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





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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 present, 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 are 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.

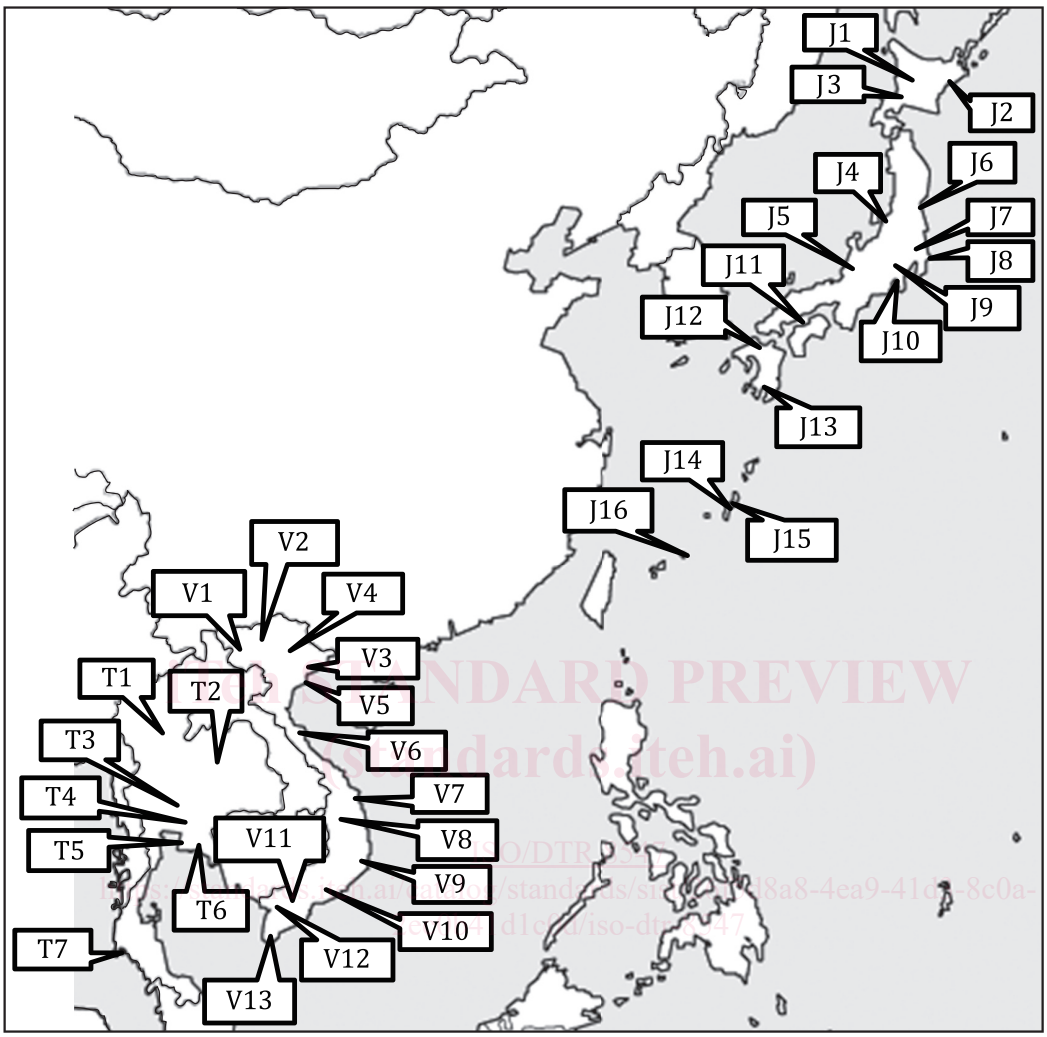
For the environmental factors, monthly amounts of airborne salinity and $SO_2$ were measured by "Dry gauze" and "$PbO_2$ cylinder", respectively, based on JIS Z 2382. The temperature, relative humidity, and ACM sensor output, I, were recorded in a microcomputer every 10 min.

