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Initial Stage of Atmospheric Corrosion of Carbon and Weathering Steels in Thailand Climate

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Corrosion of carbon and weathering steels were evaluated under 3 environmental exposures in Thailand (urban, rural and marine) for a year. The seasonal study was designed to determine different corrosion mechanisms by 6 months of dry season and 6 months of rainy season in a year. The sheltered exposure racks were used to determine the washing effect of rain. At each site, climatic and pollutants analyses were carried out.

The present study showed that the difference in corrosion rates of carbon and weathering steels was not so distinguished in both rural (AIT) and urban (TISTR) environments. The corrosion rate of weathering steel was somewhat lower than that of carbon steel and the decreasing tendency of corrosion rate with time was slightly higher for weathering steel than for carbon steel. In marine (Rayong) environment, the corrosion rate was higher and the effect of wet and dry seasons was observed.The corrosion rate in 6 dry months was higher for direct exposure than for sheltered exposure. However, in 6 rainy months, the corrosion rate of sheltered exposure was higher than that of direct exposure. In direct exposure for 1 year, that is, the first 6 dry months and the next 6 rainy months, the corrosion rate decreased with time, but in sheltered exposure, the corrosion rate did not decrease with time, instead, increased in the next 6 rainy months. This indicated that the protective layer formed in the first 6 dry months could be destroyed by high deposition of chloride for sheltered exposure in the next 6 rainy months; whereas the rust layer for direct exposure could be kept sound due to washing effect in rainy season, even though the deposition rate of chloride was almost the same for direct and sheltered exposures. In marine environment, the weathering steel showed higher corrosion resistance than carbon steel but its corrosion rate was higher than those in other environments.

Keywords : *atmospheric corrosivity, direct/sheltered exposure, corrosion rate, weathering steel, carbon steel*

1. Introduction

Carbon steels has been widely used in Thailand as building and infrastructure steel components and reinforcing steels in concrete. Corrosion of steels occurs in form of rust which can deteriorate the steels and decrease the strength of the steel structures. The weathering steels which is described as a class of low-alloy structural steels has not been used commonly in Thailand. This may be due to not enough understanding of corrosion performance of weathering steels.

The weathering steels have been extensively used in many developed countries. They develop an adherent, protective rust layer during long term exposure to the atmosphere and as a result of corrosion protection from this rust layer, weathering steels do not require painting as ordinary carbon steels do. Studies on weathering steels place focus on their corrosion behavior in atmosphere polluted with sulfurous products, SO_x. In the weathering steels, Cu and P play an important role on the performance of uniform protective rust layer on the surface of weathering steels especially at the early stage of atmospheric corrosion.The mechanism of the long term growth of a stable and protective rust layer formed on the weathering steel and the basis of the process of rusting and phase formation of iron oxide in industrial region have been proposed by Yamashita *et al.*[1),2)].

This study presents the initial results of atmospheric corrosion of carbon and weathering steels and the characteristics of their corrosion behavior in Thailand climate.

Table 1. Chemical composition of steels

	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	V	N	Al
G3101	0.15	0.01	0.74	0.014	0.006	0.02	0.03	0.02	0.01	0.01	0.0058	0.012
SPA-H	0.09	0.32	0.40	0.106	0.003	0.14	0.37	0.28	0.01	0.01	0.003	0.03

2. Experimental

The experimental steels were supplied from Sumitomo Metal Industries Co., Ltd. according to JIS G3101(carbon steel) and JIS SPA-H (weathering steel).Their chemical compositions were shown in Table 1. The specimen size was 50x150x2 mm. The coupons were scrubbed with soft cloth in acetone to remove the anti-corrosive oil, dried, marked by punching, weighed and stored in desiccator.

The specimens were exposed at three different atmospheric sites: on the roof of Asian Institute of Technology building (rural), on the roof of Thailand Institute of Scientific and Technological Research building (urban) and on the ground about 100 m far from the coast at Rayong (marine). The exposure ran in 6 months of dry season during November 1999-April 2000 and 6 months of rainy season from May- October 2000, and a period of one year started in November 1999. The specimens were divided into 2 sets ; one for exposure directly to the atmosphere and another for exposure under glass shelter in order to investigate the washing effect of rain. All specimens were set at an angle of 45^{o} from the horizontal, and facing the south.

