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Corrosion Assessment of Carbon Steel in Thailand by Atmospheric Corrosion Monitoring (ACM) Sensors

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Abstract

Atmospheric corrosion of metal depends on material compositions, weather condition (dry, dew, and rain period), temperature, relative humidity, and airborne sea salt of specific location. General testing procedure to obtain the corrosion rate is by actual exposure test of the specimen panels based on time interval plan. In Japan, atmospheric corrosion monitoring (ACM) sensor, made of an iron-silver galvanic couple, has been developed and used to sense the corrosivity in terms of galvanic current. Under some atmospheric conditions, these data can be converted to time of wetness and related to the corrosion rate of carbon steel. With ACM sensors, it is possible to monitor the corrosion rate in a shorter time than the exposure test. To apply the ACM sensors in Thailand, it is necessary to evaluate the effectiveness and correlation between the actual corrosion rate and the sensor output. In this research during June 2007 – May 2009, we performed exposure tests of carbon steel (JIS SS400) along with ACM sensors under outdoor and sheltered conditions at three locations: (1) Rama VI Road, Bangkok (2) Suvarnabhumi International Airport, Samutprakarn and (3) Royal Thai Navy Dockyard, Chonburi, representing urban, airport, and marine environments, respectively. Weather data were obtained from temperature, relative humidity, and ACM sensors. To estimate the corrosion rate, weight loss measurements were carried out on specimens exposed for 1 month period over 2 years. Average monthly weight loss ranks from high to low as marine, airport, and urban environments. The relationship between outdoor corrosion rate and ACM output is found to be linear on a log-log scale at airport and urban test stations during March 2008 – May 2009.

Key words Atmospheric corrosion, ACM sensor, Carbon steel

Introduction

Atmospheric corrosion of metal is governed by chemical composition of thin film electrolyte on the metal surface which is dependent on air pollutants, humidity, and temperature. Corrosion scientists in several countries have carried out exposure tests to investigate the effects of the environment on corrosion rates (Pourbiax, 1982), and the corrosion resistance of different materials.(2, 4, 15-18) The actual field tests usually take 10-20 years for an evaluation period. To accelerate the experimental study, simulated wet-dry cyclic tests have been performed for qualitative observation.(5-6)

Electrochemical measurement such as AC impedance monitoring sensor has been incorporated into the atmospheric corrosion tests by Nishikata et al. (2005); Shitanda et al. (2009) and Wall et al. (2005) to enhance the understanding of corrosion process and monitor quantitative parameters as a function of environmental factors. Another electrochemical measurement by atmospheric corrosion monitoring (ACM) sensor relates galvanic current with corrosion rate. The impedance and ACM sensors have been applied to monitor the corrosion in industrial plants and infrastructure. In Japan, ACM sensor, made of Fe-Ag galvanic couple, has been developed and used to monitor the corrosivity of various atmospheric conditions in the work of Motoda et al. (1994) and Shinohara et al. (2006). Linear relationship between outdoor corrosion rate and sensor galvanic current output was found at severe marine and rural/marine environments in Japan.(13)

In Thailand, atmospheric corrosion tests had been conducted on organic-coated carbon steel by

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Bhamornsut et al. (2003), zinc by Panther et al. (2003), and stainless steel by Daopiset et al. (2008). This present research is the first to apply the ACM sensor in atmospheric corrosion study of structural steel in Thailand. The exposure tests of the test panels as well as the ACM sensors were carried out from June 2007 – May 2009 at three different environmental conditions. Weight losses and sensor outputs were evaluated.

Materials and Experimental Procedures

Exposure test stations were selected for this field study. The details at each site are described in Table 1.

Table 1. Locations of exposure test sties.

Environment	Location	Description
Marine	Sattahip Navy Dockyard, Chonburi	On the ground facing the Gulf of Thailand
Airport	Suvarnabhumi International Airport, Samutprakarn	On the ground nearby the runway and industrial district
Urban	National Science and Technology Development Agency, Bangkok	On the roof top of a 7-story building influenced by heavy traffic

Structural steel plates (JIS SS400) were cut into rectangular coupons with dimension of 150mm x 70mm x 6mm. Blue oxide scales were removed by HCl acid, sandblasting, and mechanical polishing. The initial weights of the samples were recorded. Exposure tests were carried out in open-air (outdoor) and under shelter (indoor) conditions for 1 and 12 months. The tests were repeated for 24-month period. An ACM type corrosion sensor was installed on each test rack and connected to a data logger (Syrinx Inc.). Picture of a test station is illustrated in Figure 1. The ACM sensors were replaced every month. Temperature and humidity sensors were installed under a cover at each location and connected to the data logger. Electrical current (Q), temperature (T), and relative humidity (RH) were recorded in a memory card every 10 minutes. After the test, specimen panels and data were collected for analyses. Two specimens were cleaned according to ASTM G01 to remove corrosion products. The average weight loss was determined. Monthly results were related to the sensor data to evaluate correlation with ACM sensor. Annual results were fitted to a multiple linear regression model as a function of environmental parameters.

