Jurnal Energi dan Manufaktur Vol. 9 No. 1, April 2016 (109-113) ISSN: 2302-5255 (p)
http://ojs.unud.ac.id/index.php/jem

Atmospheric Corrosion of Galvanized Low-Carbon Steel at Rural, City, and Industrial area in Bandar Lampung

Khairul Ummah[1)], Abdul Azis Muslim[2)]
Irza Sukmana[2)]*

[1)] Aerospace Engineering, Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Jalan Ganesha No. 10 Bandung
[2)] Mechanical Engineering, Faculty of Engineering, Lampung University, Gedung H - Lt. 2, Jalan Prof. Soemantri Brojonegoro No. 1 Bandar Lampung

Abstract

This research conducted to continue the previous study about atmospheric corrosion phenomenon on uncoated low carbon steel at Lampung Province, where it using coated low carbon steel. The atmospheric corrosion rate at Lampung Province are 152.910 $g/m^2/y$ at rural area, 267.593 $g/m^2/y$ at city, and 420,503 $g/m^2/y$ for industrial are. Based on ISO category, the atmospheric corrosion rate is C2 at rural, C3 at city and C4 at industrial area. Coating processes of low carbon steel can decreased the atmospheric corrosion rate about 172.023 g/m^2/year or 39% at rural, and 91.746 g/m^2/year or 18% at industrial area.

Keywords: Galvanized, low carbon steel, atmospheric corrosion, corrosion rate

Abstrak

Penelitian ini untuk melengkapi studi terhadulu dimana dilakukan penelitian fenomena korosi atmosfer pada baja karbon rendah yang tidak dilapisi di Propinsi Lampung. Dalam penelitian ini digunakan baja karbon rendah yang telah dilapisi. Hasil penelitian ini menunjukkan bahwa laju korosi atmosfer di Propinsi Lampung untuk daeerah pedesaan adalah 152,910 $g/m^2/y$, perkotaan 267,593 $g/m^2/y$, dan daerah industri 420,503 $g/m^2/y$. Berdasarkan standar katagori ISO, maka laju korosi atmosfir untuk baja karbon rendah yang dilapisi di propinsi Lampung adalah pada kategori C2 di pedesaan, C3 di Kota, dan C4 di daerah industri. Pelapisan menurunkan angka laju korosi sebesar 172.023 g/m^2/year atau 39% untuk daerah perkotaan dan 91.746 g/m^2/year atau 18% di daerah industri.

Kata Kunci: Pelapisan galvanik, baja karbon rendah, korosi atmosfir, laju korosi.

1. Introduction

Atmospheric corrosion is probably the most common process of corrosion and is defined as the corrosion or degradation of material exposed to the specific atmospheric area that contain air and pollutants. A common method to determine the atmospheric corrosion phenomenon and corrosion rate has been used on various types of metals for the different types of atmospheres. The major types of atmospheric can be generalized into four types are rural, city, industrial, and marine area (Abdul-Wahab, 2003).

Low Carbon Steel is the most applied Ferrous Steel on the field of constructions, industrial and structure materials. On those applications of Low Carbon Steel, atmospheric corrosion will attack the materials and it can caused a degradation of the structure toughness. Therefore, it is important to know the specific corrosion rate of low carbon steel in a given atmospheric environment in order to effectively use of it in outdoor structures.

In the previous research founded that the atmospheric corrosion rate of uncoated low carbon steel at City, Industrial, and Marine area at Lampung Province are in the ISO category C4 with corrosion rate about 400<CR<650 g/mm2/year for short-term exposed. It means that the Corrosion Rate (CR) for those areas is very high (Sukmana, 2005). In order to continue the study on atmospheric corrosion behavior of low carbon steel in Lampung Province, the research of atmospheric corrosion at rural, city, and industrial area for coated steel is very important.

Galvanizing is an alternative process on corrosion protection of the material. It protects steel from corrosion process by providing a thick, tough metallic zinc envelope, which completely covers the steel surface and seals it from the corrosive action of its environment. This research also addressed to compare the atmospheric corrosion rate between uncoated and coated low carbon steel (using galvanizing process) at Lampung Province.

