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Corrosion-Resistant Steel (RS-COAT)**

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Synopsis :

It is well-known that atmospheric corrosion resistant steel gives beautiful rust appearance, which has been formed during long period exposure. In initial exposure, however, its rust sometimes pollutes surrounding structures, flies itself in all directions and gives uneven appearance. RS-COAT has been developed to improve the above-mentioned weak points for the purpose of increasing the maintenance-free period of atmospheric corrosion resistant steel. On the basis of the investigation by coating and long period exposure tests, it is found that RS-COAT has the following beneficial characteristics. (1) Controlling corrosion rate at a low level as a result of moderately supplying such corrosive agents as O<sub>2</sub> or H<sub>2</sub>O to steel surface. (2) Preventing the outflow of Fe ion. (3) Keeping a fairly good appearance until the rust has been stabilized. (4) Acting as barrier and trapping layer against such corrosive agents as Cl<sup>-</sup> or SO<sub>x</sub>. (5) Economical one coating process. RS-COAT has successfully been used for such structures as roofs, bridges and walls.

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# Rust Stabilizing Surface Treatment for Atmospheric Corrosion-Resistant Steel (RS-COAT)\*

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- (1) Controlling corrosion rate at a low level as a result of moderately supplying such corrosive agents as  $O_2$  or  $H_2O$  to steel surface.
- (2) Preventing the outflow of Fe ion.
- (3) Keeping a fairly good appearance until the rust has been stabilized.
- (4) Acting as barrier and trapping layer against such corrosive agents as  $Cl^-$  or  $SO_x$ .
- (5) Economical one coating process.

*RS-COAT has successfully been used for such structures as roofs, bridges and walls.*

## 1 Introduction

Atmospheric corrosion-resistant steels are low-alloy steels that contain small amounts of alloying elements effective in providing atmospheric corrosion resistance, such as P, Cu, Ni and Cr. These steels are characterized by the fact that once a dark brown rust layer called "stable rust" is formed after several years of service, the corrosion rate thereafter decreases remarkably. When an atmospheric corrosion-resistant steel is subjected to a proper repetition of wetting by rain, dew, etc. and drying by sunshine, winds, etc., its tone of color changes from yellowish-brown to reddish-brown and finally to dark brown after several years. The greater part of the dark brown stable rust is amorphous and this rust layer serves as a barrier against corrosive substances from the air and suppresses further corrosion. This is why it is said, "Fight rust with rust."

In recent years, the use of unpainted atmospheric

corrosion-resistant steels has attracted attention in terms of maintenance-free structures in the field of bridges, buildings, etc. Although the use of atmospheric corrosion-resistant steels as-rolled or as-blasted is more economical<sup>1)</sup>, the scattering of fine particles of rust and the outflow of water containing yellow rust may sometimes contaminate surrounding concrete structures, etc. in the initial stage of service. Furthermore, there may be the problem of appearance until stable rust is uniformly formed.

Surface treatment generally called "rust stabilizing surface treatment"<sup>2)</sup> is adopted to solve these problems. In rust stabilizing surface treatment, stable rust is caused to form to prevent the above-mentioned outflow of rust-containing water and scattering of rust and to improve the appearance of steel and achieve an economical effect equal to that expected from the use of atmospheric corrosion-resistant steels as-rolled or as-blasted.

The authors have developed "RS-COAT" for use in this rust stabilizing surface treatment. RS-COAT is a single coating process that can be readily performed and is economical, and the endurance of RS-COAT film has been ascertained by exposure tests. In addition, satisfactory results have been obtained with respect to the application of this coat to actual structures. This report presents the features and performance of RS-COAT.

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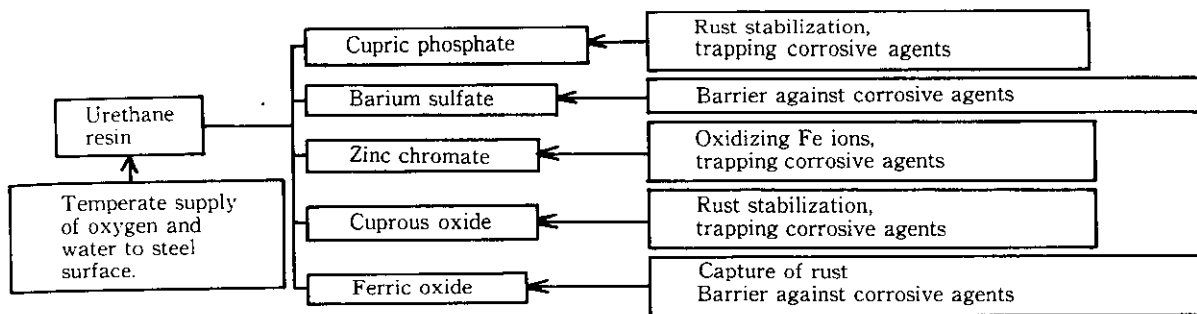


Fig. 1 Chemical composition of RS-COAT and their effects

## 2 Features of RS-COAT

RS-COAT uses a special urethane resin-based coating that contains various pigments effective in rust stabilization. It is considered that each vehicle and pigment has the effects shown in Fig. 1.

