Technical Report

UDC 669 . 14 . 018 . 821

Development and Practical Application of Corrosion Resistance Steel for Painting Cycle Extension (CORSPACE™)

Kiyonobu SUGAE*
Takayuki KAMIMURA
Ryuichi ANDO
Takeshi TSUZUKI

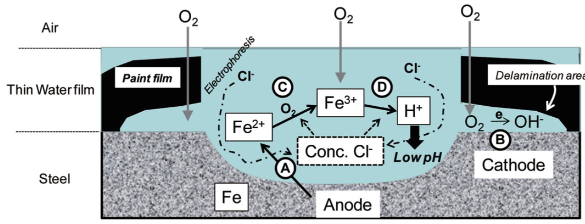
Abstract

We have developed the newly Sn-bearing steel, corrosion resistance steel for painting cycle extension (CORSPACE™). CORSPACE reduces life-cycle cost of steel structures exposed to high chloride content environments because of its superior atmospheric corrosion resistance at defect of paint film. In this report, the anti-corrosion performance at the defect of paint film of CORSPACE, and its mechanical and welding properties are mainly described for the use of steel structures.

1. Introduction

In Japan, a large number of social infrastructures such as bridges, ports, or industrial plants were constructed in the 1960s–1970s. In the near future, these social infrastructures will be over 50 years old since their constructions and will face decrepit. The rate of the social infrastructures requiring large-scale repair is expected to increase rapidly in the coming decades. One of the main decrepit factors is the corrosion of steel structure. In general, the steel structure is coated to prevent corrosion. However, it is well known that corrosion occurs at an invisible pin hole of paint film or a thinner paint film area of the edge or corner of the steel structure. Especially, the corrosion progresses markedly under the condition containing high amount of chlorides such as a coastal area. It is expected that the repairing and repainting cost of corroded steel structures will rise, and that maintenance of the steel structures would be more difficult due to economic impact of the maintenance cost. A new technology to reduce the life cycle cost (LCC) of the social infrastructures is needed. Thus, we have developed new anti-corrosion steel to reduce the LCC of the social infrastructures and to contribute to the sustainable development of our society.

We have already proposed the schematic corrosion model of steel at the paint defect under atmospheric condition containing chlorides. The corrosion model of steel at the paint defect is shown in **Fig. 1**.[1)] The corrosion model is described and based on the basic studies of atmospheric corrosion such as solution chemistry or electrochemistry.[2–4)] The atmospheric corrosion of steel occurs in a thin water film on the surface of steel under wet and dry cyclic condition. The anode, where dissolution of Fe occurs, is fixed at the paint defect. The cathode is located in the contiguous area of the paint defect under the paint film. Chloride ions (Cl^-) are concentrated into the anode site by electrophoresis. The anodic reaction, oxidation of Fe^{2+}, and hydrolysis of Fe^{3+} are accelerated by Cl^-. The solution pH in the anode is decreased by the hydrolysis of Fe^{3+}.[3)] Hence, the condition of the paint defect could be changed to a low-pH solution containing high Cl^- concentration.[1)]



Ⓐ Anode reaction: $Fe \rightarrow Fe^{2+} + 2e$

Ⓑ Cathode reaction: $H_2O + 1/2\ O_2 + 2e \rightarrow 2OH^-$
$Fe^{3+} + e \rightarrow Fe^{2+}$

Ⓒ Oxydation: $Fe^{2+} + 1/4\ O_2 + H^+ \rightarrow Fe^{3+} + 1/2\ H_2O$

Ⓓ Hydrolysis of Fe^{3+}: $Fe^{3+} + H_2O \rightarrow Fe(OH)^{2+} + H^+$
$Fe^{3+} + 2H_2O \rightarrow Fe(OH)_2^{+} + 2H^+$
$2Fe^{3+} + 2H_2O \rightarrow Fe_2(OH)_2^{4+} + 2H^+$

Fig. 1 Schematic model of atmospheric corrosion of steel in presence of Cl^- [1)]

We found that Sn improves the corrosion resistance of steel dramatically under atmospheric conditions.[1, 3, 4)] We have launched to develop Sn-bearing steel exerting superior corrosion resistance at the paint defect, corrosion resistance steel for painting cycle extension (CORSPACE™). In this report, we explain the effect of Sn on the corrosion resistance at the paint defect under an atmospheric

