Development of a Process-saving Paint for Steel Structures

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ABSTRACT

Inspection of steel girder bridges often reveals corrosion damage—typically partial and small-scale corrosion caused by water leakage from an expansion joint. this repainting work imposes a significant burden in terms of time and money. Therefore,various types of process-saving paints began to be adopted experimentally. we conducted verification testing to compare the durability of different paints with the goal of selecting a more durable process-saving paint.

Key words: corrosion damage,a process-saving paint

INTRODUCTION

Inspection of steel girder bridges often reveals corrosion damage—typically partial and small-scale corrosion caused by water leakage from an expansion joint (Figure 1).
On the Tokyo Metropolitan Expressway, this type of corrosion damage is typically handled by restricting access to the street parallel to the steel girder bridge and repainting the affected parts of the bridge from an aerial work truck. The standard specifications for this repainting work are shown in Table 1. Note that a total of five coats are applied. As the painting process requires 1 coat per day for a total of 5 days, with lane closures required each day, it imposes a significant burden in terms of time and money. Since 2011, in the face of budget restrictions that threatened the pace of repairs of ever-increasing corrosion damage, various types of process-saving paints began to be adopted experimentally in these specifications. However, as the locations that were repaired using the process-saving paints began to exhibit corrosion again a few years later, we conducted verification testing to compare the durability of different paints with the goal of selecting a more durable process-saving paint.
The verification testing revealed that a solvent-free epoxy resin paint was especially durable, although it had high viscosity and inferior workability. We made improvements to the paint and finally developed a process-saving paint with excellent durability and workability.

In this paper, we report the results of our durability comparison and verification tests and explain our improvements to the high-durability, solvent-free epoxy resin paint.

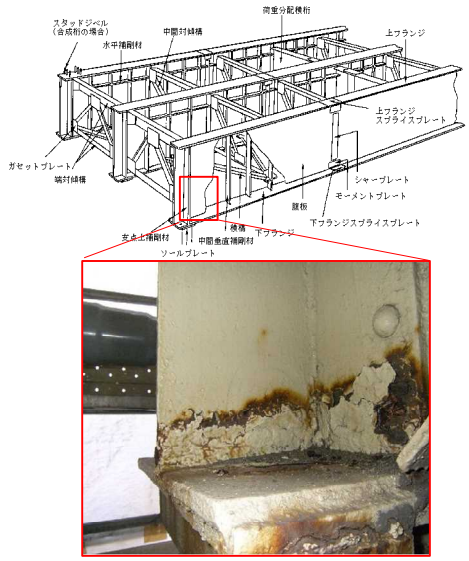


Figure 1 Corrosion damage

Table 1　Repainting work specifications

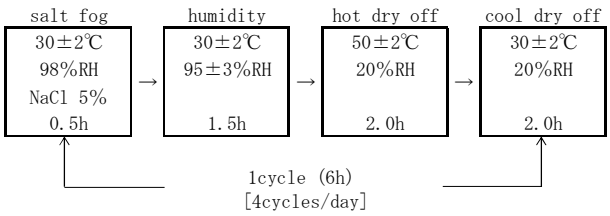
paint system	surface preparation	painting process	paint name	amount used g/m²	layer number	painting interval
NS－P3 (Tokyo Metro. Express. Standard)	cleaning type 3	undercoat (first)	modified epoxy-based resin paint ※	(200)	1	
		undercoat (second)	modified epoxy-based resin paint	200	2	1day ～10days
		undercoat (third)	super thick film type epoxy-based resin paint	500	3	1day ～10days
		undercoat (fourth)	super thick film type epoxy-based resin paint	500	4	1day ～10days
		intermediate and final coat	thick film type epoxy-based resin paint	230	5	

※for the exposed parts

DURABILITY COMPARISON AND VERIFICATION TESTS

Overview of test

To compare and verify the durability of the process-saving paints to be tested, we performed a combined cyclic corrosion test,1) which is designed to approximate the real environment. Figure 2 shows the test cycle conditions.
In the quality standards for the Tokyo Metropolitan Expressway (Table 2), a test period of 30 days (720 h) is specified, but as our goal was to select the most durable material, we used a test period of 180 days (4,320 h).
Every 7 days (168 h) during the test period, we checked the appearance of the test specimens and rotated their positions to prevent any differences in environmental conditions owing to the placement of the specimens.



