DETERIORATION CHARACTERISTICS OF Sn-BEARING STEEL BY ACCELERATED EXPOSURE TESTS

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ABSTRACT

A series of accelerated exposure tests with combined cycles during 300 days was carried out for investigating the basic corrosion characteristics of the Sn-bearing steel with paint coating. When noting the specimens with paint systems used for mild corrosion conditions, the blister of the painting from the cross scribe of the Sn-bearing steel was smaller than that of the general structural steel. In the case of the specimens with paint systems used for severe corrosion conditions, almost no blister of the painting from the cross scribe could be observed on the Sn-bearing steel even though the experiment was finished. The blister area from the boundary region between the painting and the steel substrate of the Sn-bearing steel was smaller than that of the SM490 steel. The results indicated the possibility for reducing the cost for maintenance of steel bridges by prolonging repair terms of painting by using the Sn-bearing steel.

Keywords: Steel structure, Sn-bearing steel, corrosion, paint coating, accelerated exposure test.

1. INTRODUCTION

It is required to extend the service life of aged infrastructures and to ensure their safety by maintaining them properly. With regard to steel bridges, one of the main factors of the deterioration is corrosion of steel members. Therefore, it is important to select an appropriate corrosion prevention system for maintaining them. At present, paint coating is mainly used as the typical corrosion prevention system for steel bridges. It is known that not only the paint coating but also the substrate steel with high corrosion resistance delays the corrosion deterioration of steel members. For example, effect of the weathering steel without paint coating has been confirmed. As a result, the weathering steel is widely used in appropriate conditions. On the other hand, the steel with a small amount of tin (Sn), that is, Sn-bearing steel was newly developed by noting the effect of adding such kind of trace alloy element for improving the corrosion resistance of steel (Kamimura et al. 2013). It has been confirmed that the Sn-bearing steel has high corrosion resistance compared with the general structural steel through the exposure tests on site and a kind of

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accelerate exposure test. It was reported that the high corrosion resistance of the Sn-bearing steel was caused by the inhibition of anode reaction by a small amount of Sn ion dissolved at the local anode site (Kamimura et al. 2013). The higher corrosion resistance of the Sn-bearing steel is expected when the steel is painted and then a defect in painting occurs because the anode region is fixed to the defect exposing to the surrounding environment (Kamimura et al. 2013).

However, deterioration characteristics of the Sn-bearing steel have not been clarified sufficiently yet. For example, it is necessary to elucidate the durability of the steel in a long term corresponding to the life time of bridge. Furthermore, not only the performance of the Sn-bearing steel but also the painting on it is important because the durability of the paint coating largely affects the deterioration of the substrate steel.

In this study, a series of the accelerated exposure tests with combined cycles of salt splaying, wetting and drying during 300 days was performed. A correlation between this accelerated exposure test and actual environments was confirmed (Fujiwara et al. 1997). The deterioration from the initial artificial defects of the paint coating on the Sn-bearing steel was evaluated by comparing with that of the general structural steel (SM490). Based on the results obtained, effects of the corrosion resistance around the paint defects of the Sn-bearing steel were investigated.

2. MATERIALS AND SPECIMENS

2.1. Chemical compositions of materials

The Sn-bearing steel and the general structural steel (SM490) were used for the accelerated exposure tests. Table 1 shows the chemical composition of the Sn-bearing steel and SM490 with yield stress of 492MPa. The Sn-bearing steel was basically made by adding a small amount of Sn into the general SM490 steel.

2.2. Shapes and dimensions of specimens

The steel plates of which the length, the width and the thickness were 150 mm, 70 mm and 9 mm respectively (150 x 70 x 9 mm) were used as the specimens for the accelerated exposure tests. These steel plates were painted by the specifications of painting and coating for steel highway bridges in Japan. Table 2 shows the details of the paint coatings. A-type painting is for relatively mild corrosion environments. C-type painting is for relatively severe corrosion conditions such as around the coastal area.

