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Corrosion of metals and alloys — Exposure test results in the Asian Monsoon region

Corrosion des métaux et alliages — Résultats des essais d'exposition dans la région de la mousson asiatique

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Foreword

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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

At the time of publication, the mainstream method of classifying environmental corrosion is that specified in ISO 9223. This is a method in which the corrosion rates of various metals are classified in six levels based on the results of direct exposure tests conducted around the world. However, the exposure sites were located only in Japan for the exposure tests in Asian Monsoon region, in which East-Asia, South-Asia and East-South Asia are included and the climates are affected by monsoons. Thus, standardization of an evaluation/classification method suited to the Asian Monsoon region has been strongly desired. Therefore, exposure tests were conducted in three counties including Japan, Vietnam and Thailand, under the "e-Asia Project".

This document summarizes the exposure test results for carbon steel and galvanized steel sheet.

Corrosion of metals and alloys — Exposure test results in the Asian Monsoon region

1 Scope

This document provides the data of exposure test results for carbon steel and galvanized steel sheets in three countries, Japan, Vietnam and Thailand, under the "e-Asia Project" as valuable information on the corrosivity of atmospheres in the world.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9223:2012, *Corrosion of metals and alloys — Corrosivity of atmospheres — Classification, determination and estimation*

ISO 9225:2012, *Corrosion of metals and alloys — Corrosivity of atmospheres — Measurement of environmental parameters affecting corrosivity of atmospheres*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9223 and ISO 9225 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Exposure tests

The coupons of carbon steel and galvanized steel sheet were exposed in outdoor environments at 16 exposure test sites in Japan, 13 sites in Vietnam and 7 sites in Thailand as shown in Figure 1. Specimens of 3 mm thickness and 70 mm × 150 mm of carbon steel and specimens of 1 mm thickness and 70 mm × 150 mm of galvanized steel sheet were used for exposure tests. The specimens of carbon steel were exposed both sides. For the specimens of galvanized steel sheet, the backside and cut edge of the coupons were covered by polyethylene sheet after degreasing the specimen in acetone. The exposed surfaces of specimens were exposed to skyward and groundward as shown in Figure 2. The corrosion products on the exposed specimens were removed by using chemical solutions according to ISO 8407, and the weight losses were measured to determine the corrosion rate.

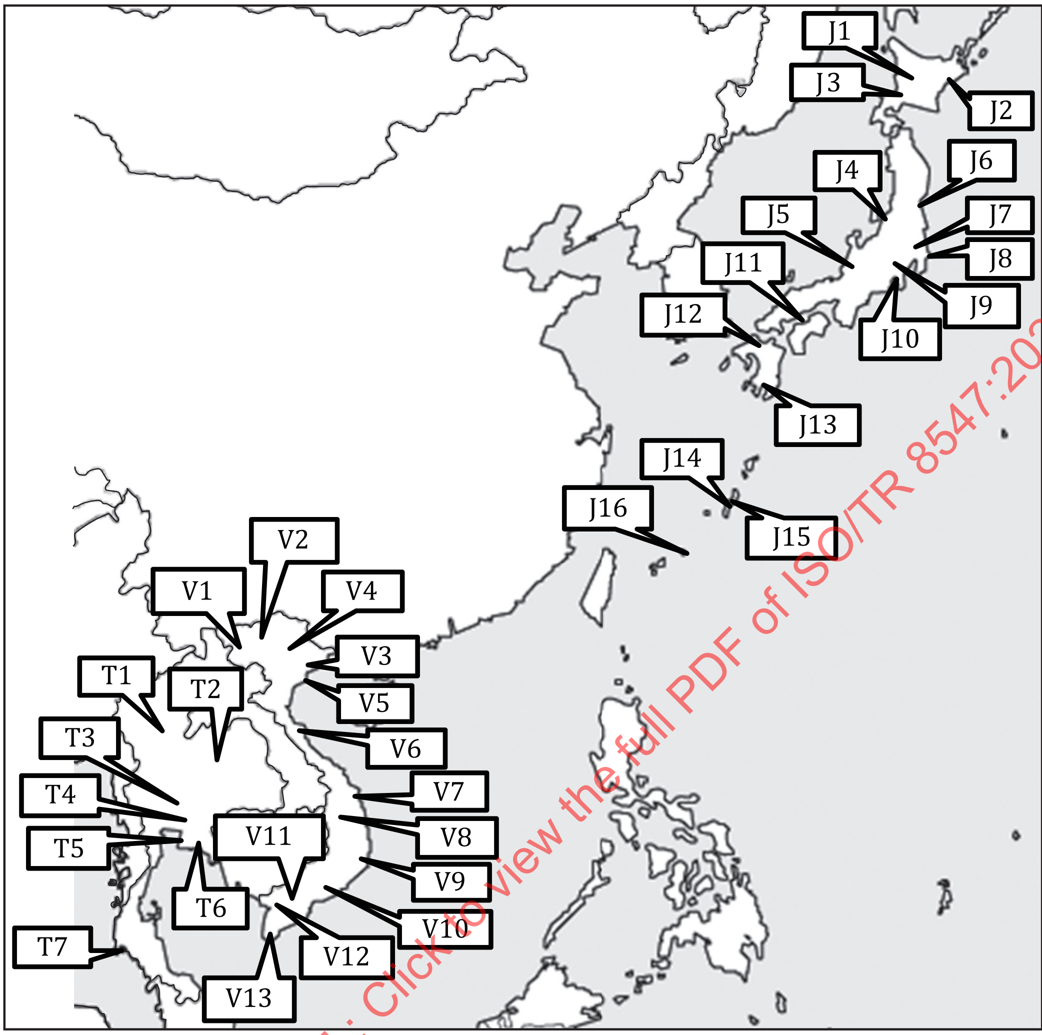
For the environmental factors, monthly amounts of airborne salinity and SO_2 were measured by "Dry gauze" and "PbO_2 cylinder", respectively, based on JIS Z 2382. The temperature, relative humidity, and ACM sensor output, I, were recorded in a microcomputer every 10 min.

For the annual average values of Cl^- deposition, S, and SO_2 deposition, P, those values based on JIS Z 2382, S(JIS) and P(JIS), respectively, were converted to S and P based on ISO 9225:2012, Annex F:

$$S = 2{,}4\ S(JIS)$$

P = 0,67P(JIS)

NOTE Some of numerical data are available from data sources given in Annex A.

