Bio-corrosion on Aluminium 6063 by *Escherichia coli* in Marine Environment

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***Abstract*—Biological corrosion is caused by presence of microbes in environment. *Escherichia coli* causes serious biofouling in various environments and its pronounced influence on marine biofouling that causing serious problems such as accelerated corrosion. *E. coli* shares similar properties with most marine bacteria and it was extensively studied for marine environment. The aims of this research was to determine the corrosion rate on Aluminium 6063 by *E. coli* in deep seawater (salinity of 33‰), medium seawater (salinity of 35‰), shallow seawater (salinity of 37‰). Based on results, bio-corrosion rate on Al 6063 were higher than control. The bio-corrosion rate Al 6063 at day 28 in salinity of 37‰ was 1.1233 mm/year, meanwhile the corrosion rate for control was 0.7225 mm/year. Visual observation showed that corrosion occured on surface on specimen. Macrostructure observation showed that white spots occured on surface of specimen with *E. coli* was higher than specimen in control (without *E. coli*, only saline water) It was indicating that presence of *E. coli* caused increasing of corrosion rate on Al 6063.**

Keywords— **bio-corrosion rate, salinity, Al 6063.**

Abstrak*—*Korosi biologis disebabkan oleh adanya mikroba di lingkungan. Escherichia coli menyebabkan biofouling serius di berbagai lingkungan dan pengaruhnya terhadap biofouling laut yang menyebabkan masalah serius seperti korosi yang dipercepat. E. coli memiliki sifat yang sama dengan kebanyakan bakteri laut dan dipelajari secara ekstensif untuk lingkungan laut. Tujuan penelitian ini adalah untuk mengetahui laju korosi pada Aluminium 6063 oleh E. coli pada air laut dalam (salinitas 33 ‰), air laut sedang (salinitas 35 ‰), air laut dangkal (salinitas 37 ‰). Berdasarkan hasil, tingkat bio-korosi pada Al 6063 lebih tinggi dari pada kontrol. Tingkat bio-korosi Al 6063 pada hari ke 28 pada salinitas 37 ‰ adalah 1,1233 mm / tahun, sedangkan laju korosi untuk kontrol adalah 0,7225 mm / tahun. Observasi visual menunjukkan bahwa korosi terjadi pada permukaan pada spesimen. Pengamatan struktur makro menunjukkan bahwa titik putih pada permukaan spesimen dengan E. coli lebih tinggi daripada spesimen yang terkontrol (tanpa E. coli, hanya air asin). Hal ini menunjukkan bahwa keberadaan E. coli menyebabkan kenaikan laju korosi pada Al 6063.

Katra Kunci— ***tingkat bio-korosi, salinitas, Al 6063.***

I. Introduction

Bacterial activity at metal surfaces may result in corrosion induction or corrosion inhibition [1] which is dependent on the type of bacteria and the attributes of the surrounding environment. Microorganisms are able to actively change the environment surrounding the metal surface to facilitate the corrosion process. Microbial influenced corrosion (MIC), also known as microbial corrosion or biological corrosion, is the deterioration of metal as a result of the metabolic

There are many bacteria can cause microbial corrosion on carbon steels, stainless steels, aluminium and aluminium alloys, nickel and nickel alloys, copper and copper alloys, zinc and zinc alloys. The MIC occored in water and soil with pH 4 – 9 and temperature 10–50^{o}C. According to Moura et al. [2], among the groups of bacteria involved in the corrosion process are included: I- EPS-producing bacteria, II- acid-producing bacteria, III- sulfuroxidizing bacteria; IV- iron-precipitating bacteria and V- sulfate-reducing bacteria (SRB). The biocorrosion occurs due to the fixation of bacteria, release of metabolites and formation of biofilms that induce or accelerate the corrosion process [2].

Both autotrophic and heterotrophic bacteria have been demonstrated to cause corrosion in aerobic systems. Autotrophic bacteria obtain them from the light or by the oxidation of inorgnic materials and the carbon by assimilation [3]. The autotrophic microorganisms oxidizers, *Thiobacillus thiooxidans* and, *T, thioparus* and the iron oxidizers Gallionella, *Ferrobacillus ferrooxidans*, and *Thiobacillus ferrooxidans*. Heterotrophic bacteria derive the energy and carbon requirements from organic source [3]. Heterotrophic species include representatives of the iron bacteria genera, Siderocasa, Spherotilus, Clonothrix, Leptothrix, and Crenothrix.

These bacteria can be classified as aerobic and anaerobic bacteria. Aerobic bacteria requires oxygen to become active, meanwhile oxygen is toxic for anaerobic bacteria. Iron and manganese oxidising bacteria are aerobic bacteria and are frequently associated with accelerated with pitting attacts on stainless steel. sulfate-reducing bacteria (SRB) is anaerobic bacteria and is responsible for corrosion damage on steel structures in ships and offshore.

If the change in coupon mass of a given materials is greater in the presence of marine bacteria for a given period of time, then it can be concluded that the bacteria accelerated the corrosion rate of that materials. Conversely, if the change in coupon mass of a given materials is the same when in the presence and absence of marine bacteria for a given time period, then it can be concluded that the bacteria had no effect on the corrosion rate of that materials [4].