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)

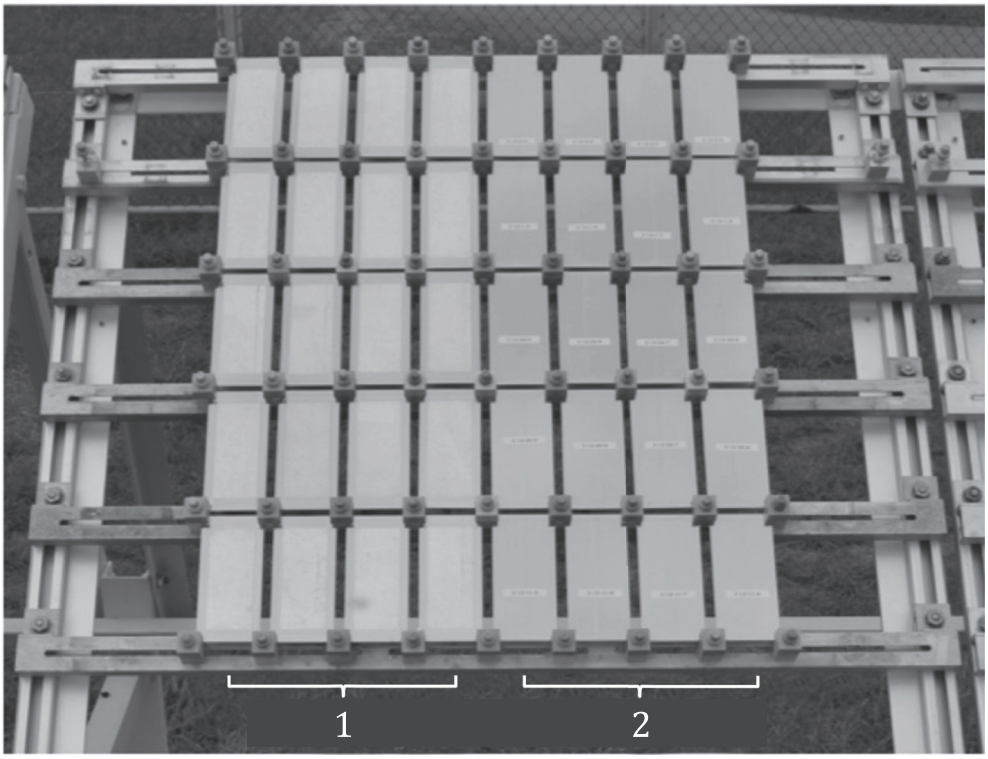
NOTE Some of numerical data are available from data sources given in Annex A.




**Key**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| J1 | Asahikawa | J14 | Nishihara | V1 | Sơn La | T1 | Chaingmai |
| J2 | Akkeshi | J15 | Uruma, | V2 | Yên Bai | T2 | Khon-Kaen |
| J3 | Sapporo | J16 | Miyakojima | V3 | Cua Ong | T3 | Pathumthani |
| J4 | Niigata | | | V4 | Hà Nội | T4 | Bangkok |
| J5 | Fukui | | | V5 | Con Vanh | T5 | Chon Buri |
| J6 | Sendai | | | V6 | Đong Hoi | T6 | Rayong |
| J7 | Tsukuba | | | V7 | Dung Quat | T7 | Phang Nga |
| J8 | Choshi | | | V8 | Pleiku | | |
| J9 | Yamanakako | | | V9 | Phan Rang | | |
| J10 | Shimizu | | | V10 | Bien Hoa | | |
| J11 | Fukuyama | | | V11 | Can Tho | | |
| J12 | Fukuoka | | | V12 | Rach Gia | | |
| J13 | Kagoshima | | | 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]

