Steel Plate for Bridges with Long-life Coating (Eco-View)

Dr. Fumio YUSE*[1], Masahiro MATSUSHITA*[2], Manabu IZUMI*[3]

*[1] Materials Research Laboratory, Technical Development Group
*[2] Plate Products Marketing & Technical Service Dept., Iron & Steel Business
*[3] Plate Products Development Dept., Research & Development Laboratory, Iron & Steel Business

Kobe Steel has developed new steels which were designed to reduce the life cycle cost of bridges. The newly developed steel plates (Eco-View) showed excellent corrosion resistance in 10-year-exposure test results. The anti-corrosion properties of this newly developed steel (Eco-View), after painting, are better than those of conventional JIS-SM steel plates. Eco-View steel is expected to contribute to the reduction of life cycle costs, because it can prolong the period before repainting, especially in urban areas or, specifically, in harsh corrosive environments.

Introduction

As of April 2013, there were approximately 699 thousand road bridges being maintained in Japan. Many of them were built during the period of high economic growth, with 16% of them having been constructed more than 50 years ago. This ratio will increase to 65% in 20 years, indicating their rapid aging and huge costs incurred for their maintenance and renewal.[1), 2)] Since steel road bridges are typically damaged by corrosion, maintenance, paint coating and corrosion protection are receiving more and more attention, while there has been a rise in the awareness of the extension of life and reduced life-cycle costs in the construction of bridges. Life-cycle cost (LCC) is a concept encompassing all stages, including construction, maintenance and re-building, for which Kobe Steel makes suggestions as to material steel plates. The company has developed, for example, a 1% Ni-Ti weathering steel with high resistance against chloride corrosion, as well as excellent weldability, allowing its use in high-salinity environments without paint coating.[3)]

Paint coating, on the other hand, is indispensable for urban areas that emphasize landscapes and for areas with severely corrosive environments. With this in mind, Kobe Steel has developed a series of steel plates for long-life coating (hereinafter "Eco-View[TM note)]", which satisfies all the conventional requirements for steels for welded structures (corresponding to Japan Industrial Standard (JIS) G 3106; structural materials (SM)) and, in addition, is itself provided with a function of inhibiting under-film corrosion.[4), 5)] The Eco-View is registered in the New Technology Information System (NETIS.) This paper introduces the results of a ten-year exposure test of the Eco-View[6)] and results of a study on corrosion resistance, as well as its development concept and the mechanism of corrosion-resistance improvement.

1. Features of steel plates for paint coating (Eco-View)

1.1 Development concept

More than 70% of the bridges in urban areas that emphasize landscaping and in areas with high-salinity environments are specified as requiring painting, and usually are made of steel for welded structures (corresponding to JIS G 3106; SM). The steel, however, does not by itself have any effective function of inhibiting corrosion due to rust, and easily permits the rust to progress from defects in paint films. This progression of rusting causes the blistering and peeling of the paint films, which is a factor in determining the life of coating. Painting accounts for 5 to 15% of the total construction cost of a superstructure, and re-painting is estimated to cost as much as the initial painting. Thus the reduction of these costs presents some big challenges.

In attempts to lengthen the cycles of re-painting, new paints have been developed and the coating methods have been improved; however, the progression of corrosion, as well as rusting and the deterioration of paint films, inevitably occurs in portions such as sharp edges that are difficult to manage, and from defects in the paint films (e.g., damage to the coating during service). Corrosion progresses from such defects in the paint film, forming rust and deteriorating the corrosion resistance of the paint film. The Eco-View is a steel material with a function that inhibits such deterioration.

In commercializing the 1% Ni-Ti weathering steel that can be used in high-salinity environments without coating, Kobe Steel adapted its original alloy system, a non-Cr, Cu-Ni-Ti system. A similar technology has been used in the Eco-View as well to improve its corrosion resistance.

