Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

THE CORROSION BEHAVIOR OF WEATHERING STEEL UNDER DIFFERENT CORROSIVE ENVIRONMENTS

TAKAHIRO UTSUMI and TOSHIHIKO ASO

Dept of Civil and Environmental Engineering, Yamaguchi University, Ube, Japan

Weathering steel is a kind of steel that can reduce the corrosion rate by generating a dense protective rust on the steel surface that exerts anti-corrosion performance. Exposure tests of weathering steel with saltwater spraying were performed under three different conditions. When the consistency of sodium chloride solutions was small (0.5% and 1.0%), the effect of rain rinse was observed. However, large consistencies of sodium chloride solutions provided small differences in rust thickness between open air and under roof conditions. From the results of iron transfer resistance measurements, it was observed that protective rust was generated only in a few cases. This result indicated that generation of protective rust was strongly dependent on the corrosive environment. From the results of exposure tests, it became clear that the change of rust thickness with time can be estimated as an exponential function. The constants in the exponential function can be expressed as a function of consistency of sodium chloride solutions.

Keywords: Weathering steel, Rust, Corrosion, Exposure test, Corrosive environment.

1 INTRODUCTION

Weathering steel is a steel that can reduce the corrosion rate by generating a dense protective rust on the steel surface that exerts anti-corrosion performance. Thus weathering steel could provide corrosion protection performance without having a painted layer. Due to these advantages in maintenance cost, the number of weathering steel bridges has increased in Japan. However, in some cases, very severe surface corrosion which can reduce load-bearing capacity has been observed (JSSC 2006, JSSC 2009). To avoid severe corrosion, it is important to evaluate the relationships between the rusting process of weathering steel and the corrosion environment.

This paper aims to clarify the corrosion behavior of weathering steels under several corrosive environments. Exposure tests of weathering steel with saltwater spraying were performed under three different conditions. In each exposure test, five kinds of consistency of saltwater were used. During exposure tests, rust thickness and iron transfer resistance were measured. From the results of exposure tests, this paper indicates the possibility that the corrosion process of weathering steel under salinity environment could be modeled by exponential function.

2 EXPOSURE TEST

Exposure tests were started from August 1, 2013. In this research, accelerated exposure tests were performed with 70 mm x 150 mm x 9 mm specimens of weathering steel. Three conditions of exposure tests were prepared as shown in Fig 1. Case 1 is in a boxed condition; this case aims to not only keep high temperature and humidity but also cut off incoming salt from the sea. Case 2 is an open-air condition, simulating the outside surface of bridge girders such as steel surfaces being rinsed by rain. Case 3 is under roofed conditions, simulating the inside surface of bridge girders in ways that cleaning water does not provide (Takebe *et al.* 2007).

In all conditions, specimens were set horizontally, and sodium chloride solutions were sprayed in once a day. The consistency of sodium chloride solutions were set as 0.5%, 1.0%, 2.0%, and 3.0% respectively. To compare with sodium chloride-sprayed specimens, pure water-sprayed specimens and non-sprayed specimens were also set in each condition. During the exposure tests, rust thickness and iron transfer resistance were measured in intervals of about ten days.

(a) Case 1 Box

(b) Case 2 Open air

(c) Case 3 Under a roof

Figure 1. Exposure tests in three-cases.

3 TEST RESULTS

3.1 Thickness of Rust

Figure 2 illustrates the growth of average rust thickness until the 181th day. Rust thickness was measured at 10 points on each specimen by an electromagnetic thickness meter. In Figure 2, the average rust thickness was calculated as average value of two specimens. The variation of the average rust thickness of non-sprayed specimen, the 1.0% saltwater-sprayed specimen and the 3.0% saltwater sprayed specimen with time are displayed in Figure 2 (a), Figure 2 (b), and Figure 2 (c), respectively.

As is well known, rust grows rapidly on specimens when sprayed with saltwater. In Figure 2(b), sprayed with 1.0% saltwater, the growth of average rust thickness in open-air conditions (Case 2) was less than that of other conditions. This tendency could be explainable by the fact that the surface of test pieces in Case 2 were washed away by rain. On the other hand, Figure 2 (c) shows no difference in average rust thickness when 3.0% saltwater was sprayed. The rain-rinse effect under 3.0% saltwater sprays is relatively small. From this, it was found that weathering steel is less sensitive to rainfall under high-salinity environment.

3.2 Rust Properties on Weathering Steel in Exposure Tests

Rust properties on weathering steel can be rated by rust thickness and iron-transfer resistance (Kihira 2011). Figure 3 indicates the time history of relationships between rust thickness and iron-transfer resistance until the 181th day. In Figure 3, the meaning of rate I-5 to I-1 are as follows: I-5: initial stage with thin rust; I-4: protective rust; I-3: protective rust under medium severity of corrosion environment; I-2 and I-2’: monitoring rust growth is required; and I-1: anomalous rust caused by severe corrosion.

