STUDY ON ANTI-ATMOSPHERIC CORROSION PERFORMANCE OF STEEL IN COASTAL AND URBAN ATMOSPHERES IN THAILAND

Thee Chowwanonthapunya *

Faculty of International Maritime Studies, Kasetsart University, Sri Racha Campus, Tungsukla, Sri Racha, Chonburi 20230, Thailand

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ABSTRACT

ISO 9223 norm and the rust analysis of steel were employed to assess atmospheric corrosion resistance of steel in the coastal environment (Sattahip). The results from ISO 9223 show that the coastal environment provides the longer duration of the atmospheric corrosion on the steel surface, which subsequently reduces the atmospheric corrosion resistance of carbon steel. The rust analysis indicates that the rust of steel exposed to the coastal environment is loose and porous, which is non-protective. Thus, the longer time of wetness and the non-protective rust attributes to the decreased atmospheric corrosion resistance of steel.

KEYWORDS: *Atmospheric corrosion; Degradation; Rust; Steel*

* Corresponding authors; e-mail: thee.c@ku.th, Tel.&Fax: +6638352606-7 Ext. 2675

INTRODUCTION

Steel is one of major materials for the development of industries due to its usefulness, e.g. its relatively low cost and attractive mechanical properties [1]. Nevertheless, the important drawback of steel is the degradation of its desired mechanical properties by natural environment, which is widely known as atmospheric corrosion [2]. Basically, atmospheric corrosion process of steel is mainly related to the formation of a very thin electrolyte layer, which is condensed from atmosphere and only temporarily present on the steel substrate [3]. The properties of this layer greatly affect the atmospheric corrosion resistance of carbon steel. The properties of this thin electrolyte layer are chiefly influenced by specific contaminations in environment [4].

Generally, Sulphur Dioxide and Chloride are known as the two most corrosion-stimulating contaminants of steel exposed to outdoor environments. In the coastal environment, Cl- plays a main role in the increased corrosion process, but in the Sulphur containing environment, SO_2 accelerates the corrosion process of steel. In fact, atmospheric corrosion of steel is an electrochemical process, taking place when a thin electrolyte layer exists on the steel surface. Thus, time of wetness (TOW) for steel substrate indicates the period of the atmospheric corrosion process. In principal, the duration of TOW depends on the variation of weathering conditions, especially humidity and temperature [5]. Anti-atmospheric corrosion performance of carbon steel is therefore influenced by the quantity of aggressive impurities and weathering conditions of its environments. Besides, the rust covering the steel substrate also plays a significant role in the long term corrosion process of steel. On one hand, if the rust is loose, the atmospheric corrosion rate of steel will increase. On the other hand, if the rust is dense and adherent to steel substrate, the atmospheric corrosion resistant of steel will increase. In order to evaluate the atmospheric corrosion resistance of steel, it is of great interest to indicate the aggressiveness of the atmosphere to which steel is exposed.

Normally, ISO 9223 methodology is extensively used to evaluate the corrosivity of the environment. Thailand is a tropical country. In addition, the areas, where the industrial infrastructure will be developed in the future, have a long coast line closed to the Gulf of Thailand [6]. So, Thailand's outdoor atmosphere will certainly affect the atmospheric corrosion resistance of steel infrastructures. Thus, it should be of great interest to apply ISO 9223 norm and the rust morphology analysis to investigate the atmospheric corrosion resistance of steel in the coastal environment of Thailand.

In this article, ISO 9223 norm and the rust analysis of steel were employed to assess atmospheric corrosion resistance of steel in the coastal environment (Sattahip). The main goal of this work is to evaluate the atmospheric corrosion resistance of steel under the coastal environment of Thailand.

MATERIALS AND METHODS

2.1 Observed areas

The areas of interest for this preliminary investigation were Sattahip and Bangkok. Table 1. indicates the types of their atmospheres

Table 1. Atmospheric types of studied areas

Selected area	Environment
Sattahip	Coastal
Bangkok	Urban

2.2 Time of Wetness (TOW)

In this study, the most influencing-weathering parameters, temperature and relative humidity of selected areas, were monitored. Technically, atmospheric corrosion occurs when a thin electrolyte covers the metal surface. Thus, it is possible to calculate TOW by the sum of all wetting times when the metal surface is wetted. In practice, the variation of temperature and relative humidity indicates the wetting time of the metal surface. According to ISO 9223 norm, the wetting time for a day can be obtained when relative humidity (RH) is higher than or equal to 80% and temperature is above 0°C. The sum of all wetting time will provide TOW for this monitoring period. To gain more accurate result, in this research, TOW for a year is calculated from the wetting period during wet season (from May to October of 2015) and that during the dry season (starting from the 2015, November to 2016, April). Meteorological data of both areas were given by the Meteorological Department of Thailand.