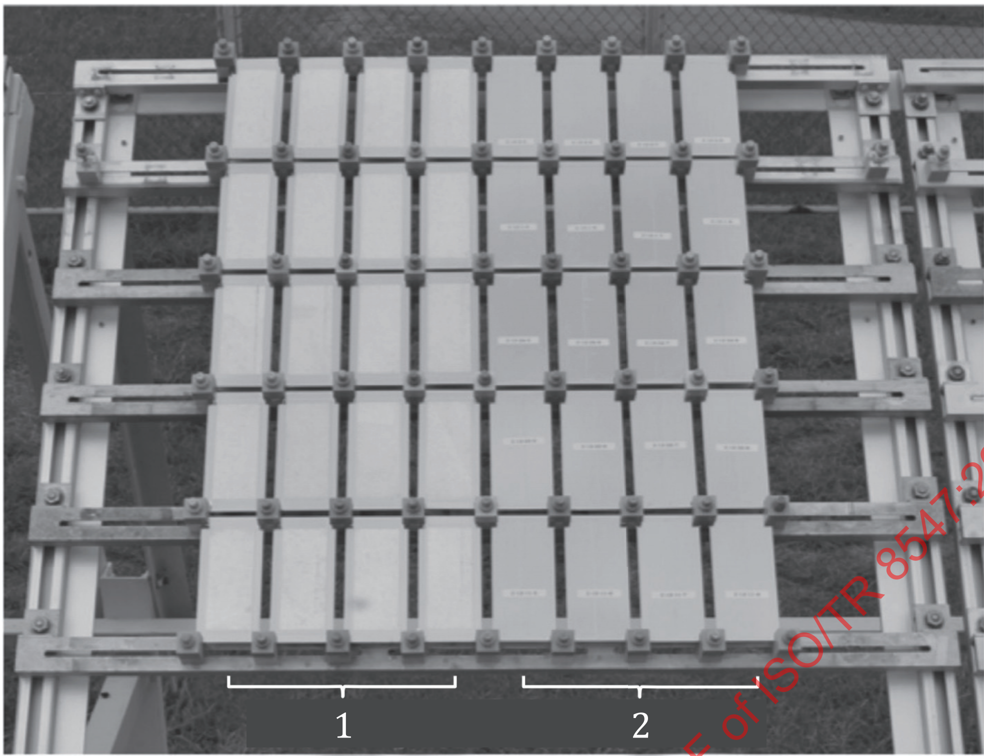


Key

J1	Asahikawa	J14	Nishihara
J2	Akkeshi	J15	Uruma
J3	Sapporo	J16	Miyakojima
J4	Niigata		
J5	Fukui		
J6	Sendai		
J7	Tsukuba		
J8	Choshi		
J9	Yamanakako		
J10	Shimizu		
J11	Fukuyama		
J12	Fukuoka		
J13	Kagoshima		

V1	Sơn La	T1	Chiang Rai
V2	Yên Bai	T2	Khon Kaen
V3	Cua Ong	T3	Pathum Thani
V4	Hà Nội	T4	Bangkok
V5	Con Vanh	T5	Chon Buri
V6	Đong Hoi	T6	Rayong
V7	Dung Quat	T7	Phangnga
V8	Pleiku		
V9	Phan Rang		
V10	Bien Hoa		
V11	Can Tho		
V12	Rach Gia		
V13	Ca Mau		

Figure 1 — Exposure test sites in Japan, Vietnam and Thailand



Key

1 skyward

2 groundward

Figure 2 — Example of exposure test for galvanized steel at Miyakojima

5 Climatic and environmental conditions[1][2]

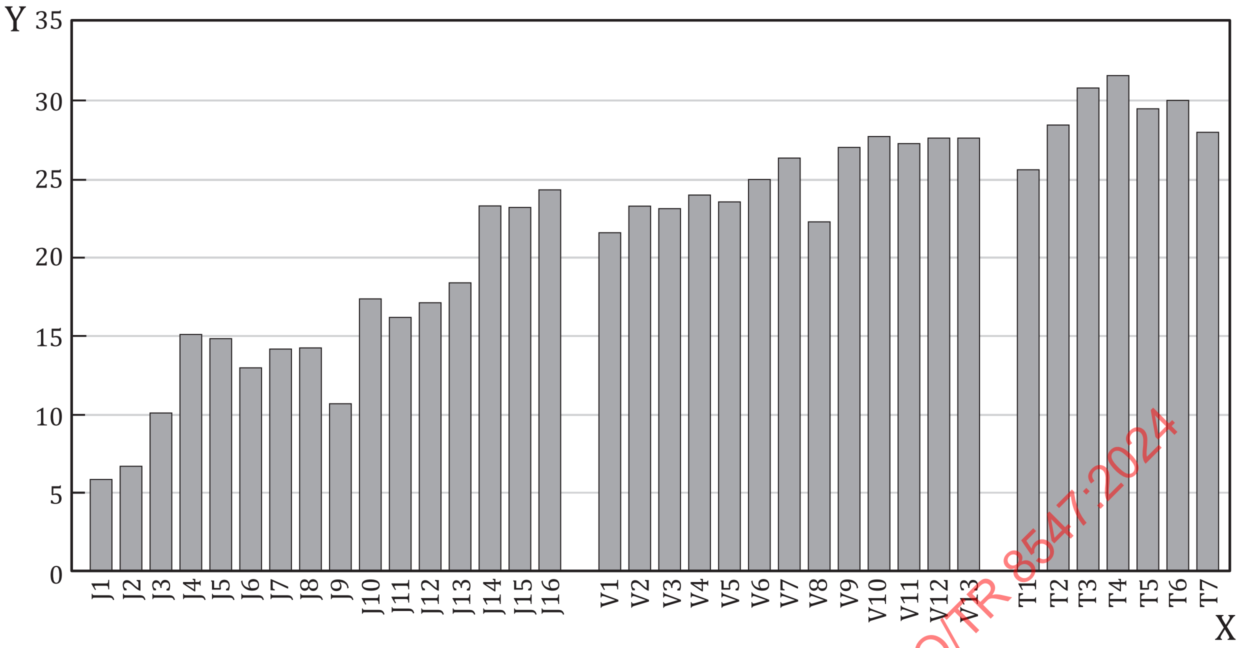
The average temperature, T, at each site is shown in Figure 3. T value increases in the order Japan<Vietnam<Thailand. In Japan, the lowest T values, in the range of approximately 5 °C to 10 °C, can be seen at the test sites in Northern area or in the mountain (Asahikawa, Akkeshi, Sapporo and Yamanakako), the remain test sites have T of about 13 °C to 24 °C. In Vietnam, the average air temperatures are rather high, and almost all Vietnam test sites have T in range of 22 °C to 27 °C. Different from Japan and Vietnam, the air temperature of Thailand is very high with the annual average values of about 28 °C to 30 °C, except one site in the North (Chiang Rai) where T is lower (25 °C).

The average relative humidity, RH, at each site is shown in Figure 4. RH of all test sites are rather high, almost all of them have RH ≥ 70 %, except several sites with RH < 70 % (as Kagoshima and Miyakojima – Japan, Khon Kaen – Thailand), among them, there are many test sites with RH ≥ 80 %, especially in some areas, RH values reach approximately 85 % to 90 %.

The total of rainfalls in Asian area are very great as shown in Figure 5. Almost all test sites show the amount of rainfall in the range of approximately 1 000 mm/y to 2 500 mm/y, in particular, there are test sites with very high total of rainfall, approximately 2 500 mm/y to 3 000 mm/y.

Figure 6 shows the annual Cl^- deposition rate, S, at each site during the exposure period. The inland sites have low S values (< 1 mmd), and the coastal sites have higher S values (> 1 mmd). Depending on the location of the test sites as well as the topography and wind regime, S values at coastal sites have different values in the range of about 1 mmd to 60 mmd. The high S values are observed at Miyakojima and Uruma (which belong to Okinawa islands, Japan) and Phangnga (which is located near Phuket, Thailand).

Figure 7 shows the annual SO_2 deposition rate, P, at each site during the exposure period. P values at almost all test sites are not significant (< 3 mmd) except only three sites in Thailand, Bangkok, Rayong and Pathum Thani.