Pigments such as  $\text{Cu}_3(\text{PO}_4)_2$  and  $\text{BaSO}_4$  lower pH-value of steel surface, promote the dissolution of steel under a urethane resin coating, and thus contribute to the early stabilization of rust<sup>3)</sup>.  $\text{Fe}_2\text{O}_3$  is added to the vehicle to supply in advance a substance similar to the main rust component in real surface film. Iron oxide red, etc. are toning agents. The pigment volume concentration of the RS-COAT film is 40 to 60%. This special coating is applied in one coating operation to the surface of an atmospheric corrosion-resistant steel descaled by blasting or pickling in thicknesses between 40 and 50  $\mu\text{m}$ .

Since the urethane resin as a vehicle has a gas and water permeability, it supplies proper amounts of water and oxygen to the steel surface until stable rust is formed on the surface of an atmospheric corrosion-resistant steel. As a result, the rate of rust formation becomes slower than in an unpainted case, but because of the effects of vehicle and pigments, almost all of dissolved Fe ions remain as rust on the steel surface or in the RS-COAT film.

This almost completely prevents the outflow of rust-containing yellow water and the scattering of rust. In addition, the RS-COAT film has a decorative capacity to maintain the same beautiful appearance as ordinary films for several years. With the lapse of time the RS-COAT film and rust become coexistent on the surface, which is finally covered with stable rust all over. Up to the stage before the formation of stable rust all over the surface, the coexistence of the RS-COAT film with rust is not very conspicuous because the RS-COAT film has the color of rust. Furthermore, the RS-COAT process is excellent in workability and economics because only one coating operation is sufficient.

## 3 Steels Applicable to RS-COAT

The main purpose of RS-COAT is to prevent the contamination of surroundings with the rust-containing yellow water in the initial stage of service, which is often an issue when atmospheric corrosion-resistant steels are used unpainted or untreated. However, the higher the atmospheric corrosion resistance of a steel, the more effective the RS-COAT film formed on this steel in preventing the outflow of rust-containing yellow water and the easier the forming of the stable rust layer. Even when RS-COAT is applied, it is necessary to use steels of excellent atmospheric corrosion resistance as with the use of atmospheric corrosion-resistant steels as-rolled or as-blasted. Table 1 gives recommendable atmospheric corrosion-resistant steels suitable for RS-COAT.

JIS G3114-1983, Hot-Rolled Atmospheric Corrosion Resisting Steels for Welded Structure, specifies both steels for use in an unpainted condition (for example,

Table 1 Suitable grades of atmospheric corrosion resistant steels for RS-COAT coating

Type	Kawasaki steel corporation's designation	Corresponding JIS designation
Superior atmospheric corrosion resistant steels	River Ten R	SPA-H, SPA-C
	River Ten 50M	—
Atmospheric corrosion resistant steels for welded structures (for unpainted use)	River Ten E41A	SMA 41AW
	River Ten E41B	SMA 41BW
	River Ten E41C	SMA 41CW
	River Ten E50A	SMA 50AW
	River Ten E50B	SMA 50BW
	River Ten E50C	SMA 50CW
Atmospheric corrosion resistant high tension bolt	River Ten E58	SMA 58W
	F10TW	—

SMA 50AW) and those for use in a painted condition (for example, SMA 50AP). Some of these steels for use in a painted condition (KSC designation: River Ten 50A, etc.) have relatively low contents of elements effective in providing atmospheric corrosion resistance and their atmospheric corrosion resistance is not always sufficient for the RS-COAT application.

However, in inland regions of less influence by SO<sub>2</sub> gas and seashore particles, rust will stabilize even on a low-content of alloyed elements, unless affected by unfavorable conditions such as stagnant water; therefore, steels for use in a painted condition can be used as steels for RS-COAT in these regions.

RS-COAT is applicable to plates and sections, and to sheets for roofs, facing, etc. in the architectural field as well. For the latter application, the sheets specified in JIS G3125, Superior Atmospheric Corrosion Resisting Rolled Steels, SPA-H and SPA-C (corresponding KSC designation: River Ten R), are best suited.

