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# DURABILITY OF STEEL BRIDGE COATING SYSTEMS ON PLATE EDGES WITH DIFFERENT CORNER GEOMETRIES

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**ABSTRACT :** Sharp free edges of bottom flanges and bolted connections in steel bridges are known to be very susceptible to corrosion because securing a desired thickness of coating film is difficult at such locations. An accelerated exposure test was performed in this study to investigate corrosion resistance on plate edges with different corner geometries. Test specimens were coated with four types of paint coating systems including A, B, C, and I-paint systems and two types of metallic coating systems including zinc hot-dip galvanizing and zinc-aluminum alloys. Test specimens were exposed to the accelerated corrosion environments conforming to Japanese Industrial Standards K5621 for 200 days for metallic coating and 1,050 days for paint coating. Based on the initial coating thickness at corners and corrosion that occurred on the edges in the accelerated tests, anticorrosive performance of different corner geometries was evaluated for various coating systems. A rounded corner had good performance for all the coating types examined in this study when compared with other corner geometries.

**KEYWORDS:** Corrosion preventive coating system, Corner chamfering, Steel bridge, Durability, Accelerated exposure test

## 1. INTRODUCTION

Paint coating systems for steel bridges are widely used to prevent corrosion damage, and metallic coating systems are partly used in Japan. It has been observed that specific areas in bridge such as sharp free edges of bottom flange, bolts and nuts are very susceptible to corrosion even when they are coated with anticorrosion systems because it is hard to secure a desired thickness of coating films on such locations. Corrosion initiated from these locations expands and affects aesthetics and ultimately structural performance of steel bridges. The Japanese bridge specifications [1] recommend that sharp corners of plate edges should be ground to have a beveled or rounded corner in steel bridges. In order to assess a remaining life of a coating system and time for repaint, the data about corrosion initiation and expansion from these edge locations are important. However, the effect of corner chamfering has not been fully understood. Therefore, the anticorrosive performance of edges with different corner geometries is experimentally examined in this study.

This study performed accelerated corrosion tests [2-6] to examine corrosion characteristics at different types of corner geometries. Three types of corner geometry were prepared for specimens, square corner without corner chamfering, 45-degree beveled corner with 1 mm long sides, and rounded corner with a radius of 2 mm. As anticorrosive coating systems, four types of paint coating systems and two types of metallic coating systems were applied for each corner geometry. Therefore, there were 18 specimen types (= 3 types of corner geometry x 6 types of anticorrosive system), and four specimens were prepared for each type of specimen. One of the four specimens of each type was cut

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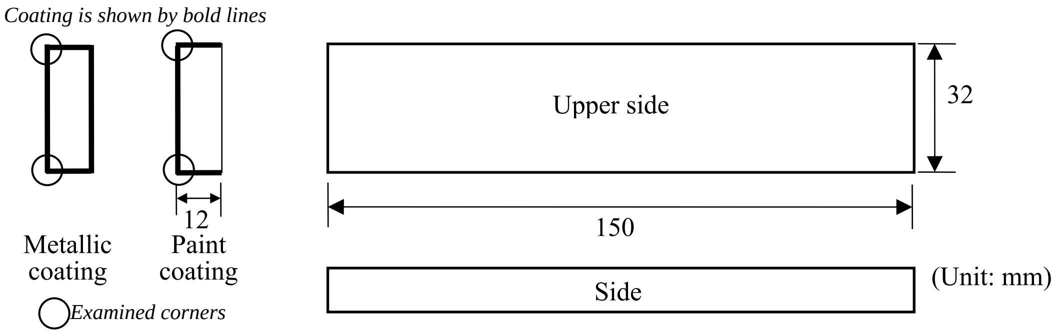
into pieces to measure the coating film thickness by using a microscope; the other three were tested in an accelerated exposure test chamber under S6-cycle corrosion conditions, conforming to Japanese Standard Industrials (JIS) K 5621, for 200 days for metallic coating systems and 1,050 days for paint coating systems. These test durations correspond to about 10 years and 55 years of exposure to a marine environment, respectively. Based on the corrosion along the corner line and the thickness of the coating, anticorrosive performance at the corner was discussed for each coating system.

