Durability of Steel Bridge Metallic Coating Systems based on Combined Cyclic Corrosion Tests

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ABSTRACT

This paper discusses durability of four types of steel bridge metallic coating systems based on combined cyclic corrosion tests. Metallic coating systems tested in this study are zinc hot dip galvanized (ZHDG) coating, zinc-aluminum alloy (ZAA) coating, zinc-aluminum pseudoalloy (ZAPA) coating, and aluminum alloy (AA) coating. The combined cyclic corrosion test followed S6 cycle conditions specified in Japanese Industrial Standard K5621. In addition to the standard S6 cycle, S6 cycle conditions with an acid rain spray period in place of a salt water spray period were also used to evaluate the effect of acid rain on durability of metallic coating systems. Steel plates with metallic coating systems were placed in a cyclic corrosion test chamber under these two different cyclic conditions for 300 days. Durability of metallic coating systems was evaluated by coating thickness loss and remaining coating area in this study, and differences in deterioration characteristics between the salt water spray and acid rain spray combined cyclic corrosion tests were investigated.

The coating thickness loss was greater in the acid rain cyclic corrosion test except for ZAPA specimens, implying that ZHDG, ZAA, and AA coatings should be used with a great care when they may be exposed to acid rain. In both salt water spray and acid rain spray cyclic corrosion tests, AA specimens showed the best durability of the four metallic coatings.

Keywords: metallic coating, accelerated exposure test, steel bridge, acid rain, durability

INTRODUCTION

Paint coating systems have been widely used to prevent corrosion on steel bridges in corrosive environments. Recently, metallic coating systems such as zinc hot dip galvanized (ZHDG) coating, zinc-aluminum alloy (ZAA) coating, zinc-aluminum pseudoalloy (ZAPA) coating, and aluminum alloy (AA) coating have been also used in Japan to expect better anticorrosive performance on steel bridges rather than paint coating systems. However, the anticorrosive performance of coating films gradually deteriorates over time. Although many studies including field weathering tests and accelerated exposure tests have been performed to examine durability of the anticorrosive coatings, durability of anticorrosive coatings has not been examined thoroughly [1] [2].

Recently, a question has been raised about how acid rain affects anticorrosive coatings of steel bridges. Acid rain is defined as rain into which NOx or SOx in air is dissolved. It is well-known that it would give serious damage to forests, lake, and marshes. Also, corrosion damages on bronze statues and structures due to acid rain have been observed. There have been some studies to examine effect of acid rain on metals. However, the influence of acid rain on anticorrosive coating systems of steel bridges has not been examined yet.

Therefore, in this study, an accelerated exposure test was performed to consider acid rain effects on test specimens with metallic coating systems. The test specimens were coated with four types of metallic coating systems including zinc hot-dip galvanizing, zinc aluminum alloys spraying, zinc-aluminum pseudoalloys spraying and aluminum spraying. These coatings are usually used to protect steel bridges coating in Japan.

The accelerated exposure test is based on the S6-cycle specified in Japanese Industrial Standard (JIS) K 5621. The S6-cycle consists of a multiple test conditions including salt water spraying, but in this study the S6-cycle conditions with the artificial acid rain period in place of the salt water spray period were also used. By comparing results from the two tests with and without acid rain, the effect of acid rain on the metallic coating systems for steel bridges was evaluated [4] [5].

EXPERIMENTAL PROCEDURE

Test Specimens

The geometry of the specimens is shown in Fig. 1. Substrate steel plates of 70×150×9 mm were made of JIS SM490A structural steels. The chemical composition of the steel is listed in Table 1. The steel plates were coated with four types of metallic coating systems including zinc hot-dip galvanizing, zinc aluminum alloys spraying, zinc-aluminum pseudoalloys spraying and aluminum spraying, as shown in Table 2 [3] [6].