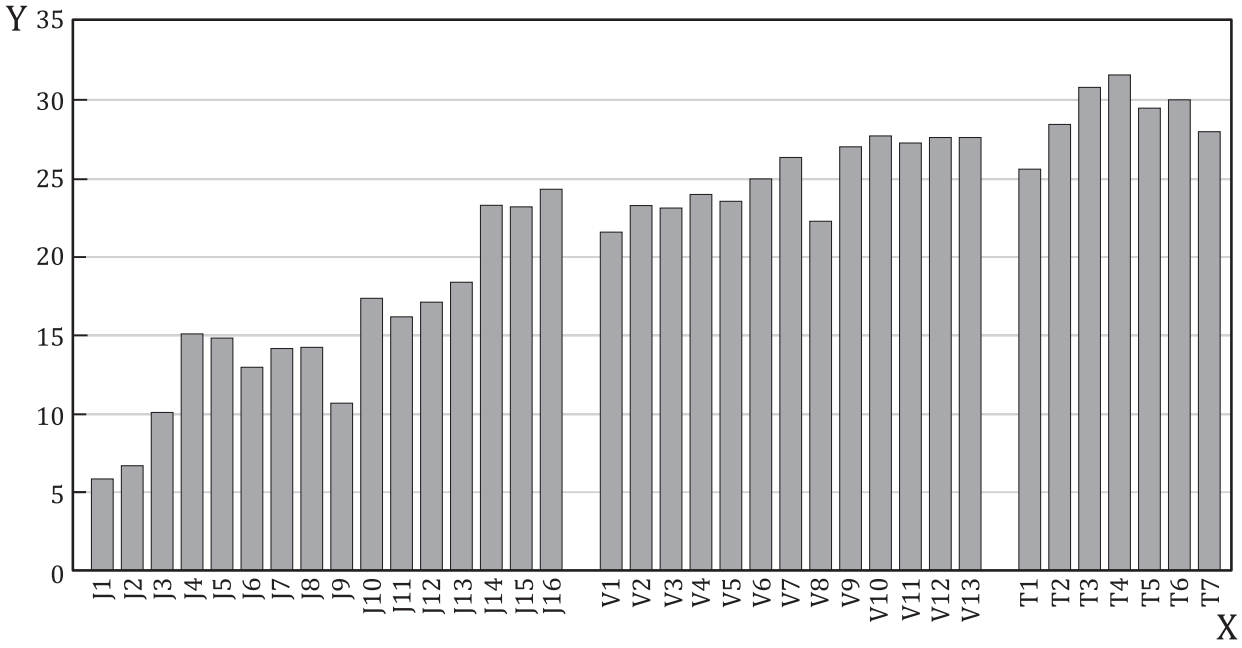
The average temperature, T, at each site is shown in Figure 3. T value increases in the order Japan<Vietnam<Thailand. In Japan, the lowest T values, in the range of approximately 5 °C to 10 °C, can be seen at the test sites in Northern area or in the mountain (Asahikawa, Akkeshi, Sapporo and Yamanakako), the remain test sites have T of about 13 °C to 24 °C. In Vietnam, the average air temperatures are rather high, except the mountain sites (Tam Dao), 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 (Chiengrai) 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, Konken – 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 island, Japan) and Phang Nga (which belongs to 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 Pathumthani.