## 2. INCREMENTAL NONLINEAR ANALYSIS

### 2.1 TEST SPECIMENS

Substrate steel plates of 150×32×12 mm were made of structural steels SM490A [7]. Corners of plate edges were prepared in 3 types of corner geometry, square corner without corner chamfering (E0), 45-degree beveled corner with 1 mm long sides (E1), and rounded corner with a radius of 2 mm (R2). Specimens were coated with 4 types of painting systems (A-painting system for a mild corrosion environment, B- and I-painting systems for a little severe corrosion environment, and C-painting system for a severe corrosion environment in Japan) and 2 types of metallic coating systems (zinc hot-dip galvanizing and zinc-aluminum alloy thermal sprayed coating). Coating details are described in [5], and corner geometries are shown in Figure 1.



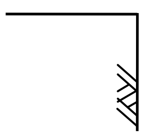
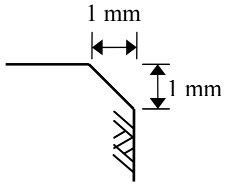
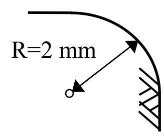

| Type | E0 | E1 | R2 |
|---|---|---|---|
| Corner chamfering | no corner-chamfering | 45-degree beveled corner with 1 mm long | rounded corner with a radius of 2 mm |
| Section geometry |  |  |  |

**Figure 1. Test specimen and corner geometry**

### 2.2 MEASUREMENT OF THICKNESS OF COATING FILMS

Four specimens were prepared for each type of specimen. One of the four specimens was cut into four pieces to measure the initial coating film thickness. Photographs of coating films were taken at an interval of 1 mm using a microscope. The thickness of coating films was measured by using the microscopic photographs, as shown in Figure 2. The coating thickness of the upper side was measured for the region where the coating thickness is not influenced by corners, while the coating thickness on the corner was taken as the minimum thickness measured on the corner.

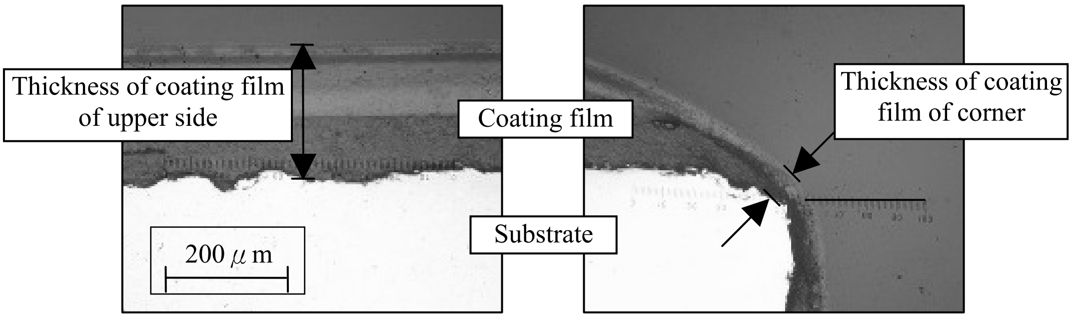



**Figure 2. Microscopic photographs of a cross-section (A-painting system: E0)**

## 2.3 MEASUREMENT PROGRESS OF CORROSION

Visual observations of the specimens with paint coating systems were performed every 25 days. As an indicator of corrosion progress, a *normalized corroded corner length* was used. The normalized corroded corner length is defined as a proportion of corroded corner length to the entire corner length. Of the corner length of 150 mm, only the middle 100 mm was used to calculate the normalized corrosion length. Metallic coating systems differ from paint coating systems in corrosion prevention mechanism. Therefore, to evaluate anticorrosive performance of metallic coating systems, a remaining coating thickness after 200 days of the exposure corrosion test was used as the indicator for corrosion progress.