Cross-scribe lines through the coating films were made on the coated specimens by using an automated milling machine to expose the underlying substrate steel. The width of the scribe line is 2 mm. The cross-scribe lines are often used in corrosion tests to evaluate corrosion performance of anticorrosive coating. In addition to these exposed lines, 20×70 mm rectangular region in the lower part of a specimen [7] was also exposed by a disc grinder for the zinc hot-dip galvanized coated specimens, or for other coating systems by peeling off the masking tape, which was attached on steel substrate prior to the coating works. Twelve test specimens were prepared for each coating type.

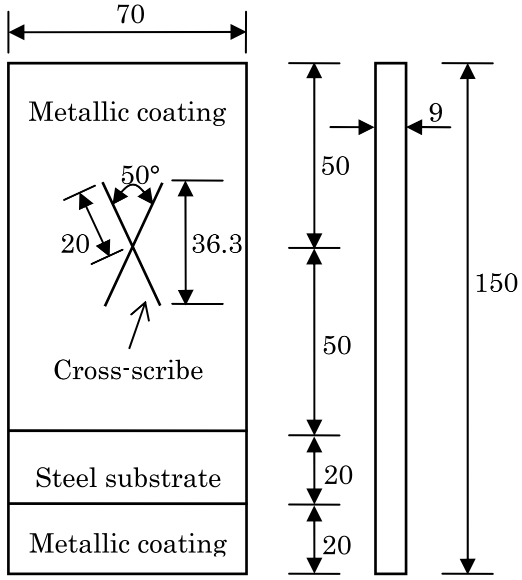


Figure 1: Geometry of the Test Specimens

Table 1: Chemical Composition of the Steel (%)

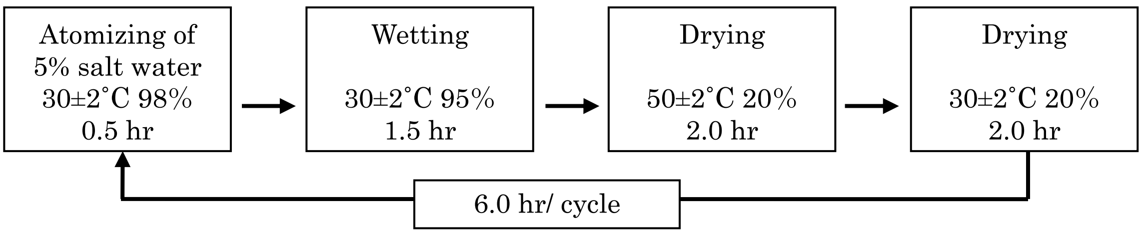
Material	C	Si	Mn	P	S
JIS G 3106 SM490A	0.17	0.34	1.43	0.016	0.004

Table 2: Metallic Coating Systems used in this Study

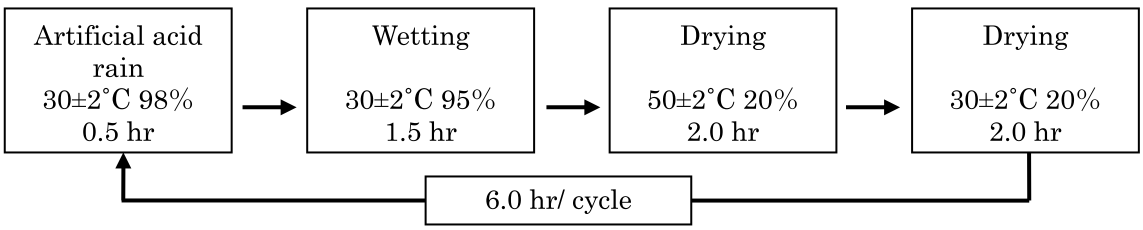
Coating systems	Coating process	Treatment	Designed thickness (μm)
Zinc hot-dip galvanizing	Surface preparation Metal plating	Acid Pickling Zinc hot dip galvanizing (JIS H 9124)	- (550 g/m^2)
Zinc-aluminum alloys spraying	Surface preparation Metal spraying Sealing treatment	Blast, SIS Sa2 1/2 Class Zinc-aluminum alloy coating Epoxy resin sealing coating	- 100 -
Zinc-aluminum pseudo-alloys spraying	Surface preparation Metal spraying Sealing treatment	Blast, SIS Sa2 1/2 Class Zinc-aluminum pseudo-alloy coating Epoxy resin sealing coating	- 100 -
Aluminum spraying	Surface preparation Metal spraying Sealing treatment	Blast, SIS Sa2 1/2 Class Aluminum coating Epoxy resin sealing coating	- 100 -