In general, Cu, Ni and Cr are regarded as elements that improve corrosion resistance, and

---

note) Eco-View is the translation of a registered Japanese trademark "エコビュー(pronounced "í:koʊ bjú")" (No. 4631892) of Kobe Steel.

the JIS requires these as indispensable alloying elements for weathering steels. Many years of research, however, have revealed that, in salinity environments, Cr lowers the pH at the corrosion tips and promotes corrosion. Meanwhile, it has been found that a minor addition of Ti is effective in inhibiting the formation of β-FeOOH, which is regarded as less stable and adversely affecting corrosion resistance. In addition, Cu and Ni have been found to promote the formation of amorphous rust, which has a favorable effect on corrosion resistance. On the basis of such knowledge, the content of Cu and Ni has been optimized, without the addition of Cr, and with a minor addition of Ti, to improve corrosion resistance by the densification of the rust that formed.[3), 4)]

Fig. 1 shows the mechanism assumed to occur in improving the corrosion resistance of paint films on the Eco-View. This mechanism is expected to work to inhibit under-film corrosion even when corrosion originates in defects in paint films. The chemical composition of the Eco-View is shown in **Table 1**. The menu covers all the steel plates with tensile strengths of 400-570 MPa class used for ordinary steel bridges. The Eco-View steels have compositions within the range stipulated by JIS SM so as to secure satisfactory performance as steel for welded bridge structures. Thanks to the low carbon content, and despite the addition of elements such as Cu and Ni, the Pcm (the critical metal parameter for weld cracking) is as low as 0.19% or less, which is lower than 0.21%, the criterion for allowing decreased preheating. Furthermore, all the steel plates have sufficient strength and toughness. Therefore, no special processing is necessary for adopting the Eco-View to actual bridges.

1.2 Application records

The former Japan Highway Public Corporation applied the Eco-View to the bridges on the Minami-Hanna road, including the Hyoge daiichi-kyo bridge and Takeuchi-bashi bridge (**Fig. 2**), as well as bridges on the Joshinetsu Expressway, including the Kannonsawagawa bridge. The Eco-View has also been used for more than ten bridges built, for

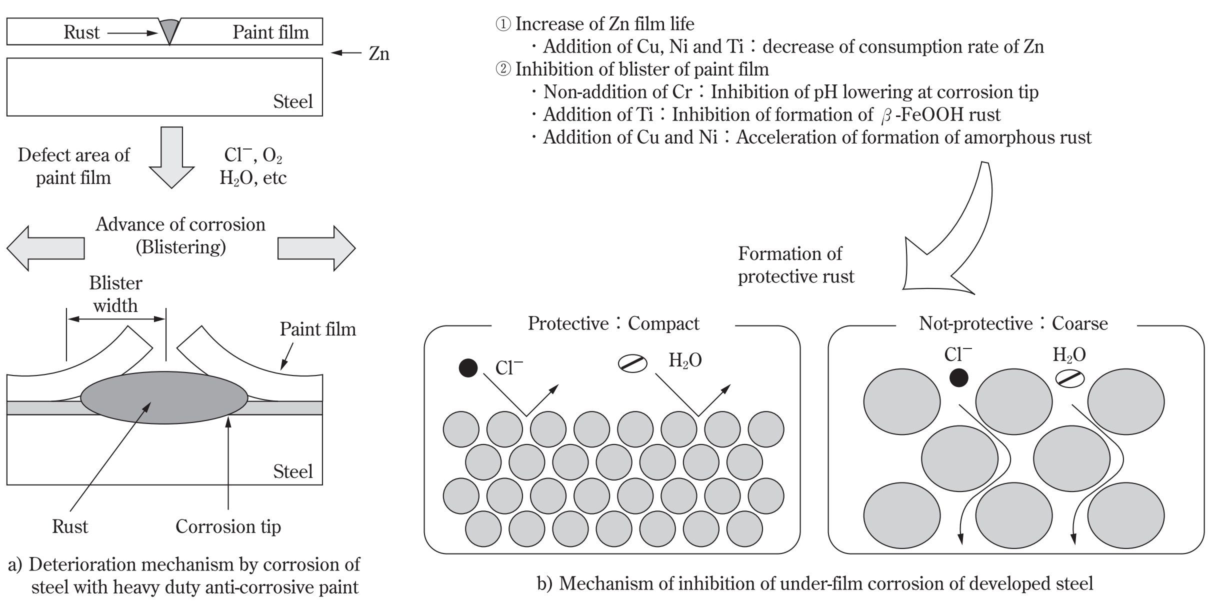


Fig. 1 Mechanism of inhibition of under-film corrosion on Eco-View

Table 1 Chemical compositions of Eco-View

Steel Class	Thickness (mm)	Chemical compositions (%)							Ceq (%)	P_{CM} (%)
		C	Si	Mn	Cu	Ni	Cr	Ti		
400MPa	25	0.05	0.30	0.65	0.78	0.41	0.01	0.045	0.24	0.14
490MPa	25	0.06	0.30	1.24	0.74	0.38	0.01	0.042	0.35	0.18
	50	0.05	0.32	1.56	0.79	0.41	0.02	0.046	0.40	0.19
570MPa	50	0.05	0.30	1.54	0.77	0.39	0.02	0.041	0.39	0.19

