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DURABILITY EVALUATION OF REPAINT-COATING ON STEEL WITH INITIAL PAINT－COATING REMOVED BY INDUCTION HEATING

Sota Inoue [1], Mikihito Hirohata [1, *] and Tomonori Nakahara [2]

[1] *Graduate School of Engineering, Osaka University, Suita, Japan*
[2] *Japan Bridge Corporation, Osaka, Japan*
* *(Corresponding author: E-mail: hirohata@civil.eng.osaka-u.ac.jp)*

A B S T R A C T

Repair of damaged paint-coating is an important issue in extending the service life of steel bridges. When repainting the paint-coating, the substrate steel is subject to surface preparation for removing the deteriorated original paint-coating and rust and appropriately making the steel surfaces rough. Although blasting and power tools are used for surface preparation, dust and noise are generated during the work. Therefore, the removal of paint-coating is performed prior to the surface preparation. A new paint-coating removal method by using induction heating (IH) is noted recently. The steel is rapidly heated by IH for removing the paint-coating easily. However, there are many unknowns regarding the influence of IH paint-coating removal on the durability of repaint-coating. In this study, the influence of removing paint-coating by IH on the durability of repaint-coating was evaluated through a series of accelerated corrosion experiments. The results of the 168-day accelerated corrosion experiments showed that the removal of paint-coating by IH did not cause a loss of the durability of repaint-coating compared to the case without using IH for the paint-coating removal.

A R T I C L E   H I S T O R Y

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K E Y W O R D S

Paint-coating;
Surface preparation;
Induction heating;
Acceleration corrosion experiment

1. Introduction

Corrosion is one of the main causes of deterioration of steel bridges, therefore, appropriate corrosion protections are required [1]. In Japan, a lot of steel bridges, such as Akashi Kaikyo Bridge and Tatara Bridge, have been built in coastal areas [2] where the environment is severe in terms of corrosion. Therefore, corrosion protection is essential to keep steel bridges in service safely. There are various corrosion protection methods such as metal spraying and use of weathering steel. The most widely used corrosion protection is paint-coating. However, due to deterioration caused by UV rays and water, the life of the coating is shorter than that of the structure itself. As a result, the paint-coating need to be replaced as necessary. A surface preparation performed in the repainting process removes rust and initial paint film from the steel surface. Furthermore, it provids an appropriate degree of roughness. The surface preparation is generally performed by blasting or power tools. In these cases, noise and dust are generated during the work because the rust and paint film are grinded from the surface. In particular, the paint-coating applied under past standards may contain toxic substances such as Pb and PCBs, it is important to ensure worker's safety. It is also necessary to prevent the dust from spreading into the surrounding environment. For these reasons, the deteriorated paint-coating might be removed by various methods prior to surface preparation.

One method that has recently been attracting attention is the use of induction heating (IH) to remove paint-coating. IH paint-coating removal has some advantages that the paint-coating can be easily removed after a short time heating and that the removed paint film can be collected in a dry sheet condition. It has been applied to the repainting of steel bridges in Japan [3]. However, the influences on the repaint-coating such as the degree of paint removal and the state of remaining paint-coating after the removal have not been fully elucidated. The objective of this study is to investigate the influence of the paint removal by IH on the durability of the repaint-coating. To accomplish this, a 168-day accelerated corrosion experiment was conducted. The specimens were paint-coated steel used in an actual bridge and were repainted for the experiment. Then, the durability of the repaint-coating with and without IH paint-coating removal prior to the surface preparation was compared.

2. Experimental specimen and condition

2.1. Experimental specimen

Fig. 1 shows the procedure for preparing the experimental specimens. In this experiment, 16 mm-thick paint-coated steel extracted from a girder of an actual bridge was cut into 150×70 mm pieces, and repainted. Prior to repaint-coating, cross-sectional observation of the initial paint-coating was conducted. As shown in Fig. 2, the initial paint film consisted of a total five layers. Three different repaint-coating systems, Rc-I, Rc-II, and Rc-III were prepared with and without IH paint-coating removal applied to each. The six conditions in total were set up for repaint-coating. The number of specimens was 18, three for each condition. All repaint-coatings are C-type based on epoxy and fluorocarbon rasins, the numbers of 'I', 'II', and 'III' indicate the degree of surface preparation. The following section describes each step of the specimen preparation process.