Artificial initial defects shown in Figure 1 were made on the painted specimens for investigating the deterioration behavior of the paint coating from the defects. In the cross cut specimen, the cross scribe defect simulated the scratch damage on the actual painting. The length and the width of the cross scribe line were 40 mm and 1 mm, respectively. The angle of the cross scribe lines was 50 degrees. The cross scribe lines reached to the substrate steels. 20 x 70 mm region at the lower part of the specimen was not coated for exposing the substrate steel. This simulated the corrosion deterioration behavior from the discontinuous part of the paint coating such as the boundary between two members in bolted joints of actual steel bridges.

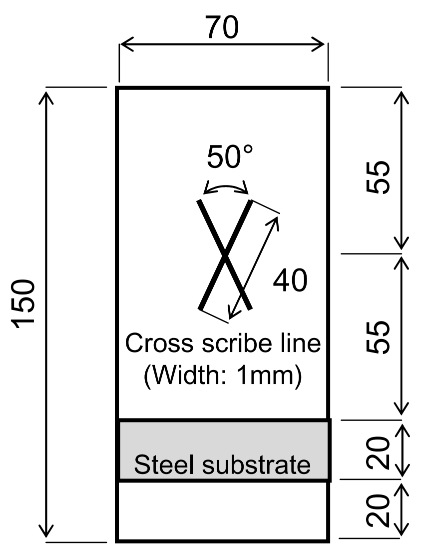
In the circular substrate specimen, the circular shape defects with different diameters (0.2, 1.0 and 2.0 mm) were made on the paint coating by using an end mill machine. The defects reached the substrate steel. This simulated the corrosion deterioration behavior from the pin-hole damage on the paint coating of actual steel bridges (Kim et al. 2007).

Table 1: Chemical composition of materials (Mass%)

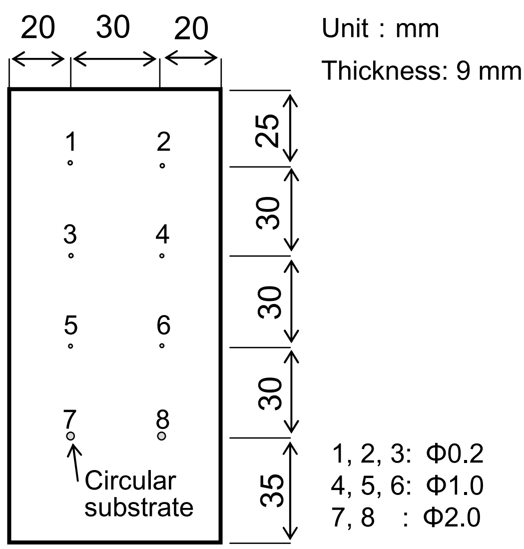
	C	Si	Mn	P	S	Sn
Sn-bearing steel	0.15	0.31	1.11	0.011	0.002	Target value: min. 0.1
SM490 steel	0.16	0.39	1.46	0.014	0.005	-

Table 2: Details of paint coatings

Coating systems	Process	Treatment	Designated thickness (μm)
A-type	Surface preparation (1st)	Blast cleaning, SIS Sa2 1/2 class	-
	Surface preparation (2nd)	Power tool cleaning, SIS St3 class	-
	Undercoat	Lead-free, Chromium-free anticorrosive paints	35
	Undercoat	Lead-free, Chromium-free anticorrosive paints	35
	Intermediate coat	Phthalic resin paint	30
	Top coat	Phthalic resin paint	25
C-type	Surface preparation (1st)	Blast cleaning, SIS Sa2 1/2 class	-
	Surface preparation (2nd)	Blast cleaning, SIS Sa2 1/2 class	-
	Undercoat	Inorganic zinc-rich paint	75
	Mist coat	Epoxy resin paint	-
	Undercoat	Epoxy resin paint	60
	Undercoat	Epoxy resin paint	60
	Intermediate coat	Fluorocarbon polymer paint	30
	Top coat	Fluorocarbon polymer paint	25



