ACCELERATED EXPOSURE TESTS OF DURABILITY FOR STEEL BRIDGES

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ABSTRACT: Special attention was paid to the environmental effects on uncoated steel plates. Using the accelerated exposure tests, the variation of the weight decrease, the mean of amount of thickness decrease, and the maximum of the amount of thickness decrease due to the corrosion were estimated. It was shown that the variation of weight decrease and the variation of thickness decrease were expressed by involution functions for time. Comparing the results of the exterior exposure tests and those of the accelerated exposure tests, the acceleration coefficients on the corrosion in these two tests were calculated. Correlation analysis between the amount of flying salt and the acceleration coefficients was conducted. The result insisted that the acceleration coefficients were highly correlated to the amount of flying salt and its relationship was able to be expressed by an involution function.

KEYWORDS: accelerated exposure test, steel, acceleration coefficient, corrosion

1. INTRODUCTION

Reducing the lifecycle cost and lifecycle environmental impact of civil engineering infrastructures is one of the significant issues. It is necessary to consider not only high efficiency and low cost toward constructing but also the lifecycle assessment (LCA) including the stages of construction, service and maintenance, and demolition and reconstruction. In order to accomplish this LCA properly, the environmental effects on the infrastructures need to be investigated. However, we tend to rely on the empirical information. One of the practical methods to obtain these characteristics is the exterior exposure test. For example, in Japan, the Ministry of Construction and a few organizations have been carried out the tests to investigate the properties of the atmospheric corrosion resisting steels. Although the exterior exposure test allows field examinations, it takes enormous time and it is difficult to obtain fundamental information since various environmental factors in accordance with the atmospheric condition affect to the test pieces at each test site. For theses reasons, the accelerated exposure tests were employed to obtain the data so as to complement the results of exterior exposure tests. The most of the accelerated exposure tests has been applied so far for the evaluation on new painting methods and new corrosion-prevention methods. The test has not been conducted to evaluate the environmental effects on the durability and the life of steel bridge members, and the fundamental data on the environmental effects to the members are insufficient.

The objectives of this study address the investigations of the environmental effects on the durability of the steel bridge members and the proposal of a LCA strategy including the evaluation of the cost due to the environmental effects. As the first step for these objectives, the accelerated exposure tests for the uncoated steel plates are carried out. The growth of the rust is observed consecutively and the time histories of the weight / thickness reduction of the steel plates due to the rust are investigated. Additionally, the results of the accelerated exposure tests are compared with those of the exterior

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exposure tests, and the relationship between these two tests is clarified. A formula to predict the steel member corrosion due to flying salt is proposed.

2. METHOD OF EXPERIMENT

2.1 EQUIPMENT OF EXPERIMENT

Combined Cyclic Corrosion Test Instrument made by SUGA TEST INSTRUMENTS Co.,Ltd., shown in Figure 1 was used in the research. This equipment can operate automatically the condition of atomizing of salt water, temperature and humidity in arbitrary order and combination. This equipment has a rectangular space 2,000 mm long, 1,000 mm wide and 500 mm high in where test pieces is arranged. 188 test pieces of 70 mm wide, 9 mm thick and 150 mm long can be arranged in maximum.

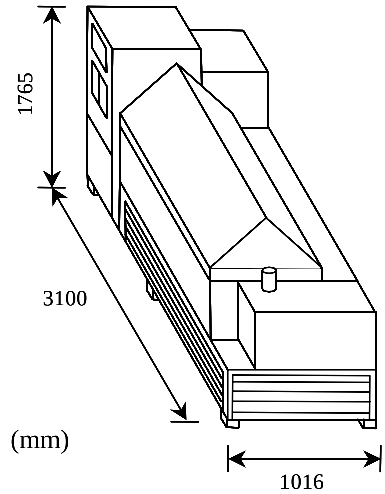

Figure 1. Combined Cyclic Corrosion Test Instrument

2.2 TEST PIECES

15 blast furnace steels and 15 electric steels standardized by Japan Industrial Standard (JIS) and called SM490 (yield stress of 325 MPa) were choosen as test pieces of the experiment. These surface treatment of each steels were carried out with No.50 grid blast called S-G50 in JIS. The size of these pieces were 70 mm wide, 9 mm thick and 150 mm long.