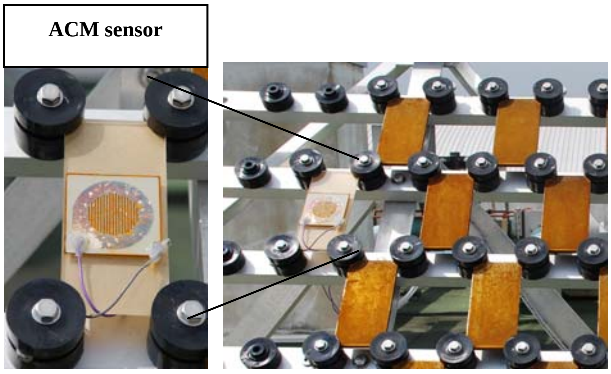


Figure 1. ACM sensor and structural steel coupon on an outdoor test rack.

Results and Discussion

Short – Term Exposure Test

Monthly results from June 2007 – November 2008 were reported in the previous work.(11) With additional data from December 2008 – May 2009, the average monthly weight losses over two years are summarized in Table 2. Corrosivity ranks from high to low as marine, airport, and urban atmosphere or in the increasing distance from the sea shore as expected. The sheltered environments are typically less corrosive than open air condition as seen by smaller magnitude of average corrosion losses. The corroded sheltered specimens were influenced only by dew condensation, temperature, relative humidity, sea salt and air pollutants, whereas the specimens exposed outdoor were influenced by rain fall as well. However, during some months in rainy season, the sheltered samples were more severely corroded than outdoor samples due to rain wash effect that removes corrosive species from the metal surface.

Table 2. Average monthly weight losses of outdoor and sheltered conditions.

Location	Phase	Weight Loss (g/ m^2)	
		sheltered	outdoor
Marine	June 07 – May 08	46.476	57.786
	June 08 – May 09	44.535	55.614
Airport	June 07 – May 08	39.452	56.333
	June 08 – May 09	37.793	48.472
Urban	June 07 – May 08	28.280	38.286
	June 08 – May 09	30.867	46.567

Correlation between Corrosion Rate and Sensor Output

Corrosion rates of one – month exposure test were plotted as a function of the ACM sensors output to evaluate their relationships. For sheltered condition, the corrosion rates were related to the daily average electricity (Q). The best correlation (R = 0.7220) was observed at urban site during March 2008 – April 2009 as shown in Figure 2(a) as:

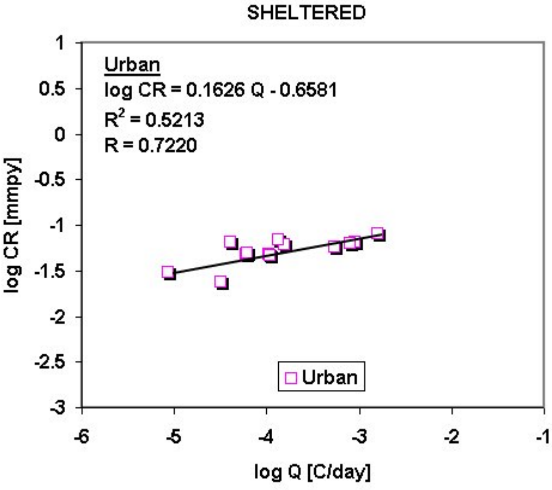
$$\log CR_{urban}\ [\text{mmpy}] = 0.165 \log Q\ [\text{C/day}] - 0.658 \quad (1)$$

No correlation was found at marine and airport test sites.

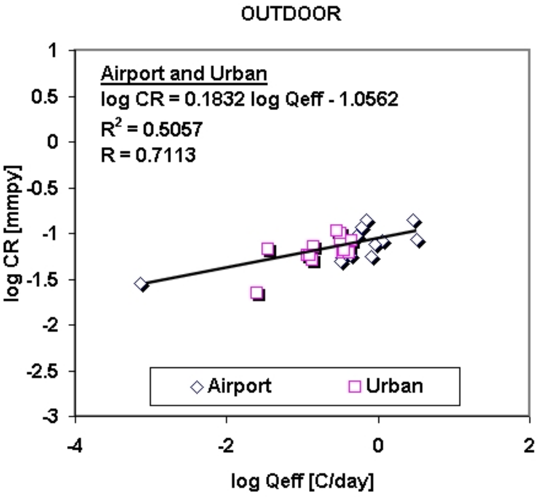
In case of outdoor environment, the current during rain period (Q_{rain}) is much higher than dew period (Q_{dew}). Thus the effective sensor output (Q_{eff}) is defined as $Q_{eff} = Q_{dew} + \alpha Q_{rain}$, where α is 0.2.(13) As shown in Figure 2(b), the relationship between corrosion rate and effective sensor output for urban site has a strong positive correlation (R = 0.7113) during March 2009 – May 2009 and follows the expression:

$$\log CR_{airport,\ urban}\ [\text{mmpy}] = 0.183 \log Q_{eff}\ [\text{C/day}] - 1.056 \quad (2)$$

No correlation is observed for marine exposure sites. In the atmospheric corrosion study with this Fe-Ag type ACM sensor in Japan (Shinohara et al., 2006) the ACM sensors could be used to estimate the atmospheric corrosion rate in severe marine and rural/marine conditions, but not in the mild marine atmosphere. Thailand has less temperature fluctuation and longer time of wetness, which may require another type of ACM sensor for marine environment. Further study by using a long life ACM sensor is under consideration.