# 3. EXPERIMENTAL RESULTS

## 3.1 MEASURED THICKNESSES OF COATING FILMS

The proportion of the coating thickness at the corner to that of the upper (under) side was used to evaluate the influence of the corner on the initial coating thickness. As shown in Figure 3 for the paint coating systems, the corner coating thickness has a general trend of E0<E1<R2, and the corner coating thicknesses for E0, E1, and R2 were 21-43%, 41-77% and over 79% of the thickness of upper (lower) side, respectively. Though metallic coating systems seem to have a similar tendency to painting systems, the differences in the corner coating thickness among different corner geometries are smaller. Therefore, the corner geometry effect on coating thickness is smaller for metallic coatings than paint coatings.

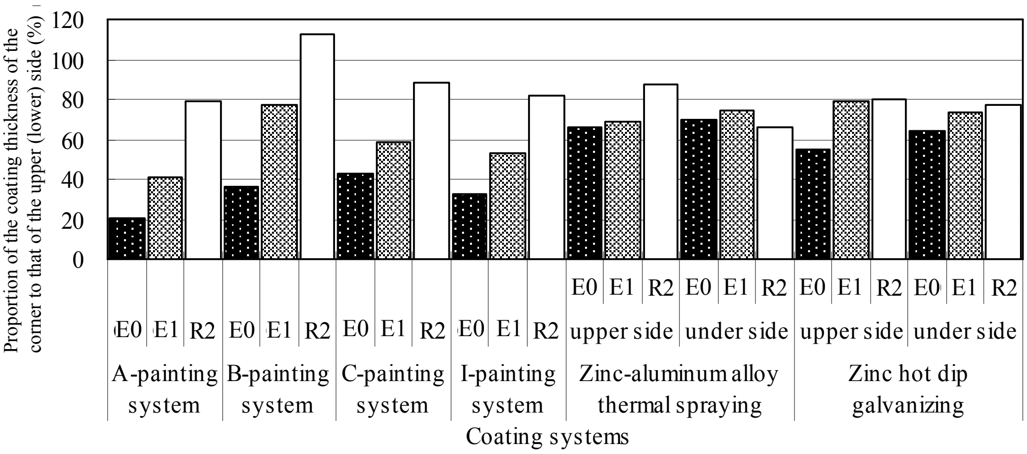



**Figure 3. Corner coating film thickness**

## 3.2 ACCELERATED EXPOSURE TEST RESULTS

### 3.2.1 Paint Coating Systems

<u>Visual observation</u>

The test specimens were exposed to S6-cycle corrosion test conditions for 1,050 days (4,200 cycles). Corrosion at the corner occurred on the specimens with A-, B- and I-painting systems. There was no corrosion found on specimens with C-painting system. The testing time at which corrosion initiated is summarized in Table 1. A-painting system specimens showed corner corrosion within 50 days for any type of corner geometry. Figure 4 shows corrosion progress for A-painting system up to 600 days. For some of the E0 specimens of A-paint system, corners corroded for the entire length after 150 days of exposure. For some of the E1 and R2 specimens, corrosion of the entire corner length was found after 300 days. Figure 5 shows the specimens of B-, C-, and I- painting systems, which have the largest corroded area at 1,050 days in each type of specimen. The corroded areas of specimens with B-painting system were larger than those of I-painting system.

**Table 1. Testing time when corrosion initiated on the edge (days)**

| Paint system | E0 | E1 | R2 |
|---|---|---|---|
| A-painting system | 10 | 25 | 50 |
| B-painting system | 275 | 325 | 725 |
| C-painting system | -- | -- | -- |
| I-painting system | 425 | 825 | 950 |

