Corrosion deterioration characteristics of Sn-bearing steel and its applicability on steel bridges

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Summary

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. In order to investigate the corrosion deterioration characteristics around paint coating defect of the Sn-bearing steel, accelerated exposure test was performed. After the test, the appearance and surface shape of paint coated Sn-bearing steel were examined for evaluating the degree of deterioration. The corrosion deterioration was evaluated by focusing on the blister of paint coating around the initial defect scribed in X shape (namely, cross-scribe defect). The blister areas from the cross scribe paint defect of the Sn-bearing steel was respectively 95 % in A-type coating and 43 % in C-type coating of those of the SM490 steel at 2200 cycles. For C-type coating, the use of Sn-bearing steel to bridges has the possibility to prolong the life span of paint coating by around 15 %.

Keywords: steel bridge, 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 and serviceability by maintaining them properly. With regard to steel bridges, corrosion is one of the main factors of the deterioration 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 has been 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[1]. 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 accelerated 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[1]. 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[1]. In order to investigate the corrosion deterioration characteristics around paint coating defect of the Sn-bearing steel, a series of accelerated exposure tests was performed. After the test, the appearance and surface shape of paint coated Sn-bearing steel were examined for evaluating the degree of deterioration. The corrosion deterioration was evaluated by focusing on the blister of paint coating around the initial defect scribed in X shape (namely, cross-cut defect).

2. Materials and specimens

2.1 Chemical composition 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 steel with yield stress of 492MPa. The Sn-bearing steel was basically made by adding a small amount of Sn into the general structural steel (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 following the specifications of painting and coating for steel highway bridges in Japan. *Table 2* shows the details of the paint coatings. A-type paint coating is used for relatively mild corrosion environments, and C-type paint coating is used for relatively severe corrosion conditions such as the coastal area.

To investigate the deterioration behavior of the paint coating from the defects, artificial initial defects shown in *Fig. 1* were made on the painted steel specimens. 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.

