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DURABILITY PREDICTION OF STEEL BRIDGE PAINTINGS WITH INITIAL DEFECTS

In-Tae KIM[1], Yoshito ITOH[2] and Jin-Hwan CHEUNG[3]

ABSTRACT: This study examined accelerated cyclic corrosion tests on three types of painting systems for steel bridges, which are called as A-painting system for mild conditions and C- and I-painting systems for severe corrosive condition in Japan, and presented corrosion-degradation of the painted steels with initial defects. According to painting systems, structural steel plates were surface-treated and multilayer-painted. After finishing painting process, scribed circles reaching the steel substrate were made mechanically in the painting layers, in order to introduce initial defects with 0.2, 1.0, and 2.0 mm diameters. The test specimens were exposure into an environment chamber, which was controlled by the combined cyclic corrosion test condition conforming to the S6-cycle test condition (Japanese Industrial Standards (JIS) K5621) during 600 days. From the results of periodic visual inspections, change in appearance of the test specimen surfaces and rust propagation from the initial defects with passage of testing time were discussed.

KEYWORDS: Steel bridge, Painting, Corrosion-degradation, Accelerated corrosion test, Rust propagation

1. INTRODUCTION

Painting has been widely used to prevent corrosion attacks, to maintain the functional ability and to keep good appearance of steel bridges. Sound paintings protect the steel substrate and limit ingress of water and oxygen. When the paintings age and degrade, the rate of infiltration increase, and eventually the performance is degraded exponentially.

The performance of steel bridge paintings were often examined by bridge inspection, and the aged degree of painted members was ranked by using the coating manual or the standard test methods, such as JH [2], JSSC [3], JIS [4], JRA [5] and ASTM [6]. For example, degradation grade of the current paintings can be evaluated by comparing it with the visual examples depicting the rusting area percentage in the standards [4] - [6]. Field exposure test at a known site is a method for performance assessment of bridge paintings. Measuring glossiness, tensile adhesion or rust rate on painted specimens in long-term exposure time gives a degradation plot for them [7], [8]. Although the bridge inspection and the exposure tests allow field examinations, it takes long time to obtain any degradation data of the paintings. It is difficult to evaluate the remaining lifetime of bridge coating systems at the stage of the bridge inspection and the performance of newly developed painting systems in a short time. This can give rise that maintenance requirements tend to become urgent and are usually constrained by an inadequately prepared budget.

[1] *Assistant Professor, Pusan National University, Korea*
[2] *Professor, Nagoya University, Japan*
[3] *Professor, Pusan National University, Korea*

In this study accelerated exposure tests, which is employed to obtain the fundamental data for corrosion behavior in a short time and to complement the data of the field exposure tests, were carried out on five types of steel bridge paintings. Based on the rusting area from the initial defects on the painted specimens, corrosion degradation is discussed. The application of the proposed degradation curves to remaining lifetime evaluation is also presented.

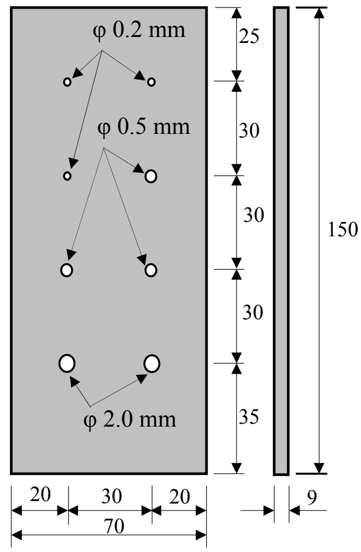


Figure 1. Test specimen (mm)

2. TEST PROCEDURE

2.1 TEST SPECIMENS

Figure 1 illustrates the geometry and dimensions of the test specimen used in this study. The steel plates of 150 mm long, 70 mm wide and 9 mm thick were cut from Japan Industrial Standards (JIS) SM490A structural steels [9]. The steel plates were grit-blasted by No.50 grit specified in JIS S-G50 or surface-treated by a power tool machine, which is a common surface treatment prior to steel bridge painting in Japan. And the steel plates were coated with five types of painting systems, which are named A-painting system applied for mild condition and C- and I- painting systems for severe corrosive condition in Japan [4]. For recently developed I-painting systems three types with different top coats was prepared, and was named I1-, I2- and I3-painting systems in this study. The coating materials and process are listed in Table 1.