#### 4 Coating Method of RS-COAT

As with ordinary coatings, the RS-COAT coating can be applied using an airless spray, air spray and brush. Furthermore, it makes shop painting and field painting both easy. Painting equipment used in ordinary coatings can be used. The agents used for RS-COAT, application conditions, color tones and coating process are described in the following.

##### 4.1 Coating Agents

RS-COAT uses a three-component urethane resin coating. The mixing ratio of base: additive: hardener is 100:4:2. The mixture is supplied in 20 kg and 40 kg packs.

#### 4.2 Application Conditions

The coating is applied under the same conditions as with ordinary coatings that dry at room temperature. The standard film thickness is 40 to 50 μm (wet film thickness: 120 to 150 μm) and the coating is applied by one coating operation.

#### 4.3 Tones of Color

The standard color of the RS-COAT film is chocolate. However, when importance is attached to the decorative character of this type of steel, reddish or blackish tones of color may be used because the tone of color of the stable rust of atmospheric corrosion-resistant steels varies somewhat depending on the environment in which they are used.

#### 4.4 Coating Process

Figure 2 shows the coating process of RS-COAT for plates (bridges, etc.) and sheets (buildings, etc.). As a rule, painting is performed in the shop and only repairs are made in the field.

### 5 Performance of RS-COAT

The weathering test of RS-COAT applied steels has been conducted since March, 1978. Various properties of the RS-COAT after five years of exposure are described in the following.

#### 5.1 Appearance

##### 5.1.1 Standard steel

Photo 1 shows the appearances of an RS-COAT applied steel (standard steel) and a non-treated steel after