* Researcher, Materials Reliability Research Lab., Steel Research Laboratories
1-8 Fuso-cho, Amagasaki City, Hyogo Pref. 660-0891

condition containing chlorides. Furthermore, we introduce superior corrosion resistance at the paint defect, mechanical properties of CORSPACE,[1, 4, 5] and also weldability and mechanical properties of weld zone of CORSPACE.[6–8]

2. Effect of Sn on Corrosion Resistance of Steel under Atmospheric Condition Containing Chlorides

2.1 Effect of Sn on corrosion resistance at the paint defect

Three types of steel compositions were cast for the experiments. First, an alloy steel without Sn and a 0.05%C addition (Fe); second, an alloy steel with 0.05%C and 0.1%Sn (Fe-0.1Sn); third, an alloy steel with 0.05% and 0.5%Sn (Fe-0.5) using the vacuum melting. Samples from cast ingots were cut in blocks. The block was reheated to 1200°C for 60 min and hot rolled to a thickness of 6–8 mm. Hot rolling was performed with 20% reduction of thickness and the finish rolling was done at 850°C. After hot rolling, the steel plate was cooled down to room temperature. Test specimen was prepared to $60 \times 100 \times 3$ mm^3 by machining works. The surface of test specimen was blast finished before coating. Paint resign was modified epoxy resin (BANNOH 200™) provided by Chugoku Marine Paints, Ltd. The paint film was prepared by spraying to a thickness of approximately 180 μm. To simulate a paint defect, paint scribes were scratched by a plastic cutter until the steel surface was exposed.

The coated test specimen was evaluated by an accelerated corrosion test of SAE J 2334 cycle test.[9] The SAE J 2334 test is one of the accelerated corrosion tests under wet and dry cyclic conditions established by the Society of Automotive Engineers, which can simulate the severe atmospheric corrosion environments with high chloride content[10] and is widely used for the evaluation of atmospheric corrosion resistance of steels.[11] The SAE J 2334 test cycle is shown in detail in **Fig. 2**.[9] Since the solution in salt application stage contains $CaCl_2$, the surface of the steels probably is not dried out completely even in the dry stage. Therefore, the environment of the thin water film could be changed to a low-pH condition with high Cl^- concentration.

After SAE J 2334 test cycle was performed, the paint film was removed by a cutter knife till the border of the corroded area. Then, delamination area and corrosion depth were measured. The changes of delamination area and corrosion depth are given in **Fig. 3**.[4, 5] The delamination area and corrosion depth for Fe-0.1 Sn were smaller than that for Fe. In addition, Sn-bearing steel showed superior corrosion resistance at the repainting defect over the surface remaining rust layer and chlorides.[5]

2.2 Effect of Sn on anodic dissolution of Fe

According the corrosion model of paint defect under atmospheric condition containing chlorides described in Fig. 1, the anode is located in the paint defect, as shown in Fig. 1. Cl^- is concentrated by electrophoresis into the anode.[1)] Cl^- accelerates the anodic reaction, oxidation of Fe^{2+}, and hydrolysis of Fe^{3+}. The solution pH of the anode decreases by the hydrolysis of Fe^{3+}. Hence, the condition of the paint defect could be changed to a low-pH solution containing high Cl^- concentration. In order to clarify the effect of Sn on the corrosion reaction, the electrochemical measurement for Sn-bearing steel were conducted in 3% NaCl solution adjusted to pH 1.0 by HCl. The polarization curves for Fe, Fe-0.1Sn, and Fe-0.5Sn are shown in **Fig. 4**.[3]

The anodic dissolution for Fe-0.1Sn and Fe-0.5Sn were markedly inhibited compared with that for Fe. Since the solution volume is small under thin electrolyte, a small amount of Sn^{2+} ion ($SnCl_2$) was added to the test solution of 3% NaCl adjusted to pH 1.0 by HCl, electrochemical measurements for Fe were conducted using a similar method. The polarization curves for Fe in the low-pH solution containing a small amount of Sn^{2+} ion are shown in **Fig. 5**.[3] It was