As shown in Figure 1, circular defects of 0.2 mm, 1.0 mm and 2.0 mm diameters reaching the steel substrate were created in the each painted specimen with an automatic milling machine. In the following φ 0.2 mm, φ 1.0 mm and φ 2.0 mm defects is named D-0.2, D-1.0 and D-2.0 defects, respectively. Total eight circular defects, three D-0.2, three D-1.0 and two D-2.0 defects, were introduced into each test specimen. Two specimens for each painting systems were prepared. Two A-painted specimens without the defects were also prepared for comparison.

Table 1. Coating systems used in this study

Test specimens	Painting process	Treatment and material	Designed film thickness (μm)
A-painted steel	Surface preparation 1st /2nd Undercoat Intermediate/Top coat	Power tool, SIS-St3 Class Lead anticorrosive paint Alkyd resin	- 35/35 30/25
C-painted steel	Surface preparation 1st Undercoat - 2nd /3rd Undercoat Intermediate/Top coat	Blast, SIS-Sa2 1/2 Class Inorganic zinc-rich paint Mist coat Epoxy resin Polyurethane resin	- 75 - 60/60 30/25
I1-painted steel	Surface preparation Undercoat Intermediate/Top coat	Brush Off Blast, SIS-Sa1 Class Organic zinc-rich paint Polyurethane resin	- 75 30/25
I2-painted steel	Surface preparation Undercoat Intermediate/Top coat	Brush Off Blast, SIS-Sa1 Class Organic zinc-rich paint Silicone acrylic resin coating	- 75 30/25
I3-painted steel	Surface preparation Undercoat Intermediate/Top coat	Brush Off Blast, SIS-Sa1 Class Organic zinc-rich coating Fluorine resin	- 75 30/25

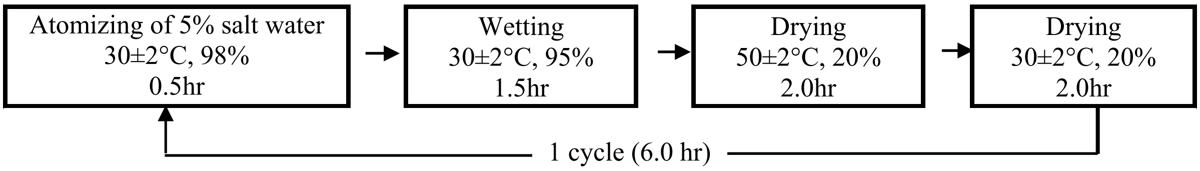


Figure 2. S6-cycle test condition

In the evaluation of performance of coating films, a scribe line or its combination are mainly used, and distance between the center of the scribe and minimum, mean or maximum edge of blistering or visible rust creepage was used in degradation evaluation. In this study scribe circle was selected as the defect shapes, based on the reasons; the rusted shape on painted main member of steel bridge is similar to a circle rather than a line and rusting area represented in graphic standards (ASTM D610) for evaluation of rust grade or rust rating closes to circle.

2.2 TEST INSTRUMENT AND CONDITIONS

A combined cyclic corrosion test instrument (Casser-20L-CYH) [10], which can operate automatically the conditions of atomizing of salt water, temperature, and humidity in arbitrary order and combination, was used to simulate corrosive environments. This equipment has an environmental test chamber of 2000 mm long, 1000 mm wide and 500 mm high in which 188 test specimens of 70 mm × 150 mm can be arranged in maximum. The environmental condition of the chamber was controlled conforming to the S6-cycle test condition, which consist of 30 minutes of slat water atomizing, 90 minutes of wetting, 120 minutes of drying by hot wind, and 120 minutes of drying by warm wind, as shown in Figure 2.

The S6-cycle test is specified as an accelerated exposure testing method for anticorrosive paintings in JIS K5600. The reproducibility of the S6-cycle test for degradation grades of painted steels under field environments was presented in literatures of Fujiwara [8] and Saito [11]. With the comparison of 7 types of accelerated exposure tests in laboratory and field exposure tests at 4 sites in Japan, Fujiwara [8] proposed that the S6-cycle corrosion test gave the good correlation with outdoor exposure tests, among the accelerated exposure tests. Saito [11] also presented the reproducibility with 4 types of accelerated exposure tests and field exposure tests at 3 sites in Japan.

2.3 TEST PROCEDURE AND MEASUREMENT

All prepared test specimens were placed at an angle of 15° from the vertical in the chamber, and exposed for up to 600 days. Every 25 days visual inspection was performed on the specimens, and every 100 days the specimens were taken out from the chamber and blotted the surface with a wet tissue to remove any attachments. And we taken photographs of the appearance and measured the surface geometry of the specimens. In the measurement the Laser Focus Measuring Systems consisting of an automatically X-Y moving stage with minimum moving interval of 1 μm, the laser distance meter of reading precision of 1μm and automatic measuring and recording systems, was used. Every 100 days using the tests the 150 mm-long and 70 mm-wide surface with the initial defects was measured at 250 μm intervals, and relative height measured by the laser distance meter was recorded for 168 thousand points.