2.1.1. IH paint-coating removal

IH paint-coating removal was performed on 9 specimens. In this experiment, the entire surface of the specimen was subjected to the paint-coating removal. Fig. 3 shows the principal of IH paint-coating removal. A high-frequency current is applied to the coil in the device. When the device is brought

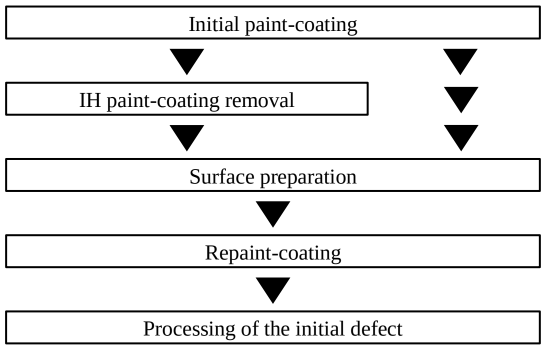


Fig. 1 Procedure for preparing specimens

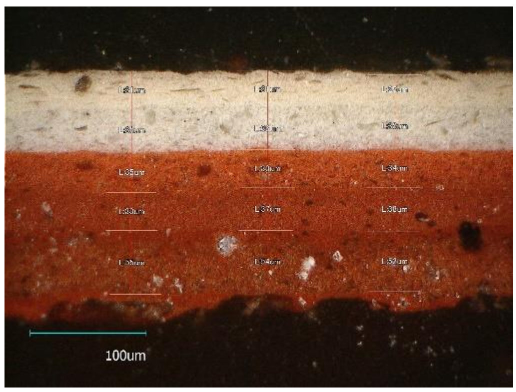


Fig. 2 Cross-section of initial paint-coating

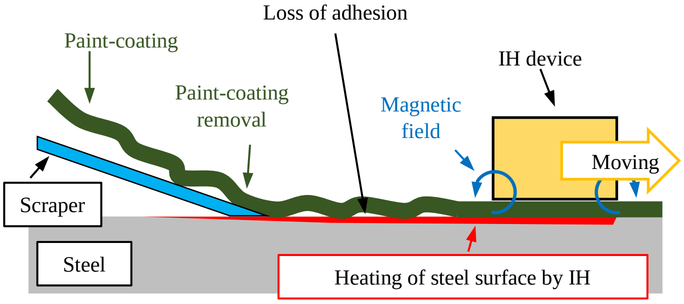


Fig. 3 Principal of IH paint-coating removal

a) Heating with IH

b) Removing by a scraper

Fig. 4 Procedure of paint-coating removal by IH

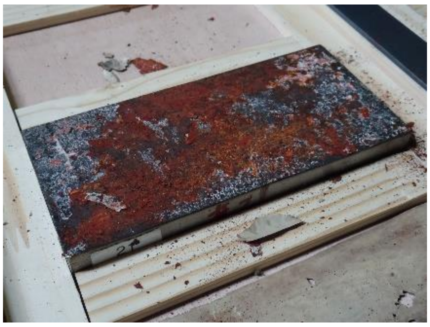


Fig. 5 Specimen after IH paint-coating removal

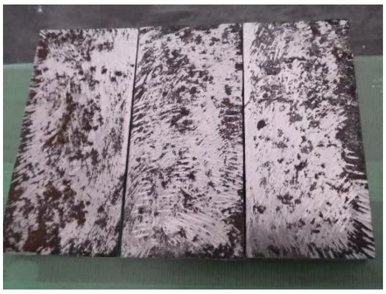
Table 1
Details of surface preparation

Type	Work method	Work content
Type-I	Blasting	Remove all rust and initial paint-coating
Type-II	Grinding	Remove all rust and initial paint-coating
Type-III	Grinding	Remove rust and deteriorated paint-coating

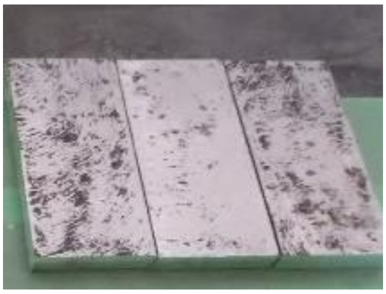
into close to the target steel surface, eddy currents are generated and the steel itself becomes a resistance and being heated. As the temperature rises to about 200 ℃, the adhesion between the paint-coating and the steel decreases. As a result, the paint-coating can be easily removed by using a scraper.