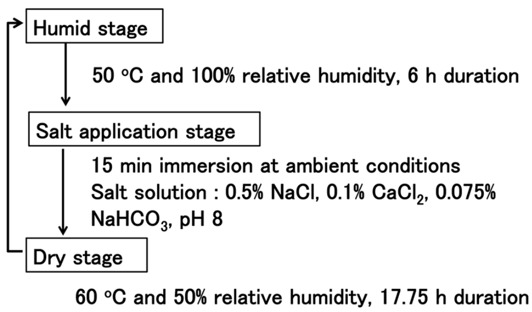


Fig. 2 Test cycle condition of SAE J 2334[9]

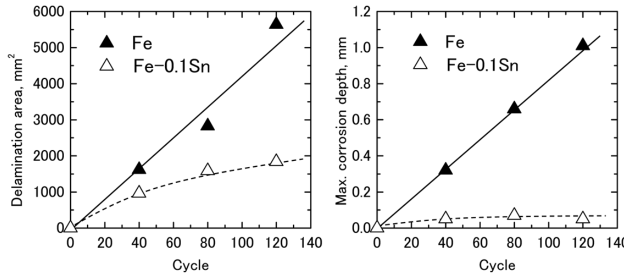


Fig. 3 Effect of Sn on changes in delamination area (left) and corrosion depth (right) as function of test cycles for epoxy resin coated steel[4, 5]

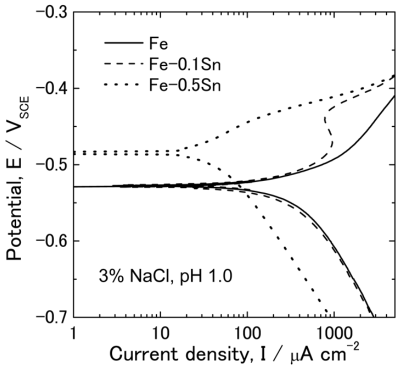


Fig. 4 Polarization curve of Sn-bearing steel in acidic solution[3]

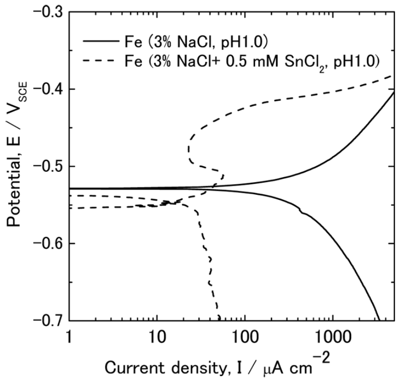


Fig. 5 Effect of Sn^{2+} on polarization behavior of Fe in acidic solution[2]

found that the anodic dissolution for Fe was dramatically inhibited only the 0.1 mM $SnCl_2$.[12] The cathodic reaction was also inhibited as well, as shown in Fig.5.[3] The inhibition of cathode reaction for Fe by Sn^{2+} ion is probably caused by the high overvoltage of deposited Sn. Therefore, the Sn bearing steel exhibits the superior atmospheric corrosion resistance at the paint defect under the atmospheric condition. The superior corrosion resistance of the Sn bearing steel can be caused by inhibition of anode reaction by a small amount of Sn ion dissolved at the local anode site.[3, 12–14]

3. Characteristics of CORSPACE

3.1 Mechanical properties of commercially produced CORSPACE

SM490YB (JIS G 3106 rolled steel for welded construction) is used for many steel structures. In this study, SM490YB was prepared as the reference steel.[15, 16] Blooms of approximately 250 tons were produced by commercial converter with a chemical composition described in **Table 1**.[4] In general, the addition of Sn to steel plate causes a decline of hot ductility,[17] and foments Cu-induced red shortness.[18] However, it has been confirmed that it is possible to manufacture CORSPACE without these difficult problems after controlling chemical compositions.[19] The mechanical properties of CORSPACE are described in **Table 2** and **3**.[4] Thus, it has been confirmed that CORSPACE meets the requirements of JIS G 3106.[15, 16] Thereby, CORSPACE is supplied as a JIS G 3106 rolled steel plate.