3. EXPERIMENTAL RESULTS

3.1 VISUAL INSPECTION

Typical surfaces of A-painted specimens every 100 cycles are shown in Figure 3**.** In the painted specimens with the initial defects, rust originated at the defects, filled up them, undercut the paint film/steel substrate interface, and spread beneath the painting films around the defects. Testing time until the defect was plugged with rusts is about 25 days on the A- and I-painted specimens and about 50 days on the C-painted specimens. According to rust propagation beneath the paintings, the area of rust creepage or blistering of A- and I-painting films was widened far away from the each defect. On the other hand, rust propagation on C-painted specimens was invisible by naked eyes.

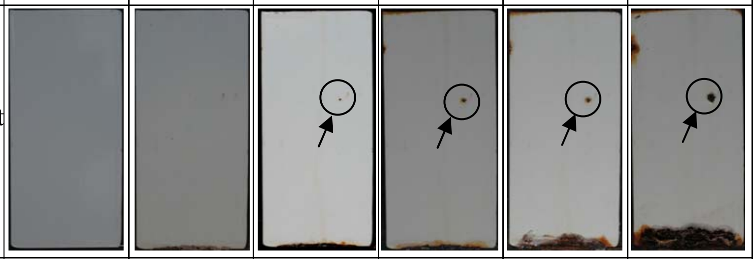
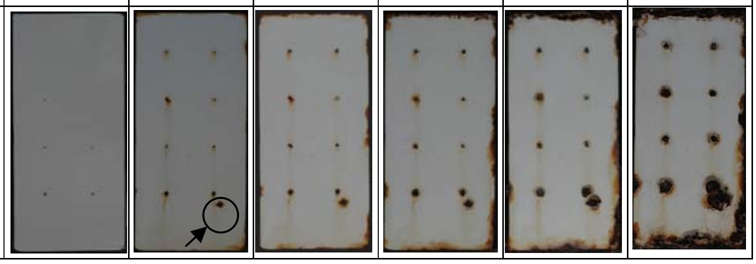
	Testing period (day)					
	0	100	200	300	400	500
(a) A-painting without defects						
(b) A-painting						

Figure 3. Appearance change in A-painted specimens

From the test specimens, rust initiation and propagation were observed only from the initial defects. In case of an A-painted specimen, a scratch near a D-2.0 defect was created by mistake in spite of all careful treatment of the test specimens, and rust at the scratch was formed, as shown in Figure 3(b). The rusting area from the scratch is not to be considered in rusting area evaluation. For one of the two A-painted specimens without the initial defects, a dot-rust was originated from a point at 125 days and it propagated with testing time, as shown in Figure 3(a).

3.2 RUST PROGATION FROM EACH DEFECT

Mean (M) and standard deviation (S) of the measured rusting areas from φ 0.2 mm (D-0.2), φ 1.0 mm (D-1.0) and φ 2.0 mm (D-2.0) defects are plotted against to the testing period in Figure 5. As shown in Figure 5, each rusting area on the A-painted specimen increases lineally until testing period reaches 300 days, and then increases rapidly. Rusting areas for the all I-painted specimens show the similar increase to those for the A-painted specimens. For the C-painted specimen no increases in rusting area from D-0.2, D-1.0 and D-2.0 defects was measured when the testing time reached 250 days, 100 days and 100 days, respectively and tend to increase lineally after that.

In the Figure 5, rusting area of the A-painted specimen without initial defects was shown. The rusting area from a dot-rust is approximately equal to the mean rusting area of the D-0.2 defects. From the comparison of the rusting area of the A-, I- and C-painted specimen it was observed that the rusting area increases in the order of the I3-, A-, I1-, I2- and C-painted specimens, even though the difference between the I3-, A- and I2-

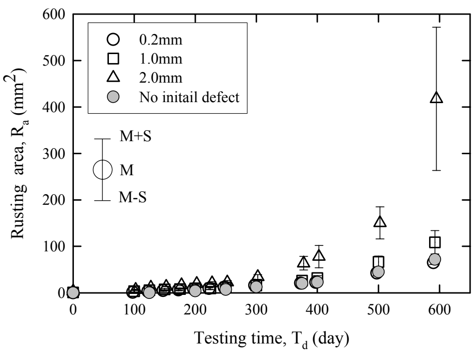


Figure 5. Rust areas of A-painted specimens

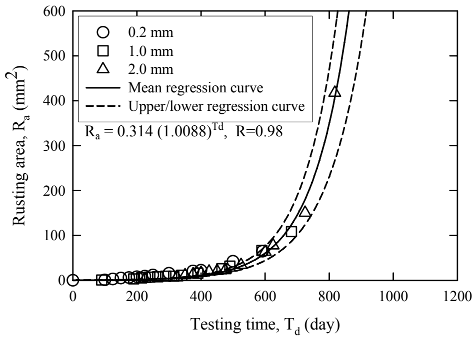
painted specimens is little. In case of the I-painted specimens with different top paints the rusting areas increased in order of the measured painting thickness prior to testing. It indicates that the thickness of painting films affects the rusting area and rust propagation.

