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EFFECT OF RATIO OF SURFACE AREA ON THE CORROSION RATE

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Abstract -- *Aluminum and steel are used to be a construction for a building outdoor panel. Aluminum and steel are connected by bolt and nut. An atmosphere due to a corrosion of the aluminum. The corrosion possibly to cause the hole diameter of bolt and nut to become larger. Thus the bolt and nut can not enough strong to hold the panel. The panel may collapse. The aim of the research is first to answer a question where does the corrosion starts. The second is to know the effect of ratio surface area of steel with aluminum on the corrosion rate of aluminum. The research is started to cut a steel and aluminum flat into variation surface areas. Next, the steel and aluminum are bolted as samples for corrosion test. The samples are divided into two groups. The group A was immersed in NaCl (10%) and the groups B was immersed in HCl 10%. The corrosion rate is calculated with loss weight method. The conclusions are as follow. The corrosion does not start from the bolt hole but from the edge of aluminum. Increasing the ratio of surface area (steel/aluminum) increases the corrosion rate of aluminum.*

Keywords: *Aluminum; Steel; Ratio of surface area; Galvanic corrosion*

INTRODUCTION

Aluminum and steel are used to be a construction for a building outdoor panel. Aluminum and steel have unique properties which can be taken advantage of in a wide variety of applications in the construction industry. Significant technological advances in materials processing have led to the development of aluminum and steel with excellent mechanical properties; important progress has also been made in the improvement of surface finishes for architectural applications. Structural research programmes across the world have laid the ground for the development of national and international specifications, codes and standards spanning both the design, fabrication, and erection processes. Recommendations are made on research activities aimed at overcoming obstacles to the wider use of stainless steel in construction. New opportunities for aluminum and steel arising from the shift towards sustainable development are reviewed, including its use in nuclear containment structures, thin-walled cladding, and composite floor systems. (Baddoo, 2008; Silberberg, 2000). Aluminum and steel are connected by bolt and nut, as shown in Fig. 1.

An atmosphere due to a corrosion of the aluminum construction (Setiyo et al., 2017). The corrosion causes the hole diameter of bolt and nut to become lager. The bolt and nut can not enough strong to hold the panel. The panel may collapse. The aim of the research is first to answer a question where does the corrosion starts. The second is to know the effect of ratio surface area of steel with aluminum on the corrosion rate of aluminum.

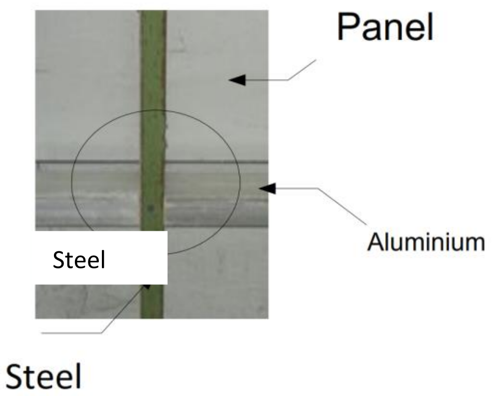


Figure 1. Steel - Aluminum are bolted (in circle) as construction for building outdoor panel

MATERIAL AND METHOD

Corrosion is defined as the deterioration of metal as a result of chemical reaction between the metal and the other element surrounding environment. The corrosion of an electrochemical process has to four components as follows (John et al., 2016; Siddiq, 2013).

Anode

An anode is corroded. The anode reaction is indicated by an increase in valence or production of an electron. The electrochemical reaction is known as oxidation shown below:

$$M \rightarrow M^{Z+} + ze- \quad (1)$$

Where z is valence of metal, (e.q z = 1, 2, or 3)

Cathode

A cathode is not corroded. The cathode is indicated by a decrease in valence or consumption of electrons. The electrochemical reaction of cathode or reduction is shown below

$$M^{Z+} + ze \rightarrow M \quad (2)$$

Where z is valence of metal, (e.q z = 1, 2, or 3)

The basic principles of corrosion: during metallic corrosion, the rate of oxidation equals the rate of reduction.

Electrolyte

An electrolyte is a solution that produces an electrical conduction such solution of acid, basic, and salt. The anode can be contacted the cathode by the solution electrolyte.

Contacting

Anode and Cathode have contact with each other so the electric current can flow in the corrosion cell.