From Figure 3, it was observed that the iron-transfer resistance increased with time. In the case of a non-sprayed specimen, the relationships between rust thickness and iron-transfer resistance is almost linear. Even after 181 days, rust in non-sprayed specimens is in an initial stage, but the growth is directed towards protective rust (Figure 3 (a)). The provision of salt changes rust properties remarkably; even a low concentration of salt causes a severe corrosion environment. In 0.5% salt-sprayed specimens, these rusts are rated as I-2 at the 181th day. With an increase in the consistency of salt, the rust rate was changed in early days of exposure tests.

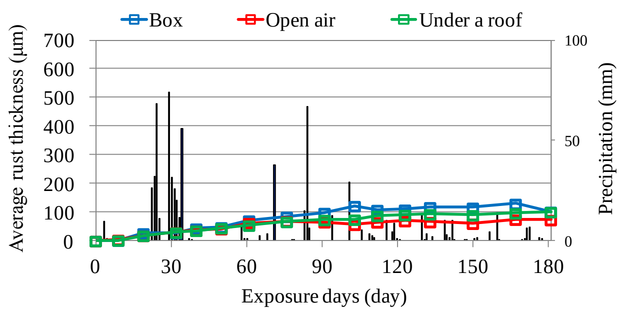
4 CORROSION MODEL

This paper also aims to establish a corrosion model to quantitatively evaluate a corrosion process of weathering steel. From the results of exposure tests, it became clear that the relationships between rust thickness and exposure duration can be assumed by using an exponential function. For example, Figure 4 displays the relationships between rust thickness and exposure days for a 3.0% salt-sprayed specimen. In this figure, the solid line is an approximated curve formed by Equation (1). It shows good agreement to the observed thickness.

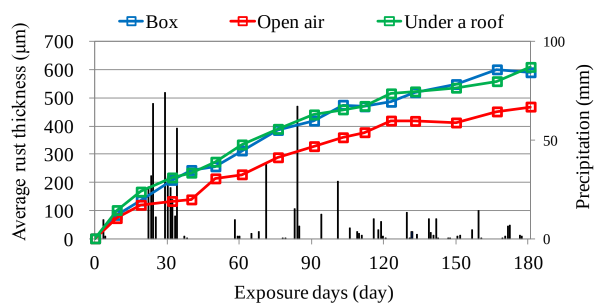
$$Y=AX^{B} \tag{1}$$

where, Y = rust thickness, X = exposure days, A and B = constants.

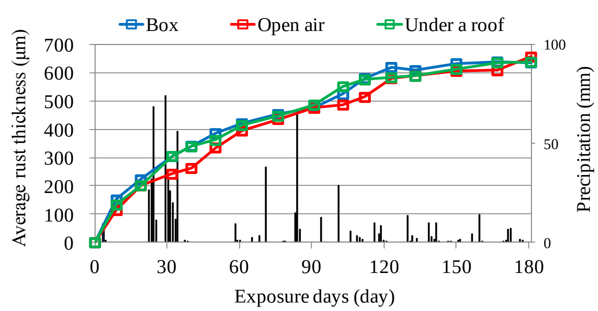
Figure 5 indicates the coefficients of determination of approximation as mentioned above for all exposure tests. Coefficients of determination of saltwater-sprayed specimens are relatively higher than non-sprayed and pure-water-sprayed specimens.



(a) Non-sprayed specimen



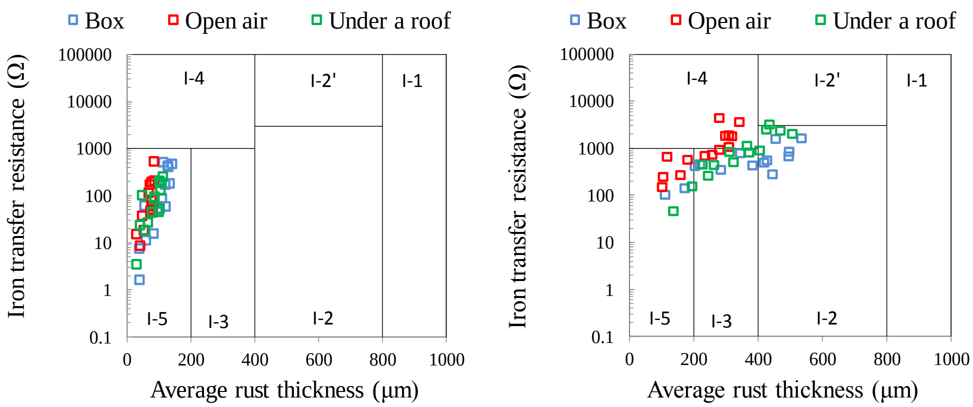
(b) 1.0% salt-sprayed specimen



(c) 3.0% salt-sprayed specimen

Figure 2. Variation of average rust thickness with time.