Fig. 4 shows the situation of IH paint-coating removal in this experiment. The induction heating coil manufactured by RPR Technologies was used as the heating device. When heating, the moving speed of the induction head was adjusted so that the temperature of the steel surface of specimen was 200 ℃. Fig. 5 shows an example of the specimen surface after the paint-coating removal. The black areas on the surface are the steel substrate, the white area is the primer of the initial paint-coating, and reddish-brown area is the undercoat. Although the degree of paint-coating remaining on each specimen was different, the upper layer of paint-coating could almost be removed from the undercoat. Possible reasons for the differences include variations in the heating temperature and the positions where the scraper blade attached.

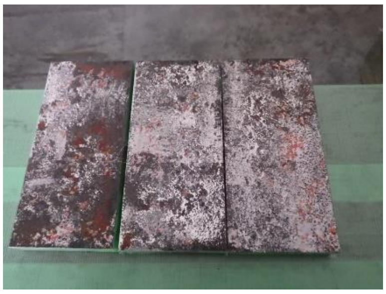
a) Type-I



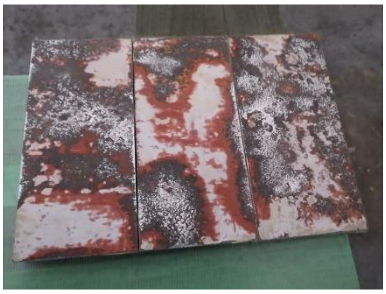
b) Type-II (IH)



c) Type-II (non-IH)



d) Type-III (IH)



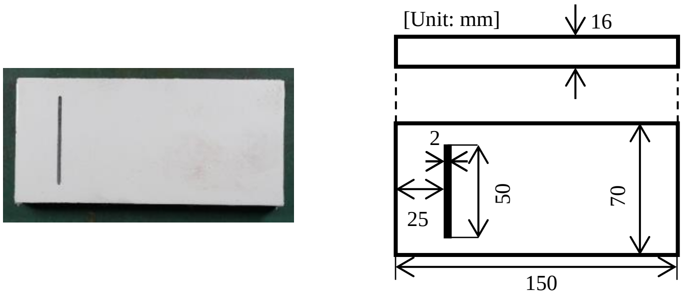
e) Type-III (non-IH)

Fig. 6 Specimens after surface preparation

2.1.2. Surface preparation

Table 1 shows the details of surface preparation. Three types of surface preparation, Type-I, Type-II, and Type-III, as regulated in the specification in Japan [4], were performed. For each type, two kinds of condition were set up. The one was that IH paint-coating removal was applied before surface preparation. The other was that the surface preparation was performed from the state where the initial paint-coating was adhered. In other words, the six different conditions in total were set for the surface preparation.

Fig. 6 shows the appearance of the specimens after surface preparation. In Type-I and Type-II, whole steel surfaces are exposed by blasting or power tools. Therefore, there was no difference in the surface condition depending on whether IH paint-coating removal was applied or not. On the other hand, Type-III specifies that the paint-coating maintains sound adhesion to the steel should be left. In this experiment, the specimens with IH paint-coating removal remained some parts of the undercoat, while the specimens without IH paint-coating removal remained some parts of the topcoat which seemed to be sound.



a) Appearance b) Dimensions

Fig. 7 Details of repaint-coated specimen

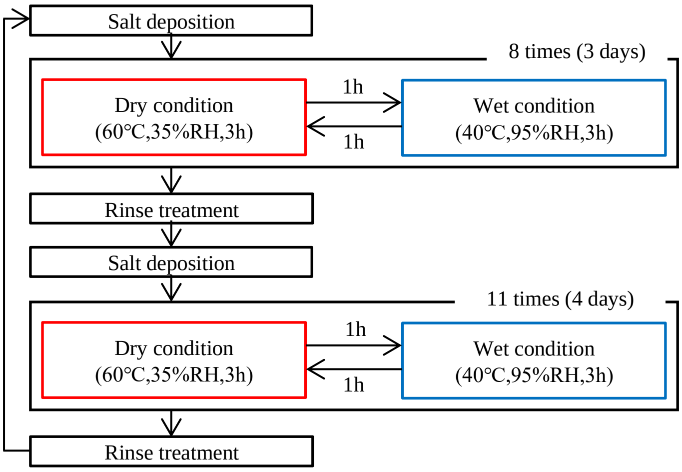


Fig. 8 Experimental condition of ISO16539-Method B

2.1.3. Repaint-coating

The specimens were repainted with Rc-I, Rc-II, and Rc-III paint-coating systems. The regulations in Japan [4] are shown in Table 2. Basically, the repaint-coating on the specimens also follows these regulations. However, for the convenience of the experiment, the paint method was changed to “spray” even if the paint method was “brush”. After the repaint was completed, the paint-coating thickness was measured and confirmed to be sufficient. After that, a linear scratch with 2 mm wide and 50 mm long reaching the steel substrate was processed as an initial defect at 25 mm from the edge of the specimen. Fig. 7 shows the appearance and dimensions of the specimen after the repainting.