Galvanic Corrosion

When two dissimilar metals immersed in a corrosive solution, the potential difference usually present. If these metals are placed in contact, this potential difference produces electron flow them. Corrosion of the less corrosion-resistance metal is usually increased and attack of the more resistant material is decreased, as compared with the behavior of these metals when they are not in contact. The less resistant metal becomes anodic and the more resistant metal cathodic. (Andreatta et al., 2016; Fontana,1986)

Area effect

One of the important factors in the galvanic corrosion is the area effect or the ratio of the cathodic to anodic areas. An unfavorable area ratio consists of a large cathode and a small anode. For a given current flow in the cell, the current density is greater for a small electrode the for a larger one. The greater the current density at an anodic area the greater the corrosion rate (Fontana, 1986)

Mansfeld and Kenkel research on the Galvanic corrosion of Al alloys-III to know the effect or area ratio. He found that the dissolution rate r_A of the anode is related to the area ratio by (Mansfeld and Kenkel, 1975).

$$rA = K\,(1 + A^C/A^A). \quad (3)$$

where A^C: area of Cathode; A^A: area of Anode

The area ratio is very important in the consideration of the likelihood of bimetallic corrosion. The larger the cathode compared to the anode, the more oxygen reduction can occur and, hence, the greater the galvanic current and, therefore, corrosion as shown in Fig. 2.

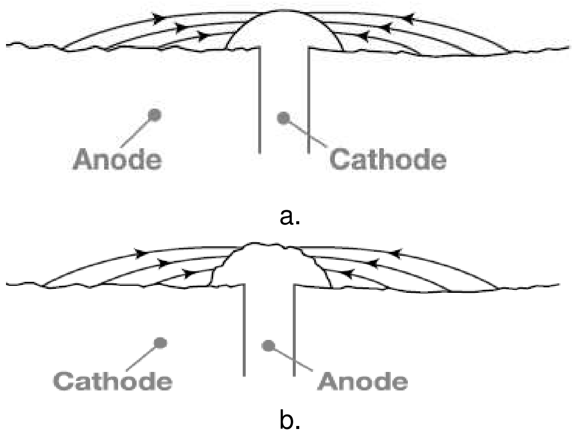


Figure 2. Effect of area ratios of bimetallic corrosion
a. Large anode area, small cathode area showing relatively insignificant attack over a wide area of the sheet.
b. Large cathode area, small anode area showing relatively pronounced attack of the rivet head.

Under static conditions, where the bimetallic corrosion current is often dependent upon the rate of diffusion of dissolved oxygen to the cathode, the amount of bimetallic corrosion is independent of the size of the anode and is proportional to the area of the cathodic metal surface. This is sometimes known as the catchment area principle and has important implications in designing to minimize the risk of bimetallic corrosion. Thus, for a constant area of cathode metal, the amount of corrosion of the anode metal is constant, but the intensity of corrosion is increased as the area of the anodic metal is decreased. (Håkansson et al., 2017; Francis.1982).

Methodology

The research flowchart is shown in Fig. 2. Steel profile and aluminum plate are cut to be a sample piece as shown in Fig. 3. The Steel and Aluminum are contacted by the bolt as corrosion samples. Next, the samples are divided into 2 groups. The group A is immersed in NaCl 10%. The group B is immersed in the HCL 10 % for 168 hours, 336 hours and 504 hours. The corrosion rate is calculated by the weight loos metal method as shown in Equ. 1. The experiment data are collected, analyzed and finally concluded.