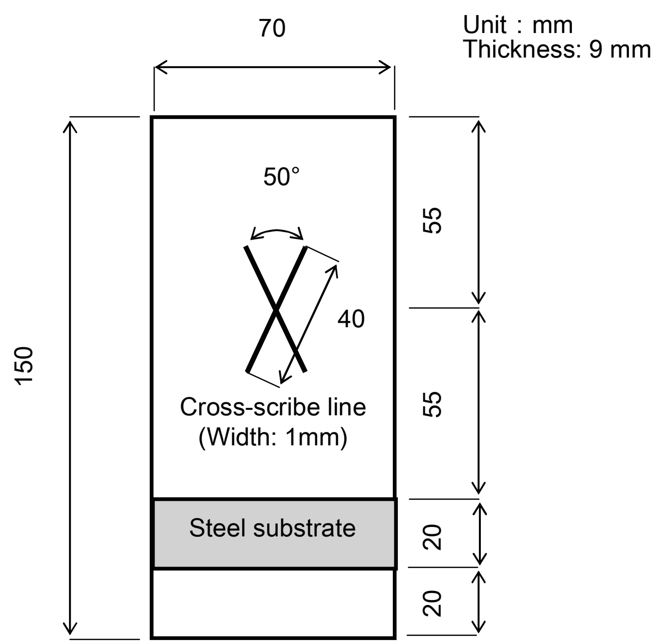

Fig. 1: The shape and dimension of cross-cut specimen

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 coating

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

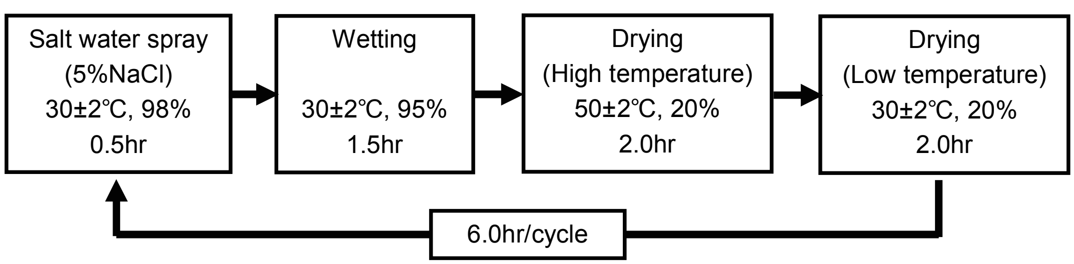

Fig. 2: Accelerated exposure test condition

3. Accelerated exposure test

A series of the accelerated exposure tests with combined cycles of salt spraying, wetting and drying (S6 cycles) was carried out for 550 days (2200 cycles). *Fig. 2* shows the test condition. The S6 cycles is specified in Japanese Industrial Standards (JIS K 5600)[2]. The correlation was confirmed between the test results of painted steels by the S6 cycles and the exposure tests on site[3].

The specimens were taken out from the test chamber 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 specimen

Fig. 3 shows the appearance of the cross-cut specimens taken out from the test chamber at specified interval of cycles. In the cases of A-type painted specimens, the rust was formed around the cross scribe lines and the substrate region from the first 400 cycles in both the Sn-bearing steel and the SM490 steel. The amount of rust was increased with the test cycles. In the cases of 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. After 1600 cycles, the rust was gradually formed around the cross scribe lines. Then, the blister of paint coating generated around the cross scribed lines.

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 the result, the blister of painting occurs. Therefore, the blister area can be used as the measure for evaluating the degree of corrosion of substrate steel[4].

After the accelerated exposure tests, the surface shape around X-cross scribe of the specimens were measured by the laser displacement meter. The measured pitch was 100 μm in both longitudinal and transverse directions. In this study, the area whose height of blister of painting was over 50 μm from the level of sound painting region was defined as blister area. *Fig. 4* shows the examples of measured blister areas.

Fig. 5 shows the relationships between the blister areas from the X-cross scribe regions and the number of the test cycle. The blister areas of A-type painted specimens were larger than those of C-type painted specimens. In A-type painted specimens, the blister area of the Sn-bearing steel was smaller than that of the general structural steel (SM490 steel). The blister areas of the Sn-bearing steel were around 95 % of those of the SM490 steel after 2200 cycles. In 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 steel was increased, that of the Sn-bearing steel was not generated even after 1200 cycles. After 1600 cycles, the blister areas of both specimens were slightly increased. For C-type coating, the blister area of the Sn-bearing steel was around 43 % of that of the SM490 steel after 2200 cycles.

5. Applicability on steel bridges

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 span of the paint coating. To compare the effects of Sn-bearing steel on blister area, estimated deterioration curve was applied as shown in *Fig. 6*. Considering the trend of each increase of blister area, bilinear straight lines were applied for A-type coating and Gompertz curves[5] for C-type coating according to each deterioration level. In this study, deterioration area ratio of 5 % was considered as repaint stage and the number of cycles at the line was compared. The number means the span in which repainting of paint coating is desirable. Table 3 shows the number of cycles when blister area reaches 5 %.

In *Table 3*, the ratio (Sn-bearing steel/SM490) shows the prolongation of paint coating life span by using Sn-bearing steel. The use of Sn-bearing steel has the possibility to prolong the life span of paint coating by 47 % for A-type coating and by 14 % for C-type coating. However, it is difficult to compare A-type coating specimen for lack of sufficient results before 400 cycles. While Sn-bearing steel is expected to prolong the lifespan of C-type coating by around 15%, there is dispersion of the test results. Thus, the value in table.3 is roughly calculated.

To evaluate the precise effect of Sn-bearing steel on lifespan of these coatings, it is necessary to check the appropriateness of estimation curve and improve the precision of by considering the future result of accelerated exposure test after 2200 cycles.

Usually, A-type coating for bridges in low floating salinity environment has shorter life span than that of C-type coating. In high floating salinity environment such as coastal area, maintenance cost of repainting of A-type coating is likely to be high. In terms of life span of paint coating, C-type paint coating requiring less maintenance is suitable to steel bridges. Thus, the prolongation of the life span for C-type paint coating is more effective to reduce maintenance cost. To utilize Sn-bearing steel for steel bridges, further investigation about how use of Sn-bearing steel can reduce the lifecycle cost should be taken.