3.2 Weldability and mechanical properties of weld zones of CORSPACE

The manufactured steel plates having thicknesses 20 and 50 mm are subjected to a groove weld test. The groove shapes are shown in **Fig. 6** and **Table 4**. Welding material is provided by Nippon Steel & Sumikin Welding Co., Ltd. Welding methods were applied gas metal arc melding and submerged arc welding. The welding conditions are shown in **Table 5**.[6] CORSPACE shows good weldability in either welding methods and with SM490 ordinary steel. The results of welded joint tests are shown in **Table 6**.[6] CORSPACE indicates good mechanical properties of weld zone in either welding methods. Thus, CORSPACE meets the requirements of JIS G 3106.[6, 15] Hence, CORSPACE is supplied as a JIS G rolled steel for welded construction.

3.3 Corrosion resistance of CORSPACE for paint defect

As mentioned in the Chapter 2, it has been clarified that Sn-bearing steel is possible to improve corrosion resistance for paint defect. In general, the steel structures such as steel bridge is coated by heavy duty coating consisting inorganic or organic zinc rich paint as a first coating.[20, 21] In order to clarify corrosion resistance of CORSPACE for paint defect of heavy duty coating, coated test

Table 1 Chemical compositions of developed steel (CORSPACE) produced at commercial plant (mass %) [4]

	Mark	Thickness (mm)	C	Si	Mn	P	S	Sn
Developed steel (CORSACE)	SM490YB-Z35S	9, 20, 50	0.16	0.35	1.42	0.010	0.002	Add*
Standard steel	SM490YB-Z35S	≦ 100	≦ 0.20	≦ 0.55	≦ 1.60	≦ 0.035	≦ 0.006	–

* Target mass% > 0.1 %

Table 2 Tensile test results of developed steel (CORSPACE) produced at commercial plant [4]

	Mark	Thickness (mm)	Yeild point or proof stress (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	
Developed steel (CORSPACE)	SM490YB-Z35S	9	450	580	No.1A test specimen	20
		20	428	564	No.1A test specimen	27
		50	393	546	No.4 test specimen	37
Standard steel	SM490YB-Z35S	5 < ≦ 16	365 ≦	490–610	No.1A test specimen	15 ≦
		16 < ≦ 40	355 ≦		No.1A test specimen	19 ≦
		40 < ≦ 75	335 ≦		No.4 test specimen	21 ≦

Table 3 Charpy impact test and tensile test results of developed steel (CORSPACE) produced by commercial plant [4]

	Mark	Thickness (mm)	Charpy absorbed energy (0°C) J	Thickness (mm)	Reduction along the thickness direction (%)	
Developed steel (CORSPACE)	SM490YB-Z35S	20	165	20	53, 64, 53	Average 57
		50	210	50	63, 64, 70	Average 66
Standard steel	SM490YB-Z35S	12 <	27 ≦ Average	15 ≦	25 ≦ Individual	35 ≦ Average

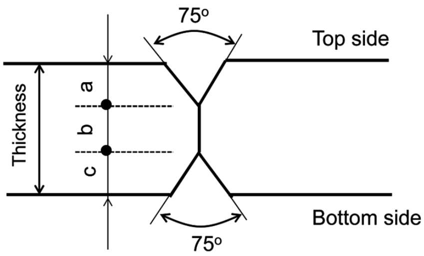


Fig. 6 Shape of groove [6]

Table 4 Shape of groove [6]

		GMAW			SAW		
		a	b	c	a	b	c
Thickness (mm)	20	10	3	7	6	7	7
	50	25	3	22	23	7	20

Table 5 Welding methods, materials and conditions (flat position welding without preheating) [6]

Welding methods		GMAW	SAW
Welding materials		NSSW FCM-1F (1.2 mm) CO_2 × 100% Standard: JIS Z 3313 YFW-C50DM	NSSW NF-100 (20 × D) × T-DS (4.8 mm) Standard: JIS Z 3183 S502-H
Thickness	20	280 A 36 V 300 mm/min 2.0 kJ/mm	Top side: 650 A 38 V 400 mm/min 3.7 kJ/mm
			Bottom side: 750 A 38 V 400 mm/min 4.9 kJ/mm
	50		Top and bottom side: 700 A 38 V 350 mm/min 4.6 kJ/mm

Table 6 Results of welding certification tests [6]