test conditions	transition time
salt fog to humidity	within 10 minutes
humidity to hot dry off (50℃)	within 15 minutes
hot dry off (50℃) to cool dry off (30℃)	within 30 minutes
cool dry off (30℃) to salt fog	instantly

Figure 2　Combined cyclic corrosion test conditions

Table 2 Quality standards
(Tokyo Metropolitan Expressway)

cyclic corrosion test				criteria
test paint			exposure time (h)	
epoxy-based undercoat paint	single paint film	ordinary part	720h (30days)	showing no abnormalities
		cross-cut part		crack & blistering widths ≦4.0mm

Test specimens

To simulate repainting of the corroded area of an existing structure, the steel plate test specimens were first corroded by applying the combined cyclic corrosion test. An issue that arises in the field is that the locations where corrosion causes a partial loss of area become recessed, and the rust cannot be completely removed by surface preparation. To reproduce these conditions, in addition to the standard test specimens, we manufactured and tested specimens with an uneven, bumpy surface.
To check the impact of residual rust, both the standard and bumpy test specimens were treated with two different surface preparations: cleaning type 1 (blasting) and cleaning type 3 (disk grinder processing). The conditions of the test specimens are shown in Figure 3.

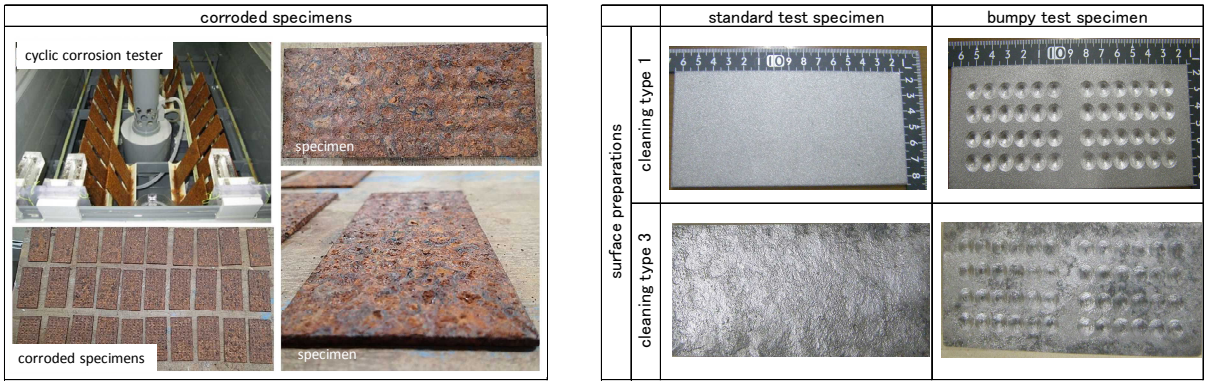


Figure 3 Test specimens

Test paints (process-saving paints)

The tests were performed on a total of six paints, comprising five paints that had a track record of use on the Tokyo Metropolitan Expressway, and a solvent-free epoxy resin paint that had never been used (Table 3). As the solvent-free epoxy resin paint had no track record of use, it was tested on only the cleaning type 1 surface preparation.

Table 3 Test paints

sign	process-saving paints (test paints)	undercoat total number of coats	undercoat total thickness μm	undercoat total working time	surface preparation cleaning type 1 (expousure time 4,320h)		surface preparation cleaning type 3 (expousure time 2,160h)	
					standard test specimen	bumpy test specimen	standard test specimen	bumpy test specimen
A	solvent-free	2	150	1day	○	○	○	○
B	zinc-based	2	400	1day	○	○	○	○
C	magnetite-based A	2	45	2days	○	○	○	○
D	aluminum-based	1	70	1day	○	○	○	○
E	magnetite-based B	1	70	1day	○	○	—※1	○
F	solvent-free epoxy resin	1	1,000	1day	○	○	—	—

※1 no-tested

TEST RESULTS

When the combined cyclic corrosion test was complete, we evaluated the appearance of the test specimen, the width of the deterioration of the cut part, and the adhesion of the paint.

Appearance

Appearance was evaluated in the four categories of rust, peeling, cracking, and blistering in accordance with the guidelines for the visual inspection of paint in the Painting Manual for Steel Highway Bridges of the Japanese Society of Steel Construction and the paint evaluation standards of the Japan Paint Inspection and Testing Association.