**Key**

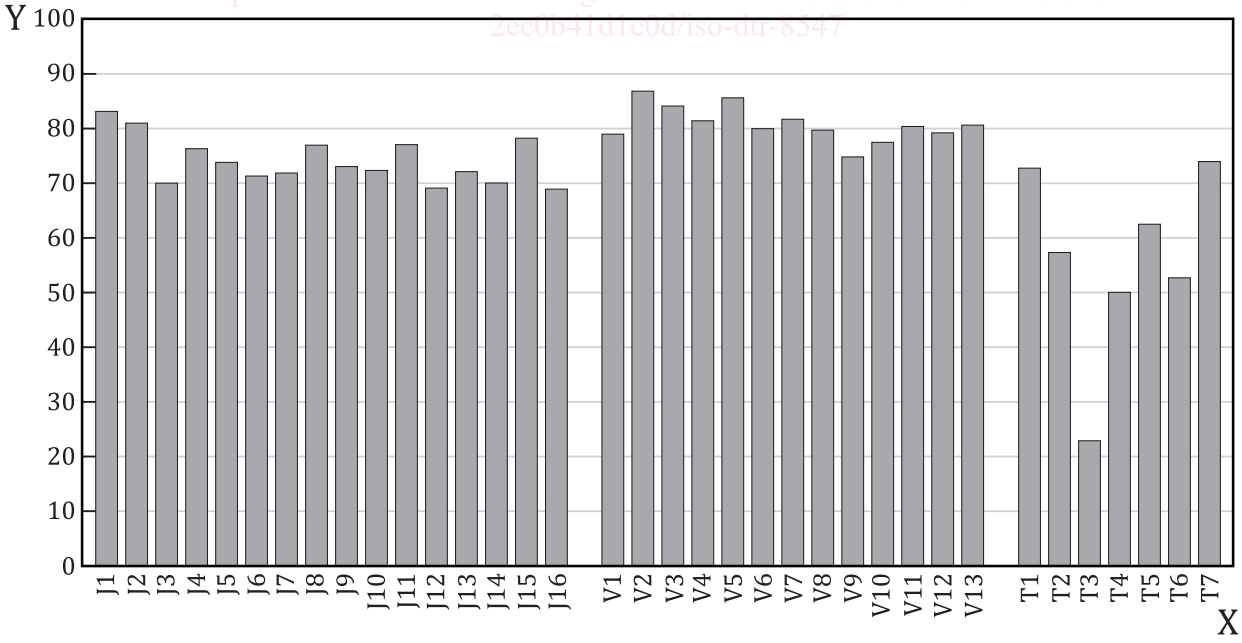
X site symbol

Y temperature °C



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



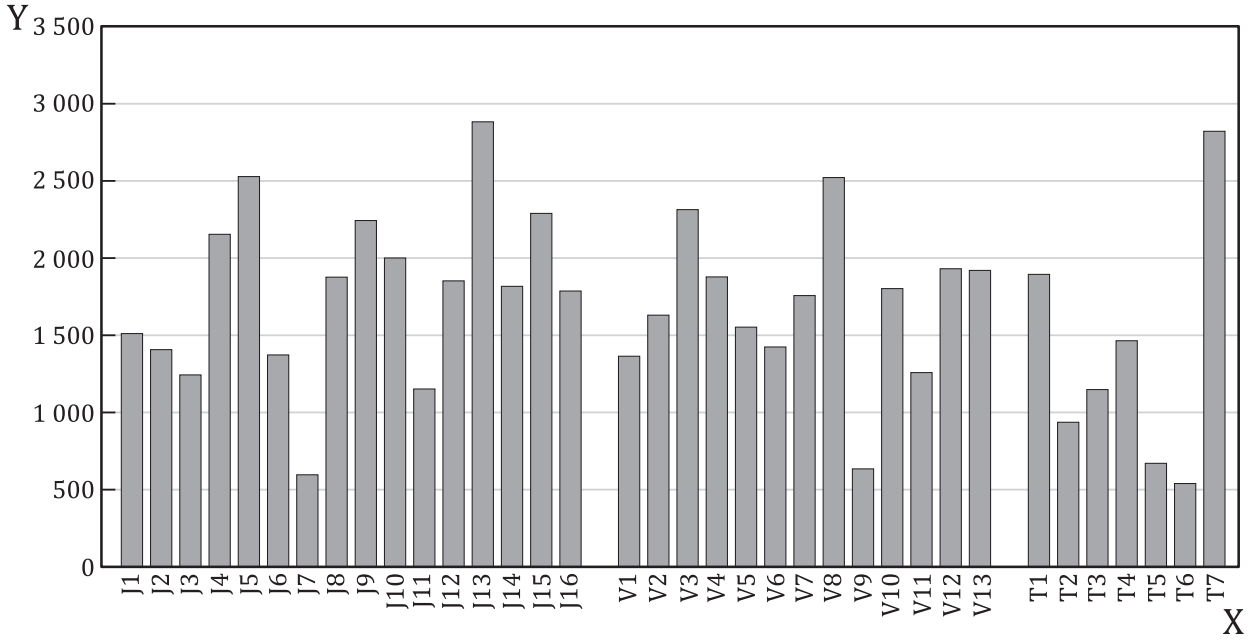



**Key**

X site symbol

Y RH %

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




**Key**

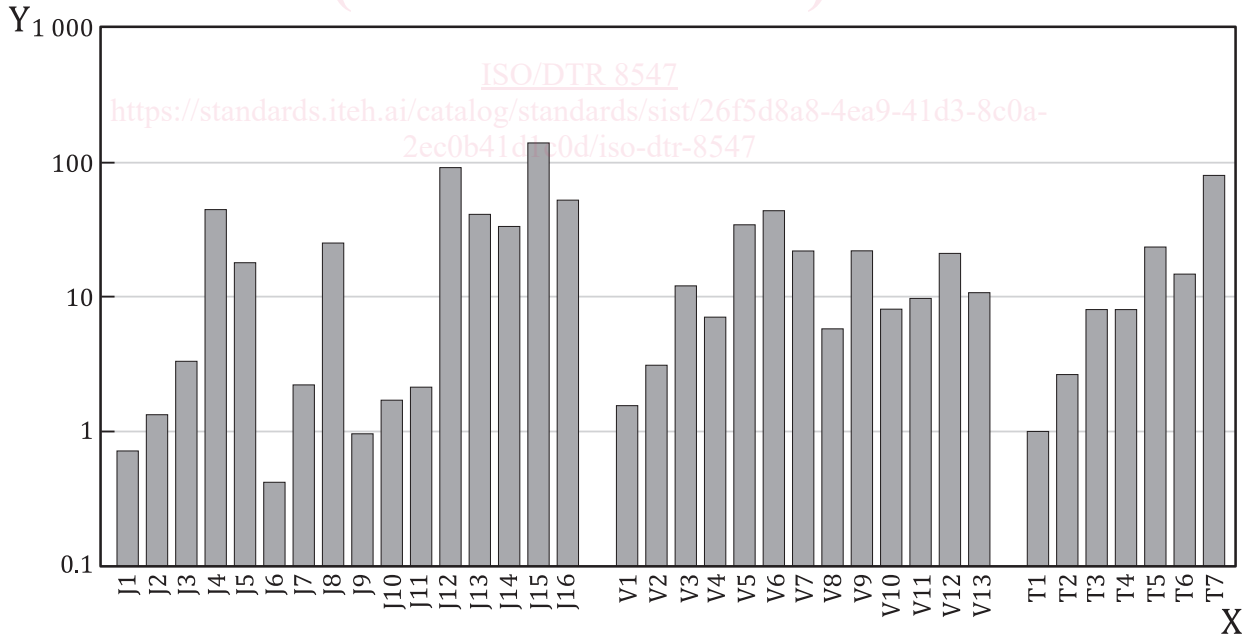