Table 2
Details of repaint-coating systems [4]

Paint systems	Process	Paint type	Weight [g/m^2]	Paint method
Rc-I	Surface preparation	Type-I, ISO Sa2 1/2	-	-
	Protective underlay	Organic Zn-rich paint	600	Spray
	Undercoat	Epoxy resin	480	Spray
	Middlecoat	Fluorocarbon resin	170	Spray
	Topcoat	Fluorocarbon resin	140	Spray
Rc-II	Surface preparation	Type-II, ISO St3	-	-
	Protective underlay	Organic Zn-rich paint	240 (600)	Brush
	Undercoat	Epoxy resin	400	Brush
	Middlecoat	Fluorocarbon resin	140	Brush
	Topcoat	Fluorocarbon resin	120	Brush
Rc-III	Surface preparation	Type-III, ISO St3	-	-
	Undercoat	Epoxy resin	400 (600)	Brush
	Middlecoat	Fluorocarbon resin	140	Brush
	Topcoat	Fluorocarbon resin	120	Brush

2.2. Experimental condition

In this study, ISO16539-Method B was applied as the accelerated corrosion experiment. Fig. 8 shows the detailed condition of this experiment and Fig. 9 shows the apparatus used in the experiment. The experiment consisted of a seven-day cycle, and was based on a process of artificial seawater spraying using a salt spray apparatus, repetition of dry and wet conditions in an environmental test chamber, and rinsing of the specimen surface. To evaluate corrosion degradation, the specimen surfaces were photographed, and surface topography was measured using a laser displacement meter (Fig. 10) at 28, 84, and 168 days after the start of the experiment. The laser displacement measurement was made at intervals of 0.1 mm in longitudinal and transverse directions over an area of 50 mm × 70 mm centered on the initial defect.

a) Salt spraying apparatus b) Environmental test chamber

Fig. 9 Experimental apparatus

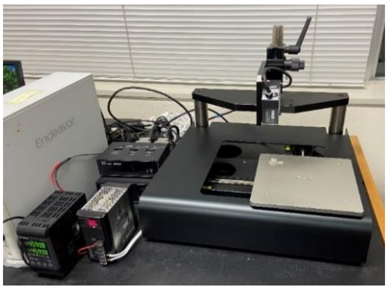


Fig. 10 Laser displacement meter

3. Experimental results ans discussions

3.1. Appearance of specimens

Fig. 11 shows the change in surface appearance of specimen during the experiment. In all paint-coating systems, there was no difference in appearance change depending on whether IH paint-coating removal was applied prior to the surface preparation or not. First, focusing on the sound areas of repaint-coating, stains due to rust fluid were observed in some areas. However, no degradation such as corrosion progress under the paint-coating, cracking or peeling of the paint-coating was observed. Next, the vicinity of the initial defect is noted. Fig. 12 shows the results of surface topography measurement by the laser displacement meter. Rust was observed at the initial defect in all specimens at 28 days after start of the experiment. Blistering was observed in the paint-coating near the initial defects, and the height and extent of the blistering tended to increase along with the experimental days. After 168 days, in some of specimens, the paint-coating were cracked or peeled off.