(a) Cross cut specimen



(b) Circular substrate specimen

Figure 1: Shapes and dimensions of specimens

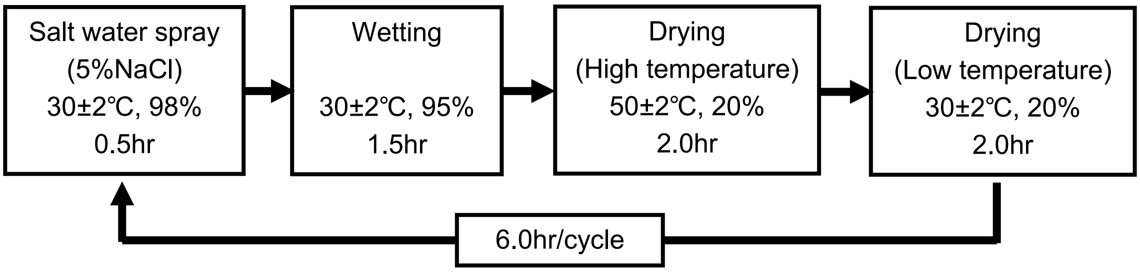


Figure 2: Accelerated exposure test condition

3. ACCELERATED EXPOSURE TESTS

A series of the accelerated exposure tests with combined cycles of salt splaying, wetting and drying (S6 cycles) was carried out for 300 days (1200 cycles). Figure 2 shows the test conditions. The S6 cycles are specified in Japanese Industrial Standards (JIS K 5621) (Japanese Industrial Standards Committee 2006). The correlation was confirmed between the test results by the S6 cycles and the exposure tests on site (Fujiwara et al. 1997).

The specimens were taken out from the test chamber by every 400 cycle (100 day) and appearances of the specimens were observed. Furthermore, the paint blister formation around the initial paint defect was investigated by using a laser displacement meter.

4. EXPERIMENTAL RESULTS

4.1. Appearance of specimens

Figure 3 shows the appearance of the cross cut specimens taken out from the test chamber by every 400 cycle. In the cases of the A-type painted specimens, the rust was formed around the cross scribe lines and the substrate region from 400 cycles in both the Sn-bearing steel and the SM490 steel. The amount of the rust increased with the test cycles. In the cases of the C-type painted specimens, the rust was scarcely formed around the cross scribe lines in both the Sn-bearing steel and the SM490 steel even after 1200 cycles. However, the amount of the rust around the substrate region spread with the test cycles. It could be seen that the rust under the substrate region of the Sn-bearing steel was fewer than that of the SM490 steel in both the A-type and the C-type painted specimens at 1200 cycles.

In the case of the circular substrate specimens, the degree of the rust was less than those of the cross cut specimens. Especially, almost no rust was observed in the C-type painted specimen regardless of the difference of the substrate steel.

4.2. Blister area of paint coatings

When the painted steel is corroded from the defect on the paint coating, the formed rust between the steel surface and the paint coating breaks the painting. As a result, the blister of painting occurs.

Therefore, the blister can be used as the measure for evaluating the degree of corrosion of substrate steel (Funke 1997).

The surface shape of the specimens after the accelerated exposure tests were measured by the laser displacement meter. The measured pitch was 0.3 mm in both the longitudinal and the transverse directions. Figure 4 shows examples of the measured results around the cross scribe regions in the specimens after the test of 1200 cycles. The area in which the height of blister of painting was over 50 μm from the level of sound painting region was determined as the blister area in this study.