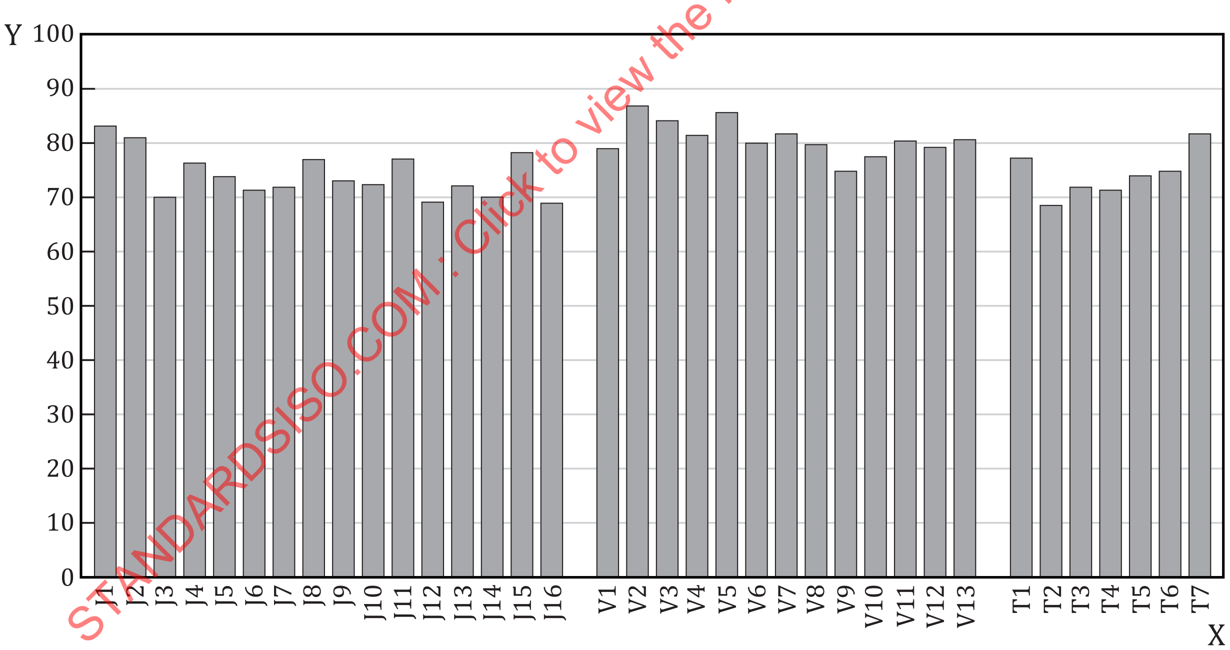


Key

X site symbol

Y temperature °C

Figure 3 — Average temperature, T, at each site during the exposure period

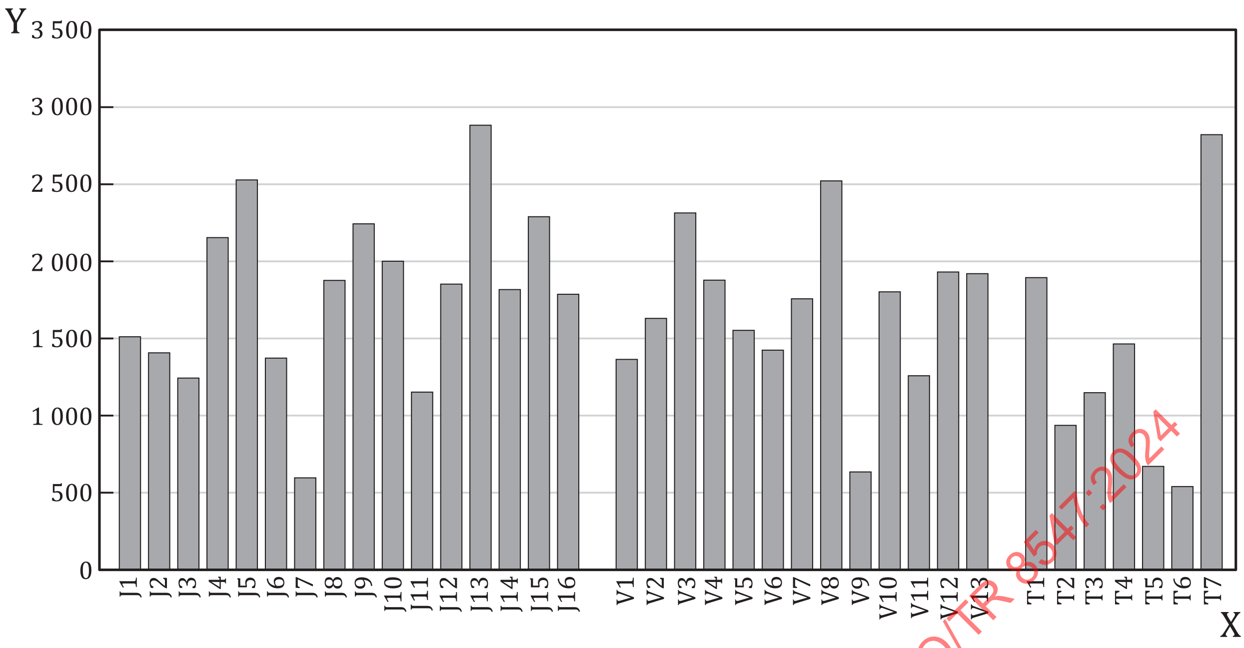


Key

X site symbol

Y RH %

Figure 4 — Average relative humidity, RH, at each site during the exposure period