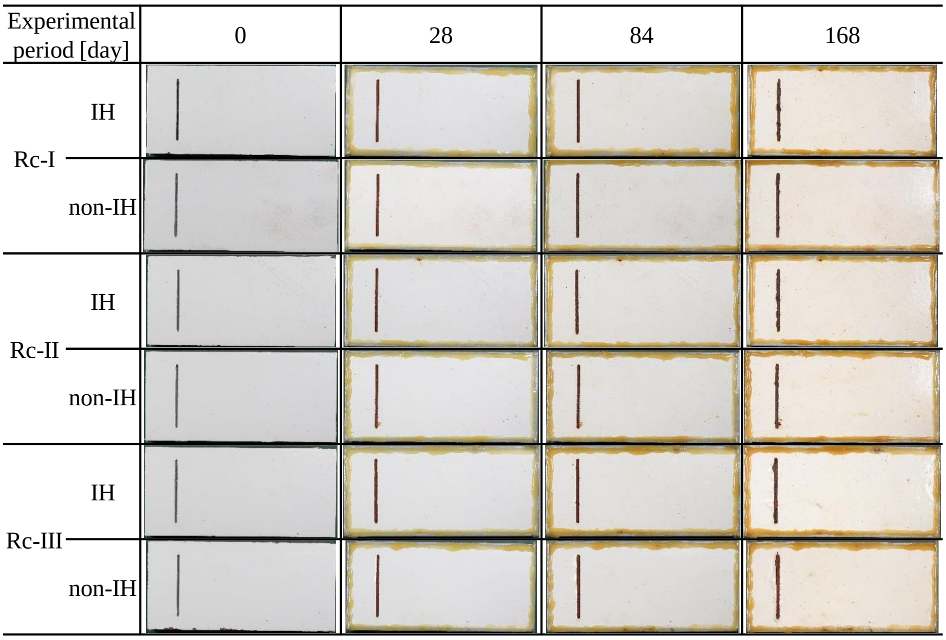


Fig. 11 Specimens after corrosion acceleration experiments

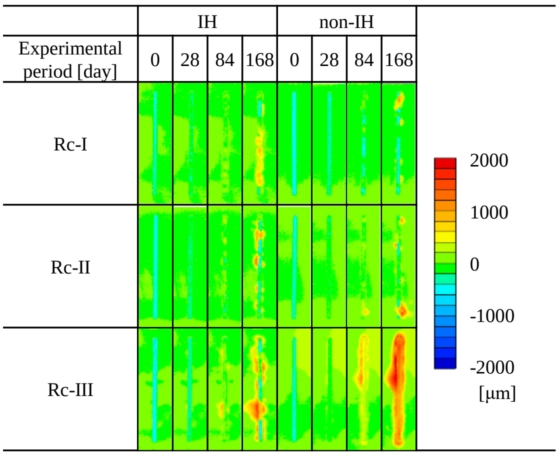


Fig. 12 Surface topography of specimens

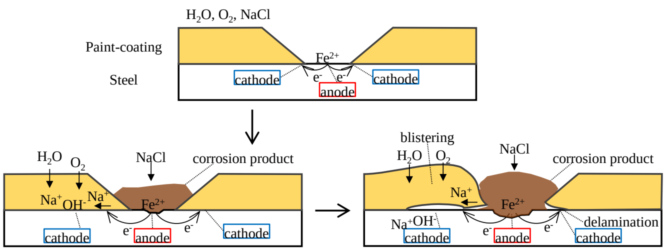


Fig. 13 Blistering mechanism [5]

3.2. Blistering area

It is known that in paint defect area reaching the steel surface, the steel just below the scratch acts as the anode and the steel under the paint-coating near the defect area acts as the cathode. Therefore, the large defects reaching the steel substrate cause blistering of the surrounding paint-coating by the mechanism shown in Fig. 13 [5]. In this experiment as well, blistering occurred near the initial defects. The height and extent of the blistering increased as the testing days progressed. This blistering might occur by the mechanism shown in Fig. 13. In this study, "blistering area" was defined as an evaluation index for paint-coating deterioration. This index indicates the area where the height of the paint film was more than 50 μm compared to the state before the experiment. The surface topography data measured by the laser displacement meter was used to calculate the blistering area.

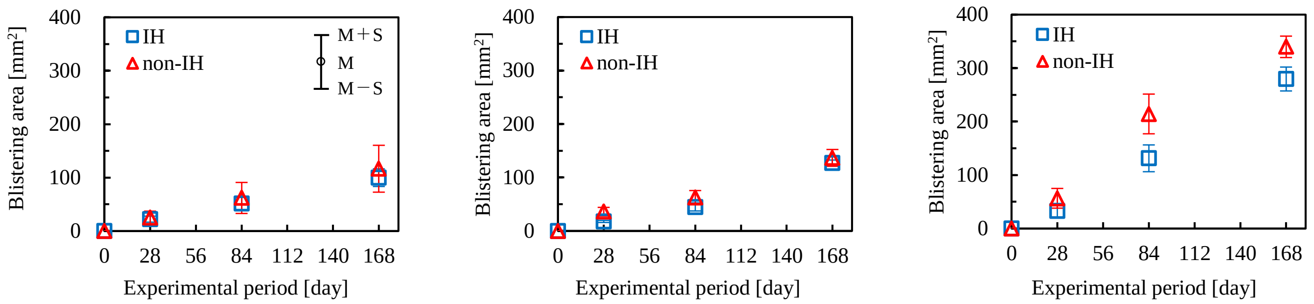
Fig. 14 shows the transitions of blistering area. The graphs show the mean value (M) and standard deviation (S) of the results of three specimens. For all paint-coating systems, the blistering area of IH specimens was slightly smaller than that of non-IH specimens. This suggests that the application of IH paint-coating removal does not cause a decrease in the durability of the repaint-coating.

