ANALYSIS OF AlMg\(_3\) MATERIAL CORROSION AS RSG-GAS BEAM TUBE

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ABSTRACT
ANALYSIS OF AlMg\(_3\) MATERIAL CORROSION AS RSG-GAS BEAM TUBE MATERIAL.
Reaktor Serba Guna G.A. Siwabessy (RSG-GAS) has been operated almost for 30 years. After operation for 30 years, degradation and corrosion are possibly occur at reactor components and structure materials. Material degradation possible occurs at RSG GAS neutron beam tube that consists of AlMg\(_3\) material. The purpose of this study is to observe the temperature and chloride ion effect to AlMg\(_3\) material. The method that used in this research is by observing the corrosion rates of AlMg\(_3\) material in NaCl concentration at several temperature conditions using Potentiostate. Tests were conducted in 28, 30, 35, 40 and 45 °C. The AlMg\(_3\) material corrodes in solution containing NaCl solution. The corrosion rates increased with increasing temperature. The results showed that corrosion rate for the AlMg\(_3\) material were very small and the highest corrosion rate occur at 45 °C and 0.1 ppm NaCl addition, that is 4.69 x 10\(^{-3}\) mpy. The media conductivity also has an effect to AlMg\(_3\) corrosion rate where the higher media conductivity the higher AlMg\(_3\) material corrosion rate occur.

Key words: degradation, corrosion, structure materials, neutron beam tube, corrosion rates

INTRODUCTION
The RSG-GAS (known as Reaktor Serba Guna G.A. Siwabessy) is a multipurpose research reactor. This reactor has two coolant systems, i.e. the primary and secondary cooling systems. The primary coolant uses demineralised water and the secondary uses PUSPIPTEK water. Both of these systems ensure that the reactor coolant temperature is controlled and safe. During normal operation, heat generated in the core is taken by primary cooling system and transferred to the secondary cooling system via heat exchangers. The heat is discharged into the environment through cooling towers by forced circulation [1].

The primary and secondary water quality must be managed to meet the specifications. Regular monitoring and measurements are conducted to make sure that the requirements are satisfied. The parameters that should be monitored are conductivity, pH, TDS (total dissolved solids) and some trace elements measurements. Mechanical and chemical
treatments are conducted on the cooling system to maintain the integrity of structure, components, and system. In the primary cooling system, water is continuously passed through a purification system that consists of a mechanical filter and ion exchange resins. In the secondary cooling system, chemical additives are used to suppress corrosion, scaling, and microorganisms growth [2].

AlMg₃ alloy usually is used as structure material of research reactor. Research reactor usually used demineralized water as primary coolant [1,2]. The quality of primary coolant is maintained to ensure the structure material safety which exists in primary coolant. Aluminum and its alloys are corroded and will form thin oxide film at its surface. This oxide film has a protective behavior and can reduce the next corrosion. Many metal and alloy have capability to form passive film from metal oxide at its surface that separated the metal and alloy from its media. Chloride ion, one of ions can cause the corrosion at material even if the material has passive film. The temperature also has an effect to material corrosion rate. Increasing the temperature usually is followed by increasing the corrosion rate. [2].

The purpose of this study is to observe the temperature and chloride ion effect to AlMg₃ material neutron beam tube of RSG –GAS. The method that used in this research is to observe the corrosion rates of AlMg₃ material in NaCl concentration at several temperature conditions using Potentiostate. Tests were conducted in 28, 30, 35, 40 and 45 °C. The AlMg₃ material corrodes in solution containing NaCl solution.

**THEORY**

In research reactors, corrosion processes are strongly affected by operational measured variables such as environment medium, pH, temperature, conductivity n chloride ion. The corrosion is a natural process which can cause degradation on material, component and the other structure. Corrosion process can not be able to stop but only can be managed with some ways [3,4]. Many efforts have been done to control corrosion such as: using the material that more resist to corrosion. Corrosive environment can determine the material resistance to corrosion. The nuclear reactors material can consist of several type depend on function and their environment. Reaktor Serba Guna (RSG-GAS) also consist of some material, one of them is an AlMg₃ used as neutron beam tube material. AlMg₃ as structure material of component reactor has reliability and safety to ensure the reactor can be operated safely. Reactor Serba Guna has a primary and secondary coolant. Those reactor coolants have function to ensure safe temperature in core. The demineralized water is used as the reactor coolant with specification as requirement as follows, [5,6]

<table>
<thead>
<tr>
<th>Table 1. RSG-GAS demineralized water requirement [3]</th>
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</thead>
<tbody>
<tr>
<td>pH 6.5 – 7.5</td>
</tr>
<tr>
<td>Conductivity ( max) 2 μS/cm</td>
</tr>
<tr>
<td>Chloride ion ( max) 0.0094 ppm</td>
</tr>
<tr>
<td>Copper ion (max) 0.0056 ppm</td>
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</tbody>
</table>