From Figure 5, it can be evaluated that the corrosion model of weathering steel under saltwater spray is established by Equation (1). The relationship between the saltwater concentration and constants A and B obtained by approximation are shown in Figure 6. Constant A shows a linearly-increasing trend when the saltwater concentration is high. However, constant B is almost always constant regardless of the salt concentration. Table 1 shows the equations for constant A and constant B under various conditions.



(a) Non-sprayed specimen (b) 0.5% salt-sprayed specimen

Figure 3. Rust properties evaluation.

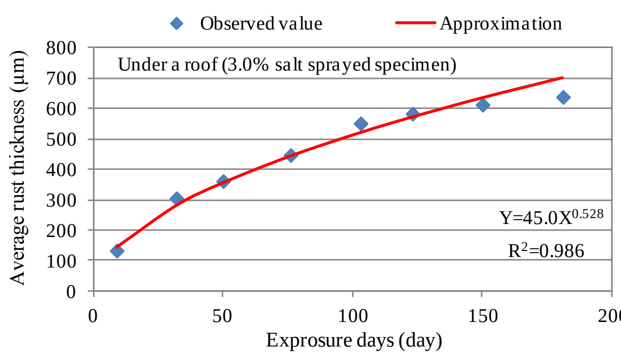


Figure 4. The approximation.

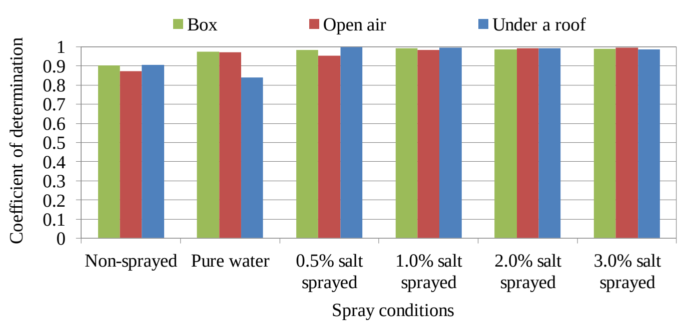
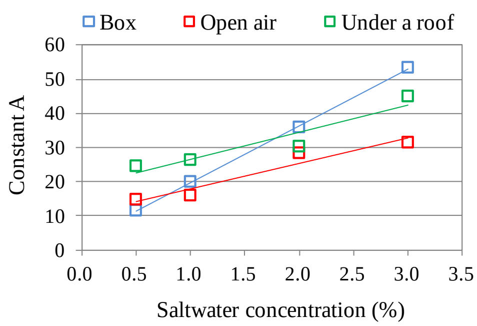


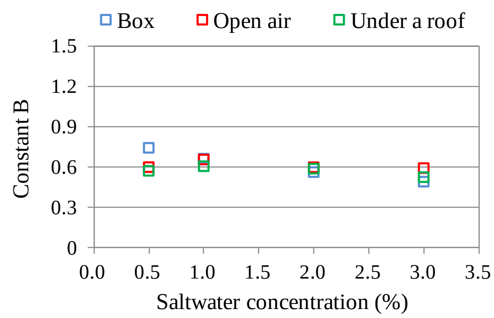
Figure 5. Coefficient of determination.

5 CONCLUSION

Exposure tests of weathering steel with saline water spraying were performed under three different conditions. When the consistency of sodium chloride solutions were small (0.5% and 1.0%), the effect of rain rinse was observed. However, large consistencies of sodium chloride solutions provided small differences in rust thicknesses between open-air and under-roof conditions. From the results of iron-transfer resistance measurements, protective rust was generated only in few cases. It means that the generation of protective rust strongly depended on the corrosive environment. From the results of the exposure tests, it was observed that the change of rust thickness with time could be approximated as an exponential function. The constants in the exponential function can be expressed as a function of the consistency of sodium chloride solutions.



(a) Constant A



(b) Constant B

Figure 6. Relationship between concentration and constants A and B.

Table 1. Estimation formula of constants A and B.

Exposure environment	Constant A	Constant B
Box	A=16.655s+3.1141	0.6182
Open air	A=7.4057s+10.573	0.6149
Under a roof	A=7.8942s+0.5762	0.5762

References

JSSC (Japan Society of Steel Construction), Potentiality of unpainted weathering steel bridges, *Technical Report No. 73*, Japan Society of Steel Construction, Tokyo, 2006. (in Japanese)

JSSC (Japan Society of Steel Construction), Proactive maintenance of weathering steel bridges, *Technical Report No. 86*, Japan Society of Steel Construction, Tokyo, 2009. (in Japanese)

Kihira, M., and Kimura, M., Advancements of weathering steel technologies in Japan, corrosion, *The Journal of Science and Engineering*, 67(9), 095002-1-13, Sep., 2011.

Takebe, M., Ohya, M., Ajiki, S., Furukawa, T., Matsuzaki, Y., and Aso, T., Relationship between corrosion level and composition of accumulating salt on the weathering steel bridges, *Proceedings of International Symposium on EcoTopia Science 2007*, 703-706, Nagoya, 2007.