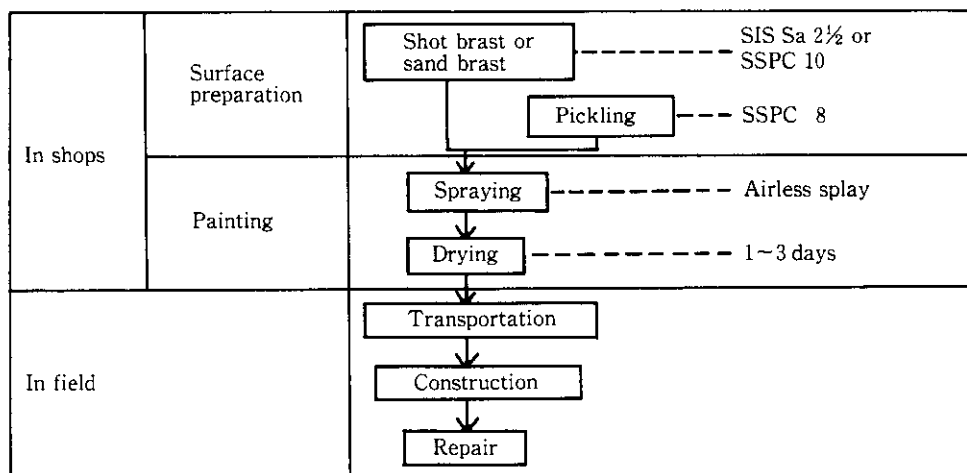


Fig. 2 Coating process of RS-COAT

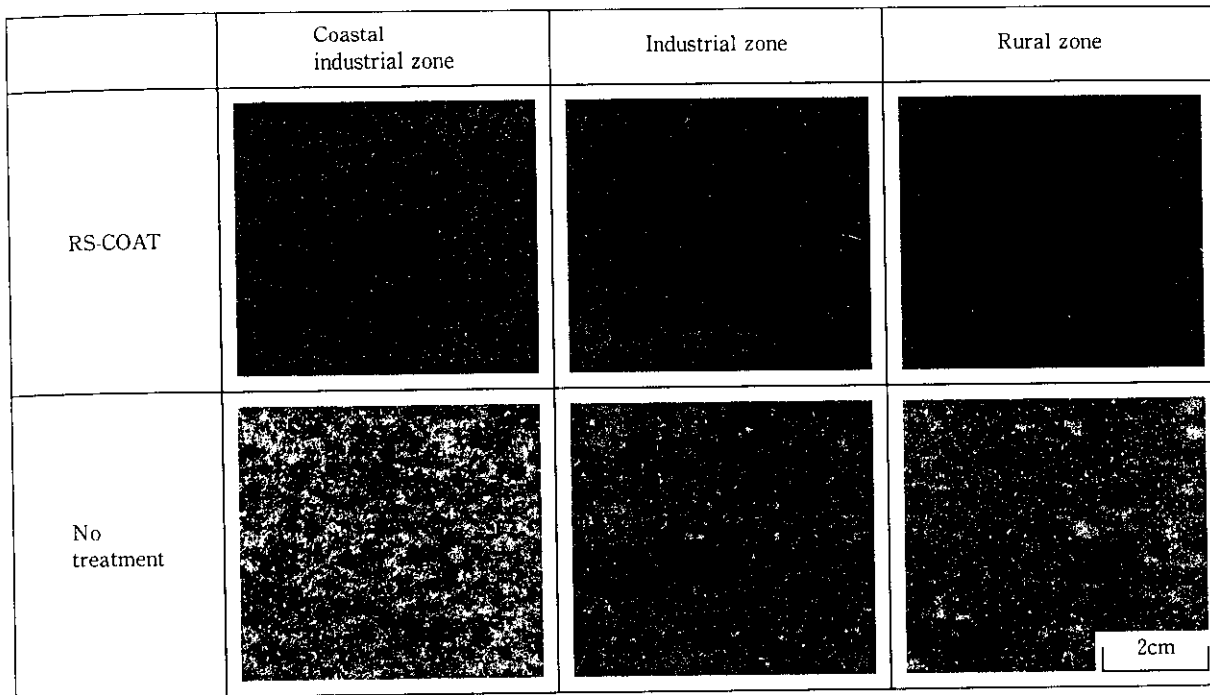


Photo 1 Appearance of specimens after five years exposure

five years of exposure in coastal industrial, industrial and rural zones in Chiba Prefecture. The atmospheric corrosion-resistant steel used is River Ten R (0.09%P-0.3%Cu-0.2%Ni-0.5%Cr).

The RS-COAT applied steel scarcely showed rusting in any zone until the second year of exposure. In the coastal industrial zone under very corrosive conditions, dot-like rust began to scatter in the third year or so and the amount of this dot-like rust increased gradually. In the fifth year, rust was observed almost all over the surface, assuming a uniform dark brown color. This suggests that stable rust was formed under the RS-COAT film. In the industrial and rural zones, the number of dots of rust was small even in the third year and dot-like rust was formed to a small degree in the fifth year.

In the RS-COAT applied steel, abrupt rusting did not occur in any zone; changes in the tone of color and rusting were very slow, and the beautiful appearance was kept good for five years. It is considered that with the exposure period getting longer, both the number of rust dots and rust area gradually increase with a result that the whole surface is finally covered with stable rust.

#### 5.1.2 Effects of surface preparation and film thickness

Specimens were subjected to three kinds of surface preparation, i.e., shot blasting, sand blasting and pickling. The RS-COAT was applied to the above specimens in film thicknesses of 20, 40 and 60  $\mu\text{m}$ . These speci-

mens were exposed to the air in the coastal industrial, industrial and rural zones for four years to investigate effects of surface preparation and film thickness.

Changes in the tone of color and the rusting behavior were almost the same in any zone and it was found that the effect of surface preparation was small.

In the coastal industrial zone, the film thickness was observed to have a great effect on the time until the formation of dot-like rust. With a film thickness of 20  $\mu\text{m}$ , the formation of dot-like rust was observed after about one year, while dot-like rust was formed after about one year and a half when the coating was applied to a film thickness of 40  $\mu\text{m}$ . In the case of 20  $\mu\text{m}$ , dot-like rust was formed in a short time because the supply of corrosive substances such as water and oxygen to the steel surface is large, and a slight outflow of rust was observed. Moreover, the formation of dot-like rust and changes in the tone of color of the appearance were rapid in this case. With a film thickness of 60  $\mu\text{m}$ , the formation of dot-like rust was observed after about two years and the rate of formation of dot-like rust was considerably lower than in the thicknesses of 20 and 40  $\mu\text{m}$ . Therefore, the appearance scarcely changed even after four years.

#### 5.2 Prevention of Outflow of Rust-Containing Yellow Water

Specimens of RS-COAT applied steel and non-treated steel were exposed to the air; rainwater streaming from these specimens was sampled, and the Fe concentration

of the rainwater was measured. In addition, a gypsum plaster board was placed under the specimen of RS-COAT applied steel to investigate the contamination with the rust-containing water that flows from the specimen. **Figure 3** shows results of the measurement of the Fe concentration of the rainwater. **Photo 2** shows the contamination of the gypsum plaster board with the rust-containing yellow water.

