, 2009; Jia, Song, & Atrens, 2007) Magnesium is the most reactive metal and at the same time a low standard potential electrode, because magnesium is the most active metal, it will cause serious galvanic corrosion if in contact with other metals (Jia, Song, & Atrens, 2007) In aqueous environment, magnesium will form a galvanic corrosion system and microgalvanized corrosion with other steels with several secondary phases (such as α phase or β phase) (Liu, & Schlesinger, 2009). Many previous international studies discuss as well as galvanized corrosion and cathodic protection systems with magnesium alloy as the sacrificial anode, this research departs from the results of previous studies that have not yet fully discovered the exact formulation of magnesium if the alloys (Liu, & Schlesinger, 2009).

2. GALVANIZED CORROSION

Corrosion is the degradation of a material because it reacts with its environment (Sidharth, 2009). Degradation results in a decrease in the function and physical form of the material. This can cause a weakening of the function because the material loses cross-sectional area,

due to contact with hydrogen elements. , degradation can occur due to sun exposure, plural corrosion is found in metal structures that are in contact with the sea and offshore because seawater or salt is a good electrolyte that is aggressive and corrosive, which explains that corrosion in marine / offshore structures / buildings occur in various types of metals and alloy steel, often very dangerous, not only for submerged structures, but also because of exposure to environmental conditions. Basically, corrosion can be divided into 3 types, namely ordinary corrosion, local corrosion, and mechanical corrosion. Local corrosion is corrosion that attacks a passive metal in a corrosive environment where the protective metal has been damaged first. The level of galvanic corrosion can basically be determined by I_g galvanized current and its distribution, which can theoretically be written as follows (Liu, & Schlesinger, 2009):

$$I_g = (\phi_c - \phi_a) / (R_a + R_c + R_s + R_m)$$

I_g is a galvanic current that occurs between the anode and cathode; ϕ_c and ϕ_a are open potential circuits between the cathode and anode; R_a and R_c are cathode and anode resistance, R_s is the solution resistance between cathode and anode, and R_m is the metal resistance from the surface of the anode to the cathode surface through metal lines.

3. MAGNESIUM AS SACRIFICIAL ANODE

The standard magnesium electrode potential $E_{Mg^{2+}/Mg}$ is -2.37 V. But, if it is in a 3% sodium chloride solution, the potential electrode becomes -1.63 V.

3.1. Material Analysis

In this study, galvanized microstructure corrosion and electrochemical patterns were tested between Magnesium Alloy AZ91D Victim Anodes on ships or underwater structures exposed to sea water. Several previous studies have tested Magnesium Alloy AZ91D material as a sacrificial anode. Research from Ambat et al (2000) tested AZ91D alloys in NaCl solutions at 3.5% and pH 7.25, using constant immersion techniques. The same material and experimental tests were carried out by Pardo et al (2008) by testing the magnesium alloy corrosion pattern at 3.5 wt% NaCl levels. Ambat et al (2000) carried out experimental tests of alloy surface changes and analytical studies using experimental optics and scanning microscopic electrons.

3.2. Material Testing

Material composition used in this study was magnesium alloy AZ91D. Because of its low potential electrode standard, in this study the AZ91D magnesium alloy resistance / durability was compared with similar magnesium materials to obtain its strength picture first. Referring to the opinions of several previous researchers who tested the galvanic strength of anode victims of magnesium alloy AZ91D, this material would be more resistant to corrosion if juxtaposed or mixed with several other materials that were proven to increase magnesium alloy durability, while keeping the market value cheap. This combination is expected to produce an overview for its use in the transportation industry, such as ships and marine structures.

3.3. Galvanized Corrosion Pattern of Magnesium Alloy AZ91D

Magnesium is one of the sacrificial anodes that are widely used in the transportation industry. Its relative strength makes it a consideration in its use. However, magnesium alloy has a low standard potential electrode, which makes it a reactive metal. This property makes it not strong enough and effective in resisting galvanic corrosion. Experimental testing by several researchers shows AZ91D is the lowest strength element compared to other materials in magnesium such as AZ31 and AZ80 (Pardo, 2008: 825).

3.4. Enhanced Resistance of Magnesium Alloy AZ91D

Referring to previous studies, several enhancing efforts can be made to increase the corrosion resistance of Magnesium Alloy AZ91D as follows:

- a. Add aluminum material as coating (Zhu and Song, 2006). In this study, an aluminum-alloy layer was applied to the surface of the magnesium alloy AZ91D. The layer formed in aluminum powder at 420 oC is added to the phase β (Mg17Al12). Polarization curves, AC impedances, salt immersions and salt sprays are carried out to investigate corrosion patterns and assess the magnesium alloy resistance that has been coated with aluminum. The results showed that AZ91D coated specimens were far more corrosion resistant and harder than non-coated specimens. If magnesium is added with aluminum alloy, the corrosion resistance is produced according to the aluminum content. That is, the higher the level of aluminum as the sacrificial anode together with magnets (in the sacrificial anode of magnesium matrix namely Al-Mn and Mg17Al12) will limit the corrosion rate itself.
- b. Adding holmium (Ho) as an element to increase magnesium resistance to corrosion (Xuehua et al., 2006). The study stated that the corrosion pattern of two Mg-9AL-Ho alloys (Mg-9AL-0.24Ho and Mg-9AL-0.44Ho) was tested by general corrosion measurements and electrochemical methods on 3.5% NaCl solution saturated with Mg (OH) 2 . The experimental results were then compared with the Mg-9AL alloy without the addition of Ho. Various levels of corrosion tests show that the addition of Ho increases the corrosion resistance of Mg-9AL alloys.
- c. Making some as a cathode, including aluminum, steel and zinc (Song et al., 2004). Galvanic corrosion testing was carried out with AZ91D magnesium alloy in contact with zinc, A380 aluminum alloy and 4150 steel alloy. A specially designed test panel is used to measure galvanic currents under conditions of salt spray. The results show the distribution of galvanic current densities at AZ91D and at different cathodes. Among the cathodes used as specimens, steel is the worst cathode and the most aggressive aluminum for AZ91D.
- d. Considering geometric elements (Jia et al., 2006). In this study, magnesium elements were combined with steel to test the effect of geometric factors on the distribution of galvanic current density for AZ91D. Geometric factors that influence the corrosion rate of AZ91D magnesium alloy are the ratio of anode / cathode area, isolation of the distance between the anode and cathode, the depth of the film solution that covers the galvanized area and the way of interaction between the two elements used.