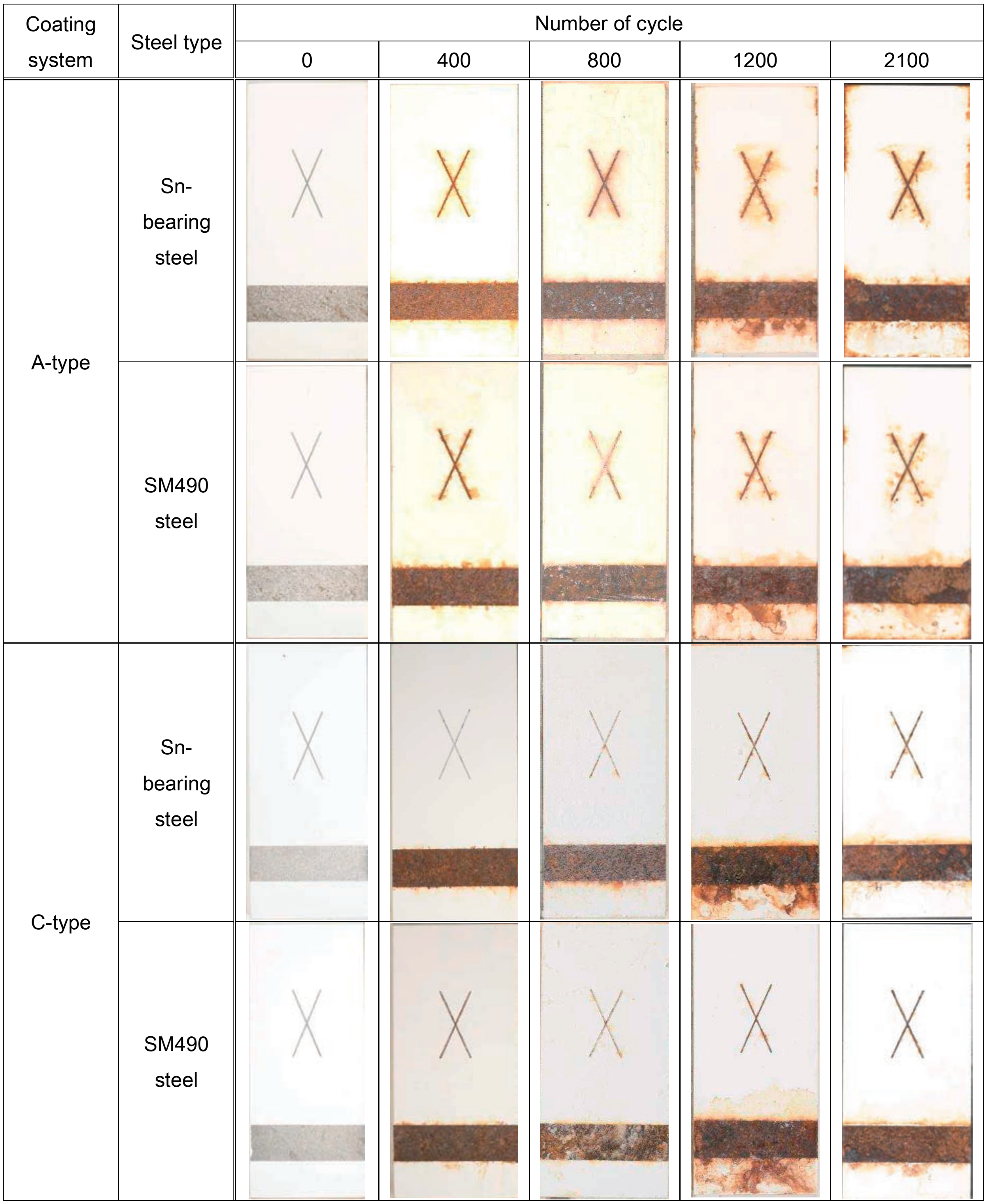

Fig. 3: Appearance of specimen

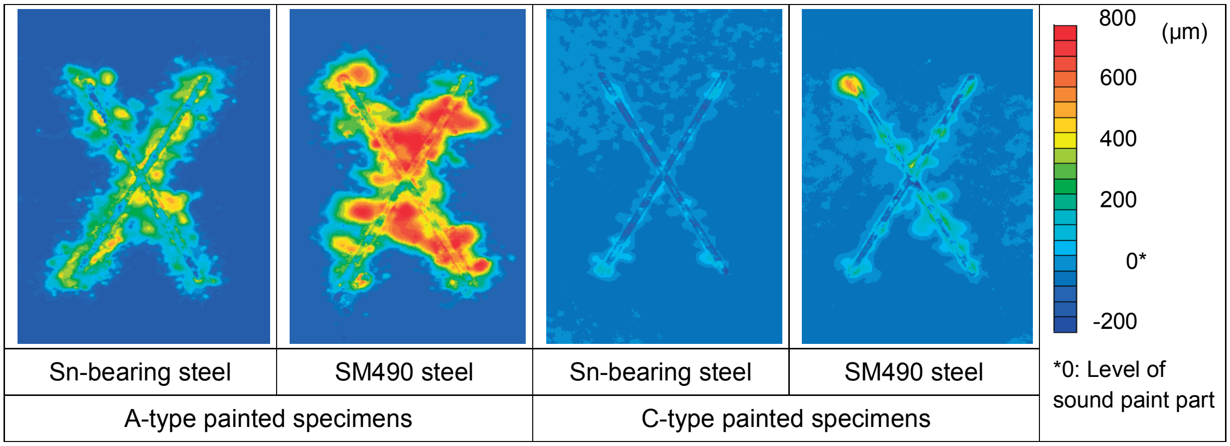

Fig. 4: Blister of X-cross scribed regions (after 2100 cycles)