2.3 Atmospheric polluants and Anti- corrosion performance determination

Usually, the classification of atmospheric corrosion resistance of steel is related to the amount of SO_2 and Cl- . In this preliminary report, the deposition rate of SO_2 and Cl- was adopted from literatures and these data were then used with estimated TOW to gain the corrosiveness of both environments. From the corrosiveness classification, the anti-atmospheric corrosion performance of steel from both sites can be determined by means of ISO 9223 international standard.

2.4 The rust morphology analysis

The rust morphology is known as the important parameter, which governs the long time corrosion behavior. In this study, the rusted steel exposed to the coastal environment for almost 7 years was cross sectioned and its morphology was then examined by the light optical microscope.

RESULTS AND DISCUSSION

3.1 The weathering characteristics of both sites during 2015–2016

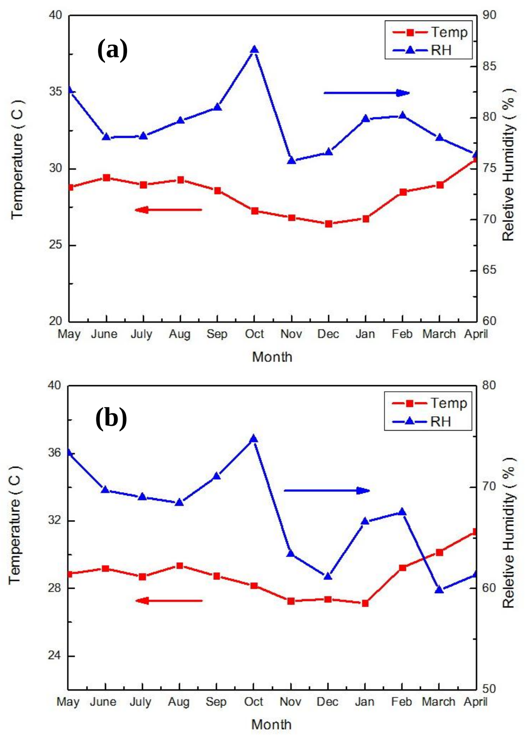


Fig. 1 The average temperature and relative humidity during 2015-2016: (a) Sattahip and (b) Bangkok

Fig.1(a) and (b) showed The average temperature and relative humidity of Sattahip and Bangkok. The average temperature of both sites varied between 26 and 32°C. In addition, the average temperature observed at the coastal site is slightly lower than that measured at urban test site.

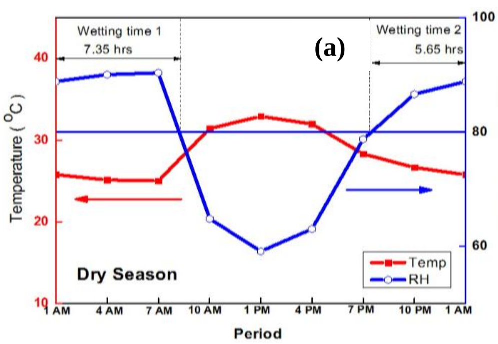
The relative humidity plays a main role in the formation of the thin electrolyte on the steel surface, which directly affects the atmospheric corrosion behavior of metals. From Fig. 1(a) and (b), the average relative humidity of both sites is in the range 60–85%. The average relative humidity from the coastal site is higher than that from the urban test site. Besides, average relative humidity during the wet season of both regions is higher than that during dry season. Thus, the wetting time of the metal surface during the wet season tends to be longer than that during the dry season. Usually, the longer period of wetting time of the steel surface leads to the longer duration of the corrosion process [7]. Therefore, the atmospheric corrosion of carbon steel during the wet season would be more severe than that during the dry season.

3.2 The variation of weathering conditions of studied areas and Their TOW

The variation of weathering conditions of atmospheres leads to the alternate wet-dry cycle on the metal surface, affecting the duration of the atmospheric corrosion process. In principal, the atmospheric corrosion proceeds electrochemically when the surface of metals is wetted with a thin electrolyte layer condensed from the atmosphere. So, it is necessary to generate the actual weathering condition of climate cyclic of both atmospheres

Fig. 2 exhibits the average temperature and relative humidity of both kinds of atmospheres. Characterized from Fig. 2, wetting time during the wet season of both environments are longer than that during the dry season. So, the duration So, the duration of the atmospheric corrosion during the wet season is longer than that during the dry season.