2.3 CONDITION OF ENVIRONMENT CYCLES

Condition of environment cycles adopted in the experiment is shown in Figure 2, which is called S6-cycle. The experiment was carried out for 600 cycles (about 150 days). The S6-cycle was proposed by the Ministry of International Trade and Industry and was specified in JIS. The past research for painted steels concluded that the result of the accelerated exposure test under this cycle was highly correlated to exterior exposure tests. Although the test pieces in this test were uncoated, the S6-cycle was used since the appropriate cycle for the uncoated steels has not been found.

atomizing of salt water (5 % density)	→	wetting	→	drying with hot wind	→	drying with warm wind
30 ± 2 °C		30 ± 2 °C		50 ± 2 °C		30 ± 2 °C
98 %		95 %		20 %		20 %
0.5 hr		1.5 hr		2.0 hr		2.0 hr

1 cycle

Figure 2. Condition of environment cycles

2.4 PREPARATION FOR MEASUREMENT

In the research, 3 test pieces were taken out from the test instrument every 120 cycles (about 30 days), and the rust was removed by boiling with ammonium citric acid and thiourea. The weight and the thickness of test pieces were measured.

3. RESULTS OF EXPERIMENT

3.1 WEIGHT DECREASE

Mean weight decrease of each 3 blast furnace steels and that of each 3 electric steels are shown in Figure 3 respectively. The relation between the weight decrease by corrosion and time is expressed with Eq. (1).

$$P = k\,t^{\,n} \qquad (1)$$

Where, P is the weight decrease (kg/m^2), t is time (year) and k, n are constant.

The cycle number n_c is used instead of t in this study, and the relation between the weight decrease w_d, and n_c is shown in Figure 3. The constants in Eq. (1) were obtained with the least-squares method, and the R in Figure 3 is a correalation coefficient. Due to the corrosion, the weight of the test pieces decreased as increase of the cycle, and the gradient of the weight-decrease curve tended to be small. The weight decrease of electric steels at each cycles is 2-8 % larger than that of blast furnace steels approximately. It is thought that the difference is enough small to be negligible.

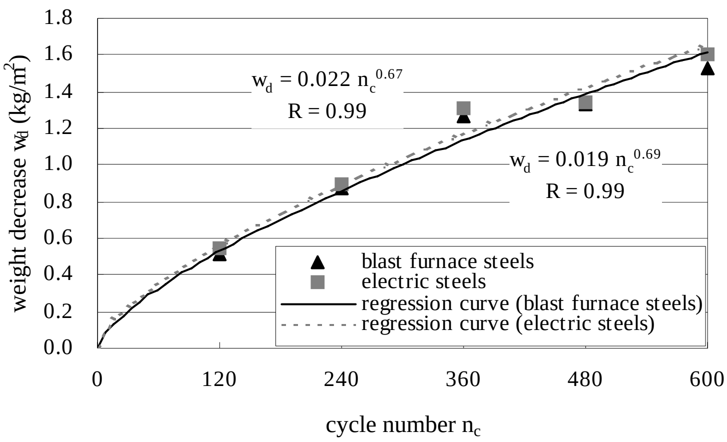

Figure 3. Mean weight decrease

3.2 THICKNESS DECREASE

The mian thickness decrease was calculated with (the weight decrease) / (density of the steel) / (surface area of the test piece), assuming that the distribution of the rust was uniform. This method had been adopted by the Ministry of Construction and used to evaluate the results of the exterior exposure tests. For comparison, using the micrometer, the thickness decrease of the test pieces was measured directly. The thickness decrease t_d obtained with these two method is shown in Figure 4. The blank circle denotes “equivalent thickness decrease” calculated from the weight decrease and the filled circle is the thickness decrease obtained with the direct measurement. The both results almost agreed. The regression curves are also illustrated in Figure 4. Similarly to the case of the weight decrease, the data were well fitted with the involution function on n_c.