*Korespondensi: Tel./Fax.: 62 81294836432/-
E-mail: irza.sukmana@gmail.com

2. Theoretical Background

2.1. Galvanizing technique.

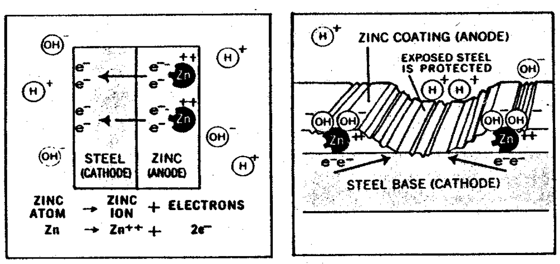
All metallic corrosion processes involve transfer of electron charge in aqueous solutions. As an example of corrosion between Ferrous and hydrochloric acid represented by the ionic form of the following reaction is (Jones, 1992):

$$Fe + 2H^+ + 2Cl^- \rightarrow Fe_2^+ + 2Cl^- + H_2 \qquad (1)$$

Eliminating Cl^- from both sides, the reaction (1) can be separated as follows:

$$Fe \rightarrow Fe_2^+ + 2e^- \qquad (2);\ \text{anodic reaction.}$$
$$2H^+ + 2e^- \rightarrow H_2 \qquad (3);\ \text{cathodic reaction.}$$

Reaction (2) is defined as anodic reaction, which oxidation reaction and known as the corrosion reaction. The corrosion process of the uncoated steel and coated steel with galvanizing process are shown on Figure 1. (American Galvanizers Association, 2016)



(a) (b)

Figure 1. Galvanize coating process (a) and Surface view of coated base metal (b)

The differences on electrochemical potential (Fig. 1) is caused on surface areas of the exposed steel. As the result, negatively electron charged electron flow from anode to cathode and the positively charged iron ions of the anode attract and react with negatively charged hydroxyl ions in the electrolyte form iron oxide rust.

Under the corrosion protection with hot dip galvanizing, zinc covers the steel surface and seals it, as on Figure 1 (b). Hence Zinc is more electrochemically active than steel, the Zinc therefore slowly consumed, providing sacrificial protection for the steel. Figure 1(c) explains that on the surface area of the protected steel, zinc ensures that the exposed steel does not corrode.

2.2. Atmospheric corrosion.

A fundamental requirement for electro-chemical atmospheric corrosion process is the presence of an electrolyte. In the presence of thin film electrolytes on metallic surface under atmospheric exposure, atmospheric corrosion proceeds by balancing anodic and cathodic reaction. The anodic oxidation reaction involves the dissolution of the metal, while the cathodic reaction is often assumed to be the oxygen reduction reaction and the corrosion species of corrosion product of iron are Fe2O3, FeOOH, and FeSO4/H2O. The atmospheric corrosion reactions are as follow (Fontana, 1987):

Anodic reaction:

$$2\ Fe \rightarrow 2Fe^{2+} + 4e \qquad (4)$$

Cathodic reaction:

$$2\ O + 2\ H_2O + 4e \rightarrow 4OH \qquad (5)$$

The severity of atmospheric corrosion tends to vary significantly among different location. The types of atmosphere are described as follows (Decker and Langer, 1987):

a. Rural area: Type of atmosphere in this area is generally the least corrosive and does not contain chemical pollutants, instead of organic and unorganic particulate.
b. City area: usually more corrosive than rural area and corrosion process is caused by the contaminants of SO_x and NO_x caused by fuel emissions of motor vehicle.
c. Industrial area: These atmospheres are associated with heavy industrial processing facilities that contain sulfur dioxide, chloride, phosphates and nitrates.

There are two practical variables that important and affecting atmospheric corrosion rate as follows:

a. Climate condition. Metal surfaces located in areas where they become wet and retain moisture generally corrode more rapidly than surface exposed to rain. The rain has a tendency to wash the surface and remove particles of dust that can lead to different aeration corrosion.
b. Atmospheric contaminants. Industrial atmospheres are more corrosive than rural atmospheres, primarily because of the sulfur compounds produced during the burning of fuels. Sulfur dioxide (SO_2) is selectively adsorbed on metal surfaces, and under humid condition the metal oxide surface catalyzes the SO_2 to sulfur trioxide (SO_3) and promotes the formation of sulfuric acid (H_2SO_4).

3. Research Methods

This research is carried out based on The ISO Methodology on Atmospheric Corrosivity and Corrosion Rate, and ASTM G 1 – 72 standard for Preparing, Cleaning, and Evaluating Corrosion Test Specimen. It will be carried out as follows:

3.1. Planed interval test.

The procedures were according to ASTM G50 "Standard Recommended Practice: Conducting Atmospheric Corrosion Test on Metals" and the duration of test was based on a planned interval test as showed at Figure 2. (Annual Book of ASTM Std., 1980).

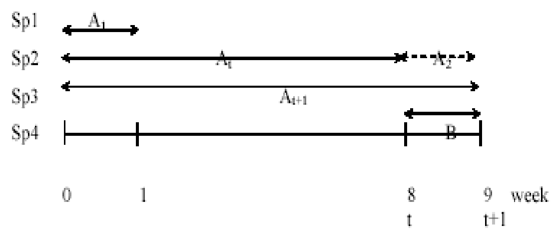


Figure 2. Planned interval test in this study

Identical specimens placed in the same environment (each 2 specimens); imposed conditions of test constant entire time (t+1); A1, At, At+1, B, represent corrosion damage experienced by each test specimen; A2 is calculated by subtracting at from At+1. The interpretation of planed interval test is based on ISO Standard, as shown on Table 1.