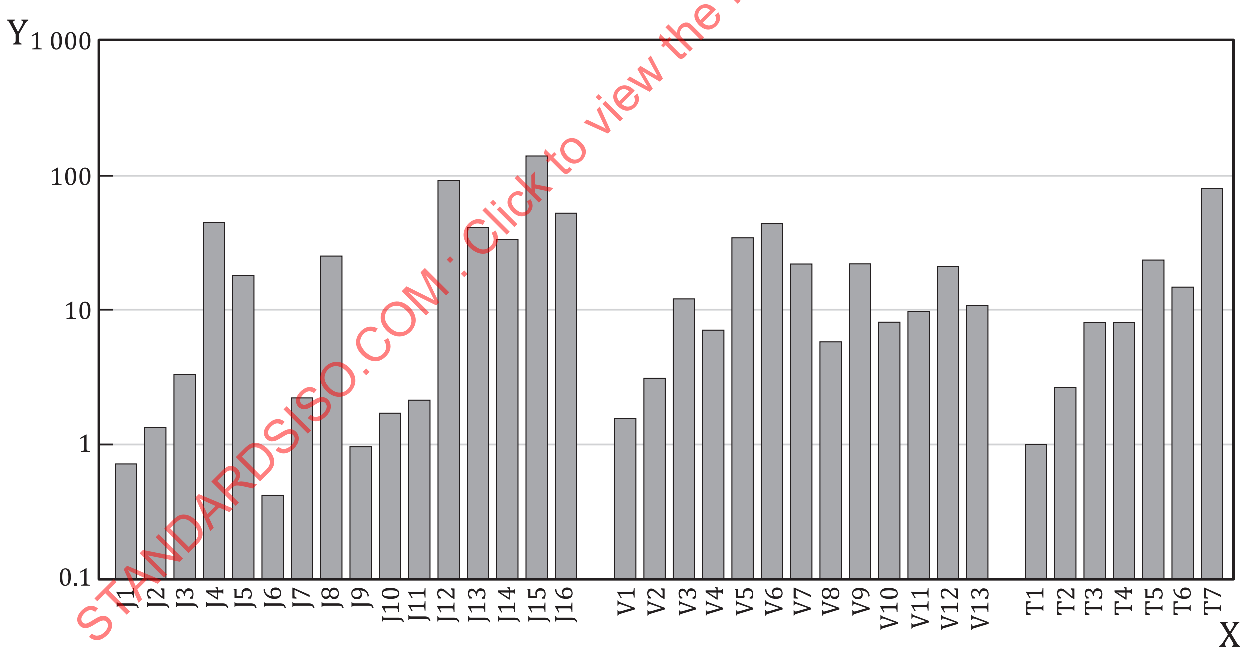


Key

X site symbol

Y rain fall mm/y

Figure 5 — Total of rainfall at each site during the exposure period

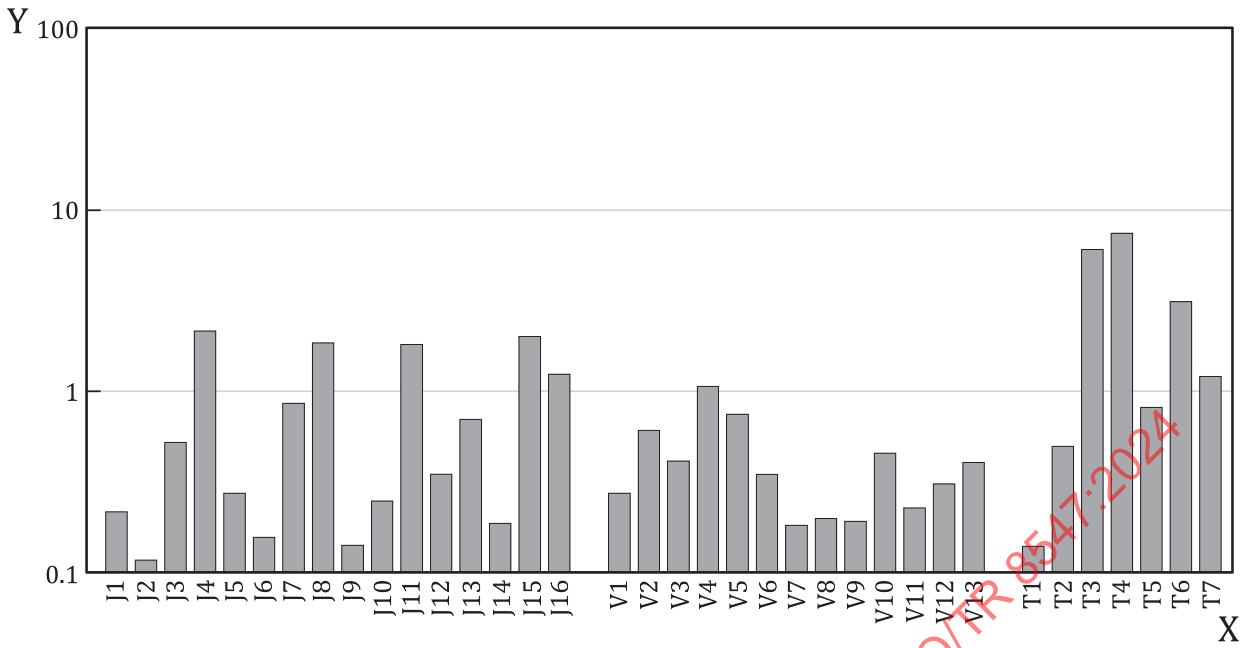


Key

X site symbol

Y Cl^- deposition rate, S mg/m^2/day

Figure 6 — Annual Cl^- deposition rate, S, at each site during the exposure period



Key

X site symbol

Y SO_2 deposition rate, P mg/m^2/day

Figure 7 — Annual SO_2 deposition rate, P, at each site during the exposure period

6 Corrosion behaviours of carbon steel[1][2]

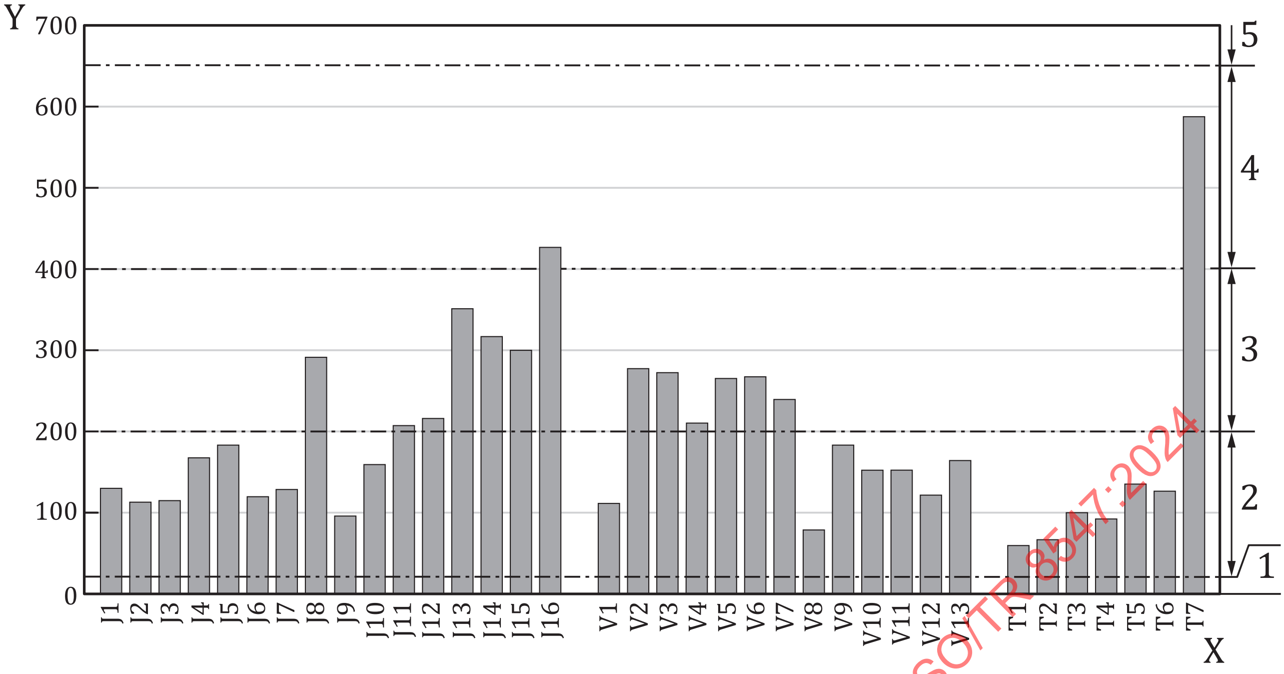
6.1 Corrosion rate (CR[CS])

Figure 8 shows the corrosion rates of carbon steel, CR[CS], after the first one-year exposure. CR values at almost all test sites are categorized to C2 (approximately 10 g/m^2/y to 200 g/m^2/y) or C3 (200 g/m^2/y to 400 g/m^2/y) except Miyakojima/Japan and Phangnga/Thailand which are categorized to C4 (400 g/m^2/y to 650 g/m^2/y).

6.2 Effect of environmental factors on corrosion rate

Figures 9 to 11 show the effects of meteorological factors - temperature, T, RH and rain fall - on corrosion rate of carbon steel, CR[CS]. For the effect of T on CR[CS], ISO 9223 states that CR[CS] value increases with increasing temperature when the temperature is lower than 10 °C, but it decreases with increasing temperature when the temperature is higher than 10 °C. Those behaviours were not observed in Asian area, the CR[CS] value has a peak at around 20 °C as shown in Figure 9. The CR[CS] value increases with increasing rain fall as shown in Figure 11, while the CR[CS] value is not affected by RH as shown in Figure 10.

For the environment factors - annual Cl^- and SO_2 deposition rates, S and P, respectively -, the CR[CS] value increases with increasing S as shown in Figure 12, while it is not affected by P as shown in Figure 13.