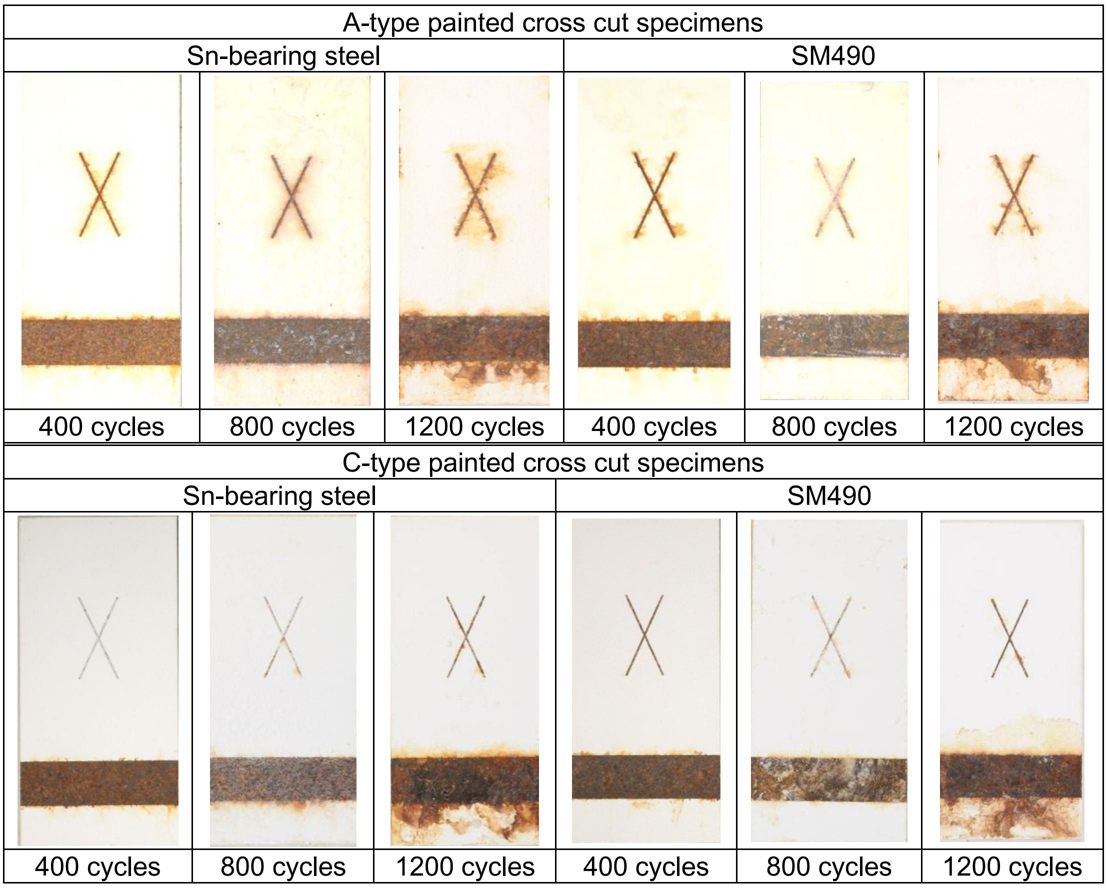


Figure 3: Appearance of specimens

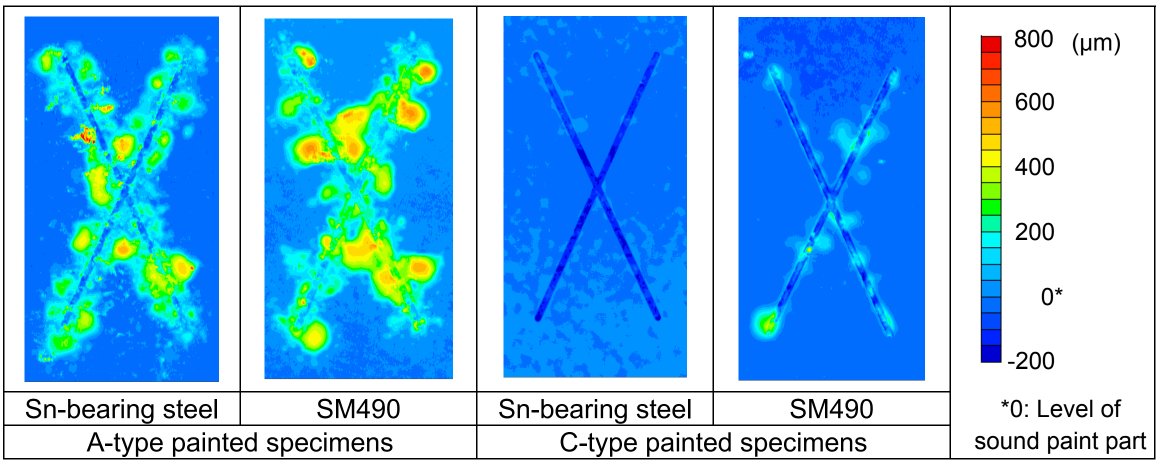


Figure 4: Blister around cross scribe regions (after the test of 1200 cycles)

Figure 5(a) shows the relationships between the blister areas from the cross scribe regions and the test cycles. The blister areas of the A-type painted specimens were larger than those of the C-type painted specimens. In the A-type painted specimens, the blister area of the Sn-bearing steel was smaller than that of the SM490 steel. The blister area of the Sn-bearing steel was around 92 % of that of the SM490 steel after 1200 cycles. In the C-type painted specimens, the blister areas of both the Sn-bearing steel and the SM490 steel were almost zero until 800 cycles. Although the blister area of the SM490 was increased, that of the Sn-bearing steel was not generated even after 1200 cycles.