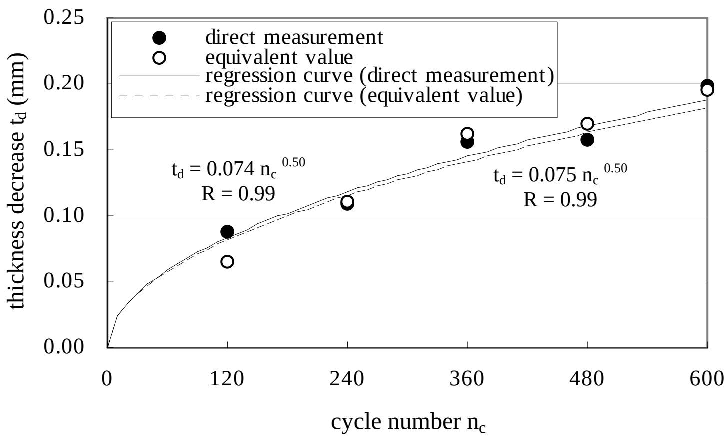

Figure 4. Mean thickness decrease

3.3 MAXIMUM DEPTH OF CORROSION PIT

Laser forcus measuring instrument of depth, that minimum measuring is 0.1 μm, was used to measure depth of one surface of test pieces. It was measured for blast furnace steels with 100 μm interval and the maximum depth of corrosion pit was obtained.

Figure 5 is the three-dimensional graph showing the depth around the central area on the surface of a test piece. On the other hand, in Figure 6, the maximum depth is plotted with the axis of the cycle

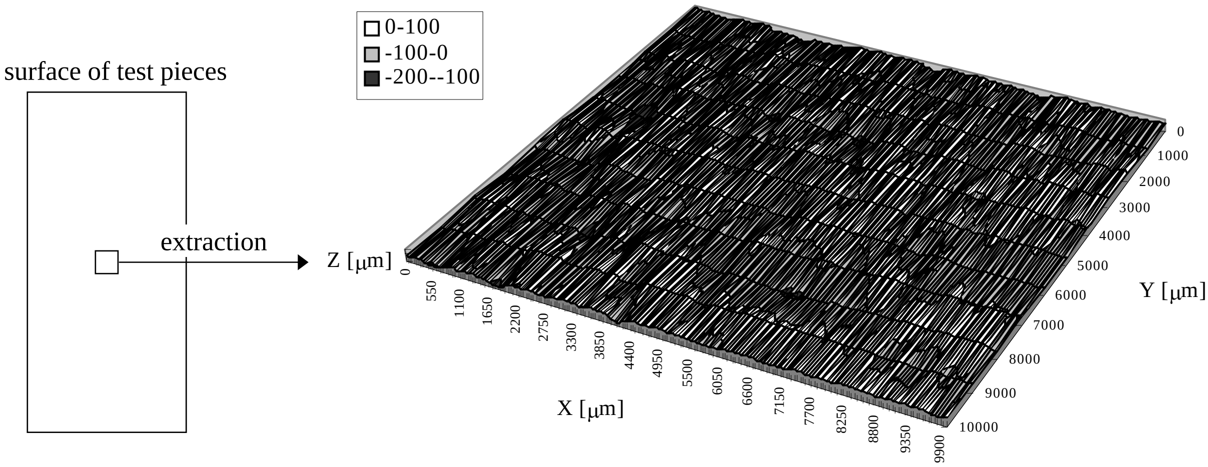

Figure 5. Measurement result with laser forcus measuring instrument of depth

number, and the standard deviation S is also configured. Although the maximum depth as well as the standard deviation tended to increase in accordance with the cycle number, the tests at much more cycle number are required to obtain the clear relation.