Mark		Thickness (mm)	Welding methods	Tensile testing of welded joint Tensile strength (N/mm²)	Face bend test	Side bend test	Charpy impact test JIS Z 3122 (0 °C) Charpy absorbed energy (J) Middle of welding material	HAZ 1 mm
Developed steel (CORSPACE)	SM490YB-Z35S	20	GMAW	616, 626 Average 621	N.C	N.C	58, 76, 65 Average 66	127, 146, 107 Average 127
			SAW	614, 620 Average 617	N.C	N.C	46, 48, 45 Average 46	93, 75, 56 Average 75
		50	GMAW	601, 605 Average 603	N.C	N.C	99, 113, 116 Average 109	133, 174, 102 Average 136
			SAW	610, 604 Average 607	N.C	N.C	119, 132, 119 Average 123	144, 153, 164 Average 154
Standard	SM490YB-Z35S	−	−	490 ≦	Do not crack		27 ≦ Avrage	

N.C means "No Crack"

specimens of CORSPACE and SM490 steel were prepared. It is well known that the heavy duty coating behaves superior corrosion resistance at paint defect for long time even under an accelerated corrosion test condition due to the high corrosion resistance of zinc rich paint. In this report, the test specimens were coated by the coating system described in **Table 7**.[4] The coated test specimen was subjected to SAE J 2334 test.

The appearance of paint defect is shown in **Fig. 7**.[4] The changes of paint delamination area and corrosion depth of paint defect are shown in **Fig. 8**.[4] After 40 test cycles, the appearance of paint defect of SM steel and CORSPACE was not observed. The corrosion and paint delamination at the paint defect were not changed. After 80 test cycle, the appearance of paint defect of SM steel was slightly observed. The corrosion depth and paint delamination at the paint defect of SM steel were slightly increased. While, the appearance of the paint defect of CORSPCE was not changed. After 120 test cycles, the appearance of paint defect of SM steel was markedly observed. The corrosion depth and paint delamination at the paint defect of SM steel were increased. Then, the appearance of paint defect of CORSPACE was slightly observed. The corrosion depth and paint delamination at the paint defect of CORSPACE were slightly increased. In case of SM steel, although the paint delamination was inhibited by zinc rich paint, the corrosion depth was larger than estimated from appearance. These results indicated that pitting corrosion type was observed at the paint defect of the bridge under the

Table 7 Coating specification [4]

	Painting process	Brand of paint	Thickness
First layer	Prime coat	Inorganic zinc rich primer	15 μm
Second layer	Under coat	Epoxy resin	60 μm
Third layer	Under coat	Epoxy resin	60 μm
Forth layer	Intermediate coat	Epoxy resin for fluorine contained resin	30 μm
Fifth layer	Top coat	Fluorine contained resin	25 μm

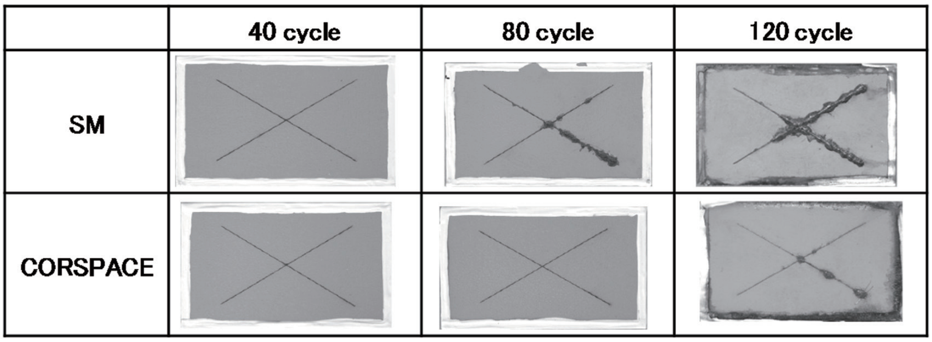


Fig. 7 Appearance of sample after removing the delaminated paint after SAE J 2334 test [4)]