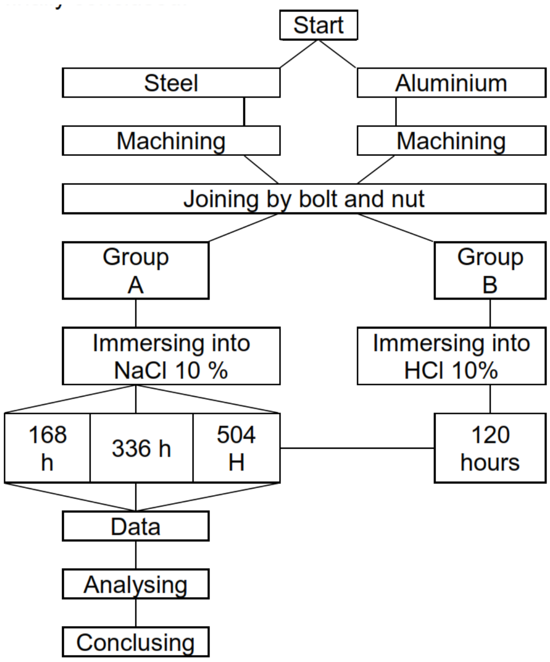
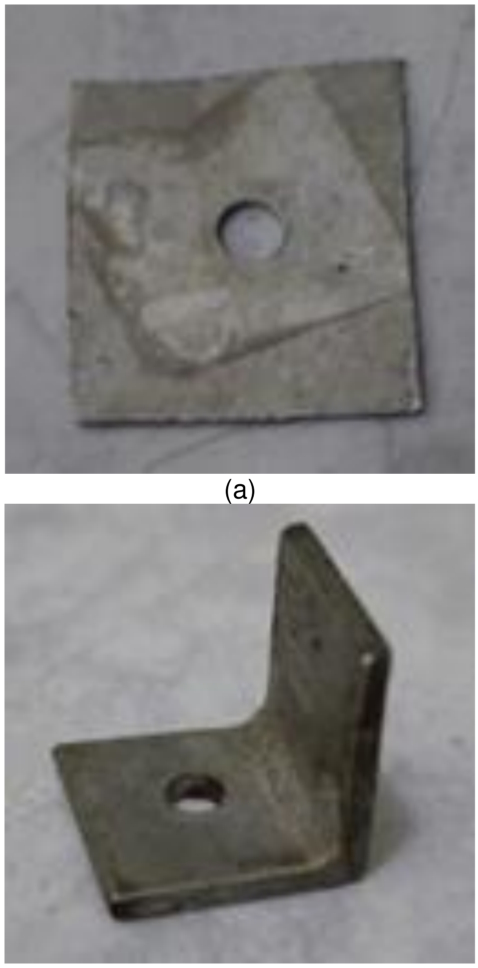


Figure 2. The research methodology



(a)

(b)

Figure 3. A Sample of Aluminum and Steel: (a) Aluminum and (b) Steel

$$CR\ (mmy) = \frac{W \ x\ K}{D A_s T} \quad (4)$$

Where CR = corrosion rate (mmy) ; W = weigth loos (gr) ; K = constanta ; D = density (g/cm^3) , A_s= surface area (cm^2); T = time (hours)

RESULT AND DISCUSSION

This section will show the experimental result and will be discussed it. The effect of the ratio of the surface area of the corrosion rate will be discussed first. Next will be discussed where the corrosion start the corrosion

Effect of ratio of surface area (steel/aluminum) on corrosion rate

Table 2 shows the dimension of aluminum and steel. The surface area of aluminum and steel samples are shown in Tabel 3. Table 3 also shows the ratio of surface area (steel/aluminum).

Table 2. Dimension of aluminum and steel samples in mm

Grup	Code	Metal	T	L	W	H
A1	1	Al	2	30.25	30.21	---
		Steel	3	19.8	25.90	25.50
	2	Al	2	30.92	30.32	---
		Steel	3	19.30	25.90	25.50
	3	Al	2	29.83	30.42	---
		Steel	3	18.20	25.90	25.50
A2	6	Al	2	29.49	30.53	---
		Steel	3	24.55	25.90	25.50
	7	Al	2	30.72	30.22	---
		Steel	3	23.80	25.90	25.50
	8	Al	2	30.84	30.12	---
		Steel	3	23.20	25.90	25.50
A3	11	Al	2	29.76	30.33	---
		Steel	3	30.50	25.90	25.50
	12	Al	2	30.45	30.43	---
		Steel	3	27.80	25.90	25.50
	13	Al	2	30.33	30.23	---
		Steel	3	27.35	25.90	25.50
B1		Al	2	30.25	30.20	
		Steel	3	19.8	30.12	

Note: T: thickness; L:Length; W: width; H: Height

Table 3. Ratio of surface area (steel/Al)

Group	Code	Surface area (mm^2)		Ratio
		Steel	Al	
A1	1	2325.840	2069.545	1.1238
	2	2274.440	2119.948	1.0729
	3	2161.360	2055.857	1.0513
		Average		1.08
A2	6	2814.140	2040.739	1.3790
	7	2737.040	2100.476	1.3031
	8	2675.360	2101.641	1.2730
		Average		1.32
A3	11	3425.800	2045.601	1.6747
	12	3148.240	2096.707	1.5015
	13	3101.980	2075.991	1.4942
		Average		1.56
B		2325.84	2069.545	1.12

Note: Ratio means Ratio of surface area (steel/aluminum)

Table 4 shows the weight loss of aluminum that immersed into NaCl (10%) for 168; 336 and 504 hours. The corrosion rate of aluminum is calculated by using Equation (1) and the corrosion rate is shown in Table 5. The average corrosion rate of aluminum for each group are as follow: The group A1 is 3.4 x 10^{-4} mmy. The Group A2 is 3.8 x 10^{-4} mmy and the group A3 is 4.3 x 10^{-4} mmy. Table 5 proved there is a galvanic corrosion when the steel and aluminum were contacted and immersed in the solution of NaCl (10%). The aluminum as anodic is corroded and the steel as cathodic is not corroded. The less resistant metal is aluminum to become anodic and the more resistant metal is steel to become cathodic.