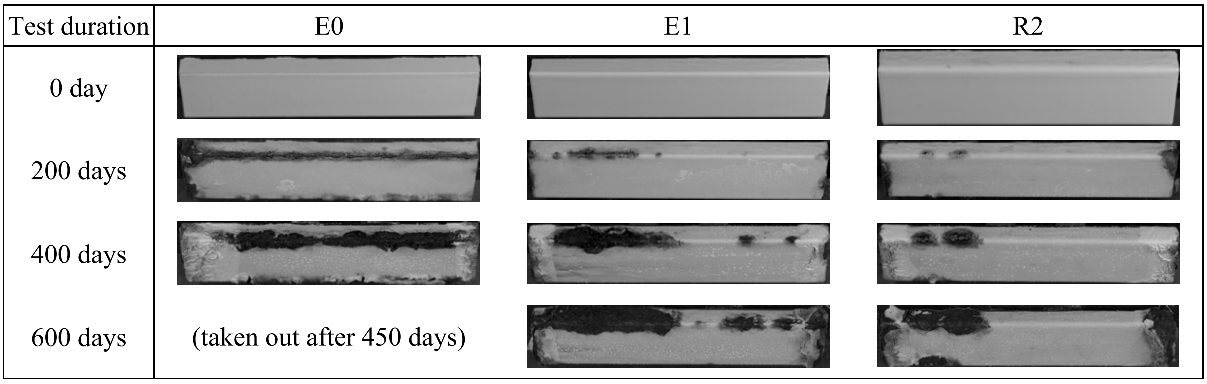



**Figure 4. Corrosion progress (A-painting system)**

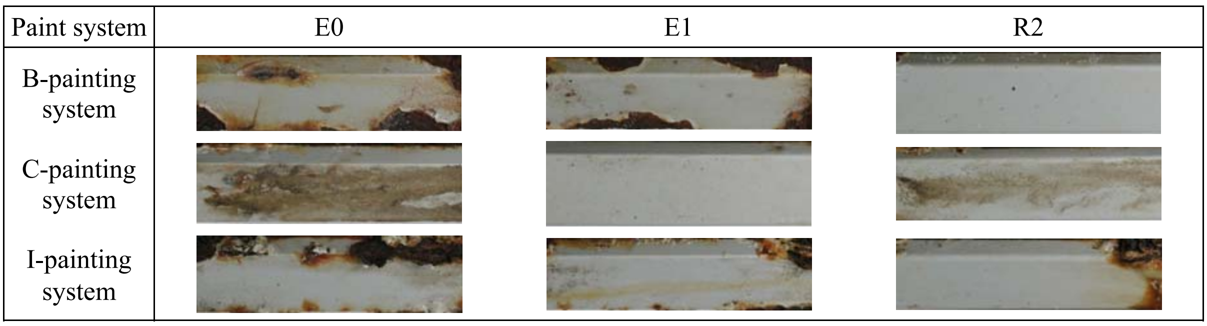
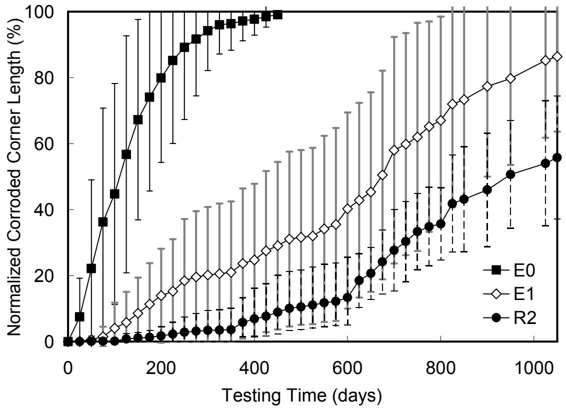