The climatic data including air temperature, relative humidity, time of wetness, total rainfall and total solar energy were collected monthly at each site. At AIT site, the data were collected from the Meteorological Department whereas at TISTR and Rayong sites, the data were obtained from electronic data logger placed at each site. The pollutant analysis was conducted according to the ISO 9225, in which the deposition of NaCl was determined by the wet candle method and SO_2 deposition rate by alkaline sulfate plate.

After each exposure period; first 6 dry months, last 6 wet months and one year, the exposed specimens were determined by weight loss for corrosion rate according to ISO 8407. The rust removed from the surfaces of specimens were collected for X-ray diffraction analysis, FT-IR analysis and EDS for elemental analysis. The surface profile of the exposed plate after removing of rust were also measured with laser surface roughness meter.

3. Results and discussion

3.1 Climatic and pollutant data

Time of wetness was the highest at Rayong site and the amount of precipitation was about three times in rainy

Table 2. Technical characteristics of the atmosphere at each exposure site

Atmosphere	Site	Period	Air Temperature (°C) *			%RH *	%TOW *	Rain (mm) **	Total sunlight **	Cl^- (mg/m^2.d) *		SO_2 (mg/m^2.d) *
			max	min	avg					out	in	
Rural	AIT	dry	33.2	17.8	26.1	70.6	28.0	338.8	1853.2	na	na	na
		wet	33.2	24.7	28.3	84.0	42.7	974.6	1839.0	na	na	na
		1 year	33.2	21.3	27.2	77.3	35.4	1313.4	3692.2	na	na	na
Urban	TISTR	dry	34.8	19.3	27.5	66.5	21.5	336.3	1734.6	6.2	6.4	14.8
		wet	36.1	23.1	28.4	74.2	45.7	960.6	1751.5	3.5	3.7	6.9
		1 year	35.5	21.2	27.9	70.4	33.6	1296.9	3486.1	4.9	5.1	10.9
Marine	Rayong	dry	38.4	20.3	28.4	74.7	59.6	279.5	1835.3	14.7	10.5	14.8
		wet	36.2	23.8	29.0	80.3	96.5	1057.5	1839	34.1	37.6	8.3
		1 year	37.3	22.1	28.7	77.5	78.1	1337.0	3674.3	24.4	24.1	11.6

* average from monthly data
** total for 6- month period
na = not analysed

dry period = November 1999- April 2000
wet period = May 2000- October 2000
1 year = November 1999- October 2000

season, compared to dry season. The deposition rate of chloride at Rayong site was also the highest among the three sites and the deposition rate of SO_2 at Rayong site and TISTR site was high due to the sites being located in the industrial and traffic congestion areas, respectively.

3.2 Corrosion rate and corrosivity category

From the first year corrosion rate of carbon steel , the corrosivity of exposure sites could be categorized according to ISO 9223 standard which was shown in Table 3. Rayong exposure site (marine) was categorized as C3 to C4 depending on exposure mode (sheltered or direct), which was the highest corrosivity among all sites.

Table 3. The first- year corrosion rate of steels and corrosivity category of exposure sites.

Site	Carbon Steel (μm/y)		Class ISO 9223 for 1st year corrosion of Carbon Steel		Weathering Steel	
	Sheltered	Direct	Sheltered	Direct	Sheltered	Direct
AIT	21.0	26.0	C2	C2/C3	19.8	22.2
TISTR	22.4	23.8	C2	C2	20.9	20.6
Rayong	46.8	34.4	C3/C4	C3	38.4	28.2

