

AN ACCELERATION-CYCLIC CORROSION TEST OF COATING SYSTEMS FOR STEEL BRIDGES

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ABSTRACT

This study examined an accelerated corrosion test to examine corrosion degradation of coating systems for steel bridges. Three types of organic coating systems called as A-, C-, and I-painting systems in Japan and four types of metallic coating systems, zinc hop-dip galvanizing, zinc-aluminum alloy spraying by two methods and aluminum spraying, were considered. Scribe circles reaching steel substrate were made mechanically on the coated steel plates, and corrosion from them was focused. Test specimens were exposed to the accelerated corrosion environments conforming to Japanese Industrial Standards K5621 during 300 days for the metal-coated specimens and 400 days for the painted specimens. From the appearance change with passage of testing time, anticorrosive performance of the coating systems was discussed. The corrosion degradation curves for the painted specimens were presented based on blistering area of painting films.

KEYWORDS

Steel structure, corrosion, coating system, accelerated cyclic corrosion test

INTRODUCTION

Painting systems have been widely used to prevent corrosion attacks, and to maintain the functional ability and good appearance of steel structures. Recently, metallic coating systems, such as zinc hop dip galvanizing and thermal sprayed coating systems become popular in Japan since reduction in recoating costs at the maintenance stage of the steel bridges is expected.

The remaining life of the coating systems, which is important to maintain steel bridges efficiently, has been often predicted based on statistical analysis on visual observation of real structural members and test specimens under atmospheric environments. Although they allow field examinations, it takes long time to obtain any deterioration data of the coating systems. The combined environmental factors, such as temperature, humidity, and salinity coming flying make it difficult to understand corrosion characteristics of the coating systems. For these reasons, accelerated cyclic exposure tests

in a laboratory are employed to obtain the fundamental data and to complement the data of the field exposure tests.

This study performed accelerated corrosion tests to examine corrosion characteristics of coating systems for steel bridges. We focus on corrosion degradation of the coating systems with initial defects or partially deteriorated regions. Three types of painting systems, A- and I-painting systems for mild corrosion environments and C-painting systems for severe corrosion environments in Japan, and four types of metal coating systems (zinc hop dip galvanizing, zinc-aluminum alloy thermal sprayed coating by JIS method, low-temperature zinc-aluminum alloy sprayed coating, and aluminum thermal sprayed coating systems) were corrosion-tested during the exposure time of 400 and 300 days, respectively. Based on appearance change with passage of testing times, anticorrosive performance of the coating systems was discussed.

TEST PROCEDURE

Fabrication of Test Specimens

Figure 1 illustrates the configuration and dimensions of the test specimen used in this study. Substrate steel plates of 70×150×9 mm were made of Japan Industrial Standards (JIS) SM490A structural steels [JSA 1999]. The chemical composition of the steel is listed in Table 1. The substrate steel plates were grit-blasted by No.50 grit specified in JIS S-G50 or surface-treated by a power tool machine. And then the surface treated steel plates were coated with three organic coating systems, A-, C- and I-painting systems in Japan [JRA 1990], and four metallic coating systems, zinc hop dip galvanizing, zinc-aluminum alloy thermal sprayed coating by JIS method, low-temperature zinc-aluminum alloy sprayed coating, and aluminum thermal sprayed coating. The coating materials and process are listed in Table 2. On the surface of the coated specimens, 8 scribe regions were made by an automatic milling machine with 3 circles of ϕ 0.2 mm, 3 circles of ϕ 1.0 mm and 2 circles of ϕ 2.0 mm through the coating films to expose the underlying substrate steel. Two test specimens for a coating system were prepared.