Key

X site symbol

Y corrosion rate, CR g/m²/y

1 C1 range (ISO 9223 corrosivity category)

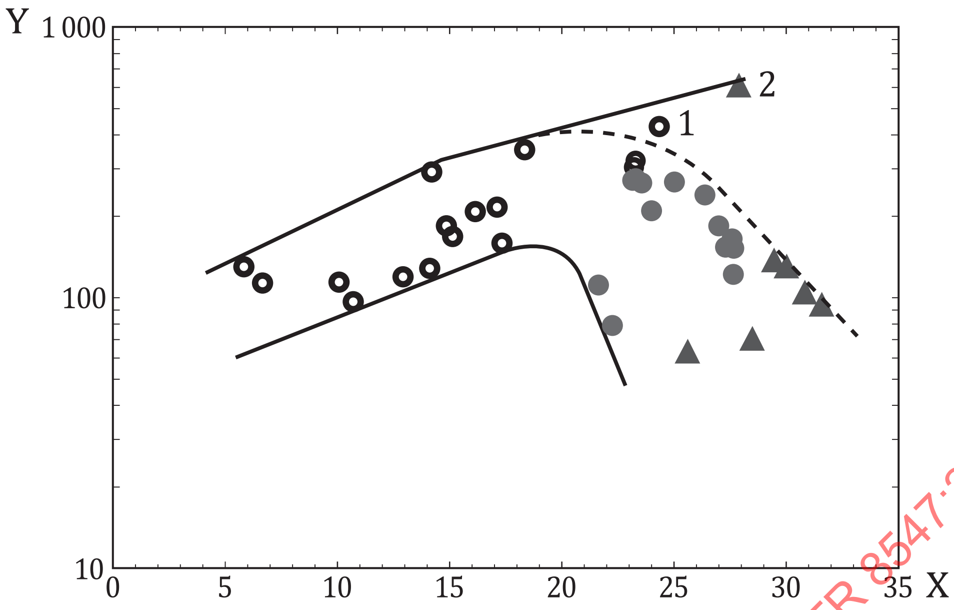
2 C2 range (ISO 9223 corrosivity category)

3 C3 range (ISO 9223 corrosivity category)

4 C4 range (ISO 9223 corrosivity category)

5 C5 range (ISO 9223 corrosivity category)

Figure 8 — Corrosion rate of carbon steel, CR[CS], at each site during the exposure period



Key

X temperature °C

Y corrosion rate, CR g/m^2/y

1 Japan site (Miyakojima)

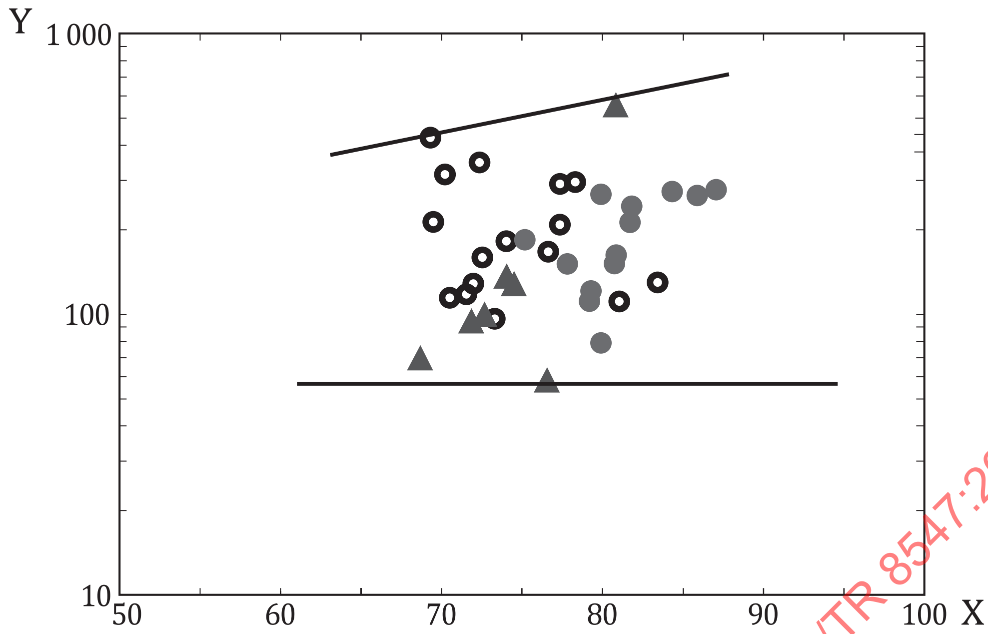
2 Thailand site (Phangnga)

○ Japan site

● Vietnam site

▲ Thailand site

Figure 9 — Effect of temperature, T, on corrosion rate of carbon steel, CR[CS]



Key

X RH %

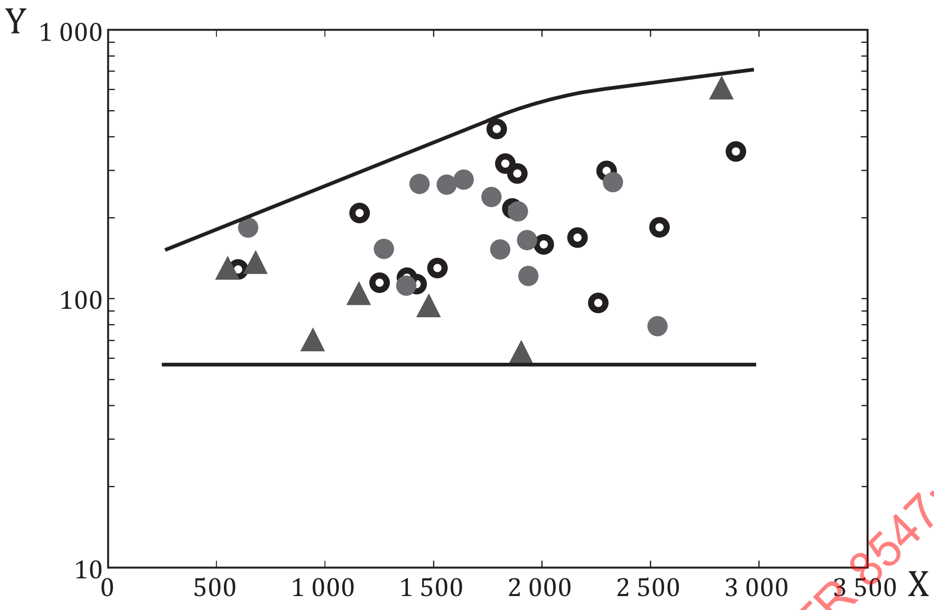
Y corrosion rate, CR g/m^2/y

○ Japan site

● Vietnam site

▲ Thailand site

Figure 10 — Effect of RH on corrosion rate of carbon steel, CR[CS]