During the day time, the average relative humidity is lower and temperature is higher, favoring the dry state for the metal surface. In contrast, during the night time and early morning, the average relative humidity is higher and temperature is lower, enhancing the atmospheric corrosion process with the formation of the thin electrolyte on the metal surfaces. The formation of the thin electrolyte can then degrade the atmospheric corrosion performance of carbon steel exposed to the outdoor environment [7]. In order to estimate the wetting time per day, the concept of ISO 9223 norm is applied



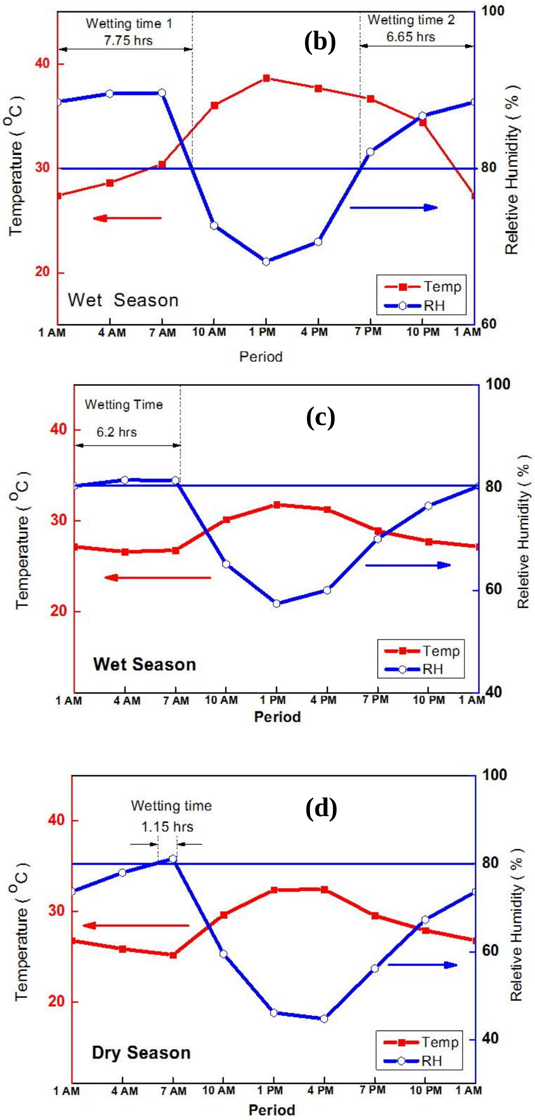


Fig. 2 The average hourly temperature and %RH within a day during 2015–2016 (1.00 am to the 1.00 am of the next day): (a) and (b) for Sattahip as coastal site; (c) and (d) for Bangkok as urban site

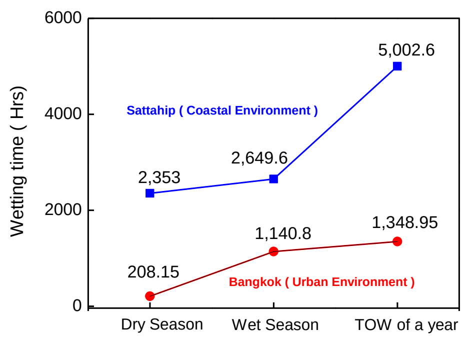


Fig. 3 The estimation of the wetting time for dry season, wet season, and TOW during 2015–2016

According to ISO 9223 Norm, the steel surface can be considered as the wetting surface when relative humidity is higher or equal to 80% and the temperature also exceeds 0°C. With this concept, the wetting time in the coastal area takes 13 hours per day for the dry season, and 14.4 hours per day for the wet season. By the same technique, the wetting time in the urban area takes 1.15 hours per day for dry season and 6.2 hours per day for the wet season. The sum of all wetting time will therefore determine TOW for the year of monitoring. The data of calculated wetting time for a day and TOW for a year of both sites taking during the dry, wet season and a year are exhibited in Fig. 3. From this figure, it is obvious that TOW for a year of the coastal site is longer than that of the urban site, meaning that the duration of the atmospheric corrosion of steel in the coastal environment is longer than that in the urban site.

3.3 Corrosivity classification

TOW for a year of study for two sites is already obtained from Fig.3 and these data will be used to evaluate the corrosiveness of both environments by the ISO 9223 Norm. From this norm, the outdoor atmospheres are divided into five categories, based on the total estimated TOW for a studied year (τ in unit of hour/year): τ1(τ is shorter than 10 hours) : τ2 (τ is longer than 10 hours, but shorter than 250 hours) : τ3 (τ is longer than 250 hours, but shorter than 2,500 hours) : τ4 (τ is longer than 2,500 hours, but shorter than 5,500 hours): τ5 (τ is longer than 5,500 hours). Therefore, TOW for a year of the coastal and urban area is categorized in τ4 and τ3.