Rust

Rust was evaluated visually according to the rust grades shown in Figure 4. The results of the test are shown in Table 4. In Table 4, the colored cells show grade 1 evaluations, which indicate virtually no rust. Beyond 1,440 h, many paints were evaluated at grade 3 or higher, with rust observed over the entire test specimen. At 2,160 h, comparing the cleaning type 1 and type 3 surface preparations, the solvent-free paint (A on Table 3) and aluminum-based paint (D) were evaluated at grade 5 on the cleaning type 3 surface preparation, in contrast to grade 3 on the cleaning type 1 surface preparation, indicating that the rust progressed faster on the cleaning type 3 surface preparation, which may be partly due to residual rust at the time of surface preparation.

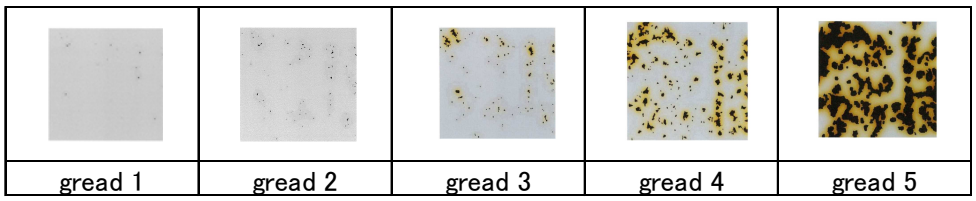


Figure 4　Rust grades

Table 4 Rust evaluation results

	surface preparation cleaning type 1	exposure time (h)						
		0	720	1,440	2,160	2,880	3,600	4,320
standard test specimen	A solvent-free	0	2	2	3	5	5	5
	B zinc-based	0	3	5	5	5	5	5
	C magnetite-based A	0	1	1	1	2	2	2
	D aluminum-based	0	2	3	3	4	4	4
	E magnetite-based B	0	1	2	2	2	2	3
	F solvent-free epoxy resin	0	0	0	1	1	1	2
bumpy test specimen	A solvent-free	0	1	3	3	5	5	5
	B zinc-based	0	3	5	5	5	5	5
	C magnetite-based A	0	2	3	3	4	4	5
	D aluminum-based	0	2	3	3	4	4	4
	E magnetite-based B	0	1	1	1	1	2	3
	F solvent-free epoxy resin	0	1	1	1	1	1	2

	surface preparation cleaning type 3	exposure time (h)						
		0	720	1,440	2,160	2,880	3,600	4,320
standard test specimen	A solvent-free	0	2	4	5	–	–	–
	B zinc-based	0	2	5	5	–	–	–
	C magnetite-based A	0	1	2	2	–	–	–
	D aluminum-based	0	3	4	5	–	–	–
	E magnetite-based B	–	–	–	–	–	–	–
	F solvent-free epoxy resin	–	–	–	–	–	–	–
bumpy test specimen	A solvent-free	0	2	4	5	–	–	–
	B zinc-based	0	2	5	5	–	–	–
	C magnetite-based A	0	2	3	4	–	–	–
	D aluminum-based	0	5	5	5	–	–	–
	E magnetite-based B	0	2	4	4	–	–	–
	F solvent-free epoxy resin	–	–	–	–	–	–	–

Peeling

Peeling was evaluated based on the surface area of peeling in accordance with Table 5. Representative results for the bumpy test specimens are shown in Table 6. In Table 6, the colored cells show grade 10 evaluations, which indicate no peeling. The solvent-free epoxy resin paint (F on Table 3) performed best, with grades of 10 all the way up to 3,600 h, whereas the other paints showed a decline in grades after 720 h.

Table 5　Peeling grade

grade	peeled area %	grade	peeled area %
10	no peeling	4	6～10%
9	0.5% or less	2	11～30%
8	06～2%	0	31% or more
6	3～5%		

Table 6 Peeling evaluation results (bumpy test specimens)

bumpy test specimen			exposure time (h)						
			0	720	1,440	2,160	2,880	3,600	4,320
surface preparation cleaning type 1	A	solvent-free	10	10	9	8	6	4	2
	B	zinc-based	10	10	0	0	0	0	0
	C	magnetite-based A	10	10	10	8	4	4	2
	D	aluminum-based	10	10	8	6	6	4	4
	E	magnetite-based B	10	10	10	8	8	6	2
	F	solvent-free epoxy resin	10	10	10	10	10	10	8
surface preparation cleaning type 3	A	solvent-free	10	10	9	8	–	–	–
	B	zinc-based	10	9	0	0	–	–	–
	C	magnetite-based A	10	10	9	9	–	–	–
	D	aluminum-based	10	9	2	0	–	–	–
	E	magnetite-based B	10	10	9	8	–	–	–
	F	solvent-free epoxy resin	–	–	–	–	–	–	–

Cracking

Cracking was evaluated in accordance with the reference diagram in Figure 5. Representative results for the bumpy test specimens are shown in Table 7. In Table 7, the colored cells show grade 10 evaluations, which indicate no cracking. The solvent-free epoxy resin paint (F on Table 3) performed best, with a grade of 8 at 4,320 h.