Table 1. Interpretation of planned interval test

Environment Aggressiveness	Criteria	Metal Corrodibility	Criteria
Unchanged	$A_1 = B$	Unchanged	$A_2 = B$
Decrease	$B < A_1$	Decrease	$A_2 < B$
Increased	$A_1 < B$	Increased	$B < A_2$

3.2. Corrosion rate.

Calculation of the corrosion rate for short time of exposure is based on the equation that stated on the Annual Book of ASTM as follow: (Annual Book of ASTM Standard, 1980)

$$\mathbf{CR = (K \times W) / (A \times T)} \qquad (6)$$

Where:

CR = Corrosion Rate in g/m2/year
K = CR Constant = 8.67x 104
W = weight reduction in gram.
A = area in m2, and
T = time of exposure in hours

Specification of the testing specimen material is based on ASTM and the dimension is 150mm x 100mm x 2.8mm. The coated specimens then scratched diagonally before exposure to the corrosive environment.

3.3. Location of the test and interpretation.

Because of the technical-field difficulties, this research planed only at three locations:

- Rural area is located at around Tegineneng village
- City area at Bandar Lampung City
- Industrial area is planned to be at area closed to PT Semen Baturaja – Tarahan, Lampung Industrial Center located on Tanjung Bintang.

The classification of atmospheric corrosive-ness is important for specifying suitable materials, corrosion protection measures and maintenance. The ISO corrosivity classification is determine the corrosivity of the specific atmospheric area, and for short- term period of the test is shown at Table 2. (Compton, 1978; and Hermawan, 2003)

Table 2. ISO corrosion rate category

ISO Category	Short-term period of the test, g/m^2/year
C1	CR $\leq$ 10
C2	10 < CR $\leq$ 200
C3	200 < CR $\leq$ 400
C4	400 < CR $\leq$ 650
C5	650 < CR

4. Results and Discussions

Daily climate data. Data of daily climate on the three location of the sample tested were recorded and presented on the Table 3.

Table 3. Data of daily climate on the three locations

Period	Daily Climate (c = cloudy , f = foggy, r = rainy, s = stormy)																				
	Rural							City							Industrial						
Day	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Week(s) 1	c	c	c	f	f	r	f	c	c	c	c	r	r	r	c	s	s	c	c	r	c
2	c	c	c	c	c	r	r	c	c	c	c	c	c	c	r	c	c	r	c	c	c
3	r	f	c	r	c	c	c	c	c	c	r	r	c	c	r	r	f	c	r	c	r
4	c	f	r	r	r	f	f	c	c	f	f	f	c	c	c	r	c	c	c	r	r
5	c	c	c	c	f	f	f	f	f	f	c	c	f	f	c	r	r	c	c	r	c
6	f	r	f	c	c	c	c	f	f	r	f	f	c	c	c	r	r	f	f	f	f
7	c	c	c	c	c	c	c	c	c	c	f	f	f	f	c	c	c	c	c	c	c
8	c	c	c	c	c	c	c	c	c	c	c	c	r	r	c	c	f	r	r	f	f
9	c	c	c	c	c	c	r	c	c	c	c	c	c	c	f	f	c	c	f	r	f

Table 4. Data of weight reduction of the speciments

Interval	Weight Reduction (gram)		
	Rural	**City**	**Industrial**
A_1 (First 1 Week)	0	0	0
A_t (8 Weeks)	0.01	0.01	0.05
$A_{(t+1)}$ (9 Weeks)	0.04	0.07	0.11
B (Last 1 Week)	0	0	0.04

4.1. Data of weight reduction

The data of weight reduction record of the corrosion samples tested at the three locations of the planned interval test is described on Table 4.

4.2. Calculation and analysis

Interpretation of environment agressiveness and metal corrodibility is explained on Table 5, and the calculation of corrosion rate as Table 6.

Table 5. Interpretation of environment agressiveness and metal corrodibility

Parameter	Rural	City	Industry
Weight Reduction Criteria Kriteria			
A1	0	0	0
A2($A_{(t+1)}$ - A_t)	0.03	0.06	0.06
B	0	0	0.04
Interpretation of Atmospheric Corrosion			
Env. Agres.	Not change	Not change	Increa-sed
Metal Corr.	Increa-sed	Increa-sed	Increa-sed

From Table 5 above, the environment agressiveness in rural and city are unchanged because the daily climate on A1 (1st week of the test) is relatively same as B (9th week), so that the weight reduction is very small and it can't be detect by the weight measurement equipment. The increasing of metal corrodibility of those three atmosphere is associated with the rainy activity between 1st week and 8th week, where the windy and rainy will caused lower humadity and wet condition on the surface area of the testing speciment will propmote the inisiation of general corrosion.