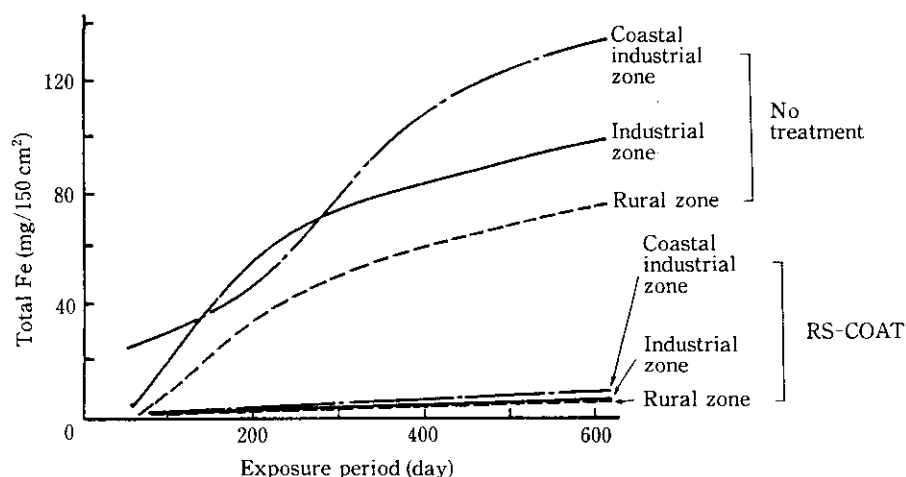
As is apparent from Fig. 3, in all the coastal industrial, industrial and rural zones, amounts of Fe that flowed from the RS-COAT applied steel specimens were less than one-tenth those of non-treated steel specimens and the contamination of the gypsum plaster board with the rust-containing yellow water was scarcely observed until the fifth year. It was ascertained from these facts that the

RS-COAT is sufficiently effective in preventing the contamination with the rust-containing yellow water.

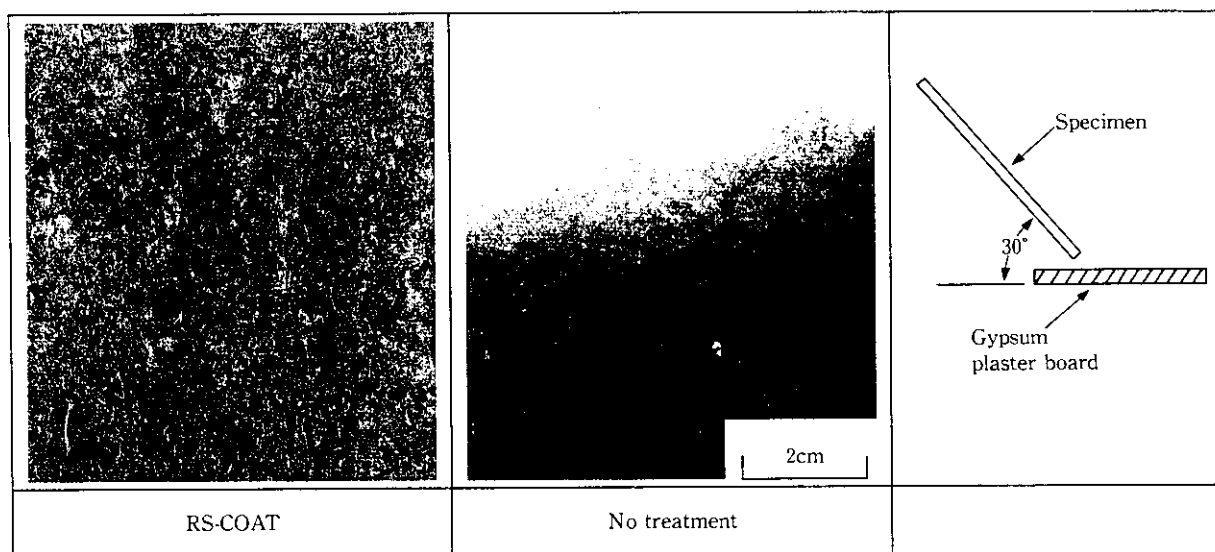
### 5.3 Formation of Stable Rust

**Figure 4** schematically illustrates a structures of rust layers on an atmospheric corrosion-resistant steel and a plain carbon steel<sup>4)</sup>.

As with plain carbon steels, the initial rust on atmospheric corrosion-resistant steels is apt to permit the permeation of corrosive substances, such as H<sub>2</sub>O and O<sub>2</sub>, and the protective capacity of this rust layer is insufficient<sup>5)</sup>. When corrosion proceeds further, a crystalline layer of FeOOH, etc. is formed as the outer layer of rust and a dense amorphous layer containing Cu, Cr, P, etc. is successively formed as the inner layer. It is generally



**Fig. 3** Accumulated amount of Fe outflowing from specimen



**Photo 2** Appearance of rust outflow on gypsum plaster board after five years exposure

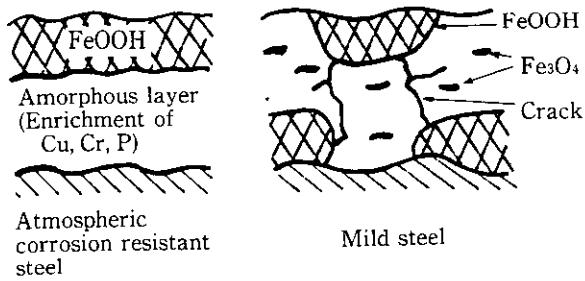


Fig. 4 Scheme of rust layer on steel

considered that the reaction of corrosion is inhibited because  $H_2O$  and  $O_2$  cannot easily permeate this successive layer of amorphous rust. Based on this concept, the formation of stable rust was judged in this study by taking into account cracks in the rust layer, existence or non-existence of the amorphous layer, position and continuity of the amorphous layer, etc. as criteria.