4. EVALUATION OF THE STRENGTH OF MAGNESIUM ALLOY AZ91D ON SHIPS AND UNDERWATER STRUCTURES

Strength measurements of magnesium alloy AZ91D on ships or underwater structures were carried out by collecting and analyzing the results of previous studies that tested this material in elements of salt water (NaCl at certain levels, and certain temperatures). Pardo (2008) stated that the corrosion pattern of AZ91D shows a higher resistance / resistance to corrosion with the mechanism of the test (3.5% NaCl) and 25oC. But there is a mechanism for changing microstructure to attack corrosion. If added with aluminum alloy, the corrosion resistance produced is in accordance with the aluminum content. That is, the higher the level of aluminum as the sacrificial anode together with magnesium (in the sacrificial anode of magnesium matrix, Al-Mn and Mg17Al12) will limit the corrosion rate itself.

Moreover, the loss of mass and time between metals of magnesium show that AZ91D magnesium is the most resistant metal in the face of galvanic corrosion when compared to other magnesium elements such as AZ31 and AZ80 which lose more mass in a shorter time. This test confirms that AZ91D magnesium is relatively more feasible to consider as an anode for victims on ships and underwater structures. The summary of this examination can be traced in Pardo's (2008) study. The result confirms the study of Zhu and Song (2006) which showed that AZ91D coated specimens were far more corrosion resistant and harder than non-coated specimens. If magnesium is added with aluminum alloy, the corrosion resistance is produced according to the aluminum content. That is, the higher the level of aluminum as the sacrificial anode together with magnets (in the sacrificial anode of magnesium matrix namely Al-Mn and Mg17Al12) will limit the corrosion rate itself.

5. SYSTEM APPLICATION

The main advantage of cathodic protection over other forms of anti-corrosion method is to maintain the current of the DC circuit, so that its effectiveness can be monitored continuously. Cathodic protection is usually applied to coated structures (coatings) to provide corrosion control to coating areas that may be damaged. This cathodic corrosion method is applied to a structure to prolong their life. Determining the use of cathodic protection will initially avoid corrosion in a thin section of the structure that may be expensive in assembly. In addition, the use of cathodic protection methods can be used to improve safety against a metal leak that cannot be tolerated for safety or environmental reasons. Cathodic protection can be applied to any metal structure in contact with mass electrolytes (including concrete). Other structures that are generally protected by cathodic protection are exterior surfaces such as pipelines, ship hulls, storage tanks, docks and port structures, sheet steel, offshore platform and platform pylons and floating structures (Kean and Davis, 1981).

Theoretically, the application of cathodic protection on ships and underwater structures is very possible. However, not all metals are suitable for use as an anode for victims in the marine environment. In the marine environment, both zinc and aluminum are suitable for use, but aluminum has better reactivation performance. Magnesium is not suitable for use in the marine environment. In addition aluminum is suitable for use as an anode victim in brackish water. Other metals such as zinc and magnesium are not suitable for use. Whereas in pure fresh water, magnesium is an anode material that has the best performance. While in polluted water conditions or when the boat is temporary in brackish water, aluminum is more suitable as the victim's anode. However, research from Pathak et al. (2012) shows that Mg is the most electrochemically active metal used in engineering applications, and can be exposed to corrosion so easily in some environments. In such environments, the application of Mg and Mg alloys can be applied as sacrifices for anodes in steel structures, such as ship hulls and steel pipes. Mg is widely used as a sacrificial anode to provide cathodic protection from metal and underground structures, ships, submarines, bridges, decks, planes and land transportation systems.

6. CONCLUSION

In the marine environment, both zinc and aluminum are suitable for use, but aluminum has better reactivation performance. Magnesium is not suitable for use in the marine environment. In addition aluminum is suitable for use as an anode victim in brackish water. Other metals such as zinc and magnesium are not suitable for use. Whereas in pure fresh water, magnesium is an anode material that has the best performance. While in polluted water conditions or when the boat is temporary in brackish water, aluminum is more suitable as the victim's anode. Moreover, specifically for magnesium alloy AZ91D, it can be applied due to tightness

or higher resistance to galvanized corrosion. The AZ91D magnesium alloy has a longer time resistance in marine or saline (NaCl) environmental conditions, with a lower mass loss rate. To improve magnesium resistance on ships and underwater structures, AZ91D specimens are better coated with aluminum metal to increase corrosion resistance and are harder than non-coated specimens. If magnesium is added with aluminum alloy, the corrosion resistance is produced according to the aluminum content. That is, the higher the level of aluminum as the sacrificial anode together with magnets (in the sacrificial anode of magnesium matrix namely Al-Mn and Mg17Al12) will limit the corrosion rate itself. In general, this study concludes that the mixing of magnesium AZ91D sacrificial anodes will be more effective in resisting the corrosion rate if mixed with other anodes such as aluminum

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