Key

X rain fall mm/y

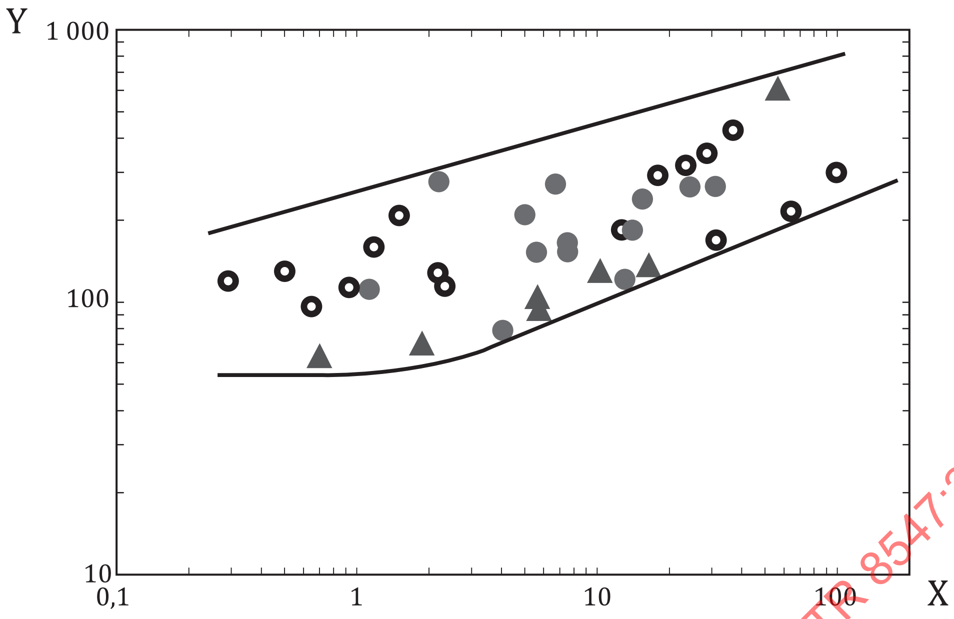
Y corrosion rate, CR g/m^2/y

Japan site

Vietnam site

Thailand site

Figure 11 — Effect of rain fall on corrosion rate of carbon steel, CR[CS]



Key

X Cl⁻ deposition rate, S mg/m^2/day

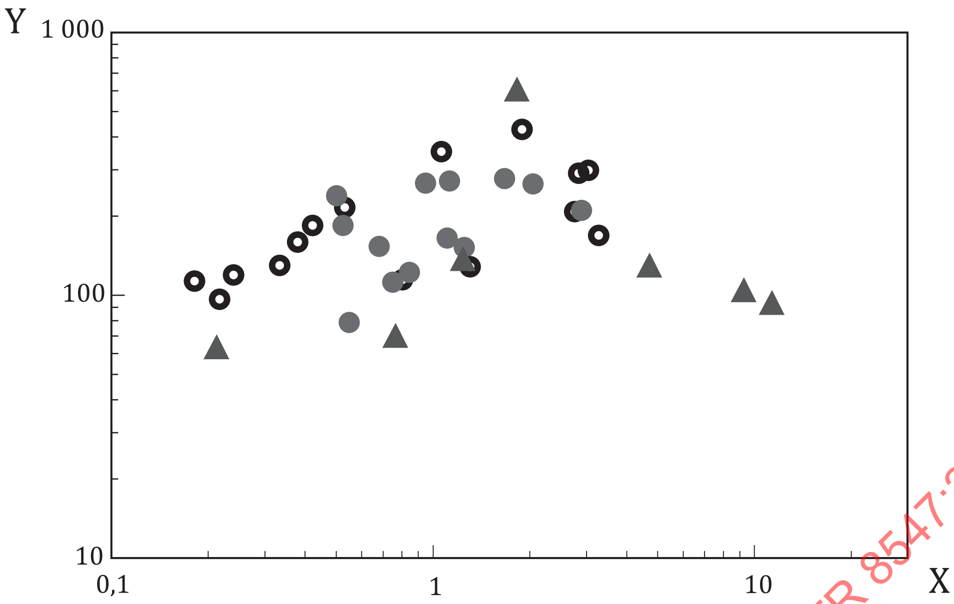
Y corrosion rate, CR g/m^2/y

Japan site

Vietnam site

Thailand site

Figure 12 — Effect of annual Cl⁻ deposition rate, S, on corrosion rate of carbon steel, CR[CS]



Key

X SO_2 deposition rate, P mg/m^2/day

Y corrosion rate, CR g/m^2/y

Japan site

Vietnam site

Thailand site

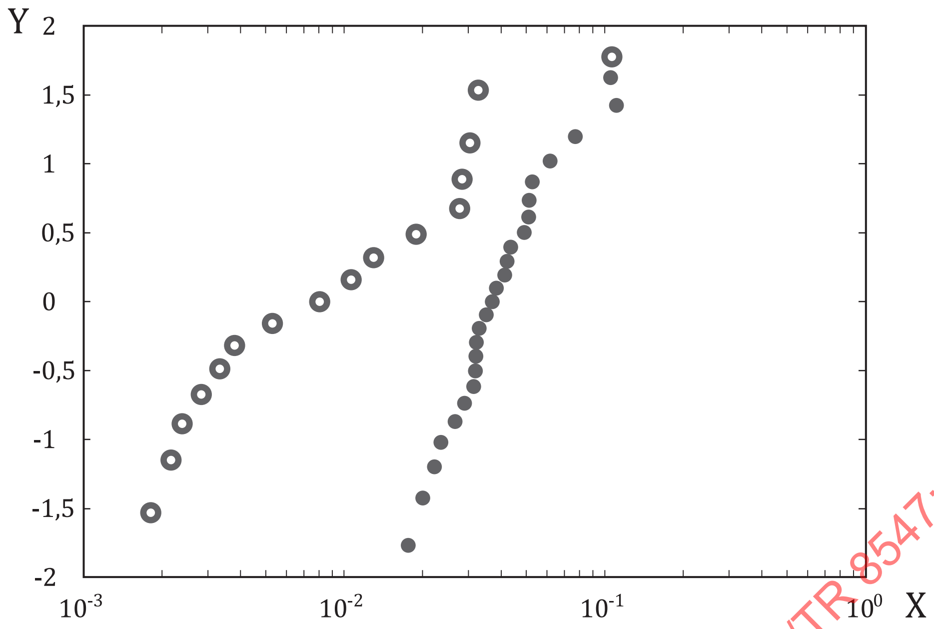
Figure 13 — Effect of annual SO_2 deposition rate, P, on corrosion rate of carbon steel, CR[CS]

7 Corrosion behaviours of zinc[3]

7.1 Comparison with the previous or published study

Distributions of meteorological and environmental factors in this study were compared with the previous study[4] (25 sites, by JWTC) by using the normal or log-normal distribution plots. It was confirmed that the distributions of meteorological and environmental factors in both studies were almost the same except the distribution of P. The P values in this study are less than approximately 1/2 to 1/10 of those in the previous study (see Figure 14).

The log-normal distribution plots of CR[Zn] in this study and the previous study are shown in Figure 15. The distribution plots of CR[CS] in this study are also plotted in Figure 15. CR[Zn] values are less than 1/10 of CR[CS], and the average value is fitted well to that in the previous study.[4] Both sides were exposed in the previous study,[4] thus the average value in this study is suitable to compare that in the previous study.[4]



Key

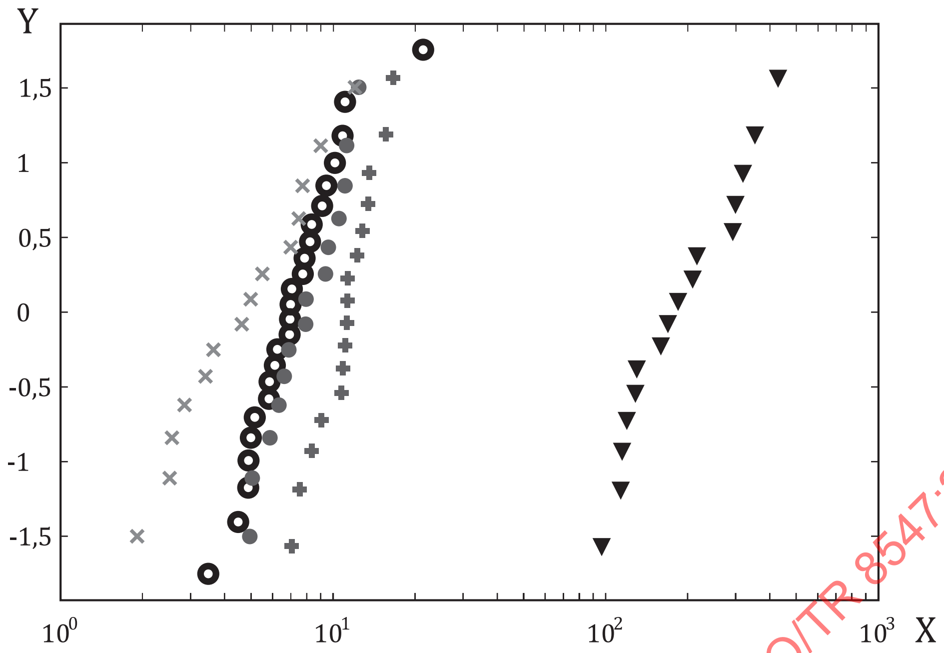
X SO_2 deposition rate, P mg/m^2/day

Y standardized value, s

○ 16 sites (this document)