X site symbol

Y rain fall mm/y



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





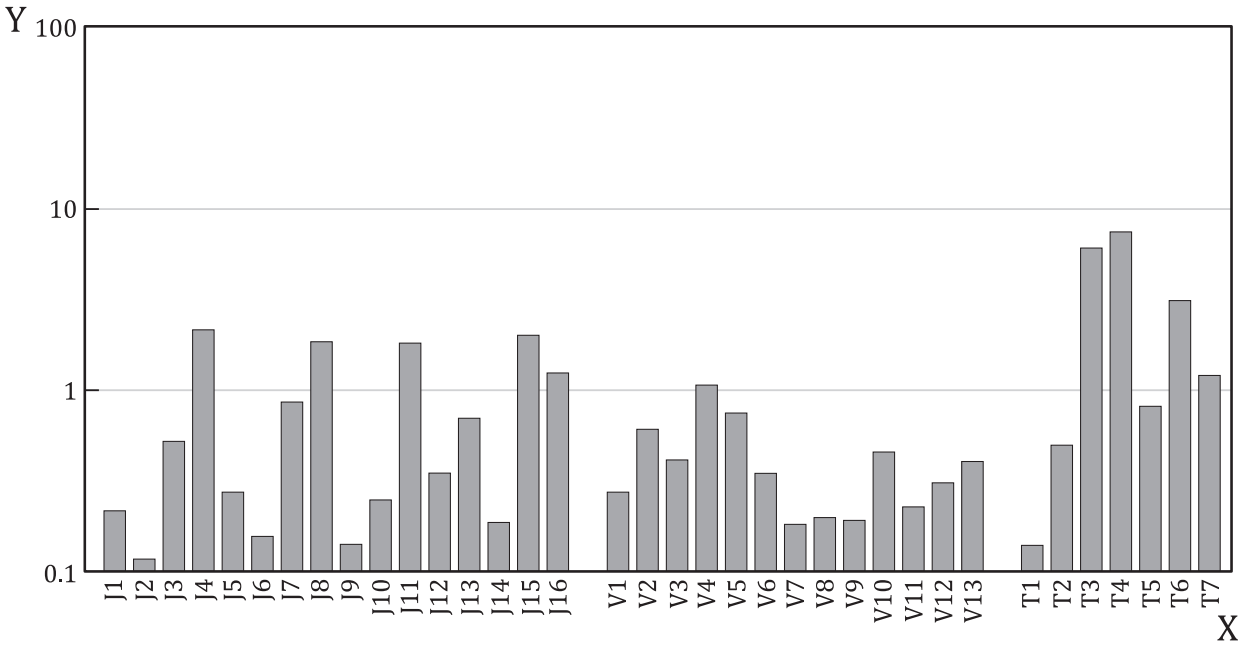



**Key**

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 Phang Nga/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 peek 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.