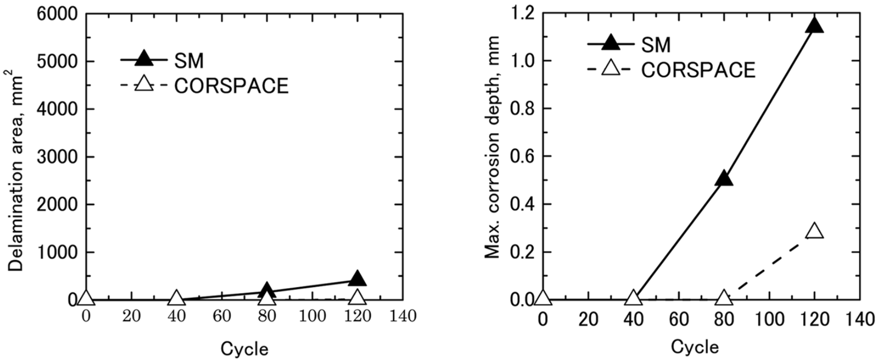


Fig. 8 Changes in delamination area and corrosion depth as function of test cycles for zinc primer painted steel [4)]
Left: Delamination area, Right: Corrosion depth

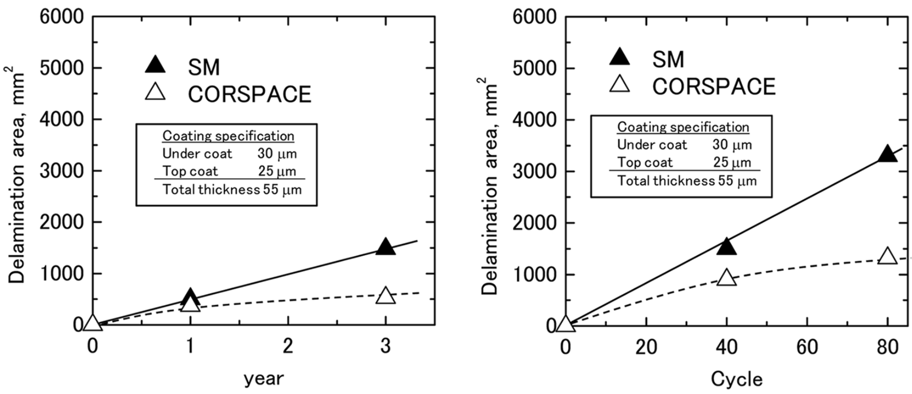


Fig. 9 Change in delamination area as function of exposed time for painted steel
Left: Exposed test at Higashi Kobe bridge [25)]**, Right: SAE J 2334 test**

environment with instance corrosion.[22, 23)]

It is confirmed that CORSPACE inhibits the paint delamination and corrosion depth and extends the periods of zinc-rich paint exerting corrosion resistance. CORSPACE also shows the superior corrosion resistance for paint defect and extends the effective periods of zinc-rich paint under S6 cycle test.[24)] S6 cycle test is also one of the simulated tests for atmospheric corrosion condition. It has been reported that corrosion loss for CORSPACE at the paint defect of heavy duty coating was inhibited by approximately 1.8 times compared with that for SM steel.[24)] In case of exposed test at Higashi Kobe bridge of Hanshin express way and Ohnaruto bridge of Kobe-Awaji-Naruto express way, the corrosion loss of CORSPACE at the paint defect was inhibited by approximately two times compared with that for SM steel.[25, 26)]

The results of exposed test at the Higashi Kobe bridge and SAE J 2334 cycle test are shown in **Fig. 9**.[25)] The test specimens were coated by the coating systems described in Fig. 9. CORSPACE-inhibited corrosion of paint defect under the exposed test. This result indicates that the environment of paint defect is changed to a low-pH solution containing high Cl^- concentration. Hence, CORSPACE exerts superior corrosion resistance by inhibition of a small amount of Sn ion for the anodic reaction at the paint defect of any kind of coating system. Therefore, CORSPACE extends to the cycle of maintenance periods including the life time of initial coating and repainting.

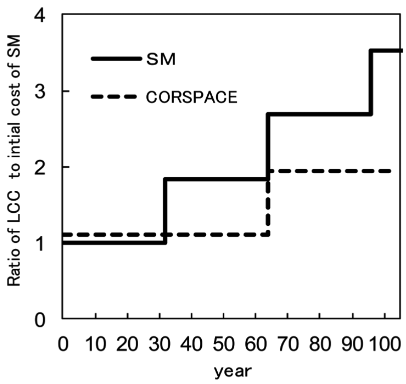


Fig. 10 Result of life cycle cost analysis of CORSPACE

Fig. 11 Example of the application of CORSPACE (Higashiharima-namboku Road)

4. LCC Reducing Effect of CORSPACE

The reducing impact of CORSPACE for LCC was calculated by the following four preconditions.