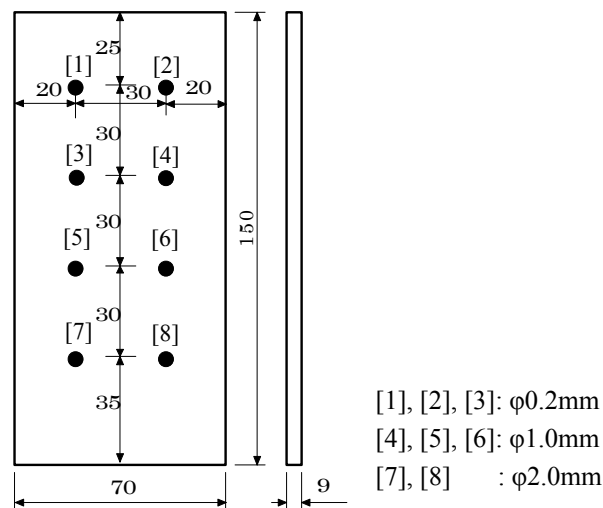


Figure 1: Geometry and dimension of tested specimen (Unit in mm)

TABLE 1
 CHEMICAL COMPOSITION OF STRUCTURAL STEELS (IN PERCENTAGE)

Material	C	Si	Mn	P	S
JIS G3106 SM490A	0.16	0.37	1.44	0.01	0.001

TABLE 2
COATING SYSTEMS USED IN THIS STUDY

Coating system	Process	Coating process	Designed thickness (μm)
A-painting system	Surface preparation	Power tool, SIS St3 Class	-
	Undercoat	Lead anticorrosive paint	35
	"	"	35
	Intermediate coat	Alkyd resin	30
	Top coat	Alkyd resin	25
C-painting system	Surface preparation	Blast, SIS Sa2 1/2 Class	-
	Undercoat	Inorganic zinc-rich paint	75
		Mist coat	-
	Undercoat	Epoxy resin	60
	"	Epoxy resin	60
	Intermediate coat	Polyurethane resin	30
	Top coat	Polyurethane resin	25
I(1)-painting system	Surface preparation	Brush Off Blast, SIS Sa1 Class	-
	Undercoat	Organic zinc-rich paint	75
	Intermediate coat	Polyurethane resin	30
	Top coat	Polyurethane resin	25
I(2)-painting system	Surface preparation	Brush Off Blast, SIS Sa1 Class	-
	Undercoat	Organic zinc-rich paint	75
	Intermediate coat	Silicone acrylic resin coating	30
	Top coat	Silicone acrylic resin coating	25
I(3)-painting system	Surface preparation	Brush Off Blast, SIS Sa1 Class	-
	Undercoat	Inorganic zinc-rich coating	75
	Intermediate coat	Fluorine resin	30
	Top coat	Fluorine resin	25
Zinc hot dip galvanizing	Surface preparation	Blast, SIS Sa2 1/2 Class	
	Metal plating	Zinc hot dip galvanizing (JIS H8641)	(550g/m ²)
Zinc-aluminum alloy thermal spraying	Surface preparation	Blast, SIS Sa2 1/2 Class	-
	Rough surface preparation		-
	Metal spraying	Zinc-aluminum alloy coating	100
	Sealing treatment	Epoxy resin sealing coating	-
Low-temperature Zinc-aluminum alloy spraying	Surface preparation	Brush Off Blast, SIS Sa1 Class	-
	Rough surface preparation	Non-brass #21	-
	Low-temperature metal spraying	Zinc-aluminum alloy coating	100
	Sealing treatment	Non-brass sealing coating	-
Aluminum thermal spraying	Surface preparation	Blast, SIS Sa2 1/2 Class	-
	Rough surface preparation		-
	Metal spraying	Aluminum coating	100
	Sealing treatment	Epoxy resin sealing coating	-

Test Procedure

A Combined Cyclic Corrosion Test Instrument made by SUGA Test Instruments Co., Ltd. was used to simulate cyclic corrosion environments. This equipment can operate automatically the conditions of atomizing of salt water, temperature, and humidity in arbitrary order and combination. It has an environment chamber of 2000 × 1000 × 500 mm, in which 188 test specimens of 70 × 150 mm can be arranged. The environment in the chamber was controlled conforming to the S6-cycle test condition specified in JIS K5621, as shown in Figure 2.