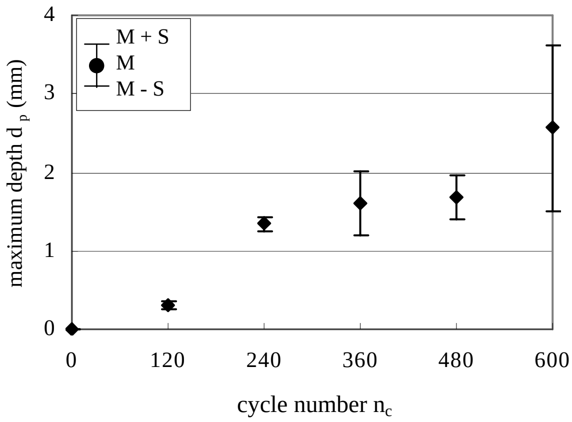

Figure 6. Mean maximum depth

3.4 ACCELERATION COEFFICIENT

The Ministry of Construction carried out the exterior exposure tests of steels as well as the investigation of the amount of flying salt at 41 sites in Japan. Results of 31 tests for 9 years and results of the accelerated exposure tests for 600 cycles (about 5 months) were compared, and the acceleration coefficient A_c was calculated. The acceleration coefficient was obtained with (time scale of exterior exposure test) / (time scale of accelerated exposure test) as shown in Figure 7, and is the parameter for connecting the results of the accelerated exposure test to the phenomena at the sites of the exterior exposure test. The results of accelerated exposure tests and exterior exposure tests on the seaside area in Kinki region are shown in Figure 8, and A_c was obtained as 55. The calculated acceleration coefficients were 6 to 75 on the seaside area, 70 to 178 on the urban/rural area, and 53 to

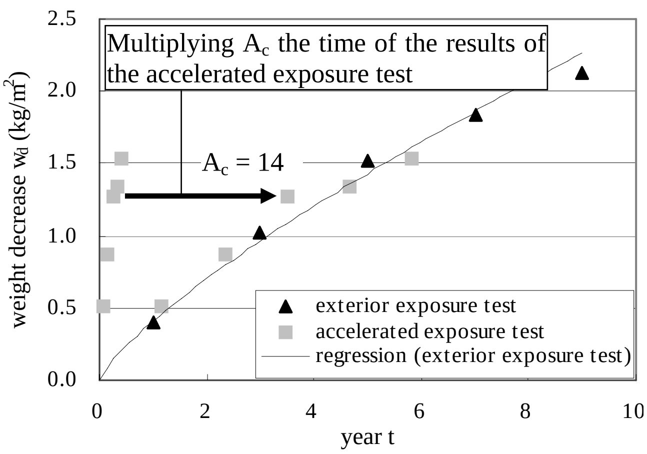

Figure 7. Method of calculating (Shikoku region, the seaside area)

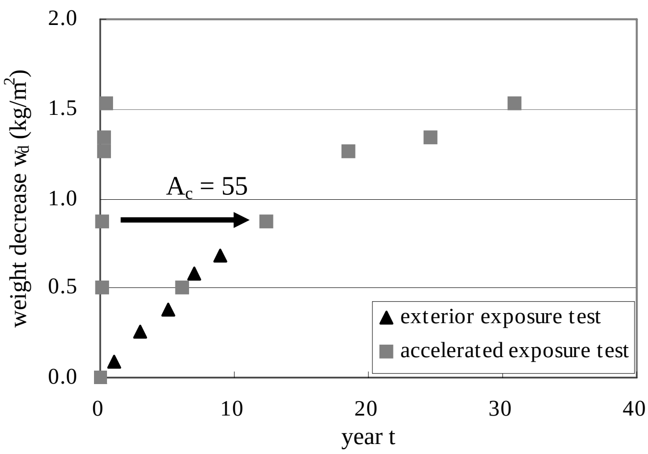

Figure 8. A_c in the case for Kinki region, the seaside area.

189 on the mountainous area. These results mean that the acceleration coefficient does not always depend on the regional characteristics.

3.5 CORROSION INFLUENCE FACTOR AND ACCELERATION COEFFICIENT

The relation between distance from the shoreline to the exterior test site and the acceleration coefficient is shown in Figure 9. The coefficients within 5 km seemed to be correlated to the distance. However, in the field over 5 km away, the acceleration coefficients showed large difference even at same distance and no tendency was obtained.

On the other hand, the relation between the amount of flying salt w_s and the acceleration coefficient is shown in Figure 10. Solid line is a regression curve of acceleration coefficient with the involution function.

$$A_c = 9.14\ w_s^{-0.62} \qquad (2)$$

Where, w_s is the amount of flying salt (mg/dm^2/day, mdd), and A_c is the acceleration coefficient.