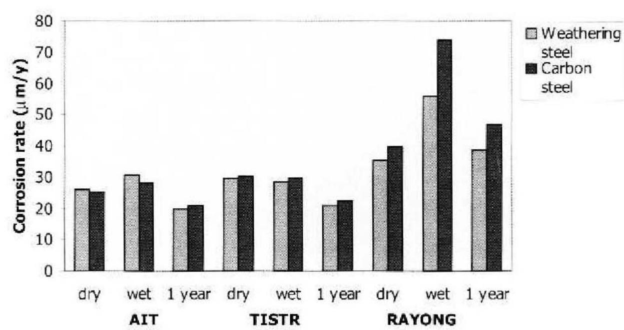

Fig. 1a. Corrosion rate of steels in sheltered exposure

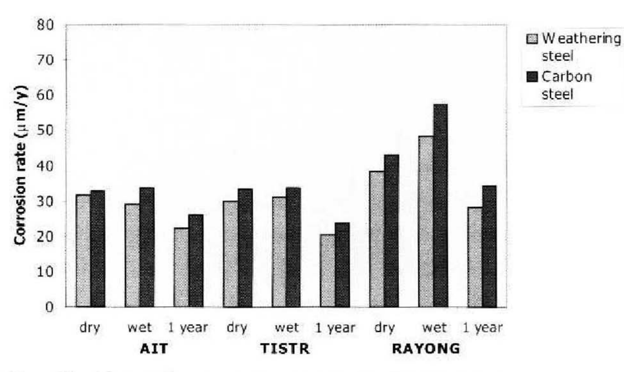

Fig. 1b. Corrosion rate of steels in direct exposure

The corrosion rate of carbon and weathering steels exposed in sheltered and direct exposure at different periods and sites was shown in Figs. 1a and 1b. It was found that at AIT (rural) and TISTR (urban) sites, the decreasing tendency of corrosion rate with time was slightly higher for weathering steel than carbon steel.

At AIT, the corrosion rate of direct exposure was somewhat higher than that of sheltered exposure, but the difference was not clear in rainy season, whereas at TISTR the difference in corrosion rate between direct and sheltered exposure was not observed.

At Rayong (marine) site, the weathering steel showed higher corrosion resistance than carbon steel but its corrosion rate of both carbon and weathering steels was higher than those of AIT and TISTR sites.

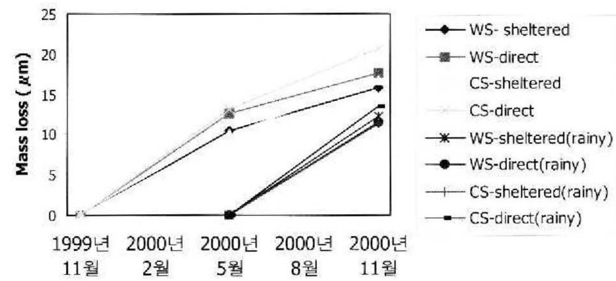

Fig. 2a. Mass loss of carbon and weathering steels at AIT site

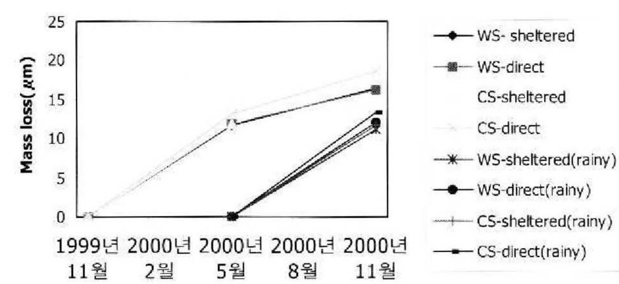

Fig. 2b. Mass loss of carbon and weathering steels at TISTR site

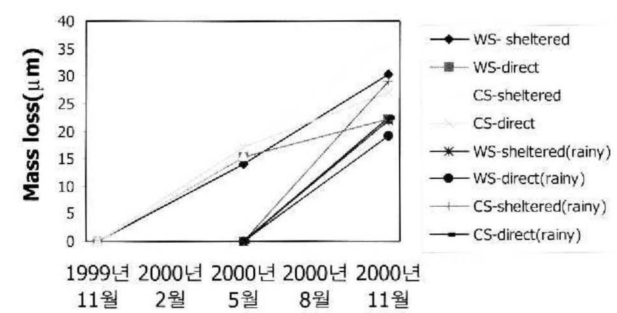

Fig. 2c. Mass loss of carbon and weathering steels at Rayong site

The corrosion behavior could clearly be seen in Figs. 2a-2c which presented the differences of corrosion mass loss (in term of thickness loss, μm) of carbon and weathering steels exposed at different periods and sites.