1) CORSPACE is exposed to the environment with instance corrosion containing high amount of air-borne chlorides.
2) When corrosion area or paint delamination area reach to 5% of the total area of steel structure, repainting is conducted.[27]
3) Steel structure is coated by the heavy duty coating. Then, effective period of initial coating on the edge or corner of steel structure is 30 years.
4) LCC in 100 years is calculated based on the initial and repainting costs in a handbook for high anti-corrosion performance coating.

As mentioned in the Chapter 3, CORSPACE extends the effective periods of zinc-rich paint and initial coating about two times longer than SM steel as the results of the exposed test and accelerated corrosion test.[24–26] LCC of CORSPACE was calculated according to these results of corrosion tests and the four preconditions. In general, the heavy duty coating applied to steel bridges include75 μm thickness of zinc rich paint as a first coating. Thus, it is considered that the heavy duty coating will help in showing superior performance for over 20 years.[28] However, it is well known that the periods of superior performance is decreased at the edge or corner of steel structure by corrosion because the edge or corner of steel is impossible to secure sufficient thickness of paint film. In this report, we assumed that the available periods of zinc-rich paint was for less than 20 years, and decided that the cycle of repainting was 32 years.

The changes of repainting cost of SM steel and CORSPACE coated by the high anti-corrosion performance coating are shown in **Fig. 10**. For SM steel, repainting is done three times in 100 years. In case of CORSPACE, repainting is required only once in 100 years due to high corrosion resistance of CORSPACE. Hence, it is expected that CORSPACE can reduce LCC to about half of that of SM steel.

5. Application Example

CORSPACE was applied for the first time in 2012 to “Mizuashi Shintsuji No. 5 Elevated Bridge” on the Higashi–Harima Namboku Highway in Kakogawa City, Hyogo Prefecture. Then, in 2013, it was adopted for Sampo Junction Bridge on Hanshin Expressway Route 4 Bayshore Line in Sakai City, Osaka. The point of application of CORSPACE to the Higashi-Harima Namboku Highway is shown in **Fig. 11**. In order to substantiate the effect of CORSPACE on the extension of painting cycle and the reduction of LCC, compact exposure test equipment has been installed to the actual bridge. The application of CORSPACE to steel structures other than bridges is also being pressed ahead positively.

6. Conclusion

According to the corrosion mechanism under the atmospheric condition containing high amount of air-borne salt particles, we developed a new high corrosion resistance steel, CORSPACE. CORPACE can extend the paint cycle due to its high corrosion resistance at the paint defect. It is confirmed that CORSPACE meets the mechanical properties and weldablilty of requirement for JIS G 3106 (rolled steel for welded steel structure). We hope that CORSPACE reduces the LCC of steel structures, including steel bridges, and helps in the sustainable development of our society.