Figure 5(b) shows the sum of the blister areas of the upper and lower parts of the substrate regions. In the A-type painted specimens, the blister area of the Sn-bearing steel was around 92 % of that of the SM490 steel at 1200 cycles as well as the cross scribe region. However, in the C-type painted specimens, a clear difference of the blister areas between the Sn-bearing steel and the SM490 steel could be confirmed. The difference of the blister areas between the Sn-bearing steel and the SM490 steel became larger with an increase of the test cycle. The blister area of the Sn-bearing steel was around 16 % of that of the SM490 steel after 1200 cycles.

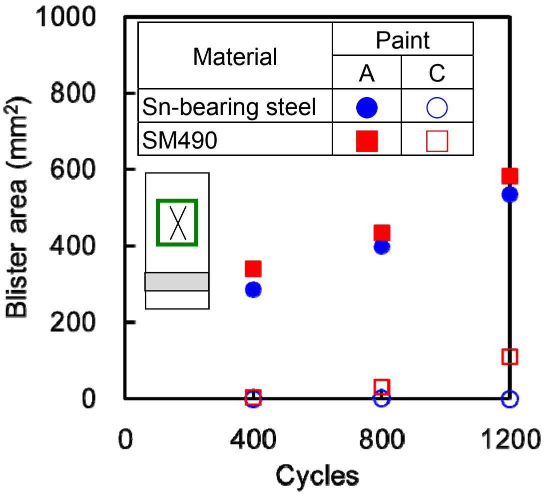
Figures 5(c) and (d) show the relationships between the blister areas from the circular substrates regions with diameters of 1.0 mm and 2.0 mm and the test cycles respectively. The scarce blister could be observed around the circular substrate region with diameters of 0.2 mm.

In the A-type painted specimens, the blister areas of the Sn-bearing steel around the circular substrates with diameters of 1.0 mm and 2.0 mm were around 80 % and 68 % of those of the SM490 steel at 1200 cycles respectively. In the C-type painted specimens, the blister hardly occurred even though the diameter of the circular defect was 2.0 mm at the 1200 cycles

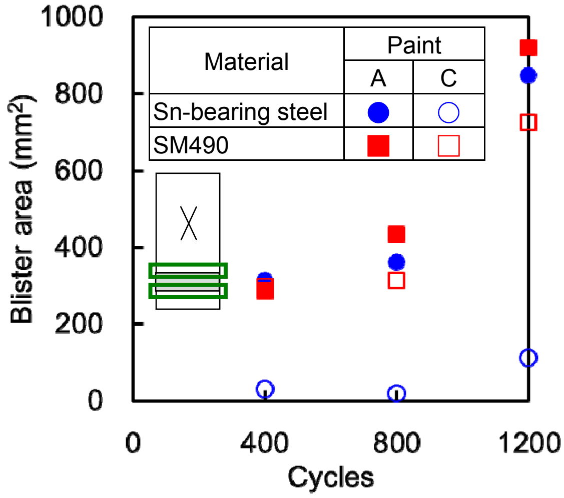
In the A-type painted specimens, the effect of Sn-bearing steel on the deterioration of paint coating could be seen although the difference between the Sn-bearing steel and the SM490 steel was not so large. In the case of the A-type paint system of which the anti-corrosion performance was not so high, the deterioration of the painting was severe. Therefore, the rust occurrence might not concentrate around the defect. However, the considerable effect of Sn on the anti-corrosion performance of the steel was confirmed.