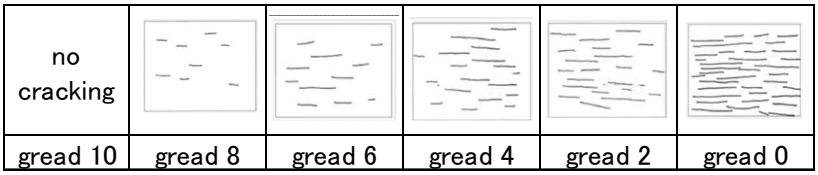


Figure 5　Gracking grades

Table 7 Cracking evaluation results (bumpy test specimens)

bumpy test specimen			exposure time (h)						
			0	720	1,440	2,160	2,880	3,600	4,320
surface preparation cleaning type 1	A	solvent-free	10	10	8	8	8	6	4
	B	zinc-based	10	8	0	0	0	0	0
	C	magnetite-based A	10	8	6	6	4	2	2
	D	aluminum-based	10	10	8	8	6	6	6
	E	magnetite-based B	10	10	10	10	10	8	8
	F	solvent-free epoxy resin	10	10	10	10	10	10	10
surface preparation cleaning type 3	A	solvent-free	10	10	8	8	–	–	–
	B	zinc-based	10	8	0	0	–	–	–
	C	magnetite-based A	10	10	10	10	–	–	–
	D	aluminum-based	10	10	10	8	–	–	–
	E	magnetite-based B	10	10	8	8	–	–	–
	F	solvent-free epoxy resin	–	–	–	–	–	–	–

Blistering

Blistering was evaluated according to the blister size as indicated in Table 8. Representative results for the bumpy test specimens are shown in Table 9. In Table 9, the colored cells show grade 10 evaluations, which indicate no blistering. The solvent-free epoxy resin paint (F on Table 3) performed best, with no evidence of blistering.

Table 8 Blistering grade

grade	diameter of blistering	grade	diameter of blistering
10	no blistering	4	0.6～1mm
8	0.1mm or less	2	2～3mm
6	0.2～0.5mm	0	4mm or more

Table 9 Blistering evaluation results (bumpy test specimens)

bumpy test specimen		exposure time (h)						
		0	720	1,440	2,160	2,880	3,600	4,320
surface preparation cleaning type 1	A solvent-free	10	10	10	8	6	2	2
	B zinc-based	10	10	0	0	0	0	0
	C magnetite-based A	10	10	10	4	2	2	0
	D aluminum-based	10	10	8	8	6	4	4
	E magnetite-based B	10	10	10	8	8	6	4
	F solvent-free epoxy resin	10	10	10	10	10	10	10
surface preparation cleaning type 3	A solvent-free	10	10	8	2	–	–	–
	B zinc-based	10	0	0	0	–	–	–
	C magnetite-based A	10	10	10	6	–	–	–
	D aluminum-based	10	4	4	2	–	–	–
	E magnetite-based B	10	10	8	6	–	–	–
	F solvent-free epoxy resin	–	–	–	–	–	–	–

Width of deterioration of the cut part

Table 10 shows the width of the deterioration (on the bumpy test specimens) from the part of the test specimen that was cut with an X shape. In Table 10, the colored cells show widths less than 4 mm. The solvent-free epoxy resin paint performed best, with almost no change up to 4,320 h. The other paints tended to show greater cut widths after 2,160 h.