3.3 DETERMINING DEGRADATION CURVES FOR EACH PAINTED SPECIMEN

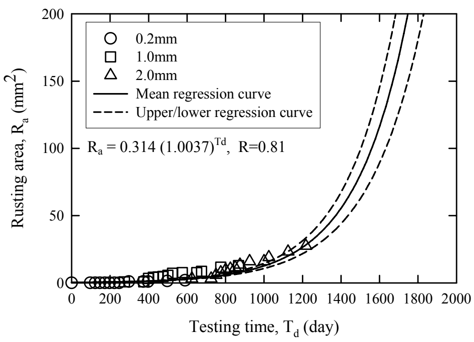
Although the measured rusting area represented only one stage along the rust propagation process from D-0.2, D-1.0 and D-2.0 defects, gathering the data enabled us to reconstruct the rust propagation the overall procedure. If the testing time until rusting area of 0.2 mm diameter (D-0.2 defect) reaches the 1.0 mm (D-1.0 defect) and 2.0 mm diameter (D-2.0 defect) was determined, all measured rusting areas from the D-0.2, D-1.0 and D-2.0 defects can be expressed with only those from D-0.2 defect. This combination gives that the rust propagation curve from the D-0.2 defect can be determined with the higher reliability than only considering D-0.2 defect and extended to the long testing time based on the test data.

In this study, the rust propagation time from D-0.2 defect to D-1.0 and D-2.0 defect was determined from the rust propagation curve of the D-0.2 defect. The required testing times are respectively 75 and 200 days for the A-painted specimen, 275 and 625 days for C-painted specimen, 125 and 225 days for I-painted specimens. Considering these testing times, the rusting areas from the defects was rearranged by the shifted testing time. In addition to this, the testing time was shifted by 25 days for A- and I-painted specimens and by 50 days for C-painted specimen, which are the elapsed time from rust initiation at the defects to rust filling up them, as the previous description.

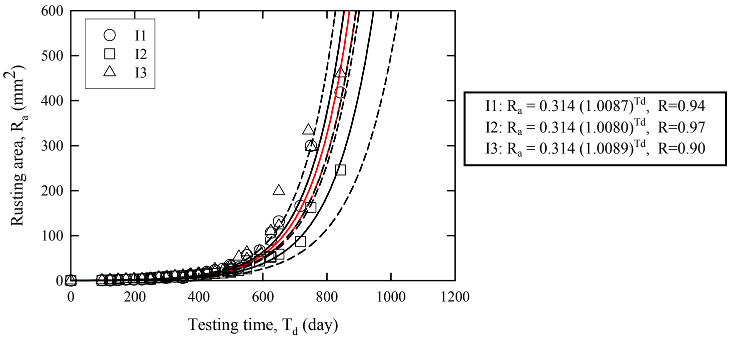
The rust propagation curves for each painted specimen are shown in Figure 6. The mean regression curves ($y = ab^x$, where a and b are constant) obtained by the least squares method are also plotted. The upper and lower regression curves, located a standard deviation far away from the mean regression curve, are plotted by dotted lines. In calculating the regression curves, the constant a is fixed as 0.314 showing the higher correlation coefficient for all data. Figure 6 indicates that the rusting areas from the three different defects, D-0.1, D-1.0 and D-2.0 defects, can be rearranged by the above procedure



(a) A-painted specimen



(b) C-painted specimen



(c) I-painted specimen

Figure 6. Rust propagation curves (Degradation Curves)

and be expressed by the mean regression curve with high correlation coefficient R of over 0.81.

4. SUMMARY

In order to determine rust degradation curves for steel bridge paintings, this study carried out accelerated S6-cyclic corrosion tests on painted steels with five types of steel bridge painting systems during 600 days. Based on rusting area from initial defects with 0.2 mm, 1.0 mm and 2.0 mm diameters, rust degradation curves for each painting systems was presented. And the application of the degradation curves for remaining lifetime evaluation from one to another degradation grade was also presented.

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