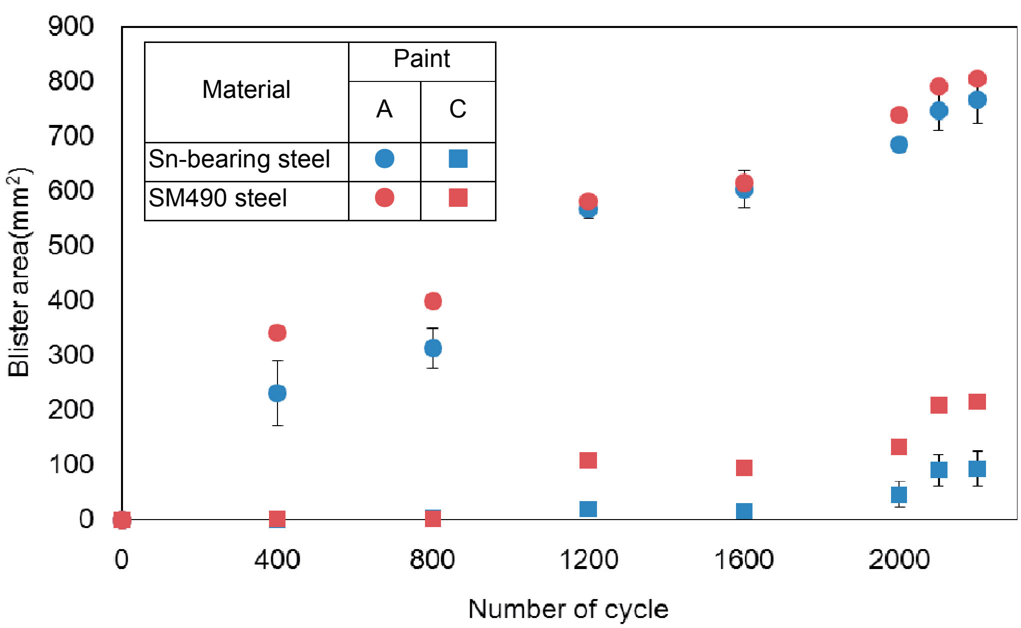

Fig. 5: Changes of blister area

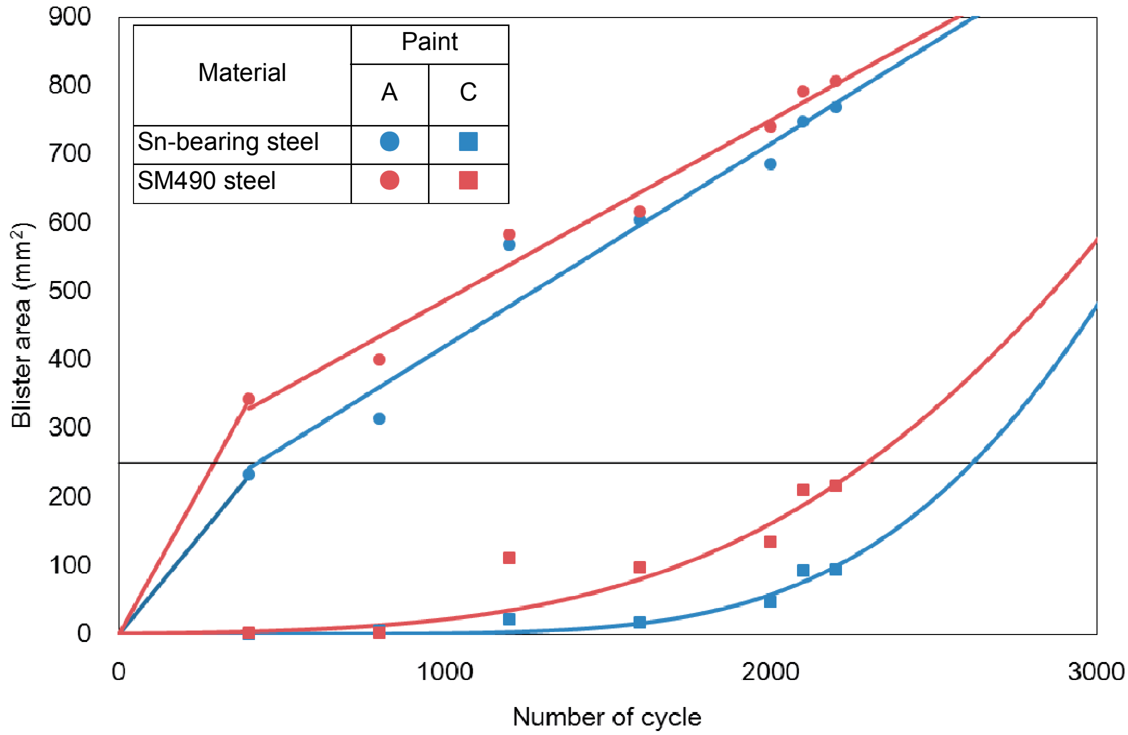

Fig. 6: Estimation line or curve of blister area

Table 3: The number of cycles when blister area percent is 5 %

	A-type coating	C-type coating
Sn-bearing steel	432	2620
SM490 steel	293	2296
Ratio (Sn-bearing steel /SM490 steel)	1.47	1.14

6. Conclusion

For investigating basic corrosion characteristics of the newly developed Sn-bearing steel, a series of the accelerated exposure tests with combined cycles of salt spraying, wetting and drying (S6 cycles) during 2200 cycles (550 days) was carried out. The results showed that Sn-bearing steel inhibited the blister of paint coating. In the case of using Sn-bearing steel for steel bridges, the contribution to life span of paint coatings was discussed. The obtained results are as follows.

(1) In A-type painted specimens, the blister area from the cross scribe paint defect of the Sn-bearing steel was around 95 % of that of the SM490 steel at 2200 cycles. In C-type painted specimens, the blister areas from the cross scribe paint defect of the Sn-bearing steel was around 43% of that of the SM490 steel at 2200 cycles.

(2) 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 using the Sn-bearing steel. For C-type coating, the use of Sn-bearing steel to bridges has the possibility to prolong the life span of paint coating by around 15 %.

Because there is the dispersion of the test results and estimation curve, it is necessary to check the appropriateness of estimation curve and improve the precision of by considering the future result of accelerated exposure test after 2200 cycles.

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