Many industries are affected by MIC, such as chemicals processing industries, nuclear power generation, onshore and offshore oil and gas industries, underground pipeline industry, water treatment plan,

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sewage handling and treatment industry, highway maintenance industry, aviation industry, metal working industry, and marine and shipping industries.

A joint project of different european aircraft manufacturers confirmed the involvement of isolates from genera *Micrococcus*, *Enterococcus*, *Staphylococcus* and *Bacillus* in strong corrosion damage in aluminium alloy, commonly used in aircraft construction [5]. These bacteria may create a microacidic environment (acid producing bacteria), which favors the development of other bacteria, or produce EPS, favoring the formation of biofilm (EPS-producing bacteria) [2].

As typical rod-shaped bacterium, *Escherichia coli* causes serious biofouling in various environments especially for fabric and medical devices and its pronounced influence on marine biofouling that causing serious problems such as accelerated corrosion was reported [6]. Elguindi et al. [7] reported that moist layer on copper alloys with 85% or greater copper content of *Escherichia coli* and it caused corrosion on copper alloy. *E. coli* shares similar properties with most marine bacteria and it was extensively studied for marine environment [6].

The main objective of the study is to determine bio-corrosion rate on Al 6063 in marine environment by *E. coli* in salinity of 33, 35 and 37‰. The difference of salinity showed the difference of seawater depth. The deep seawater (salinity of 33‰), medium seawater (salinity of 35‰), shallow seawater (salinity of 37‰).

II. METHOD

A. Preparation of bacteria

The pure culture of each bacteria was be inoculated onto nutrient agar (NA) media using streak plate tehnique based on Harley and Prescott [8]. The age of bacteria for bio-corrosion test was 24 h. After that, one coloni of bacteria was tranferred to nurient borth (NB) and keep in shaker incubator at 150 rpm and room temperature, 33 ^{o}C for 24 h. The suspension of bacteria was ready to be used in bio-corrosion test.

B. Preparation of speciment

Preparation of speciment for corrosion test was according to the American Society of Mechanical Engineers (ASME).

C. Preparation of sea water medium for corrosion test

Preparation of medium for corrosion test based on ASTM standard D1 141-90 [9].

D. Bio-corrosion

The detail of bio-corrosion test steps was described in Pratikno and Titah [10]. Amount of 5% (v/v) of bacteria was added in corrosion test solution.

E. Corrosion Rate

The corrosion rate and bio-corrosion rate in millimeter per year (mm/year) were calculated from weight of material loss during test, with this formula [11,12] :

$$ {}^{mm}/_{year} = 12 \times \frac{(7290\ W)}{(A.t.d)} $$

t=time of exposure (hours)

A=area (cm^2)

W=weight loss (gram)

$$ d=\text{density } \left({}^{gram}/_{cm^3}\right) = 2.67\ {}^{gram}/_{cm^3} $$

F. Macrostructure

Macrostructure observation on the specimen was conducted using a Keller reagent. Keller reagent was prepared based on the ASM Handbook (1998) [13], which is to make 200 ml reagent Keller needed:

a. 2 ml hydrofloride concentrated acids, HF (density 40%),
b. 3 ml of concentrated hydrochloric acid, HCl (density 37%),
c. 5 ml of concentrated nitric acid, HNO3 (density 70%),
d. 190 ml of distilled water.

The dyeing process was conducted based on the ASTM G163 (2010) [14],. Test specimens immersed into the Keller reagent solution for 15 seconds, then removed, rinsed with distilled water and dried. Furthermore makrostucture were observed with a microscope Olympus CX41 (Japan).

III. RESULTS AND DISCUSSION

Based on the results, Figure 1 showed high salinity caused value of corrosion rate increasing. The corrosion rate of Al 6063 as a control after immersion in salinity of 33‰, 35‰ and 37‰ at day 28 were 0.5671, 0.7489 and 0.7255 mm/year, respectively. Based on Al-Tai [15], the corrosion rate of aluminum alloy were 0.0292 and 0.0474 mm/year respectively at day 15 and 30 in 20‰ of NaCl or brackish water. The ion of chloride increased during salinity increased. According to Paul [16], chloride ion increases the corrosion rate. The range of aluminium corrosion rate at coastal area were <0.01 – 0.125 mm/year [17]. Hagioglu et al [18] reported that Al has very low resistance to a corrosive environment (30‰ NaCl) in a static regime, and corrosion processes take place on the Al surface.