**Figure 5. Specimens with the largest corroded area for B-, C-, and I-painting systems (at 1,050 days)**

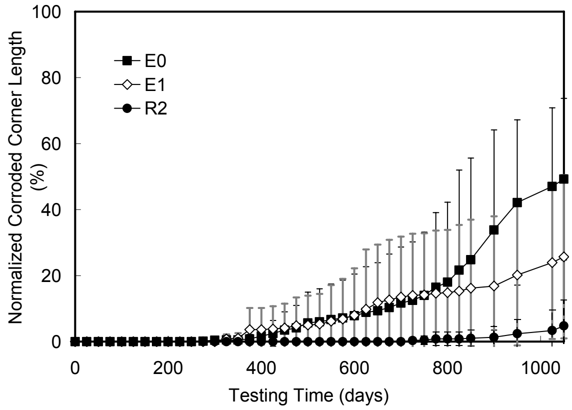
Progress of corrosion at the corner

The average normalized corroded corner length and its dispersion of three specimens for each type of specimen are plotted against the testing time in Figure 6 for A-, B-, and I-painting systems. The error bars in the figure shows ±standard deviations. For A-painting system, the normalized corroded corner length of E0 specimens increases linearly until the testing time reaches 200 days. Its increasing rate decreases gradually, and at 475 days the normalized corroded corner length becomes 100%. Corrosion was first observed at the corners of E1 and R2 specimens of A-painting system at 25 days and 50 days, respectively. Thereafter, the normalized corroded corner length increases almost linearly, and it reached 86% for E1 and 56% for R2 at 1,050 days. Results from the A-painting system clearly show that corner chamfering can significantly increase corrosion resistance at the corner for A-painting system.

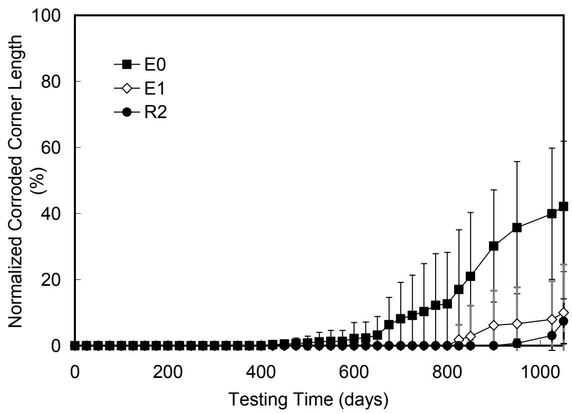
For B-painting system, the first corrosion at the corner was observed at 275 days, 325 days, and 725 days for E0, E1, and R2 specimens, respectively. E0 and E1 specimens had a very similar trend up to 800 days, but the increasing rate of E0 became greater after 800 days. This is because additional corrosion initiation points emerged on the corners of E0 specimens at 800 days. At 1,050 days, the normalized corroded corner length reached 49%, 26%, and 4.8% for E0, E1, and R2 specimens of B-painting system, respectively.




(a) A-painting system




(b) B-painting system



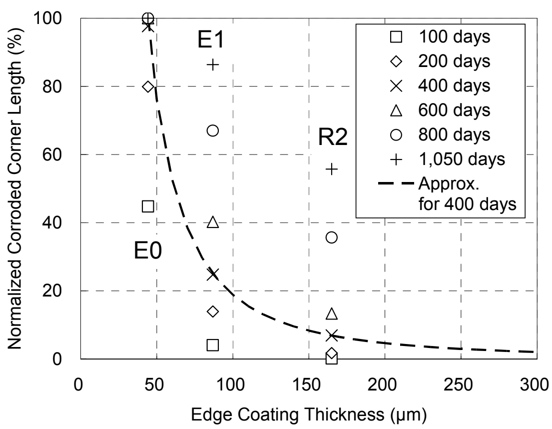

(c) I-painting system

**Figure 6. Normalized corroded corner length for A-, B-, and I-painting systems**

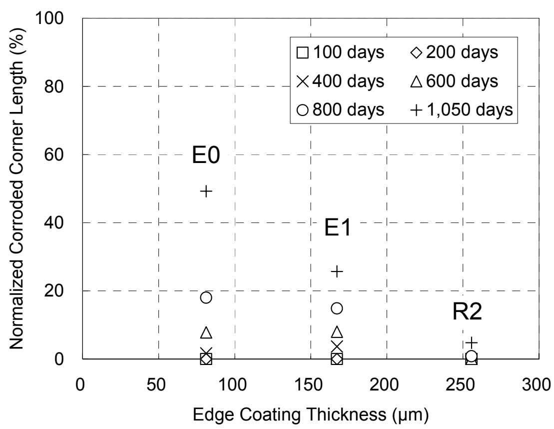
For I-painting system, the first corrosion at the corner was observed at 425 days, 825 days, and 950 days for E0, E1, and R2 specimens, respectively. Corrosion at the corner of E0 specimens expanded very slowly after 425 days until additional corrosion initiation points emerged at 600 days. At 1,050 days, the normalized corroded corner length reached 42%, 10%, and 7.4% for E0, E1, and R2 specimens of I-painting system, respectively.