● 25 sites (JWTC)

Figure 14 — Log-normal distribution plots of annual SO_2 deposition rate, P, in Japan



Key

X corrosion rate, CR $g/m^2/y$

Y standardized value, s

⭘ Zn (JWTC)

● GS (this study); average

✚ GS (this study); skyward

× GS (this study); groundward

▼ CS (this study)

Figure 15 — Log-normal distribution plots of CR[Zn] and CR[CS] in Japan

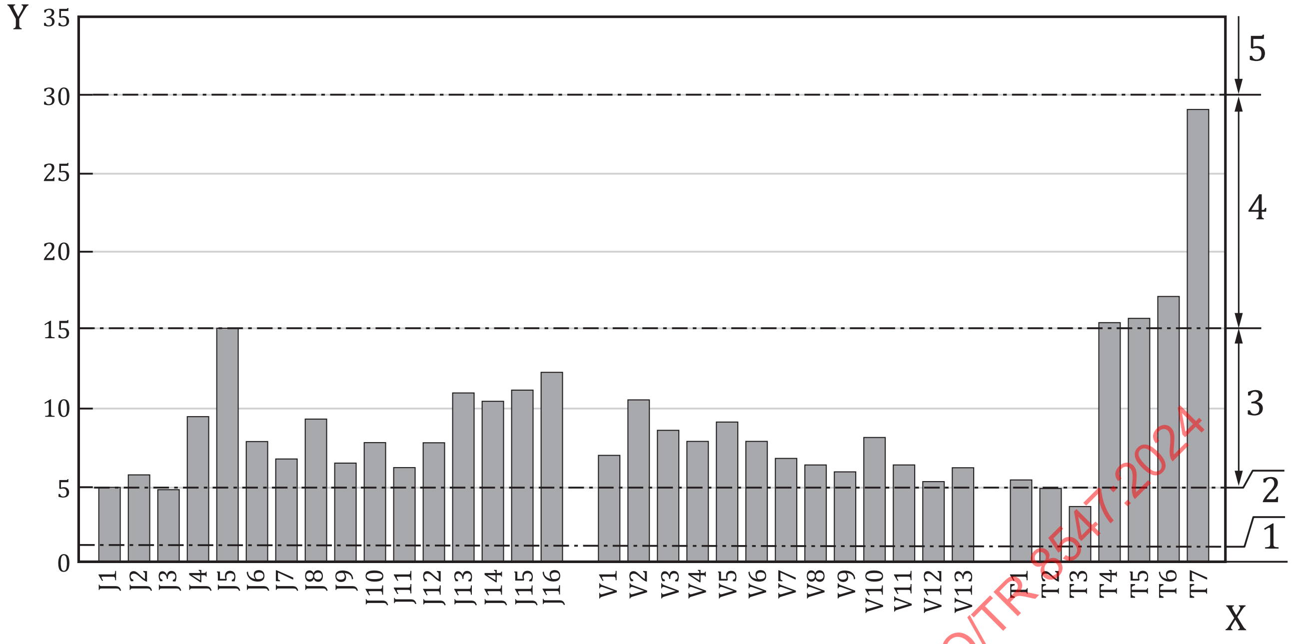
7.2 Corrosion rate (CR[Zn])

Figure 16 shows the corrosion rates of zinc, CR[Zn], after the first one-year exposure. CR values at almost all test sites are categorized to C3 (approximately 5 $g/m^2/y$ to 15 $g/m^2/y$). Pathum Thani/Thailand is categorized to C2 (approximately 0,7 $g/m^2/y$ to 5 $g/m^2/y$), and Fukui/Japan and four sites (Bangkok, Rayong, Chon Buri, Phangnga) in Thailand are categorized to C4 (approximately 15 $g/m^2/y$ to 30 $g/m^2/y$).

7.3 Effect of environmental factors on corrosion rate

As mentioned before, the average value of CR[Zn] in this study is comparable to that in the previous study.[4] Thus, the average value of CR[Zn] for three countries, Japan, Vietnam and Thailand, in this study are compared. Figures 17 to 19 show the effects of meteorological factors - temperature, T, RH and rain fall - on corrosion rate of zinc, CR[Zn]. For the effect of T on CR[Zn], ISO 9223 states that CR[Zn] value increases with increasing temperature when the temperature is lower than 10 °C, but it decreases with increasing temperature when the temperature is higher than 10 °C. Those behaviours were not observed in Asian area, the CR[Zn] value has a peak at around 20 °C as shown in Figure 17. The CR[Zn] value increases with increasing rain fall as shown in Figure 19, while the CR[Zn] values are not affected by RH as shown in Figure 18.

For the environment factors - annual Cl^- and SO_2 deposition rates, S and P, respectively -, the CR[Zn] value increases with increasing S as shown in Figure 20, while it is not affected by P as shown in Figure 21.



Key

X site symbol

Y corrosion rate, CR g/m²/y

1 C1 range (ISO 9223 corrosivity category)

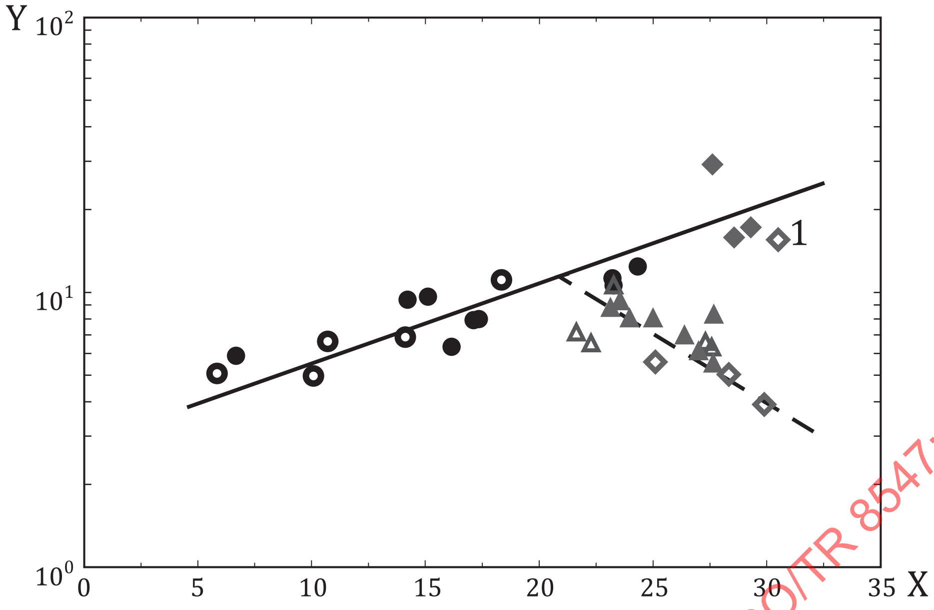
2 C2 range (ISO 9223 corrosivity category)