### 5.3.1 Observation by SEM and polarized light microscope

An RS-COAT applied steel and a wash-primed steel were exposed to the air in the coastal industrial zone for five years and were then observed under a scanning electron microscope and a polarized light microscope. Photos 3 and 4 show results of the observation of the surfaces and cross sections of these steels, respectively.

In the wash-primed steel specimen, there were large cracks on the whole surface of the film, and yellowish-brown rust formed under the film had flown out on the film surface. The RS-COAT applied steel specimen scarcely showed any film defect such as cracks, blister and exfoliation and only a thin dark brown rust layer was observed over the whole surface of the steel under the film. In the wash-primed steel specimen, corrosive

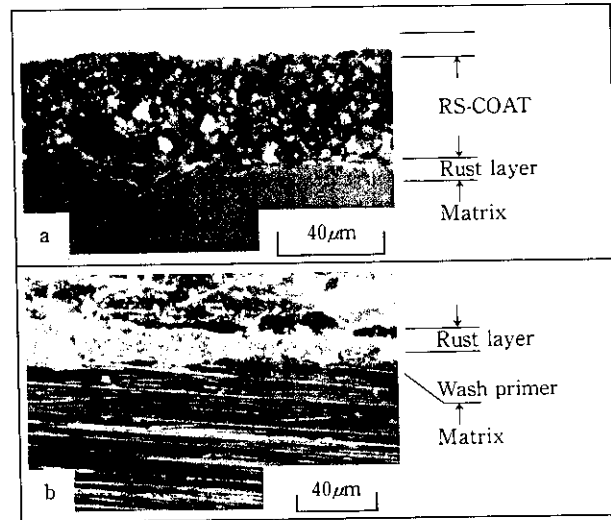


Photo 4 Polarized light microscopic observation of cross section of paint films on steel after five years exposure in coastal industrial zone

substances such as  $H_2O$ ,  $O_2$ ,  $SO_x$  and  $Cl$  which had entered the steel through cracks accelerate corrosion, and as a result rust-containing yellow water flowed out. In the RS-COAT applied steel specimen, it seems that corrosive substances were moderately supplied to the steel through the RS-COAT film because there was scarcely any film defect, and the outflow of rust could be prevented by the formation of a small quantity of rust.

As shown in Photo 4, the greater part of the rust formed in the RS-COAT applied steel was amorphous<sup>6)</sup> and this rust existed all over the whole surface.