(1) At Rayong, the corrosion rate in rainy season was much higher than that in dry season due to the higher degree of pollution and the longer time of wetness.

(2) At Rayong, the corrosion rate for direct exposure was higher than the sheltered exposure in dry 6 months due to the longer time of wetness for direct exposure, whereas the corrosion rate for sheltered exposure was higher than direct exposure in 6 rainy months due to the less washing- out effect for sheltered exposure.

(3) At Rayong, the corrosion rate for direct exposure decreased in the next 6 rainy months by washing-out of pollutants by rain. However, the corrosion rate for sheltered exposure increased in the next 6 rainy months by the accumulation of pollutants in rust layer due to high deposition and less washing-out of pollutants by rain. Even in this condition, the rust layer formed in the first 6 dry months still showed a slight protectiveness in the next 6 rainy months, as the corrosion rate in the latter 6 rainy months was higher for the fresh specimen than for the rusted specimen previously exposed in the former 6 dry months.

(4) The protective rust layer formed in the first 6 dry months could be destroyed by the high deposition of chloride which was accumulated in sheltered exposure in the next 6 rainy months, whereas, the rust layer could be protective for direct exposure, due to the washing of chloride by rain water in the rainy season, though the deposition rate was nearly the same for direct and sheltered exposure.

3.3 Surface analysis

3.3.1 Corrosion products

The rust layer was analysed by XRD and FT-IR for corrosion product analysis. It was shown that corrosion product which was formed as the rust layer on both carbon and weathering steels was amorphous ferricoxyhydroxide (FeOOH). Thus it could be explained that in the initial corrosion stage, the oxyhydroxide of iron was formed on the steel surfaces.

From the elemental analysis by EDS of rust from the specimens exposed at Rayong site (marine) in 6- month seasonal periods, it was found that in the initial development of rust, S and Cl could be detected in both the rust formed on carbon and weathering steels but there is no correlation of the chloride residue in rust layer with corrosion rate of the steels. Si was found in rust formed on weathering steel. For 1- year exposure results, Cu was also found in the rust formed on weathering steel. The results in longer exposure period reported by Yamashita *et. al.*[1),2)] were that the inner layer of the corrosion product on weathering steel exposed in industrial region contained a considerable amount of Cr, P and Cu, and Si was found only in the outer layer of weathering steel rust. S was also detected in the outer and the inner layer, and Cl was scarcely found in rust. However, in our study Cl was found in considerable amount at marine exposure site.