The test specimens were placed in the chamber at an angle of 15 degree from the vertical, and then

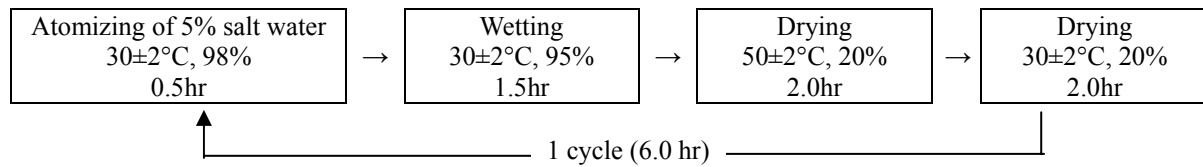


Figure 2: S6-cycle corrosion test condition

they were exposed for 300 days (S6-1200 cycles) for the metal-coated specimens and 400 days (S6-1600 cycles) for the painted specimens. After testing time of 100 days, surface geometry of the painted specimens was measured by a Laser Focus Measuring Instrument periodically, and appearance of all specimens was also observed.

EXPERIMENTAL RESULTS

Metal-Coated Specimens

The appearances of four types of metallic coating systems used in this study were observed periodically. In the beginning of the corrosion tests, white rust layers were formed at scribe circles and filled up the circles. No red rusting from the exposed circles was observed. This is attributed to that the exposed circles are galvanically protected by the preferential anodic dissolution of the zinc and/or aluminum coating and isolated from the corrosive environment by the white rust layer covered.

In zinc hot dip galvanizing (ZH), zinc-aluminum alloy thermal spraying (ZAS) and low-temperature zinc-aluminum alloy spraying (LZAS) specimens, white rust completely covered the surfaces of the specimens at testing times of 25, 100, 50 days, respectively. Red rusting on the surface of the metal coating was observed at 50 days for ZH, 200 days for ZAS, and 150 days for LZAS specimens, respectively. However, no red rusts were observed from the surface of aluminum thermal spraying (AS) specimens.

Painted Specimens

Visual inspection

Typical surfaces of A-painted specimens every 100 days and C- and I-painted specimens corresponding to 400 days are shown in Figures 3 and 4, respectively. At early stage of the exposure testing, red rust filled up the scribe circles, undercut the paint film/steel substrate interface, and moved out under paint films. The rust in A- and I-painted specimens spread out, and the blistering region of painting films was widened far away from the circles according to the exposure time. On the other hand, under-film rust propagation from the exposed circles on C-painted specimens was limited to near each circle, and the blistering area was small compared with those on the other specimens, as shown in Figure 4(a). In the A-painted specimens, color of the surface changed from white to light-yellow, even though no change in the other specimens was observed.

Blistering area

The geometry of the painted surfaces was measured at 250 μm interval in both width and length direction using a Laser Focus Measuring Instrument. From these data, blistering area from each circle, ϕ 0.2, 1.0, or 2.0 mm, was calculated, and its mean (M) and standard deviation (S) are plotted against to the testing time in Figure 5. The blistering area increases linearly until testing time reaches 250 days, and it increases abruptly, while the increase in C-painted specimens is linear.