Table 10 Width of deterioration of the cut part (bumpy test specimens)

bumby test specimen		exposure time (h)					
		720	1,440	2,160	2,880	3,600	4,320
surface preparation cleaning type 1	A solvent-free	0.45	0.75	5.00	5.00	5.00	5.00
	B zinc-based	0.45	0.45	0.45	paint peeling		
	C magnetite-based A	0.45	0.65	1.80	1.00	2.00	3.00
	D aluminum-based	0.50	0.95	0.70	7.00	9.00	9.00
	E magnetite-based B	0.45	0.60	1.30	7.00	7.00	7.00
	F solvent-free epoxy resin	0.45	0.45	0.45	0.45	0.45	0.45
surface preparation cleaning type 3	A solvent-free	0.5	0.6	0.7	–	–	–
	B zinc-based	0.45	0.45	0.45	–	–	–
	C magnetite-based A	0.45	0.45	0.5	–	–	–
	D aluminum-based	0.45	0.55	0.7	–	–	–
	E magnetite-based B	0.45	0.5	0.7	–	–	–
	F solvent-free epoxy resin	–	–	–	–	–	–

unit : mm

Paint adhesion

The adhesive force of the paint was measured quantitatively using an adhesion test after the end of the combined cyclic corrosion test (Figure 6).
All the paints exhibited weak adhesion to the cleaning type 3 surface preparation, with all the scores below 2.0 MPa. In contrast, for the cleaning type 3 surface preparation, the magnetite paint A (C on Table 3) and magnetite paint B (E on Table 3), aluminum-based paint (D on Table 3), and solvent-free epoxy resin paints (F on Table 3) exhibited high adhesion with scores above 2.0 MPa.
The paints exerted less adhesive force on the cleaning type 3 surface preparation likely owing to the effect of residual rust.

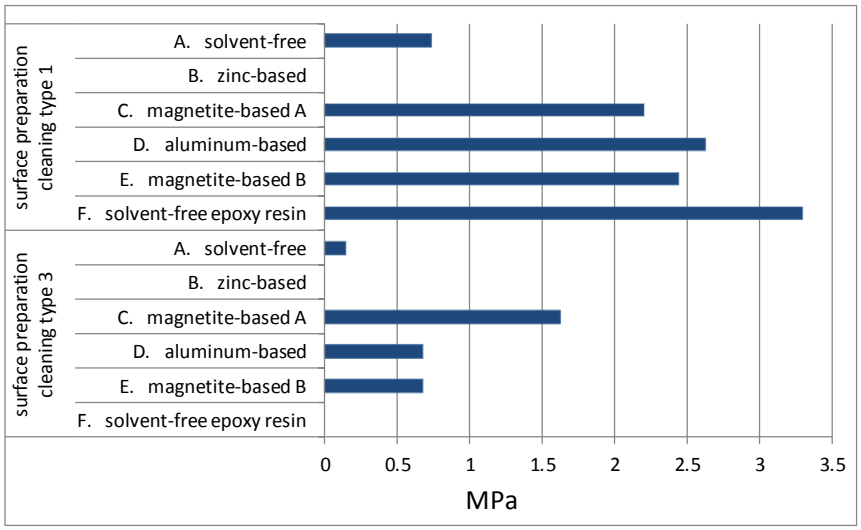


Figure 6 Paint adhesion results

Summary of test results

In our testing, most of the paints satisfied the standards of the Tokyo Metropolitan Expressway shown in Table 2; namely, at 30 days (720 h) of cycle testing, the paints showed no abnormalities, and the width of cracking and blistering was less than 4.0 mm.
However, beyond 30 days, most of the paints showed reduced durability. In contrast, the solvent-free epoxy resin paint, whose durability did not degrade even after 180 days (4,320 h) of cycle testing, proved to be a highly durable process-saving paint.

IMPROVEMENTS TO THE SOLVENT-FREE EPOXY RESIN PAINT

Overview of paint improvements

The combined cyclic corrosion testing confirmed that the solvent-free epoxy resin paint was highly durable. However, according to the paint performance analysis shown in Table 11, the pot life was only 20 min, the curing time was 16 h, and the paint was not suitable for brush painting because of its high viscosity.
Therefore, we improved its workability by changing the mixing ratio of the main agent and the curing agent. Table 12 summarizes the improvements to the paint. Owing to the possibility that our improvements might change the durability of the paint, we performed durability verification testing (combined cyclic corrosion testing) of the improved paint.