(a) Urban sheltered environment



(b) Airport and urban outdoor environment

Figure 2. Linear correlations between monthly corrosion rate and effective sensor output were found at (a) urban sheltered condition (March 2008 – April 2009) and (b) airport and urban outdoor condition (March 2008 – May 2009).

Multiple Linear Regression Model

The conventional method to predict the corrosion rate is by finding an empirical relationship with the active environmental parameters such as in the atmospheric corrosion study of Vietnam by Lien et al. (2009). The simplest model is a multiple linear function. Generally, one –year exposure tests are conducted and repeated to obtain reliable sampling data. In this study, two sets of one – year exposure tests were carried out at each test station during June 2007 to May 2009. The average corrosion rates of each phase and other environmental parameters are reported in Table 3.

Table 3. Corrosion rate of one- year exposure test and environmental parameters: temperature (T), relative humidity (RH), and time of rain (T_{rain}).

Site	Phase	CR [g/ m^2 / y]	T [°C]	RH [%]	T_{rain} [h/ y]
Marine	June 07 – May 08	137.381	29.187	66.010	269.833
	June 08 – May 09	167.857	28.305	55.079	1089.667
Airport	June 07 – May 08	n/a	29.302	58.140	975.833
	June 08 – May 09	165.238	28.761	48.594	802.167
Urban	June 07 – May 08	110.238	31.7668	55.807	524.167
	June 08 – May 09	99.048	32.490	40.281	428.667

Based on our one – year exposure test data shown in Table 3, the best correlation suggests that the outdoor corrosion rate (CR) is a function of temperature, relative humidity, and total rain time as:

$$CR\ [g/\ m^2/\ y] = 446.9 - 11.850\ T\ [°C\ ] + 0.535\ RH\ [\%] + 0.028\ T_{rain}\ [h/\ y] \quad (3)$$

Temperature has a negative affect on corrosion rate. Higher temperature causes the water droplet on the specimen surface to evaporate; thereby, the corrosion rate is reduced. Both relative humidity and total rain time have positive affects on corrosion rate due to increasing time of wetness. Time of rain slightly contributes to corrosion because it also washes away the corrosive residues. The calculated corrosion rates (Eq. 3) were plotted against the actual values as shown in Figure 3 with R = 0.9733. However, other dependent variables such as SO_2 and Cl^- ions were not taken into account since they were not monitored during the exposure period.

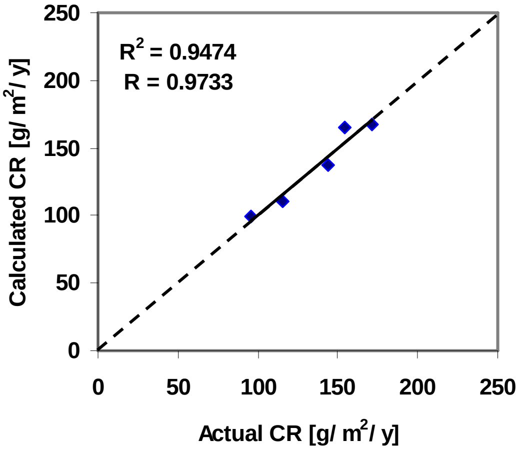


Figure 3. Calculated values compared to the actual values.

Comparing the two correlation methods discussed above, the ACM sensor is applicable for corrosion prediction at airport and urban environments. With the use of ACM sensor, corrosion rate can be monitored in real time without the need to conduct a long-term field test. For marine site, the multi-variable model can be applied.

Conclusions

1. For sheltered condition, the corrosion losses can be estimated by the ACM sensor at urban test station as shown by linear correlation between sensor current output and corrosion rate as:

$$\log CR_{urban}\ [mmpy] = 0.165 \log Q\ [C/day] – 0.658.$$

2. For outdoor condition, the corrosion losses can be estimated by the ACM sensor at airport and urban test stations as confirmed by linear correlation between sensor current output and corrosion rate as:

$$\log CR_{airport,\ urban}\ [mmpy] = 0.183 \log Q_{eff}\ [C/day] – 1.056.$$

3. At marine environment, the Fe-Ag ACM sensor cannot provide any correlation to the corrosion rate. However, the obtained exposure test data were evaluated by conventional method using linear regression model as:

$$CR\ [g/\ m^2/\ y] = 446.9 - 11.850\ T\ [°C\ ] + 0.535\ RH\ [\%] + 0.028\ T_{rain}\ [h/\ y].$$

4. In Thailand, the atmospheric corrosion of structural steel under sheltered environment is generally less corrosive than that under outdoor environment. The rain wash effect is not a major contribution.

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