Note) 1) Ceq=C+Mn/6+Si/24+Ni/40+Cr/5+Mo/4+V/14+(Cu/13)
(Cu: applied when Cu≧0.50%)
2) P_{CM}= C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B

Fig. 2 Takeuchi-bashi Bridge of Minami Hanna Road

example, by local governments.[7] Since the Minami-Hanna road is a highway running through ancient cities, particular attention was paid to the scenery, which included involving specialists in determining the colors. There are six bridges, each with two girders, on this highway in the Taima district. A total of approximately seven-hundred tonnes of the Eco-View was used for these bridges to lengthen the cycles of re-painting. The Takeuchi-bashi bridge is the largest of the six bridges, and its particulars are as follows:

Ordering party: The Japan Highway Public Corporation (NEXCO West Japan)
Place of erection: Nara prefecture
Year of erection: 2002
Type: 4-span continuous composite 2-main-girder steel bridge
Length: 160 m (span lengths; 41.25 + 41.4 + 41.4 + 34.44 m)
Amount of steel used: Approximately 310 tonnes
Features: Eco-View + thin-film heavy-anticorrosion coat (I-coating system).

2. Corrosion resistance of coating

The effect of the Eco-View has been verified by exposure tests conducted at the Hyoge daiichi-kyo bridge near the Takeuchi-bashi bridge. This section reports the results of a 10-year exposure test.

2.1 Study outline

Since 2003, an exposure test has been in progress at the Hyoge daiichi-kyo bridge on the Minami-Hanna road. Small samples of ordinary steel (SM490) and the Eco-View were placed on the inspection catwalk of this bridge. Each small sample (150×70×6 mm) was sealed with tape on its sides and back, and the I-coating system (organic zinc, 75 μm; polyurethane resin, 30 μm; polyurethane resin, 25 μm: Total 130 μm), used in the construction of this bridge, was applied to the test surface. In order to simulate the paint scratches and sharp edges where rusting tends to begin, defects were artificially introduced into the paint film after curing, using a cutter knife. For comparison, a non-painted sample was provided on the same exposure stand. The appearance of one of the test samples and of the exposure test situation are shown in **Figs. 3** and **4**, respectively.

After ten years of exposure, each sample was inspected (for cracks and peeling in the painted

Fig. 4 Exposure test

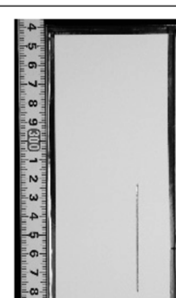
	I-paint system		Appearance
Number of painting processes	3		150×70×6mm With artificial film defect (scratch)
Film thickness	130 μm		
Applicable regions	Urban regions		
Details of paint films	Polyuretane resin Organic Zn Primer Steel	Top-coat (55μm) Under-coat (75μm)	

Fig. 3 Coating system and appearance of test samples

portion) and the blister width on the artificial film defect was measured. To measure the blister width, the cut portion was divided into 5 equal sections, and the maximum value was measured for each of the sections. For some coated samples, paint films were removed using a peeling agent. These samples were cut for cross-sectional scanning electron microscope (SEM) observation and electron probe micro analyzer (EPMA) analysis. The rust on the non-painted sample was removed and subjected to X-ray diffraction (XRD) for its identification and quantification.

2.2 Results for painted samples

Fig. 5-left shows the samples (placed horizontally; dust removed) of ordinary steel and the Eco-View after the exposure test. Neither rust, nor blister of paint film, was observed on either steel. Fig. 5-right shows the blister width determined for each artificial defect in the paint film. The blister width tends to be greater for the horizontally-placed samples than for the ones placed vertically. This is attributable to the fact that the horizontally-placed samples can collect moisture and dust more easily, which promotes corrosion.

It has turned out that Eco-View has a blister width that is, on the average, smaller by 10% or more than that of the ordinary steel.