Pitting is a highly localized type of corrosion in the presence of aggressive chloride ions. Pits are initiated by chloride attack at weak sites in the met al. oxide; the pits propagate according to the two following reaction [15,19]:

$$ Al = Al^{3+} + 3e- \quad (1) $$

$$ Al^{+3} + 3H_2O = Al(OH)_3 + 3H^+ \quad (2) $$

While hydrogen evaluation and oxygen reduction are the important reduction processes at anode and cathodes.

$$ \text{Anodic } 2H^+ + 2e- \rightarrow H_2 \quad (3) $$

$$ \text{Cathodic } O_2 + 2H_2O + 4e- \rightarrow 4\ OH^- \quad (4) $$

The high bio-corrosion rate on Al 6063 was 1.1233 mm/year at day 28 in salinity of 37‰ by E. coli (Figure 1). Meanwhile, the bio-corrosion at salinity of 33 and 35‰ were 1.0141 and 0.8113 mm/year at similar day respectively. It was indicating that salinity affected the bio-corrosion rate on Al 6063. The bio-corrosion rate showed higher value than corrosion rate in control. It means that presence of E. coli for a given period of time could be accelerated the corrosion rate.The bio-corrosion rate by *E. coli* showed value up to 1 mm/year and it increased by one point five-fold compared with corrosion rate without bacteria. Based on Al-Tai [15], the corrosion rate on aluminium alloy in 20‰ of NaCl inoculated with 4 mL of *Pseudomonas aeruginosa* bacteria or 0.5% (v/v) of bacteria were 0.0949 and 0.0876 mm/year after 15 and 30 days, respectively.

Based on visual observation (Figure 2), the corrosion on both sides of the test specimen. looked a brownish color on the surface of the aluminum specimens in all salinity 33, 35 and 37 ‰ after immersed in artificial sea water. The difference between the corrosion occured in

only saline solution with corrosion by addition of E. coli were a brownish color seemed more and it were more spread in specimens in saline solution with the bacteria.

Figure 3 describe observation of macrostructure in 40X magnification. The corrosion on control occured in all salinity. The corrosion appeared on surface of the specimen at salinity of 33 ‰ still looked flat and smooth, but at salinity of 37 ‰ control was visible white spots of corrosion on the surface of the specimen. With the addition of bacteria in marine water replacement solution, it showed the acceleration of the corrosion of the surface specimen. The corrosion on surface of specimen with the addition of *E. coli* bacteria after 28 days showed that corrosion occured in all salinity. The salinity was higher so that the macro structure of corrosion was higher too. It looked white spots on the all surface of the specimen.

CONCLUSION

Based on the results, the bio-corrosion rate by *E. coli* on Al 6063 at salinity of 37‰ was 1.1233 mm/year or increased by one point five-fold compared with the condition without bacteria addition. In conclusion, *E. coli* caused the increasing of corrosion rate on Al 6063.

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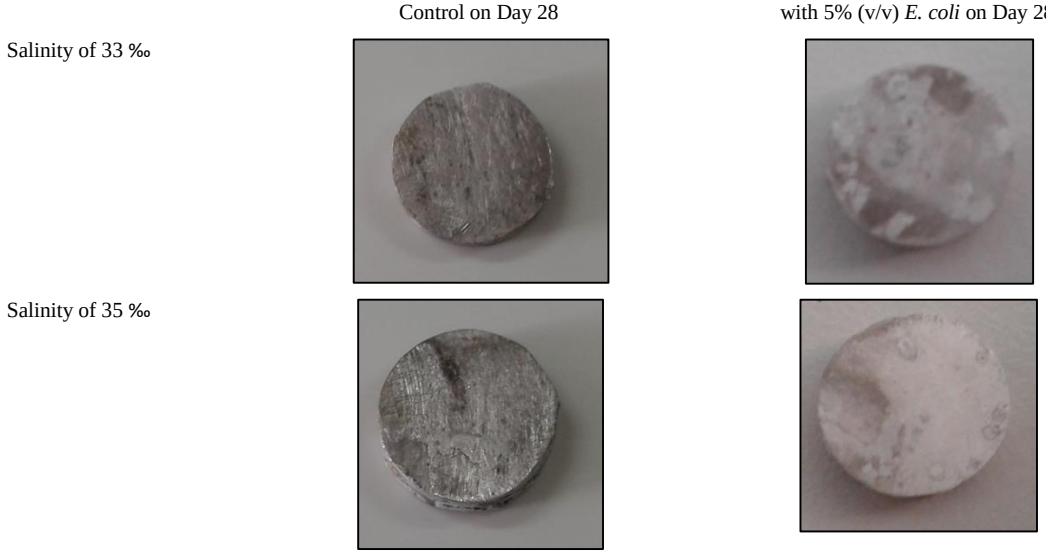

Salinity of 37 ‰

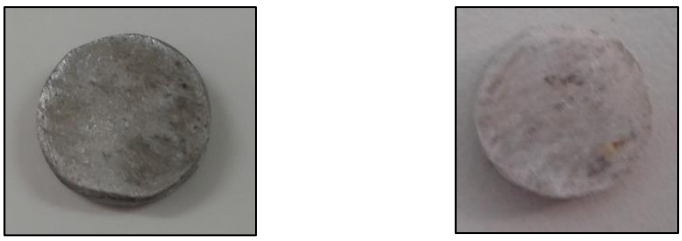

Figure 2. Visual Observation On Testing Specimens

	Control on Day 28	with 5% (v/v) *E. coli* on Day 28
Salinity of 33 ‰		
Salinity of 35 ‰		
Salinity of 37 ‰		

Figure 3. Macrostructure Observation On Testing Specimens