Condition of Accelerated Exposure Test

To evaluate how acid rain affects anticorrosive coatings of steel bridges, accelerated exposure tests with an artificial acid rain period were performed. The accelerated exposure test can evaluate the coating anticorrosive performance in a short term and has been performed in many studies. However, an evaluation the method of the influence of acid rain on an anticorrosive coating has not been established. In this study, the accelerated exposure test based on the S6-cycle specified in Japanese Industrial Standard (JIS) K 5621 was performed with the salt water spray period replaced with the artificial acid rain spray period. The artificial acid rain consists of sodium chloride of 4.7 wt%, nitric acid of 0.094 wt%, sulfuric acid of 0.30 wt%, and sodium hydroxide of 0.30 wt%, and its pH was adjusted to 3.5. Fig.2 shows test conditions used in this study. In this study, a test following the S6-cycle is referred to as *a salt water spray test*, and the one following the S6 cycle with an acid rain spray period in place of a salt water spray period is referred to as *a acid rain spray test*.



(a) Salt water spray combined cyclic test



(b) Acid rain spray combined cyclic test

Figure 2: Accelerated Exposure Test Condition

Performance Measures

To evaluate the durability of metallic coating, coating thickness is often measured, because the metallic coating thickness decreases sacrificially to protect substrate steel. In this study, the thickness loss of the metallic coating is used as an index to evaluate anticorrosive performance of the metallic coating systems. The thickness was measured at 11 points as shown in Fig. 3. Since Point 4 to Point 11 were in the cross-scribe region and boundary region, the average values from Point 1 to Point 3 were used to calculate the coating thickness loss. The measured initial thicknesses of different metallic coatings are shown in Table 3. Three test pieces were taken out from the test chamber every 100 days, and the rust was removed by boiling in water with ammonium citric and thiourea. After the rust removal, the thicknesses of test specimens were measured.

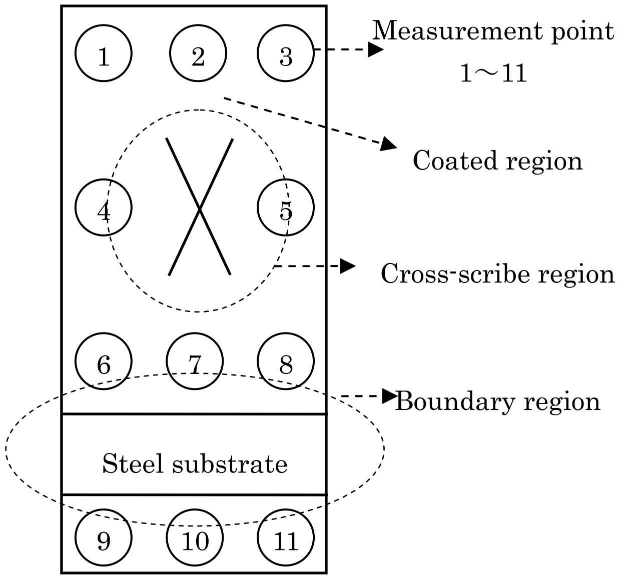


Figure 3: Classification of Regions in a Test Specimen and Thickness Measurement Points