This pH level will minimize aluminum corrosion [7]. Tight control of pH is essential in reactors where the same cooling water to protect the component in reactor primary coolant. The protection mechanism to be outlined focuses mainly on maintaining high quality of coolant water. It is the single most important factor in controlling corrosion of aluminum and its alloy in the pool. Treatment and purification of the coolant water in the pool and any make-up water with the aid of filters and ion exchange resins is essential to achieve optimum performance. The recommended water parameters are used to minimize pitting and other forms of corrosion on aluminum.

**Chloride (Cl).** The chloride ion content of the water should be maintained as low as achievable and at less than 0.0094 ppm for optimum corrosion protection. Chloride ions can destroy the passive film on aluminum and promote metal dissolution. The chloride ions in these chemicals in small amount will destroy the passive film on aluminum and cause aggressive pitting corrosion. The corrosion process of aluminum increases with increasing temperature [7].

**Conductivity.** The conductivity is very important to be controlled in reactor primary coolant. Conductivity has in impact to material corrosion and radiation field. This level is generally achievable if water conductivity is maintained less than 2 μS/cm [8].
Other impurities. Impurity ions such as iron, aluminum, nitrates and nitrites should be maintained at levels as low as possible. Normal deionization of the water in the storage pool to conductivity levels of 1–3 μS/cm should keep these impurities at or below the 1 ppm level. The presence of impurity ions increases water conductivity and the flow of corrosion current, thereby increasing the corrosion of the aluminum material.

Temperature. The water temperature should be maintained at 40°C or below. The rate of pitting at 40°C has been found to be five times that it at 25°C. The density and probability of pitting have been found to increase with temperature. The corrosion rate of metal and its alloys increase with increasing temperature.

From Table 1, it is shown that RSG-GAS primary cooling system has a very tight requirement for chloride ion, cooper ion, pH and conductivity [5].

Pits can exist on some fuel when it enters the storage basin [9]. Not all Almost of all metals and its alloys can form passive film at their surface that has protective behavior. Those passive films usually are formed from metal oxide or other elements which separated metal or alloys from media.

The pitting corrosion occurs when passive film on material surface start to destroy.

A part of material surface will open to environment. This part is more active than the other part and become anode.

At open part (anode), pitting corrosion occur in small pit form. In the pit, solution pH become low and chloride ion will be accumulated in higher concentration than the other part of material. Pitting corrosion process develops with material release in metallic ion to media (reaction 1) and high acidity degree condition occurs in pit through hydrolysis of solvated metallic ion (reaction 3). Solvated metallic reaction at bottom of pit (reaction 1) will be equalized by cathodic reaction at material surface (reaction 2). Fe$^{2+}$ ion increasing in pit will cause of chloride ion migration into the pit. Pitting corrosion development growth can be seen at Figure 1. [7,10]

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\begin{align*}
Fe & \rightarrow Fe^{2+} + 2e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldot...
corrosion is small comparing loss metal cause of general corrosion. Pitting corrosion can cause more risk. Pitting can penetrate base metal that initiate leakage.

METHODOLOGY

The experiment were conducted in several steps:

- Specimen preparation
- AlMg₃ material corrosion test using Potentiostat.
- Data analysis and report.

AlMg₃ was used as specimen in this experiment. The specimen dimension is 10 mm in length, 10 mm in width and 3 mm in thickness. The specimen surface was polished with polished paper from grade 400 until grade 1000 and then polished with alumina powder. This report presents experimental data on corrosion rates in NaCl solution at several temperatures. Anodic polarization was obtained by a potential scanning from −500 mV at an open circuit potential (OCP) to 600 mV OCP at a rate of 0.2 mV/sec. A Silver/Silver chloride (Ag/AgCl) and Pt wire were used as reference electrode and a counter electrode respectively. For each condition, temperature was changed to simulate the corrosion effect to material. According to the purpose of this research is to get related document which connected to corrosion of AlMg₃ as neutron beam reactor material evaluation. Corrosion test conducted in several temperatures and NaCl 0.1 ppm addition by using Potentiostate. The outlet Mix Bed water (pH 6.7 and conductivity 0.4 μS/cm) and outlet Storage Tank water (pH 6.2 and conductivity 1.2 μS/cm) are used in the experiment. Data that found by Potentiostat will be analysed to get corrosion rate data.