In the C-type painted specimens, the effect of the Sn-bearing steel was obviously observed around the cross scribe lines and the substrate region. The clear difference between the Sn-bearing steel and the SM490 steel could not be seen around the circular substrates because the deterioration of paint coating itself did not almost occur.

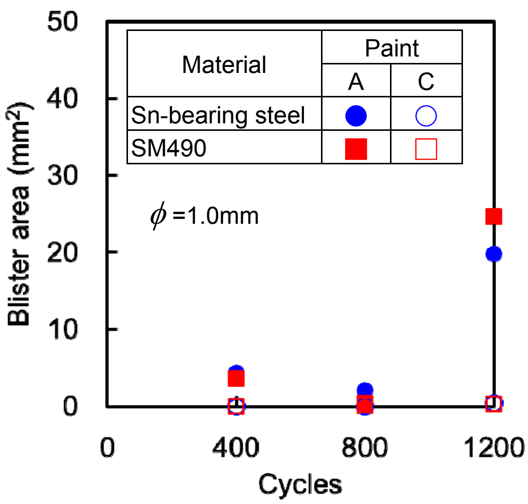
In any case, the experimental result indicated the higher corrosion resistance of the Sn-bearing steel compared with the SM490 steel. It is possible that the use of the Sn-bearing steel in steel bridges prolong the life of the paint coating. Due to it, there is a possibility that the cost for the maintenance of bridges is controlled.



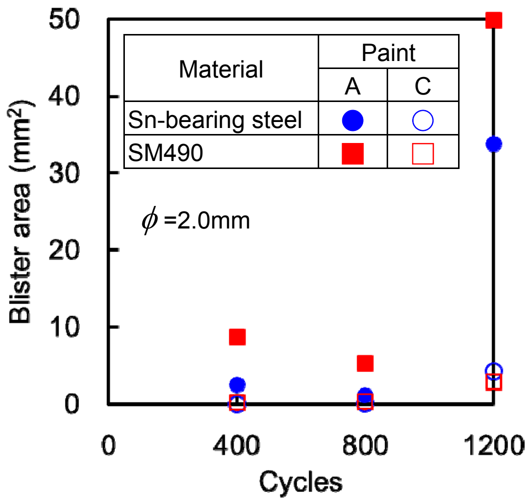
(a) Cross scribe region



(b) Substrate region



(c) Circular substrate region with diameter of 1.0 mm



(d) Circular substrate region with diameter of 2.0 mm

Figure 5: Relationships between blister area and test cycles

5. CONCLUSIONS

For investigating basic corrosion characteristics of the newly developed Sn-bearing steel, a series of the accelerated exposure tests with combined cycles of salt splaying, wetting and drying (S6 cycles) during 1200 cycles (300 days) was carried out. The obtained main results are as follows.

(1) In the A-type painted specimens, the blister area from the cross scribe paint defect of the Sn-bearing steel was around 92 % of that of the SM490 steel at 1200 cycles. In the C-type painted specimens, the blister areas from the cross scribe paint defect of both the Sn-bearing steel and the SM490 steel were not almost observed until 800 cycles. Although the blister of the SM490 was increased, that of the Sn-bearing steel was not generated even after 1200 cycles.

(2) In the A-type painted specimens, the blister area from the boundary between the painted and not painted regions of the Sn-bearing steel was around 92 % of that of the SM490 steel at 1200 cycles. In the C-type painted specimens, the difference of blister areas between the Sn-bearing steel and the SM490 steel became larger with increase of the test cycle. The blister area from the boundary region of the Sn-bearing steel was around 16 % of that of the SM490 steel at 1200 cycles.

(3) In the A-type painted specimens, the blister areas of the Sn-bearing steel around the circular substrates with diameters of 1.0 mm and 2.0 mm were around 80 % and 68 % of those of the SM490 steels at 1200 cycles respectively. The scarce blister could be observed around the circular substrate region with diameters of 0.2 mm. In the C-type painted specimens, the blister hardly occurred even though the diameter of the circular defect was 2.0 mm at the 1200 cycles.

(4) Although the conditions of the experiments in this study were limited, the results indicated the possibility for reduction of the cost for maintenance of steel bridges by prolonging the repair terms of the paint coating by using the Sn-bearing steel.

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