### 5.3.2 Element analysis of rust layer by EPMA

Figure 5 shows results of an EPMA line analysis of

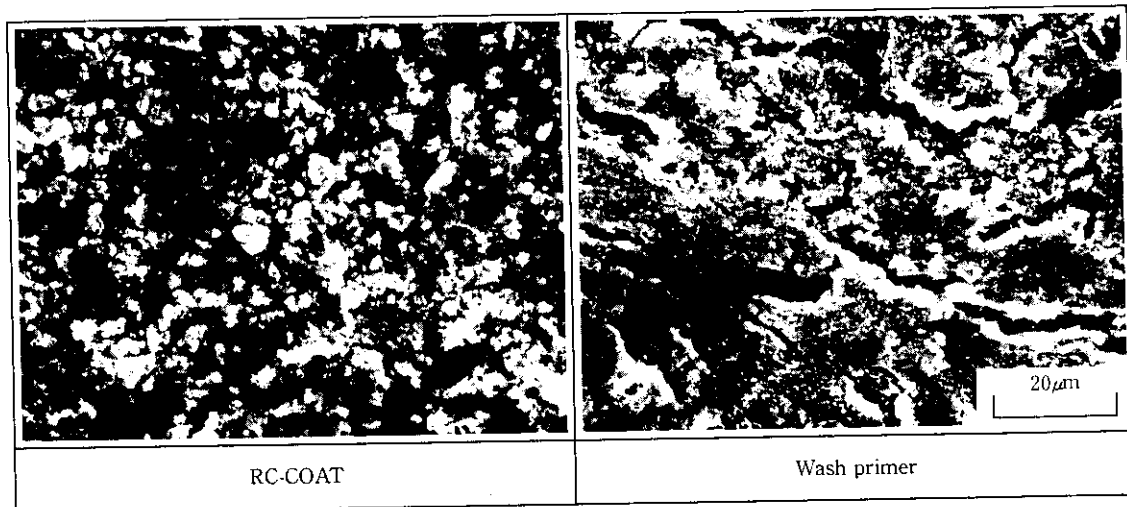
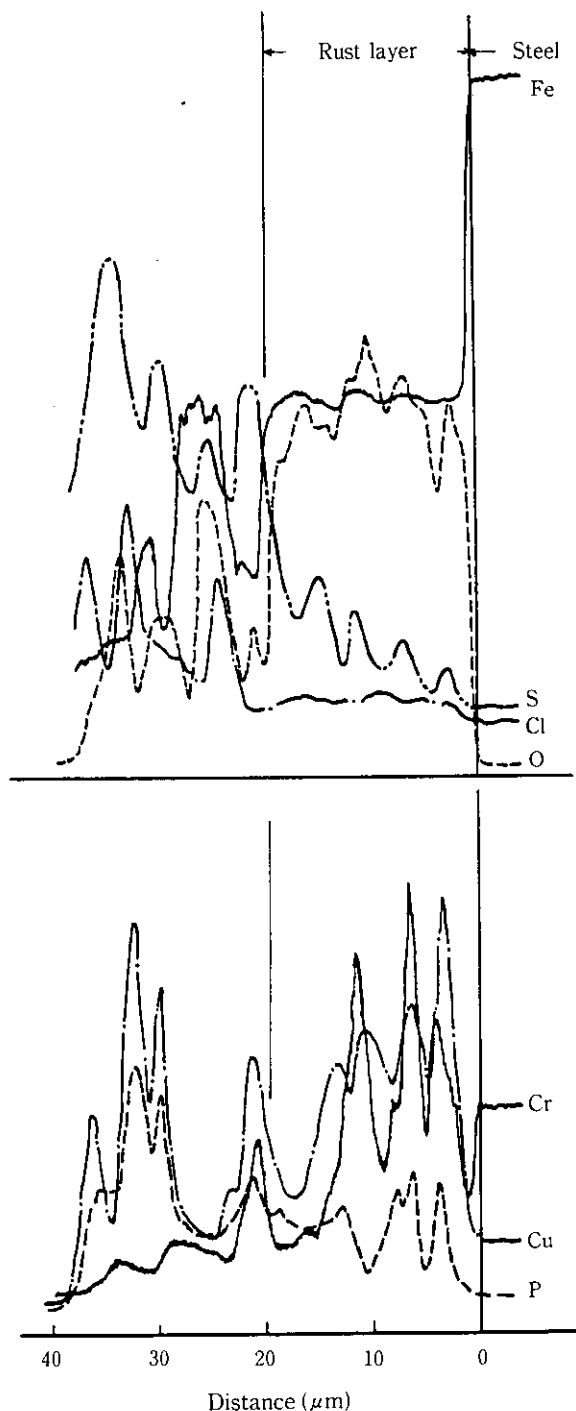


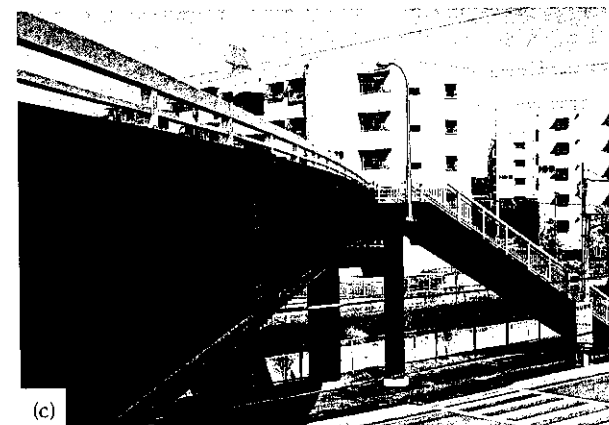
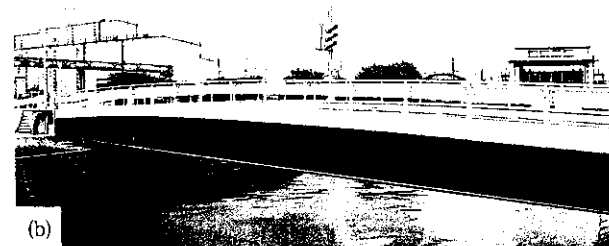
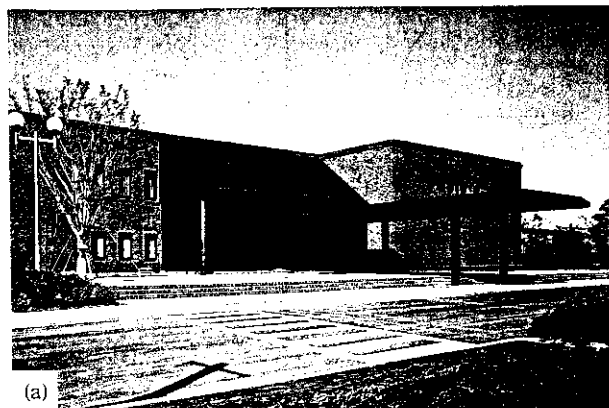
Photo 3 Surface of paint films on steels after five years exposure in coastal industrial zone