References

1) Kamimura, T., Kashima, K., Sugae, K., Miyuki, H., Kudo, T.: Materials. 62 (3), 207 (2013)
2) Kamimura, T., Kashima, K., Sugae, K., Miyuki, H., Kudo, T.: Proc. JSCE Zairyo-to-Kankyo 2008. 2008, p. 335
3) Kamimura, T., Kashima, K., Sugae, K., Miyuki, H., Kudo, T.: Corros. Sci. 62, 34 (2012)
4) Kamimura, T., Nishio, M., Maeda, T., Yoshida, N., Kashima, K., Sugae, K., Miyuki, H., Kudo, T.: Zairyo-to-Kankyo. 62, 187 (2013)
5) Kamimura, T., Kashima, K., Sugae, K., Miyuki, H., Kudo, T.: Proc. JSCE Zairyo-to-Kankyo 2010. JSCE, 2010, p. 481
6) Nishio, M., Nakamura, H., Kamimura, T.: Proceedings of 65th Annual Academic Meeting of Japan Society of Civil Engineers. V-205, 2010, p. 409
7) Nishio, M., Kamimura, H., Yonemura, H., Okabe, K.: Proceedings of 66th Annual Academic Meeting of Japan Society of Civil Engineers. I-593, 2011, p. 1185
8) Kamimura, T., Nishio, M., Kashima, K., Miyuki, H., Nakamura, H.: CAMP-ISIJ. 24, 352 (2011)
9) SAE J 2334: Cosmetic Corrosion Lab Test. June 1998, SAE International, Warrendale, PA.
10) Nagano, H., Uchida, H., Yamashita, M.: Environmentally Benign Materials—Corrosion & Anticorrosion Engineering for Protection of Global Environment. Kyoritsu Shuppan Co., Ltd., 2004, p. 74
11) For example, Damgaard, N., Walbridge, S., Hansson, C., Yeung, J.: J. Const. Steel Res. 66, 1174 (2010)
12) Kashima, K., Kamimura, T., Sugae, K., Miyuki, H., Kudo, T.: Proc. 58th Japan Conf. Zairyo-to-Kankyo. JSCE, 2011, p. 101
13) Kashima, K., Kamimura, T., Sugae, K., Miyuki, H., Kudo, T.: Proc. 57th Japan Conf. Zairyo-to-Kankyo. JSCE, 2010, p. 284
14) Kashima, K., Kamimura, T., Sugae, K., Miyuki, H., Kudo, T.: Proc. 56th Japan Conf. Zairyo-to-Kankyo. JSCE, 2009, p. 317
15) JIS G 3106: Rolled Steels for Welded Structure, Japanese Industrial Standards, 2008
16) Japan Road Association: Road Bridge Specification with Explanations.

2002.
17) Song, S. H., Yuan, Z.-X., Jia, J., Guo, A.-M., Shen, D.-D.: Metall. Mater. Trans. A. 34A, 1611 (2003)
18) For example, Imai, N., Komatsubara, N., Kunishige, K.: ISIJ Int. 37, 217 (1997)
19) Yoshida, N., Taguchi, K.: CAMP-ISIJ. 24, 868 (2011)
20) Japanese Society of Steel Construction: Heavy-Duty Anticorrosion Coating—from Principles of Corrosion Prevention to Design, Execution and Maintenance Management. Gihodo Publishing Co., 2012, p. 33
21) Japan Road Association: Manual of Painting/Corrosion Prevention of Steel Road Bridges with Data. II-32, Maruzen Co., Ltd., 2005
22) Japan Road Association: Manual of Painting/Corrosion Prevention of Steel Road Bridges with Data. II-24, 25, Maruzen Co., Ltd., 2010
23) Tanaka, M.: Structure Painting. 38, 18 (2010)
24) Okuno, T., Hirohata, M., Kamimura, T., Ito, Y.: Presentation Meeting of Chubu Branch of Japan Society of Civil Engineers. I-003, 2014
25) Kanjo, N., Tobigaya, A., Maeda, T., Kamimura, T., Nishio, M.: Proceedings of 66th Annual Academic Meeting of Japan Society of Civil Engineers. I-595, 2011, p. 1189
26) Tabata, A., Tobigaya, A., Sumi, K., Kamimura, T., Maeda, T., Nishio, M.: Proceedings of 67th Annual Academic Meeting of Japan Society of Civil Engineers. I-144, 2012, p. 287
27) Hosoi, A., Ito, Y., Kaneko, K., Sugiura, Y.: Collection of Papers on Structural Engineering. 57A, 2011, p. 669
28) Japanese Society of Steel Construction: Heavy-Duty Anticorrosion Coating—from Principles of Corrosion Prevention to Design, Execution, and Maintenance Management. Gihodo Publishing Co., 2012, p. 68


Kiyonobu SUGAE
Researcher
Materials Reliability Research Lab.
Steel Research Laboratories
1-8 Fuso-cho, Amagasaki City, Hyogo Pref. 660-0891


Ryuichi ANDO
Senior Manager
Plate Products Technical Service & Solution Dept.
Plate Technology Div.
Plate Unit


Takayuki KAMIMURA
General Manager, Head of Lab., Dr.Eng.
Materials Reliability Research Lab.
Steel Research Laboratories


Takeshi TSUZUKI
Senior Manager
Plate Products Technical Service & Solution Dept.
Plate Technology Div.
Plate Unit