Table 3: Measured Initial Thickness of Metallic Coating

Metallic coating	Thickness using for salt water spray test (μm)		Thickness using for acid rain spray test (μm)	
	Mean	Standard deviation	Mean	Standard deviation
Zink hot-dip galvanizing	108.3	19.8	90.7	11.1
Zink-aluminum alloys spraying	154.5	23.5	127.0	20.7
Zinc-aluminum pseudo-alloys spraying	170.2	11.7	232.7	22.8
Aluminum spraying	172.4	36.7	131.4	27.2

EXPERIMENTAL RESULTS

Visual Inspection

Appearances of the test specimens tested for 300 days are shown in Fig. 4. On zinc hot-dip galvanizing coatings exposed to acid rain, white rust ($Zn(OH)_2$) from the metallic coating and red rust ($Fe(OH)_2$) from the substrate steel were observed, while red rust from the coated region was not observed on the test specimens exposed to salt water. Zinc aluminum alloys spraying specimens showed little differences between the two test conditions. In both tests, peeled coatings and red rust were observed. On the zinc-aluminum pseudoalloys spraying specimens tested with acid rain spray, red rust was observed all over the steel substrate region and in a part of the coated region. However, the specimens tested with salt water spray showed no red rust in the coated region and red rust in a small part of the exposed steel substrate region. On the aluminum spraying specimens, red rust was observed in and around the exposed steel substrate region for the salt water spray test while red rust was observed also in the cross-scribe region for the acid rain spray test. Therefore, for the aluminum spraying coating, deterioration was lager in the acid rain spray test than in the salt water spray test. The deterioration of coating clearly started from the steel substrate region.

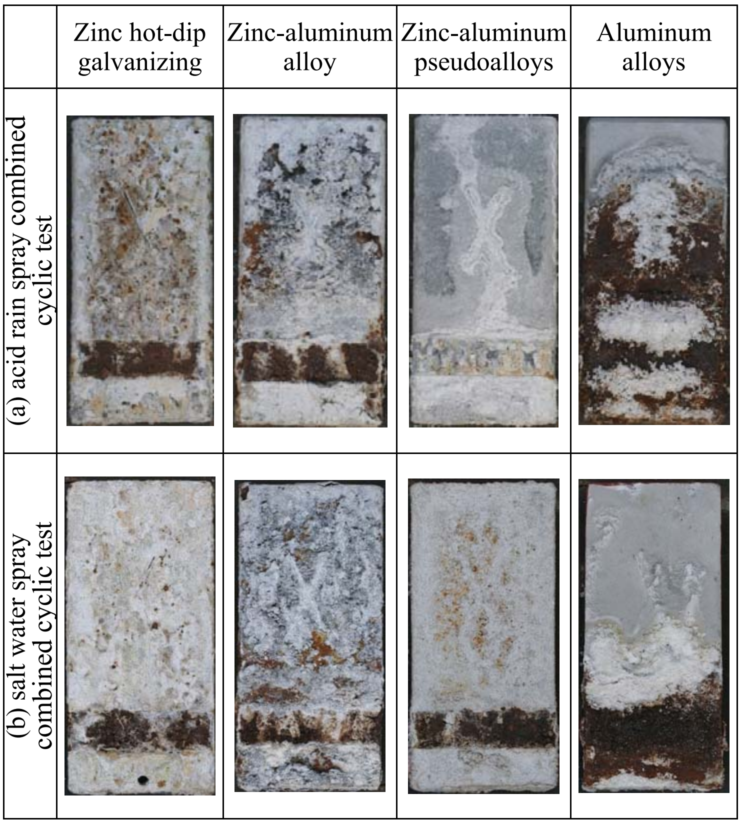


Figure 4: Photographs Illustrating the Surface Condition of Test specimens

Thickness Loss of Metallic Coating Systems

Rust of the test specimens tested for 100, 200 and 300 days was removed, and remained coating thickness was measured. The mean thickness of Point 1 to Point 3 shown in Fig. 3 was calculated. Then, the coating thickness loss was obtained from the initial thickness. Fig. 6 shows the relationship between coating thickness loss and testing time for each metallic coating. The dotted lines show the data measured after the coating thickness had been lost completely. Therefore, these data are shown only for a reference.