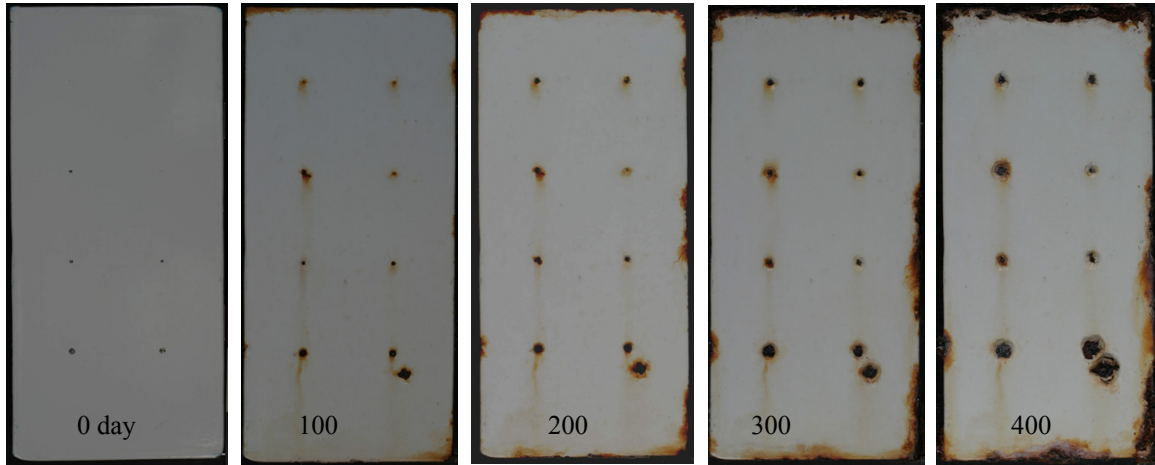


Figure 3: Appearance change with passage of testing times (A-painted specimens)

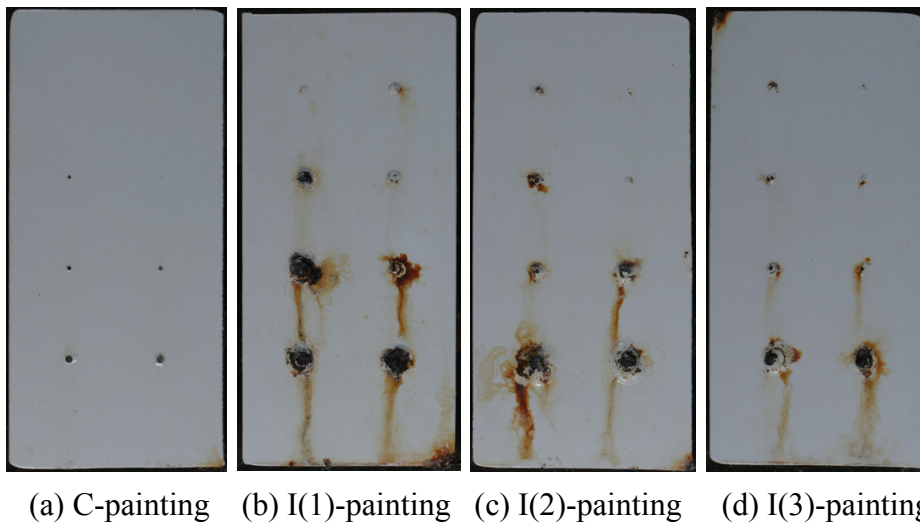


Figure 4: Appearance C- and I-painted specimens after testing time of 400 days

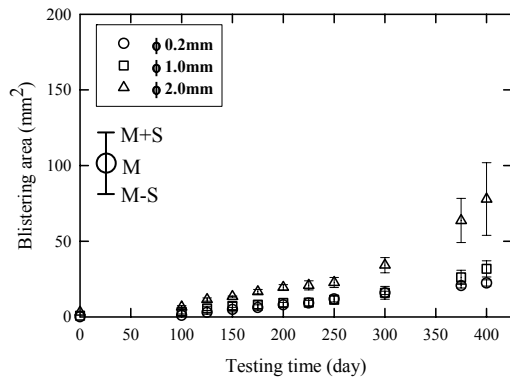
The sum of blistering area of each tested specimen is plotted in Figure 5(d). The regression curves ($y = ab^x$, where a and b are constant) obtained by the least squares method are also plotted. The blistering area increases in the order of C-, I(2), A-, I(1), and I(3)-painted specimens. Difference between the blistering areas of the coating systems is clear with increase in the testing time. At the blistering area of 100 mm^2 showing rapid increase, the testing time is 223 days for A-painted specimens, 223 to 265 days for I-painted specimens, and 595 days for C-painted specimens.