RESULT AND DISCUSSION

Effect of NaCl addition and temperature on AlMg₃ Corrosion

The Figure 1. shows experiment results that increasing temperature tend to increase AlMg₃ corrosion rate as neutron beam tube material eventhough is not so significant. AlMg₃ corrosion rate in outlet Mix Bed water (pH 6.7 and conductivity 0.4 μS/cm) with no NaCl at 28 °C is 8.45 x 10⁻⁷ mpy and corrosion rate increase to be 3.79 x 10⁻⁶ mpy at temperature 30 °C. AlMg₃ corrosion rate increase to 3.53 x 10⁻⁵ mpy at 35 °C, 1.29 x 10⁻⁴ mpy at 40 °C and become 9.44 x 10⁻⁴ mpy at temperature 45 °C. With 0.1 ppm NaCl addition, AlMg₃ corrosion rate tend to increase, with no NaCl at 28 °C without NaCl addition, corrosion rate is 8.45 x 10⁻⁷ mpy, with 0.1 ppm NaCl addition, corrosion rate increase to 2.22 x 10⁻⁶ mpy. At other temperatures (30, 35, 40, and 45 °C), the AlMg₃ corrosion rate also increases cause of 0.1 ppm NaCl addition. Chloride as an aggressive ion can destroy the passive film on the alloys and metal surface. Many metal and alloys have ability to form the passive film from metal oxide which separated metal from its media. Ion chloride concentration determine the incubation time of pitting corrosion. The higher the ion chloride concentration is the higher possibility chloride ion to be absorbed at material surface.
Almost all chemistry reaction rates increase with temperature increasing. Higher temperatures increase the corrosion rate by accelerating the diffusion of oxygen. In open vessel, where the oxygen freely to escape, the corrosion rate increases with temperature up to 80 °C. Then, as the temperature is increased further, the corrosion rate also decrease. This is due to a drop in the oxygen solubility of water above 80 °C. In closed system, oxygen cannot escape, and the corrosion rate increase with temperature until all of the oxygen is consumed. From data at Figure 1 and 2, can be shown that temperature increasing tend to increase the AlMg₃ corrosion rate. In Outlet Mix Bed water at temperature 28 °C without NaCl addition, corrosion rate is 8.45 x 10⁻⁷ mpy, 3.79 x 10⁻⁶ mpy at 30 °C, 3.53 x 10⁻⁵ mpy at 35 °C, 1.29 x 10⁻⁴ mpy at 40 °C and 9.44 x 10⁻⁴ mpy at 45 °C. The AlMg₃ corrosion rates in Outlet Mix Bed Tank water (pH 6.7 and conductivity 0.4 µS/cm) have the same tendency increase with temperature. From the experiments result, it has a linear relation between corrosion rate and temperature, increase temperature also increase the corrosion rate.
From Figure 1 and 2 shown, AlMg₃ corrosion rate in outlet Mix Bed water (pH 6.7 and conductivity 0.4 μS/cm) at 28 °C is 8.45 x 10⁻⁷ mpy and in outlet Storage Tank water (pH 6.2 and conductivity 1.2 μS/cm) at 28 °C is 2.21 x 10⁻⁶ mpy. Comparing these data, corrosion rate in outlet Storage Tank water (pH 6.2 and conductivity 1.2 μS/cm) is 2.21 x 10⁻⁶ mpy higher than in outlet Mix Bed water (pH 6.7 and conductivity 0.4 μS/cm) is 8.45 x 10⁻⁷ mpy. Lower pH and higher conductivity have effect to increase the corrosion rate.

Key factor affecting the corrosion rate of material in water is the acidity of solution. More acidity (lower pH) is more corrosive to material because the cathodic reaction evolves hydrogen, enabling it to proceed rapidly. The acid salt as sources of conductivity has an effect on corrosion rate. Media with higher conductivity has higher ability to conduct ion in solution.

CONCLUSION

From data experiments shows that AlMg₃ corrosion rate is relative small in all of experiment conditions and the highest corrosion rate occur at 45 °C with 0.1 ppm NaCl addition in outlet Storage Tank water (pH 6.2 and conductivity 1.2 μS/cm) namely 4.69 x 10⁻³ mpy. Experiment results also show the relation between temperature and corrosion rate. The corrosion rates increased with increasing temperature and chloride ion addition. The corrosion rate in 0.1 ppm NaCl addition is bigger than corrosion rate in media without NaCl addition. Media conductivity and pH also have an effect to corrosion rate. The higher media conductivity the bigger AlMg₃ corrosion rate is. Media pH also has an effect to corrosion rate. The lower media pH, the solution become more acidity and aggressive. The corrosion rate of AlMg₃ as reactor neutron beam tube material is very small in all of experiment conditions. The corrosion resistance material is important requirement for material that used in nuclear reactor. Ion chloride concentration and conductivity have to controll to ensure the reactor safety.

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