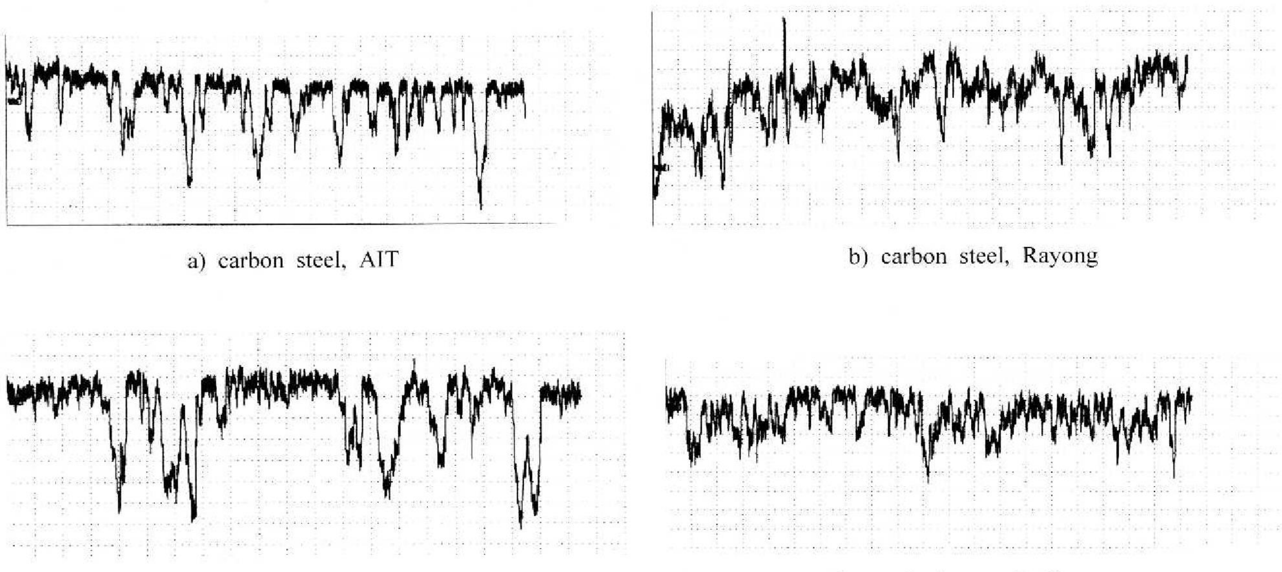

Fig. 3(a-d). Typical data of surface roughness of steels exposed in direct exposure for 1 year

3.3.2 Surface roughness

The typical data of surface roughness of steels exposed directly for 1 year at AIT and Rayong sites were shown in Figs. 3 (a-d). The difference in surface roughness of specimens exposed in different modes and sites was summarized as follows:

(1) At AIT, the type of corrosion was pitting-like due to the low level of pollution, and the depth of pitting was larger for direct exposure than for sheltered exposure, and increased with exposure time.

(2) At TISTR, the corrosion behavior was similar to that at AIT, although more uniform corrosion was observed.

(3) At Rayong, on the other hand, the type of corrosion was rather uniform-like with some pitting due to the highest level of pollution among the three sites. Although the corrosion loss of the specimen exposed in the latter 6 rainy months under the shelter was nearly equal to that value exposed for 1 year directly, the pattern of surface roughening was quite different. The former showed a rather smooth surface, which was caused by uniform corrosion in the heaviest pollution, whereas the latter showed a marked surface roughening, which suggested the superposition of uniform corrosion and pitting- like corrosion during the process of deposition and washing-out of pollutants.

(4) There was no distinguished difference between carbon and weathering steels at every sites.

(5) Surface roughness of the steels was smaller for 6-month exposure than that of one year exposure for every sites.

(6) If exposed only in either wet or dry period, the surface roughening was not so severe but dry/wet cyclic period in a year like Thailand's climate caused more severe roughening of the steel surfaces. This difference was clearly shown in Rayong (marine) atmosphere.

4. Conclusions

The initial stage of atmospheric corrosion in Thailand has been studied. The following are the conclusions drawn from the study.

(1) The atmospheric corrosion rate is controlled by a combination of (1) time of wetness, (2) deposition rate of pollutants, and (3) washing- out of pollutants by rain.

(2) At AIT (rural), where the deposition rate of pollutants is low, the time of wetness is predominant. At this site, the corrosion rate for direct exposure (the longer time of wetness) is higher than that for sheltered exposure.

(3) At TISTR (urban), though the level of pollution is higher than AIT, the corrosion rate is nearly the same as that at AIT. The difference in corrosion rate between direct exposure and sheltered exposure is small due to an increased effect of pollutants.

(4) At Rayong (marine), where the level of pollution by SO_2 and NaCl is highest among the three sites, the effect of deposition of pollutants and their washing out by rain becomes more prominent. The corrosion rate is highest among the three exposure sites, and is widely varied between seasons (dry and rainy) and between exposure modes (direct and sheltered), depending on degree of pollution.

(5) The rust layer formed in the first 6 dry months is protective. The corrosion rate decreases in the next 6 rainy months at every exposure site and every exposure condition, except for the sheltered exposure at Rayong.

(6) The corrosion product which is formed as the rust layer on both carbon and weathering steels is amorphous ferricoxyhydroxide (FeOOH). The chloride in the rust layers exists on both carbon and weathering steels exposed at Rayong site, but no correlation was found with corrosion rate.

(7) The roughening pattern of surface after exposure is different between the exposure sites, depending on the level of pollution. The low level of pollution has a tendency to cause pitting-like corrosion, whereas the high level of pollution tends to increase the uniform-like corrosion.

(8) There is no distinguishable difference in surface roughening between carbon steel and weathering steel.

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