Comparing thickness losses between the two test conditions for each metallic coating type, the largest difference was observed for zinc hot-dip galvanizing. In the acid rain spray test, almost all the coating thickness was consumed during the first 100 days. However, in the salt water spray test, the coating thickness remained after 300 days of testing. After 100 days of testing, the coating thickness was reduced by 100 μm in the acid rain spray test while the reduction was 70 μm in the salt water spray test.

Zinc-aluminum alloys spraying and aluminum spraying specimens showed a similar tendency to zinc hot-dip galvanizing specimens. However, for aluminum spraying specimens, the difference between the two test conditions was insignificant, and so was the thickness loss of coating.

Zinc-aluminum pseudoalloys spraying specimens showed different results from other three types of metallic coating. The thickness loss of the specimens tested with salt water spraying was greater than that tested with acid rain spraying.

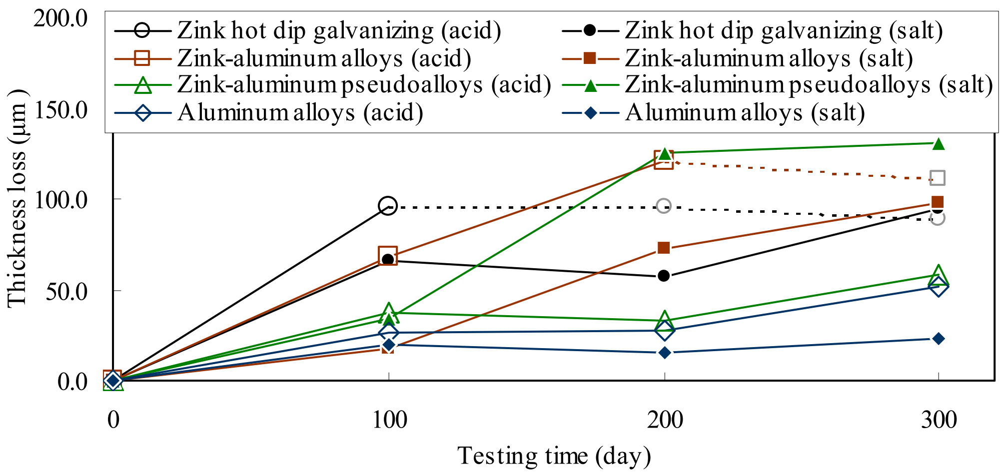


Figure 5: Thickness Loss of Metallic Coating Systems

CONCLUSION

The purpose of this study was to evaluate performance of anticorrosive metallic coating systems used for steel bridges – especially the effect of acid rain on the anticorrosive metallic coating. Accelerated exposure tests including an acid rain spray period was performed as well as those with a salt water spray period. Main conclusions obtained in this study can be summarized as follows:

1) The deterioration characteristics of four type of metallic coating systems, zinc hot dip galvanized (ZHDG) coating, zinc-aluminum alloy (ZAA) coating, zinc-aluminum pseudoalloy (ZAPA) coating, and aluminum alloy (AA) coating, were investigated under both salt water spray and acid rain spray combined cyclic tests to obtain the anticorrosive performance.

2) Comparing thickness losses between the two test conditions for each metallic coating type, zinc hot-dip galvanizing, zinc-aluminum alloy spraying and aluminum spraying specimens showed greater thickness losses in the acid rain spray combined cyclic test. Therefore, acid rain reduces durability of anticorrosive metallic coatings of zinc hot-dip galvanizing, zinc-aluminum alloy spraying, and aluminum spraying.

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