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# Corrosion of Steel and Zinc in Tropics

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**Abstract**

Mild steel and zinc specimens were tested in five atmospheric testing sites of Vietnam in order to collect the corrosion databank as well as to study the corrosion mechanism in tropical conditions, in period of 1997-2000.

The results obtained showed that the corrosion rate of steel is in the range of 10-50 μm/year and of zinc is of 1-5 μm/year. They are interpretable in the comparison with the data obtained in different countries in the South East Asian as well as previous reports of Vietnamese nation project in atmospheric corrosion. The main factors affecting the corrosion in Vietnam tropical conditions are TOW (time of wetness) and salinity. The relationship between sulfur dioxide and corrosion of metals, particularly, zinc was not found clearly. An explanation was suggested about the complex effect of different pieces present in tropical atmosphere and about the alternative of the dominant factors such as humidity, salinity or temperature.

*Keywords* : *Tropical conditions, Corrosion databank, Corrosion rate, Time of wetness, Sulfur dioxide, Salinity, Durability*

## 1. INTRODUCTION

The durability of materials in atmosphere is one of most important database for industry and building development in each region, because nearly 80% of materials are used in atmospheric conditions. It is also useful reference for investment and exportation of materials and machinery to any preselected region.

Tropical zone with high humidity and temperature has long been considered as a severe environment for corrosion of materials, particularly for the metals. Unfortunately, there are not many corrosion studies on the tropical countries until now and there is no so clear mechanism of metal corrosion on this zone.

A recent five-nation scientific cooperation study program was undertaken by Australia, Indonesia, Thailand, The Philippines and Vietnam to gain a database not only for the industry development of each partner, but also for an understanding of the relationship between pollutants and corrosion of steel and zinc and looking for thereby the corrosion mechanism in tropical zone[1].

## 2. Experimental

In the framework of this program, in period 1997-2000, mild steel and zinc were tested in five sites in Vietnam.

The geographic parameters are formulated in table 1

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Table 1. Testing sites in Vietnam

| Location | Type | Latitude/Longitude | Salient features |
|---|---|---|---|
| Doson | Marine | 20°80'N 108°36'E | On the North beach facing E. |
| Hanoi | Urban | 21°01'N 105°52'E | Small industry, 100km from sea. |
| Hue | Rural | 16°28'N 107°36'E | Rural city, 10 km from sea. |
| Nhatrang | Marine | 12°20'N 109°00'E | On South beach facing E. |
| HohiMinh City | Urban/ industrial | 10°46'N 106°43'E | Medium industrial city, 60 km from sea facing E and 200 km from sea facing W. |

### 2. 1 Testing procedure

Steel and zinc specimens were exposed on the quarterly and yearly basis, with the 45° angle facing to the sea, according to ASTM G1.

Airborne salinity is measured using a standard wet candle technique according to ISO 9223, where NOx, SOx and $HNO_3$ are measured using a passive sampling technique and time of wetness (TOW) is measured using gold grid mounted on zinc specimen. Humidity and temperature are measured by meteorology instruments. All pollutants and climate factors are measured monthly. The relative humidity measured is also transferred into the ISO TOW (The total time with relative humidity more than 80 % and temperature more than 0℃).

All measurements were used as data for computer processing to assess the regression analysis for life-cyclic-prediction of materials, which was performed in DBCE, CSIRO*

### 2. 2 Testing materials

The composition of steel and zinc used in corrosion tests is listed in table 2.

Specimens surface were polished by 1000 SiC grit paper, cleaned by aceton before exposure. The size of steel is 3×100×50 mm and zinc is 1 ×100×150 mm.

Besides mass loss, all exposed specimens (both seasonal and yearly exposures) were examined by Fourier transform infra-red spectroscopy (FTIR) for rust composition determination[2] and surface rust was observed by scanning electron microscopy (SEM)[3].

## 3. RESULTS AND DISCUSION

### 3. 1 Corrsion rate of mild steel

The corrosion rate of steel at exposed sites is listed in table 3, where data are made in each season at the test sites

Data in table 3 and table 5 pronounced that the steel corrosion rate in Vietnam is in the range of 10-50 ㎛/year. Corrosion rate is high in Winter and partly in Spring, because in these seasons, the humidity is very high always reaching nearly up 100%. Hue is a region where there are many drizzles and lasting rain stretching day-to-day, nearly whole Winter and

Table 2. Composition of tested materials (%w)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Zinc | Cu 0.064 | Ti 0.006 | Fe 0.003 | Cd 0.002 | Pb 0.001 | Sn 0.001 | Al <0.001 | Zn remainder |
| Mild steel | C 0.17 | P 0.019 | Si 0.043 | Mn 0.57 | S 0.05 | Cu 0.05 | Cr, Ni 0.02 | Fe remainder |