Table 11 Paint performance

pot life（25℃）	20 minutes
curing time（25℃）	16 hours
heatproof temperature	180℃
ignition point	none
flash point	main agent: 204.4℃ curing agent: 93.3℃
fire service act (in Japan)	main agent: designated combustibles curing agent: dengerous goods 4-class /petroleums Ⅲ

Table 12 Workability problems and improvements

	workability problems	after improvement
① viscosity	high viscosity and unsuitable for brushing	reduced viscosity to brush paint
② pot life	short (20 minutes)	improve to 50～60 minutes
③ curing time	long (16 hours)	improve to 8 hours (top coating is possible in 10 minutes)

Durability verification test results

The durability verification testing was performed in the same way as the comparison testing. The testing was performed for 360 days (8,640 h) on standard and bumpy test specimens with cleaning type 3 surface preparation, which is harsher owing to the residual rust.
Figure 7 shows the appearance of selected test specimens. As shown in the picture, rust from the cross-cut section was observed, but there was no peeling or cracking at the end of the 360-day test period. The width of the deterioration of the cut part was less than 1 mm, easily satisfying the standard of the Tokyo Metropolitan Expressway (4 mm or less at 30 days of cycle testing).
Similarly, the adhesion test results were between 2.68 and 8.93 MPa, satisfying the standard of 2.0 MPa required for adhesion, and demonstrating that the durability did not change after the improvements.
Based on the above results, we have begun using this paint for small-scale repainting work according to the specifications shown in Table 13. We have already established a track record covering approximately 1,800 m2 with the paint.

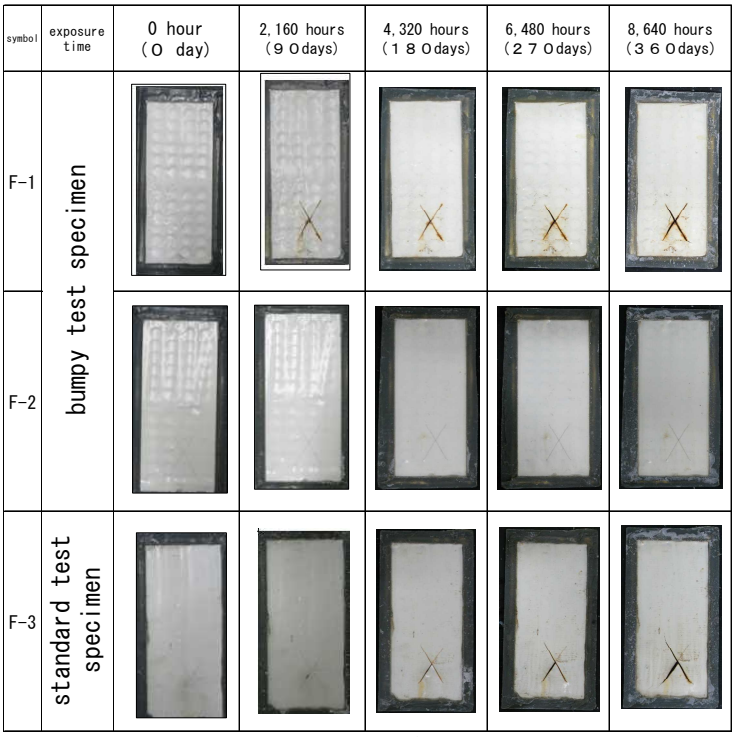


Figure **7 Appearance of test specimens**

Table 13 Small-scale repainting specifications

painting process	paint name	paint system	amount used g/m²	layer	painting method	painting interval
undercoat	solvent-free epoxy resin paint 【Devcon Brushable-S】	–	1,000	1	brushing	10minutes ～
finalcoat	water-based polyurethane resin paint	SDK W－531 ※	120	1		

※ Tokyo Metropolitan Expressway Standard

CONCLUSIONS

We conducted durability comparison and verification testing with the goal of applying a more durable process-saving paint for partial and small-scale corrosion damage repair. Our testing confirmed that the solvent-free epoxy resin paint had excellent durability, but because it was ultra-thick, its workability was low. Therefore, we made improvements to the paint to enhance its workability. We then conducted a durability verification test of the improved paint and confirmed that the durability did not change before and after the improvements.

Applying this paint, we were able to repair the affected areas in only one day of work, compared with the five days that were required in the past. Thus, it was possible to reduce costs by 70% and work time by 80%. Furthermore, as the paint is solvent-free and fire-safe, we plan to apply it widely to repair work in the future.

REFERENCES

1) Japanese Standards Association JIS K 5600-7-9:2006, Testing Methods for Paints - Part 7: Determination of Resistance to Cyclic Corrosion Conditions - Section 9: Salt Fog/Dry/Humidity - Annex 1 (Regulation) Cycle D

2) “Devcon Brushable-S Labor-Saving Heavy-Duty Anti-Corrosion Paint” (catalog)