In general, corrosion at the corner extends along the corner and expands in the perpendicular to the corner line. One corroded area merges with an adjacent corroded area, resulting in a larger corroded area. Ultimately, all the corroded areas are connected, and the normalized corroded corner length becomes 100%.

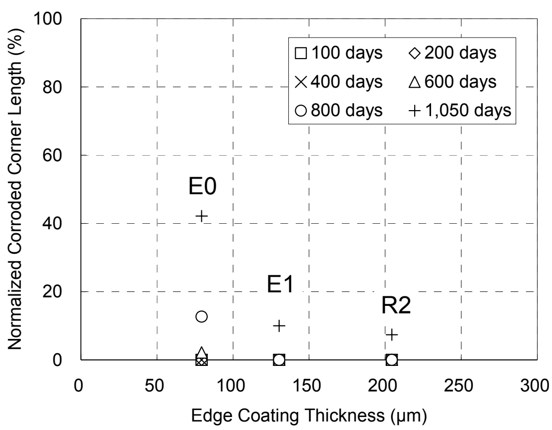
To evaluate the effect of the coating film thickness on the corroded corner length, the measured coating thicknesses and the normalized corroded corner lengths at different testing times were plotted in Figure 7. Since there are three corner geometries examined in this study, the average coating thickness at the corner of each type is plotted in the figure. For A-painting system, the corner coating thicknesses for E0, E1, and R2 specimens were 44 μm, 87 μm, and 165 μm, respectively. This figure indicates that there is a significant difference in corrosion resistance between coating thicknesses of 44 μm and 87 μm, which can be easily observed on the trend line in Figure 7(a) for 400 days, corresponding to about a 20-year exposure in a marine environment. It also implies that when a coating thickness is more than 200 μm on the corner, corrosion at the corner hardly occurs in 20 years in a marine environment.




(a) A-painting system




(b) B-painting system




(c) I-painting system

**Figure 7. Relationship between coating film thickness and corroded corner length**

For other painting systems, when more than 200 µm of a coating thickness is provided for the corner, corrosion on the corner is not going to be a significant problem for more than 50 years. For the C-painting system specimens, the coating thickness at the corner was more than 200 µm for any type of corner geometries (208 µm, 282 µm, and 417 µm for E0, E1, and R2 specimens). Therefore, it can be concluded that the coating thickness of the specimens of C-painting system was too thick to initiate corrosion at the corner.

### 3.2.2 Metallic Coating Systems

Specimens with metallic coating systems tested for 200 days in the accelerated exposure testing chamber are shown in Figure 9. White rust occurred on almost the whole surface of specimens coated with zinc-aluminum alloy, and coatings separated from the substrate steel at many locations. As for specimens coated with zinc hot-dip galvanizing system, the entire surface was covered with white rust, and red rust was also observed on some parts of the specimens. However, for both metallic coating systems, there was no difference in deterioration of the coating system among different types of corner geometries.