**Fig. 5** Result of EPMA at the cross section of rust layer on RS-COAT coated steel after five years exposure in coastal industrial zone

the rust layer formed on the RS-COAT applied steel.

The rust layer formed on the steel surface under the film was 5 to 20  $\mu\text{m}$  thick and the enrichment of Cu, Cr and P was observed in the almost whole rust layer. The enrichment of Cu, Cr, P, etc. was observed also in the film; this is caused largely by the pigments that form the



- (a) Roof
- (b) Bridge
- (c) Footpath bridge

**Photo 5** Examples of RS-COAT applied structure

RS-COAT. A considerable enrichment of Cl was observed in the outer layer of the film. However, the Cl concentration decreased gradually toward the inner layer and only slight amounts of Cl were present in the rust layer and on the steel surface. The permeation of Cl to near the steel surface was very small even in the coastal industrial zone where the specimens showed larger amounts of permeated Cl than in the industrial and rural zones. S is contained in the vehicle. However, it is presumed that the S in the rust layer, for the most part, came from the air because S concentration in the specimen exposed in the industrial zone was high. The



S concentration in the rust formed under film is low compared with that of rust formed in the non-treated steel and it is thought that S, along with Cl, was shielded by the RS-COAT film.

From this, the RS-COAT film is considered to have a function for preventing the permeation of corrosive substances such as Cl and SO<sub>x</sub> into the steel surface. Furthermore, it is assumed that the rust layer under the RS-COAT film has the same function as the stable rust formed in non-treated steels because the greater part of this rust layer is amorphous and the enrichment of Cu, Cr and P is observed in this amorphous layer.

## 6 Examples of Application

The RS-COAT process was for the first time applied to structures, especially bridges in 1980. The number of applications has since been increasing. **Photo 5** shows examples of application to a roof, bridge and footbridge.

According to follow-up surveys of structures to which RS-COAT had been applied, bridges and roofs showed no film defects such as blisters, cracks and exfoliation or contamination of surroundings with the outflow of rust-containing yellow water in the third year of service. In bridges in industrial and rural zones, slight changes in the tone of color were observed in the third year or so in places such as outer girders, where the wetting by rain, etc. and the drying by the direct rays of the sun, winds, etc. occur moderately. In these parts, the RS-COAT film and rust were coexistent and it was presumed that rusting was preceeding on almost all the steel surfaces. In places where wetting and drying are slight, rusting is slow under the RS-COAT film and therefore, any noticeable change in the appearance was not observed. In the case of a roofing material in an industrial zone, only a small change in the tone of color was observed in the third year of service. There are few examples of application in coastal zones because stable rust cannot be easily formed because of the effect of Cl in the sea wind. The application of this RS-COAT process in coastal zones requires thorough examination as with the use of atmospheric corrosion-resistant steels with no paint or as-blasted.

## 7 Conclusions

KSC has developed a rust stabilizing surface treatment method called "RS-COAT" by solving the contamination of surroundings with the outflow of rust-containing yellow water, poor appearance until the formation of stable rust and other problems associated with the use of atmospheric corrosion-resistant steels as-rolled or as-blasted. The features of the RS-COAT process are summarized as follows:

- (1) The RS-COAT film supplies the steel surface with proper amounts of H<sub>2</sub>O and O<sub>2</sub> necessary for the formation of rust, prevents the outflow of rust-containing yellow water, and causes stable rust to form on the steel surface.
- (2) The RS-COAT film serves as a barrier against corrosive substances such as Cl and SO<sub>x</sub>.
- (3) The forming rate of stable rust is lower than in the case of using atmospheric corrosion-resistant steels as-rolled or as-blasted. However, the same beautiful appearance as with ordinary films is kept for about five years. Moreover, the coexistence of rust and the RS-COAT film is deemed not very conspicuous before the formation of stable rust all over the surface.
- (4) This process is easy to perform and very economical because it requires only one coating operation after blasting or pickling.
- (5) The rust layer formed on an RS-COAT applied steel is considered to have the same function as in the case of using atmospheric corrosion-resistant steels as-rolled or as-blasted.

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