3.3. Discussions

In Rc-III paint-coating system, the difference in blistering area between IH and non-IH was larger compared to the other paint-coating systems. In Rc-I and Rc-II paint-coating systems, all rust and initial paint film were removed in the surface preparation. Therefore, there was no difference in the steel substrate after surface preparation when comparing IH and non-IH. On the other hand, Rc-III paint-coating system left the sound paint film in surface preparation. This might be the reason for the larger difference in blister area in Rc-III paint-coating system.

Therefore, the percentage of remaining paint-coating on the specimens with Rc-III paint-coating system after surface preparation was calculated using the image analysis software WinROOF 2018. The calculated area percentage of remaining paint-coating is shown in Table 3, and the picture used for the calculation is shown in Fig. 15. In Fig. 15, the areas where the paint-coating remained are extracted and colored green. The area percentage of remaining paint-coating was about 20% in IH compared to non-IH. In non-IH, the topcoat remained in some areas, while in IH, remaining paint-coating was only undercoat. Therefore, the thickness of remaining paint-coating was also different. The difference in area and thickness might be the reason for the difference in blistering area.

However, it is difficult to evaluate whether the topcoat should be removed or not. It is possible that the undercoat deteriorates even under the sound topcoat. In the case of IH, almost all of the undercoat is exposed and then the surface is prepared using a power tool, which ensures that the deteriorated undercoat is removed. On the other hand, in the case of non-IH, where the sound topcoat is left, the repaint-coating is applied on the sound topcoat. It means that the paint film thickness is increased, therefore, the corrosion factors cannot penetrate the coating and reach the surface of the steel. The validity of these discussions depends on the types of the paint-coating system and the degradation degree of the initial paint-coating. It is necessary to accumulate data using other paint-coated steels and examine other aspects such as the adhesive strength of the initial paint-coating.

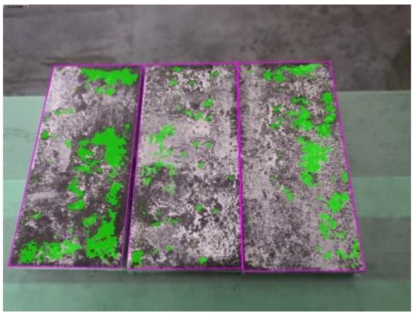


a) Rc-I b) Rc-II c) Rc-III

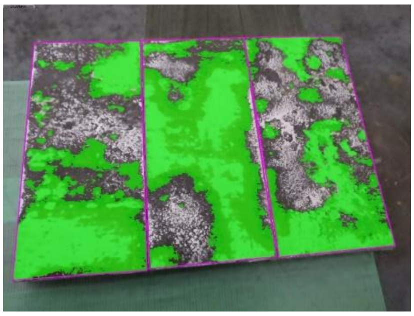
Fig. 14 Change in blistering area

Table 3
Percentage of remaining paint-coating

[%]	IH	non-IH
Undercoat	12.9	35.1
Topcoat	-	22.1
total	12.9	57.2



a) IH



b) non-IH

Fig. 15 Remained area of paint-coating

4. Conclusions

In this study, a series of accelerated corrosion experiments was conducted to investigate the influence of the removal of paint-coating by IH on the durability of repaint-coating. The main results are as follows.

(1) IH paint-coating removal was able to remove most of the upper layer of paint-coating from the undercoat on the actual bridge.
(2) After surface preparation, the condition of the steel substrate differed depending on whether IH paint-coating was applied prior to Type-III surface preparation only removing deteriorated paint-coating. On the other hand, no difference in the steel substrate was observed in Type-I and Type-II surface preparation removing all of rust and paint-coating.
(3) After 168-day accelerated corrosion experiment, rust occurred at the initial defects of specimens, and the paint-coating in the vicinity of the defects became blistering. It was confirmed that the extent and height of the blistering increased with the passage of experimental period, regardless of the paint-coating system and the use of IH paint-coating removal.
(4) Based on the results of blistering area, IH paint-coating removal did not cause a loss of the durability of repaint-coating compared to the case without using IH.

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