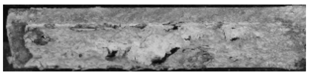
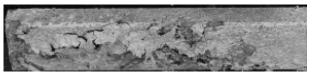
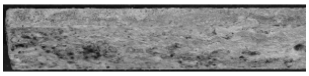
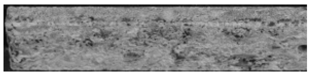
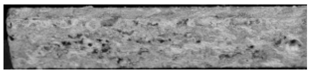
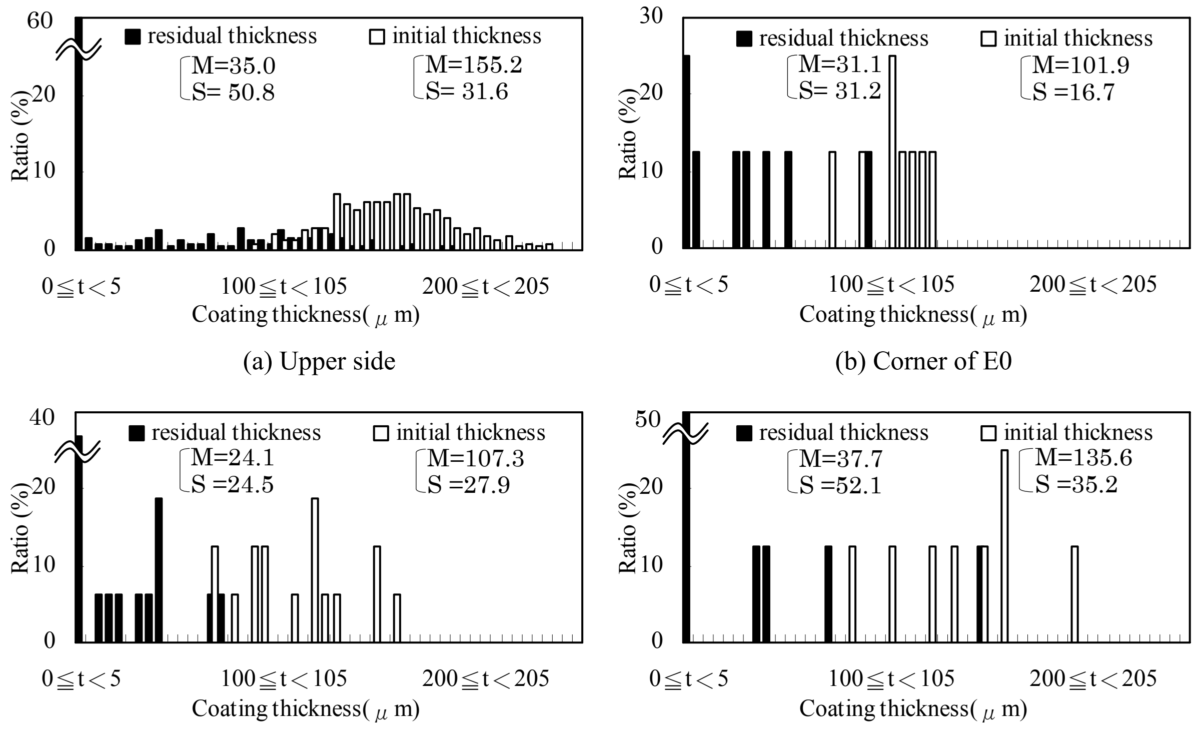
| Coating system | E0 | E1 | R2 |
|---|---|---|---|
| Zn-Al alloy thermal spraying |  |  |  |
| Zn hot-dip galvanizing |  |  |  |

**Figure 9. Corroded specimens with metallic coating systems at 200 days**




(a) Upper side

(b) Corner of E0

(c) Corner of E1

(d) Corner of R2

**Figure 8. Distributions of coating thickness (zinc-aluminum alloy thermal sprayed coating)**

Distributions of the initial and remaining thicknesses of metallic coating are summarized in Figure 8. It is found that the corner geometry does not affect an initial thickness for both metallic coating systems. Although there was a large dispersion in the results, the corner geometry does not affect the thickness loss and anticorrosive performance significantly.

## 4. CONCLUSIONS

This study performed accelerated cyclic corrosion tests to examine the influence of the corner chamfering on the anticorrosion performance of the edge. Three types of corner geometry, square corner without corner-chamfering (E0), 45-degree beveled corner with 1 mm long sides (E1), and rounded corner with a radius of 2 mm (R2) were examined. In addition, four types of paint coating systems and two types of metallic coating systems were applied on the test specimens. Based on the test results of visual inspection and thickness measurement of coating films, anticorrosive performance of paint coating systems is significantly affected by corner geometries, while for metallic coating systems it is not significantly affected by corner geometries. The initiation time of corrosion and corroded corner length for paint coating systems clearly show that corrosion resistance at the corner is related to the coating film thickness at the corner. The applicability of the accelerated test results reported in this paper to actual bridges to determine an appropriate repainting cycle and maintenance strategy should be examined in the future study.

## ACKNOWLEDGEMENTS

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