Table 4. Weight loos of aluminum in gram

Group	Code	Weight loos of aluminum		
		168 h	336 h	504 h
A1	1	0.0067	0.0119	0.0169
	2	0.0008	0.0020	0.0031
	3	0.0040	0.0082	0.0088
A2	6	0.0072	0.0144	0.0208
	7	0.0048	0.0101	0.0131
	8	0.0011	0.0028	0.0048
A3	11	0.0039	0.0069	0.0101
	12	0.0017	0.0041	0.0083
	13	0.0080	0.0160	0.0235

Note h: Hours

Table 5. Corrosion rate of aluminum (CR)

Group	Code	CR 10^{-4} (mmy)			
		168 h	336 h	504 h	Avg
A1	1	6	5.5523	5.2568	
	2	1	0.9107	0.9413	3.4
	3	4	3.8514	2.7555	
A2	6	7	6.8136	6.5612	
	7	4	4.6431	4.0148	3.8
	8	1	1.2865	1.4703	
A3	11	4	3.2571	3.1784	
	12	2	1.8882	2.5483	4.3
	13	7	7.4421	7.2871	

Note h: hours, Avg: Average

The correlation between the ratio of surface area of (steel/aluminum) with the corrosion rate of aluminum is shown in Table 6. The samples are immersed in NaCl 10 % solution. The corrosion rate of aluminum for the ratio of surface area (1.08) is 3.4 x 10^{-4} mmy. For a ratio of surface area 1.32 the corrosion rate of aluminum is 3.8 x 10^{-4} mmy. For the ratio of surface area 1.56, the corrosion rate of aluminum is 4.3 x 10^{-4} mmy.

Table 6. The Correlation between ratio of surface area (steel/aluminum) with corrosion rate of aluminum

Ratio of surface area (steel/aluminum)	Average of corrosion rate of aluminum x 10^{-4}(mmy)
1.08	3.4
1.32	3.8
1.56	4.3

Fig. 4 shows the effect of ratio surface area (steel/aluminum) on the corrosion rate of aluminum. Increasing ratio of surface area (steel/aluminum) increases the corrosion rate of aluminum. Since the steel is a cathode and the aluminum is an anode, thus increasing a ratio of surface area between cathode with anode increase a corrosion of anode. The corrosion rate of an anode is higher when the surface area of a cathode is larger than an anode.

The Equation (5) shows the relation between the corrosion rate of aluminum with the ratio of surface area (steel/anode). In this galvanic corrosion, the steel is a cathode and the aluminum is an anode. The NaCl 10 % is used as an electrolyte solution.:

$$Y = 1.875X + 1.3882 \quad (5)$$

Where Y : corrosion rate of aluminum (mmy); X : ratio of surface area (steel/aluminum)

Observation to know where the corrosion begins

The samples were immersed into the HCl (10%) to know where the corrosion of steel-aluminum joined begin. The result of observation is illustrated in Table 7. At the start position, the shape of steel and aluminum is an initial shape as Fig. 4. There is no corrosion at the start position. Since the sample has been immersed for 96 hours, the corrosion of aluminum done. The edge of aluminum damaged. The dimension of aluminum became smaller than the initial shape. The shape of aluminum became a hexagonal as illustrated in Fig. 5.