* DBCE,CSIRO: Division of Building, Construction & Engineering, Commonwealth Scientific and Industrial Research Organization of Australia

Table 3. Corrosion rate of steel in Vietnam (㎛/year)

| Location | Summer | Autumn | Winter | Spring | Annual |
|---|---|---|---|---|---|
| Doson | 20 | – | – | 45 | – |
| Hanoi | 18 | 25 | 35 | 41 | 34 |
| Hue | 10 | – | 56 | 51 | – |
| Nhatrang | 15 | 9 | – | 20 | 39 |
| HohiMinh | 34 | 40 | 45 | – | 22 |

Table 4. Corrosion rate of zinc in Vietnam (㎛/year)

| Location | Summer | Autumn | Winter | Spring | Annual |
|---|---|---|---|---|---|
| Doson | 1.5 | – | – | 4.4 | – |
| Hanoi | 1.9 | 2.4 | 1.0 | 4.1 | 1.3 |
| Hue | 1.6 | – | 5.5 | – | – |
| Nhatrang | 0.62 | 3.2 | – | 5.0 | 2.5 |
| HoChiMinh | 0.8 | 1.7 | 1.1 | 0.8 | 0.9 |

Table 5. Climate factors, $SO_2$ and Salinity in Vietnam sites

| Location | Average relative humidity (%) | Average temperature (℃) | Average $SO_2$ (㎍/m³) | Average salinity (mg/m².day) |
|---|---|---|---|---|
| Doson | 88 | 24 | 0.2 | 18 |
| Hanoi | 89 | 22 | 5 | 10 |
| Hue | 90 | 25 | 0.4 | 15 |
| Nhatrang | 81 | 27 | 0.2 | 25 |
| HoChiMinh | 78 | 28 | 20 | 10 |

Spring. The humidity is always 100%, so the corrosion rate of steel reaches a maximum. Nhatrang has higher salinity than Doson (both are in the beach), but the corrosion rate of steel is similar in two sites. It is suggested that in Doson there is a complexity between high salinity with high humidity. Doson is located in the Red River Delta where by the blocking of Loichau Peninsula and Hainan Island - formed so-called "closed Ocean" - the humidity is higher than in the South - "an opened Ocean". HoChiMinh site with higher sulfur dioxide than in Hanoi, the seasonal corrosion rate of steel is higher, whilst the annual is lower, probably the higher solar radiation together with high temperature strengthen the protective ability of rust layer formed on steel surface during testing period and lower the effect of humidity and sulfur dioxide[4]. In Nhatrang, the effect of salinity is dominate, thereby the protective ability of rust product does not appeared clearly after 1 year testing. Unfortunately, the corrosion rate is continuously increased by the porous and hygroscopic behaviors of the rust layer.

It is assessed that, in the typical tropics, the dominant factor affecting the corrosion of steel is humidity expressed by TOW, in addition, temperature and sulfur dioxide. Solar radiation is also a factor effecting considerably the corrosion of metals. The effect of salinity in dry zone (Nhatrang) is suppressed more than in the wet zone (Doson). The corrosion product in marine environment is very hygroscopic but the higher temperature and lower humidity suppress considerably the effect of airborne salinity.

Published reference[5] indicated that the sulfur dioxide has superior role in the corrosion of steel in industry zone, but it is not found in Vietnam. The sulfur dioxide in an urban industry city as in H℃hiMinh site is about 4 times higher than in Hanoi - an urban city, but the seasonal corrosion rate of steel in HoChiMinh site is slightly higher than in Hanoi, whereas the annual corrosion rate is even lower than in Hanoi.

All data obtained by testing in Vietnam and other countries were used for computer processing and a regression formula for life-cyclic-assessment was drawn as following expression:

Mass loss of steel =

$$\eta\,(\text{salinity} + 1.5\ H^+]_{\text{CONC.}})^{\varepsilon}T^{\Phi}RH^{\gamma}$$

*Where: T is average temperature, RH is relative humidity and $\varepsilon,\Phi,\gamma$ and $\eta$ are the regression constants having the values 0.2, 4.8, 2.6 and 0.041 respectively*

### 3. 2 Corrosion rate of Zinc

Corrosion of zinc in Vietnam conditions showed again that the corrosion rate is high in

Winter and Spring seasons because of higher humidity during the period of a year. No difference of zinc corrosion between Hanoi, Doson and Nhatrang pronounced that the corrosion of zinc is not affected by only salinity, though the presence of chloride compound in corrosion product of zinc was confirmed by FTIR analysis (table 6). It is interesting that the corrosion of zinc in H℃hiMinh City site is lower than that in Hanoi, despite higher sulfur dioxide and the sulfate compounds in corrosion product is detected on specimens tested in H℃hiMinh (table 6).