In addition to TOW, the deposition rate of Sulphur Dioxide and Chloride is also required for the atmosphere corrosiveness by the method of ISO 9223. According to ISO 9223, deposition rate of Chloride (S in unit of mg $m^{-2}d^{-1}$) can be classified as follows: S0 (S is less than 3): S1 (S is higher than 3, but less than 60): S2 (S is higher than 60, but less than 300): S3 (S is higher than 300, but less than 1500). In this preliminary report, the deposition rate of Sulphur Dioxide and Chloride is adopted [8], the category of which for the coastal and urban area is S1 and S0, respectively.

In case of the deposition rate of Sulphur Dioxide (Pd in unit of mg $m^{-2}d^{-1}$), classified based on ISO 9223, P0 (Pd is less than or equal to 10) : P1 (Pd is higher than 10, but less than 35) : P2 (Pd is higher than 35, but less than 80): P3 (Pd is higher than 80, but less than 200). The deposit rate of Sulphur from Nil K. et al. is P1 for the coastal environment and P0 for the urban area.

From ISO 9223 Norm, the corrosiveness of atmosphere depends on TOW, deposition rate of Chloride and Sulphur Dioxide, which can simply be expressed as follows:

$$\text{Corrosiveness (C)} = f(\text{TOW},\tau,\text{Pd}) \qquad (1)$$

The corrosivity of atmosphere based on ISO 9223 for TOW category of τ3 and τ4 is demonstrated in Table 2 and 3.

Table 2. The category of corrosivity according to ISO 9223 for carbon steel

P	τ3	τ4
	S0 - S1	S0 - S1
P0 - P1	2	3
P2	3	4

Table 3. Corrosivity classification of all studied sites.

Site	TOW	Cl^-	SO_2	C
Sattahip	τ4	S1	P1	3
Bangkok	τ3	S0	P0	2

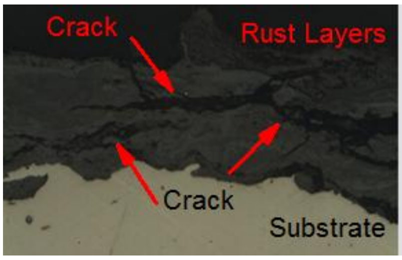
Based on Table 2, the corrosivity of Sattahip (coastal site) and Bangkok (urban site) is evaluated and shown in Table 3. From the atmospheric corrosivity of Table 3, the estimated corrosion rate of carbon steel for a year of study for two sites can be obtained and shown in Table 4. The corrosiveness assessment from Table 3 suggests that the coastal environment of Sattahip is more aggressive for carbon steel than the urban environment of Bangkok. Estimated corrosion mass loss from Table 4 indicates that atmospheric corrosion performance of carbon steel exposed to Sattahip's atmosphere is obviously lower than that subjected to Bangkok's atmosphere. In order to increase the atmospheric corrosion performance of carbon steel in the coastal environment, the painting or coating with good care should be applied on the surface of carbon steel.

Table 4. Estimated corrosion rate (R) as a function of the atmospheric corrosiveness category (unit in g/m^2)

Site	C	R of Carbon Steel
Sattahip	3	200–400
Bangkok	2	10–200

In addition, the design of structure which can avoid the accumulation of the condensed electrolyte is recommended. Furthermore, the improved atmospheric corrosion resistant steel, e.g. weathering steel, would be an alternative choice for the new structures [9]. For aged steel structures in coastal environment, the inspection of the structure integrity should be carried out.

3.4 Rust Morphology Observation



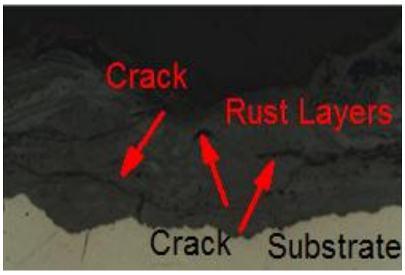


Fig. 4. Cross-sectional morphology of rust layers of rusted steel at magnificent of 20 X

The rusted steel plate which has been exposed to coastal environment for 7 years was cross-sectioned and examined by the light optical microscope as shown in Figure4. It is clear that the rust layers were thick, but contained many cracks. These cracks provide the path for chloride to attack the steel substrate. It is thus obvious that the rust of steel after 7 years exposure in coastal climate of Thailand is non-protective.

CONCLUSION

In this paper, the investigation of anti-atmospheric corrosion performance of carbon steel in the coastal environment was conducted by the application of ISO 9223 Norm and the rust analysis. The results from ISO 9223 show that the longer TOW in the coastal environment provides the longer duration of the atmospheric corrosion on the steel surface, which subsequently lower the atmospheric corrosion resistance of steel. The result from rust analysis pointed out that the rust of steel which has been exposed to the coastal environment for 7 years contains several cracks and the structure is loose and not compact. This kind of rust is clearly non-protective. Therefore, the longer time of wetness and the non-protective rust attributes to the decreased atmospheric corrosion resistance of steel.

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