3 C3 range (ISO 9223 corrosivity category)

4 C4 range (ISO 9223 corrosivity category)

5 C5 range (ISO 9223 corrosivity category)

Figure 16 — Corrosion rate of zinc, CR[Zn], at each site during the exposure period



Key

X temperature °C

Y corrosion rate, CR g/m^2/y

1 Thailand site (Bangkok)

○ Japan site; rural, urban, industrial

● Japan site; coastal, coastal-industrial

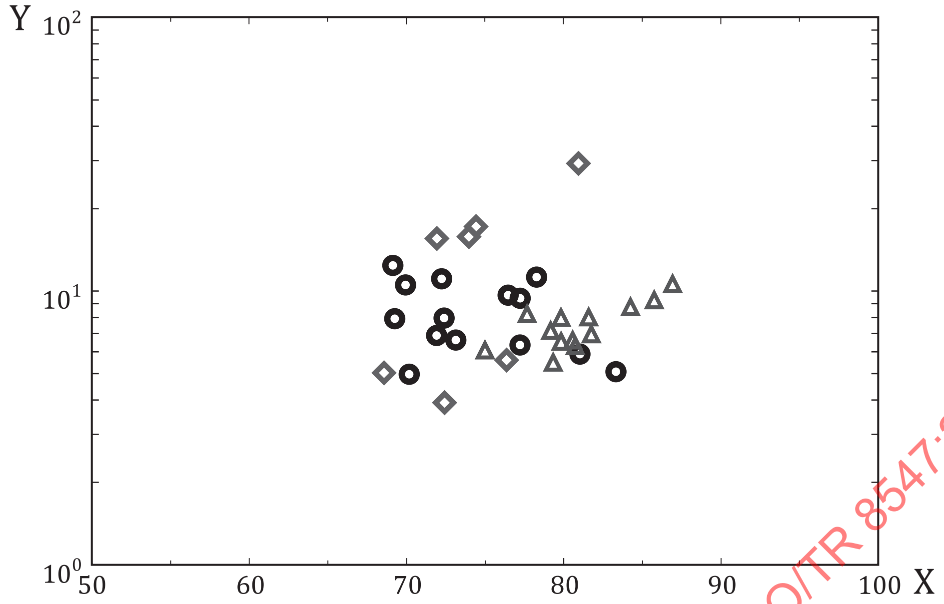
△ Vietnam site; rural, urban, industrial

▲ Vietnam site; coastal, coastal-industrial

◇ Thailand site; rural, urban, industrial

◆ Thailand site; coastal, coastal-industrial

Figure 17 — Effect of temperature, T, on corrosion rate of zinc, CR[Zn]



Key

X RH %

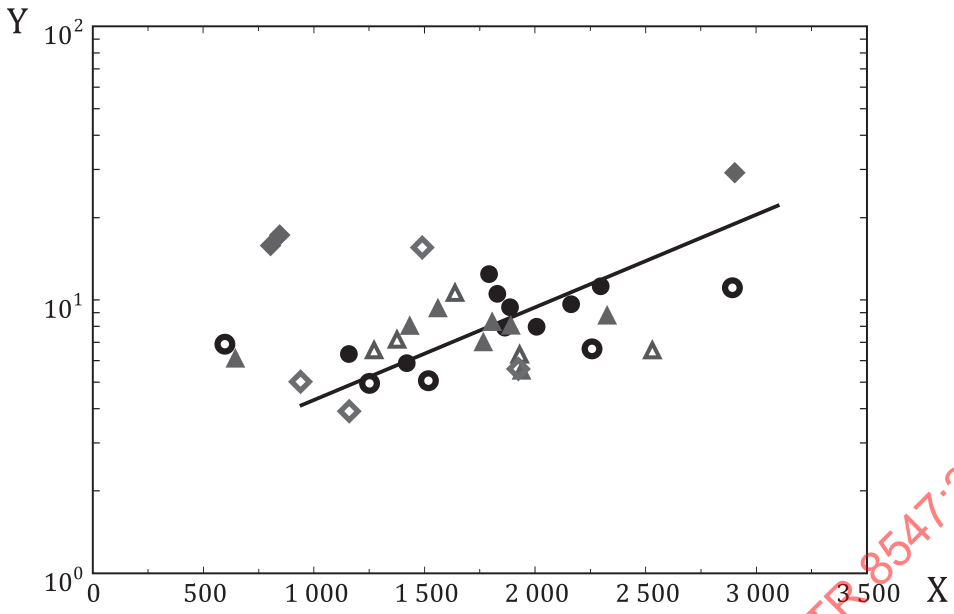
Y corrosion rate, CR g/m²/y

Japan site

Vietnam site

Thailand site

Figure 18 — Effect of relative humidity, RH, on corrosion rate of zinc, CR[Zn]



Key

X rain fall mm/y

Y corrosion rate, CR g/m^2/y

Japan site; rural, urban, industrial

Japan site; coastal, coastal-industrial

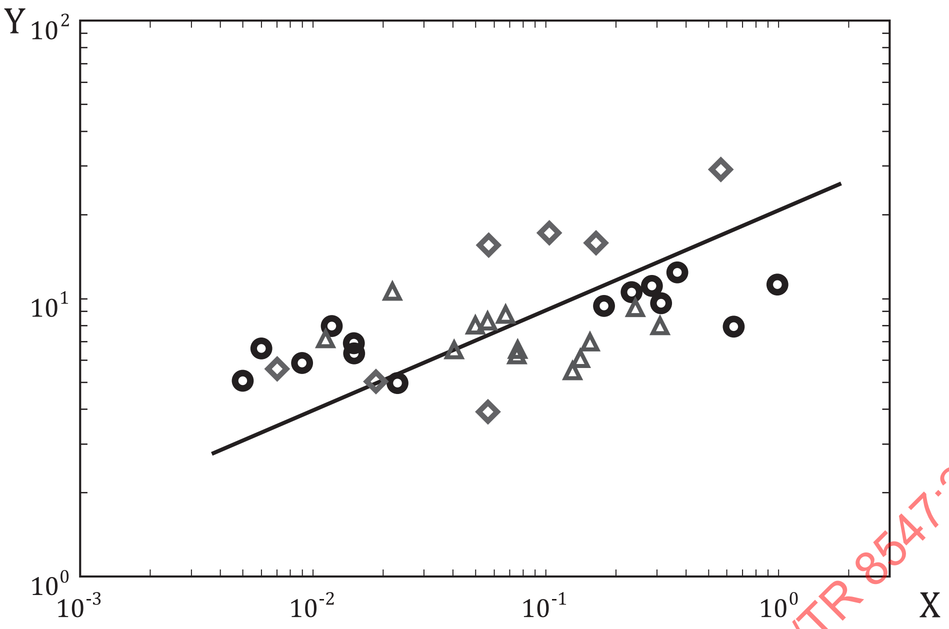
Vietnam site; rural, urban, industrial

Vietnam site; coastal, coastal-industrial

Thailand site; rural, urban, industrial

Thailand site; coastal, coastal-industrial

Figure 19 — Effect of rain fall on corrosion rate of zinc, CR[Zn]



Key

X Cl^- deposition rate, S mg/m^2/day

Y corrosion rate, CR g/m^2/y

○ Japan site

△ Vietnam site

◇ Thailand site

Figure 20 — Effect of annual Cl^- deposition rate, S, on corrosion rate of zinc, CR[Zn]