Table 6. FTIR on zinc of seasonal and annual exposures [1])

| Location | Summer | Autumn | Winter | Spring | Annual |
|---|---|---|---|---|---|
| Hanoi | $CO_3$ | $CO_3$ | $CO_3$ | $SO_4$ | $CO_3$ |
| Hue | | $CO_3$ | $CO_3$ | $CO_3$ | $CO_3$ |
| Nhatrang | | $Cl/CO_3$ | $CO_3/Cl$ | $CO_3/Cl$ | $CO_3$ |
| HoChiMinh | $CO_3/SO_4$ | $CO_3/SO_4$ | $CO_3/SO_4$ | $CO_3/SO_4$ | $CO_3/SO_4$ |

The formula expressing the relationship of corrosion rate (mass loss) of zinc and environment factors in tropical countries obeys the following form:

**Mass liss df zine** $= \delta T^{\alpha} R^{\beta} TOW^{\lambda}$

*Where: T is average temperature, R is average rainfall, TOW is time of wetness and α, β, λ and δ are the regression constants having values 2.8, 0.57, 0.88 and 0.15 respectively.*

1) In the regression formula for life-cyclic-assessment for metals in Vietnam, the variable concerning with sulfur dioxide is absent as suggested frequently in previous publications.

Considering a comparison between corrosion of metals in Vietnam and other Asian Countries[1)], it could be seen that the corrosion rate of both steel and zinc is a slightly higher in Vietnam than in other tropical area, except in the Cowley Beach site of Australia where the salinity is very high. For example, a maximum of steel corrosion rate in Thailand, Philippines, and Indonesia is 40μm/yearμm/year μm/year μm/year, but in Vietnam is 50μm/year; corrosion rate of zinc in Asian is 2μm/year, in Vietnam is 5μm/year. A suggested explanation is based on the geography of Vietnam land. Locating in Indochina's Peninsula facing to East with Pacific Ocean and to the West by Continent with high mountains ranging in the West border, the climate of Vietnam divides clearly onto four seasons with typical tropical-marine-wet and sea-

Table 7. Corrosion rate of steel and zinc in Asian Countries [1]

| Country | Sites | Ave. RH (%) | Ave. temp. (℃) | $SO_2$ μg/m³ | Salinity (mg/m². day) | TOW measured (% time) | Steel mass loss (μm/year) | Zinc mass loss (μm/year) |
|---|---|---|---|---|---|---|---|---|
| Philippines | Bagiou | 86 | 22 | 2 | 3 | 94 | 13.0 | 2.1 |
| | Bicatun | 78 | 27 | 21 | 6 | 39 | 37.1 | 1.1 |
| | Cabuyao | 75 | 27 | 14 | 6 | 65 | 41.3 | 1.8 |
| Thailand | Phrapradaeng | 73 | 30 | 68 | 6 | 61 | 40.1 | 1.5 |
| | Rayong | 70 | 30 | 15 | 23 | 74 | 24.9 | 2.6 |
| | Phuket | 77 | 30 | 4 | 87 | 67 | 30.9 | 1.9 |
| | Bangkok | 70 | 29 | 21 | 6 | 34 | 18.0 | 1.2 |
| Australia | Cowley Beach | 80 | 25 | 0.8 | 400 | 94 | 285.5 | 7.6 |
| | | | | 0.5 | | | | |
| | Walkamin | 70 | 21 | | 8 | 53 | 6.8 | 0.4 |
| Indonesia | Lambang | 77 | 22 | 4 | 11 | 49 | 6.4 | 0.9 |
| | Jebus | 85 | 27 | 1 | 79 | 65 | 37.0 | 2.0 |
| | Mentok | 81 | 28 | 50 | 39 | 70 | 40.1 | 2.7 |
| | Gresik | 74 | 29 | 25 | 24 | 64 | 30.3 | 2.5 |
| | Cikampek | 73 | 28 | 19 | 25 | 99 | 28.6 | 2.4 |

sonal East-South windy. Vietnam has long coastline (3200 km) enclosed East and South part of the land, so the effect of salinity from the seawater is rather dominant. Consequently, Vietnam has a lot of drizzles, which last rains. It is quite different to other countries in Asian, including Thailand located on the same latitude. This is also a reason why the corrosion rate in HoChiMinh City site is higher than in Bangkok.

## 4. CONCLUSION

1) In tropical conditions of Vietnam, the corrosion rate of mild steel is about 10-50㎛/year and that of zinc is about 1-5㎛/year.

2) The corrosion rate of metals in Vietnam pronounces a little higher than in others tropical Countries. The reasons for high corrosion rate in Vietnam can be produced by high humidity, salinity and complicated interaction of different climatic factors.

3) In the regression formula for life-cyclic-assessment for metals in Vietnam, the variable concerning with the sulfur dioxide is absent do not agree with suggestions in previous publications.

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