Table 6. Corrosion Rate of coated low carbon steel after 9 weeks of exposure

Atmosphere	After 9 Weeks exposure	
	ΔW (gram)	CR (g/m²/year)
Rural	0.04	152.910
City	0.07	267.593
Industrial	0.11	420.503

The trend in weight reduction and corrosion rate is increasing from rural, city, and industrial area and it is conjugated with the theory of atmospheric corrosion. From the data above, it can be generated that corrosion aggressiveness at Lampung province for coated low carbon steel is higher than at West Sumatra province that has been published by Hermawan, 2003. It is because of the sea wind at Lampung province keeps more chlorides contain in the atmosphere and it is more corrosive.

Based on ISO Corrosion Rate category of atmospheric corrosion as on Table 2, the CR of coated steel is C2 at rural, C3 at city, and C4 at industrial area. The trend in weight reduction and corrosion rate is increasing from rural, city, and industrial area and it is conjugated with the theory of atmospheric corrosion. From the data above, it can be generated that corrosion aggressiveness at

Lampung province for coated low carbon steel is higher than at West Sumatra province that has been published by Hermawan (2003). It is because of the sea wind at Lampung province keeps more chlorides contain in the atmosphere and it is more corrosive.

Based on ISO Corrosion Rate category of atmospheric corrosion as on Table 2, the CR of coated steel is C2 at rural, C3 at city, and C4 at industrial area. Data of CR from the previous reseach of uncoated low carbon steel for city, industrial and marine area at Lampung Province as shown on Table 7 (Sukmana, I., 2005).

Table 7. Corrosion Rate of uncoated low carbon steel after 9 weeks of exposure

Atmosphere	After 9 Weeks exposure	
	ΔW (gram)	CR (g/m^2/year)
City	1.15	439.616
Industrial	1.34	512.249
Marine	1.64	626.931

Comparing Table 6 with Table 7 can inform that decreasing of corrosion rete for coated low carbon steel is 172.023 g/m2/year, or about 39% at city and 91.746 g/m2/year or about 18% at industrial area. It can be concluded generalized that galvanizing process for corrosion protection of low carbon steel at Lampung province is more effective at city area than industrial area.

5. Conclusions

During the test, environment aggressiveness is unchanged at rural and city area and increased at industrial area. Metal corrodibility is increasing at rural, city, and industrial area. Atmospheric corrosion rates at Lampung province for coated low carbon steel is increases from of rural area (152.910 g/m2/y), city (267.593 g/m2/y), and industrial (420.503 g/m2/y). ISO Corrosion Rate category of coated steel is C2 at rural, C3 at city, and C4 at industrial area. The decreasing of CR for coated steel is 172.023 g/m2/year, or about 39% at city and 91.746 g/m2/year or about 18% at industrial area.

Acknowledgement

The author express acknowledge to PT Tambang Batubara Bukit Asam Tbk for the financial support.

Reference

[1] Abdul-Wahab, S.A, *Atmospheric Corrosion of Metals*, JCSE Vol. 5, 2003.

[2] American Galvanizers Association, *Hot-Dip Galvanizing (HDG)*, 2016. [http://www.galvanizeit.org/corrosion/corrosion-protection/hot-dip-galvanizing]. (Date of access: March 2nd 2016).

[3] Annual Book of ASTM Standard, *Metals: Physical, Mechanical and Corrosion Testing*, 1980.

[4] Compton, K.G., *Atmospheric Corrosion – NACE Basic Corrosion Course*. National Association of Corrosion Engineer,Houston, Texas, 1978.

[5] Decker, R.F., Langer, E.L., *Metals Handbook of ASM: Corrosion*, Vol. 13, 9th Edition, 1987.

[6] Fontana M.G., *Corrosion Engineering*, Third Edition, McGraw-Hill, Singapore, 1987.

[7] Jones, D.A., *Principles and Prevention of Corrosion*, McMillan Publishing Company, New York, 1992.

[8] Hermawan, H., *Study of Atmospheric Corrosion at Rural, Industrial, and Marine Environment In West Sumatra*. SNTTM II UNAND Padang, Indonesia, 2003.

[9] Sukmana, I., *Laporan Penelitian: Research on the Atmospheric Corrosion of Low Carbon Steel at Rural, Urban, Industrial and Marine Area at Lampung Province*, Jurusan Teknik Mesin, Universitas Lampung, 2005.