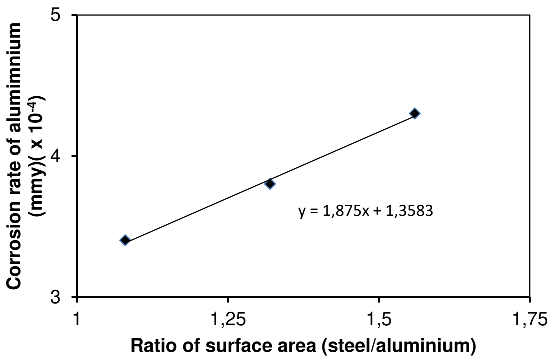


Figure 4. Effect of ratio of surface area (steel/aluminum) on the corrosion rate of aluminum

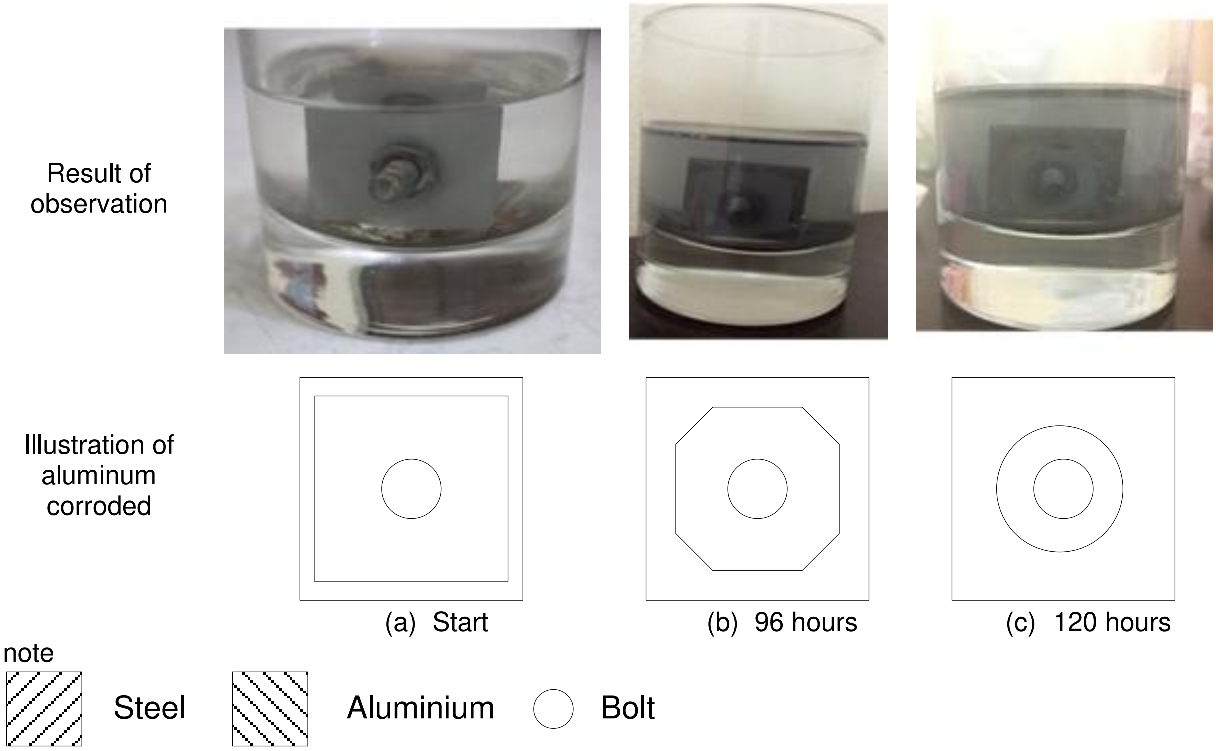


Figure 5. The corrosion of aluminum progressive at the steel-aluminum joined.

However, the steel did not corrode. The increasing time of immersing from 96 hours to 120 hours more corrode the aluminum. The dimension of aluminum reduces sharply. The aluminum becomes a small circle. The steel still exists, no corroded. A diameter of a hole where the bolt and nut are joined does not become large.

The observation result proves that since the steel-aluminum joined by bolt and nut was immersed in electrolyte solution (NaCl 10%), the aluminum starts from corroding. The corrosion starts at the edge of aluminum. The edge is a longer distance from the hole where the bolt and nut joined. However, the edge of aluminum is the best location for the anodic reaction. The electron flow from the anode through the bolt and nut to the cathode (steel). The shape of aluminum become a hexagonal shape. The corrosion still moves from the edge to the center of the hole. Thus the shape of aluminum changes from the hexagonal to be a circle. The experiment shows the corrosion of steel with an aluminum start from the edge of aluminum and finishes at the center of a hole where the bolt and nut are joined.

CONCLUSION

There is a galvanic corrosion since the steel and aluminum were joined by bolt and nut for construction of outdoor building panel. The aluminum becomes an anode while the steel becomes a cathode. The corrosion of aluminum start from the edge and finish at near the hole where the bolt and nut joined. Increasing of a ratio of surface area (steel/aluminum) increase the corrosion rate of aluminum.

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