Dotted line is an envelope curve with the standard deviation S. The correlation coefficient R was 0.88, thus the relation between the amount of flying salt and the acceleration coefficient can be expressed as Eq. (2).

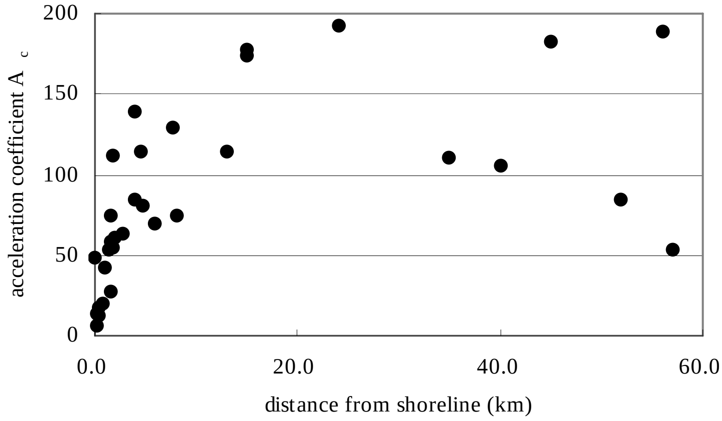

Figure 9. Relation between distance from shoreline and acceleration coefficient

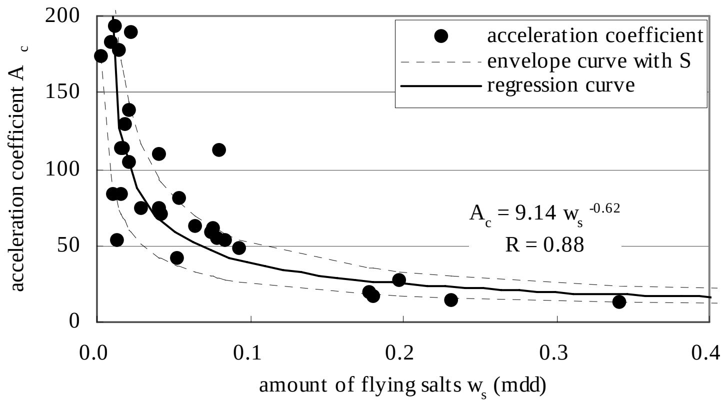

Figure 10. Relation between the amount of flying salt and acceleration coefficient

3.6 PRESUMPTION OF AMOUNT OF THICKNESS DECREASE

Using the equation $t_d = 0.0074 \times n_c^{\ 0.50}$ shown in Figure 4 and Eq. (2), the following equation was obtained:

$$t_d = 0.094 \times (\ w_s^{\ 0.62} \times t\ )^{0.50} \qquad (3)$$

where t_d is the amount of thickness of steels decrease (mm). Eq. (3) enables the prediction of the mean thickness decrease due to the flying salt. In the accelerated exposure test, the test pieces were mounted vertically in the experiment instrument, thereby Eq. (3) can be applied to only vertically placed members of bridges. Also, as mentioned in section 3.2 it is assumed that the distribution of the rust is uniform.

4. CONCLUSIONS

The accelerated exposure tests were carried out to clarify the environmental effects on corrosion growth of steels, and the results were compared with the exterior exposure tests. The followings are main conclusions in this study.

(1) The amount of the weight decrease became large monotonously and the decrease could be

expressed with the involution function.

(2) The difference between characteristics of blast furnace steels and electric steels for corrosion was examined with the experiment, and the weight decrease of electric steels was a little bit larger than that of blast furnace steels.

(3) The correlation between distance from a shoreline and the acceleration coefficient, and the correlation between the amount of flying salt and the acceleration coefficient was examined. While it was difficult to find clear consistency between the coefficients and the distance from shoreline, the coefficients were highly correlated to the amount of flying salt.

(4) Mean thickness decrease due to flying salt for verticaly placed steels could be predicted with Eq. (3).

The experiment in the research was carried out for uncoated steels, thus results about the accleration coefficient or presumption of the amount of thickness decrease of steels can be used in limited conditions. Experiments for coated steels or couplings are required.

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