Application of present results to corrosion degradation prediction in atmospheric environments

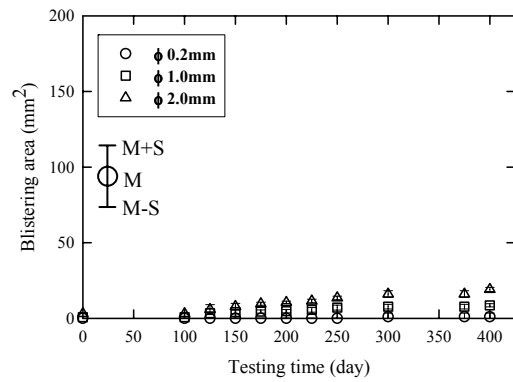
When salinity coming flying at a site of a steel bridge is determined, the corrosion degradation of painting systems under field environments is predictable using the acceleration coefficient factors expressed by the following equation [Itoh et al., 2002]:

$$A_c = 9.14 \cdot W_s^{-0.62} \quad (1)$$

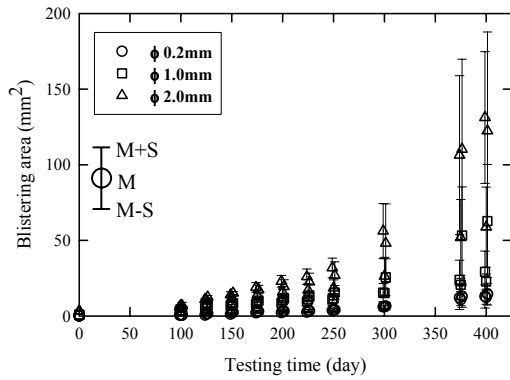
where A_c is acceleration coefficient factor of S6 cycle to atmospheric environment and W_s is weight of salinity coming flying (mdd).



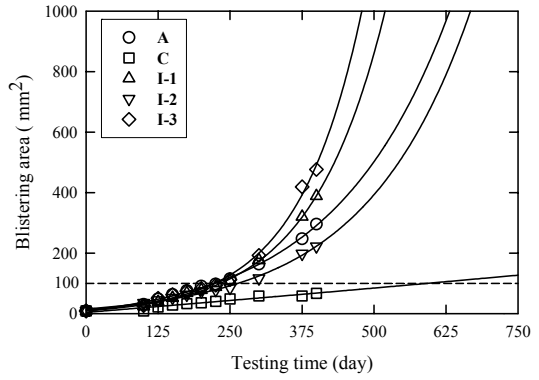
(a) A-painted specimen



(b) C-painted specimen



(c) I-painted specimens



(d) Sum of blistering area for each painted specimen

Figure 5: Blistering area

For example, 0.3 mdd corresponding to a severe corrosion condition, the factor is 19.3 and the testing time required for 100 mm² deteriorated area is 11.8 years for A-painting system, 11.8 - 14.2 years for I-painting systems, and 31.9 years for C-painting systems.

CONCLUSION

This study performed accelerated S6-cyclic corrosion tests on coating systems for steel bridges, three types of painting systems and four types of metallic coating systems with ϕ 0.2, 1.0, and 2.0 mm scribe circles. No red rusting from the scribe circles in the metal coating systems was observed due to galvanic protection of the metal coating. In painting systems, blistering area of the painting films indicated that the anticorrosive performance increased in the order of A-, I-, and C-painting systems. This is applicable to predict anticorrosive performance for filed environments using the acceleration coefficient factor.

References

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