Fig. 6 shows the surfaces of the steels after removing the paint films. The degree of corrosion for each of the steels indicates that the Eco-View offers superior corrosion resistance.

2.3 Results of cross-sectional observations

Fig. 7 shows the cross-sectional SEM images with EPMA (Cl) mapping. They indicate that in the ordinary steel, chlorine ions (Cl^-), a corrosion factor, exist at the tip of the rust (i.e., the interface on the side of the iron), while in the Eco-View, they stay in the outer surface of the rust layer, showing that the penetration of Cl^- has been effectively inhibited. The result indicates that the Eco-View effectively prevents under-film corrosion, resulting in the smaller width of the blister from the film defect.

2.4 Results of XRD analyses of rust

Since the amount of rust on the corroded portion of the painted sample was too small to be analyzed, the XRD analysis was performed on rust collected from the non-painted sample exposed in the same manner as the painted samples. The analysis focused on β-FeOOH, which is characteristically

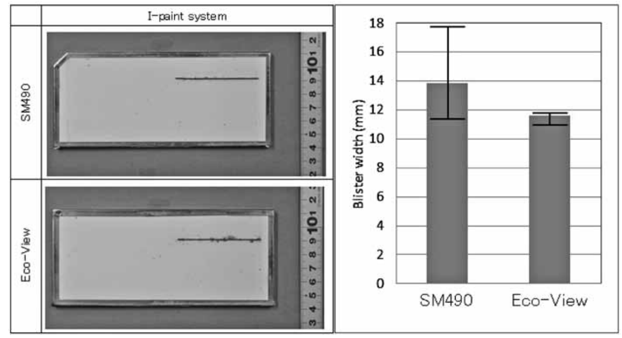


Fig. 5 Appearance and blister width of painted steels

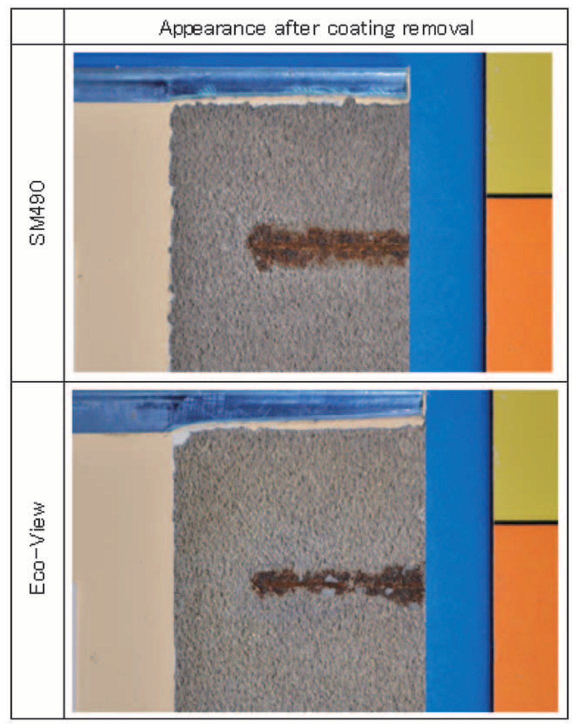


Fig. 6 Appearances of the test pieces after coating removal

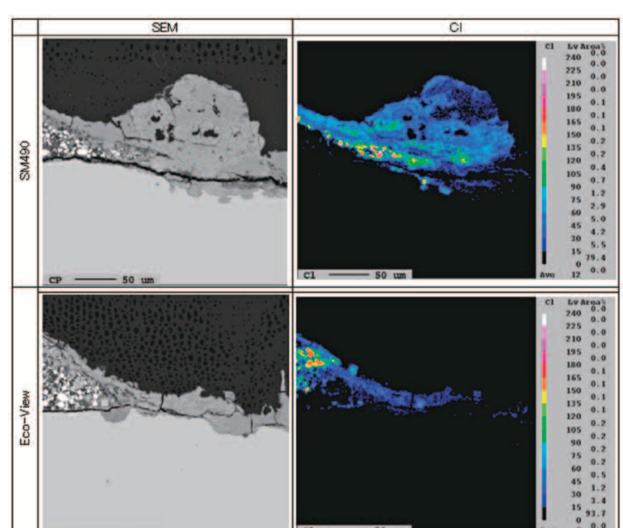


Fig. 7 Cross-sectional images of SEM and EPMA of Cl

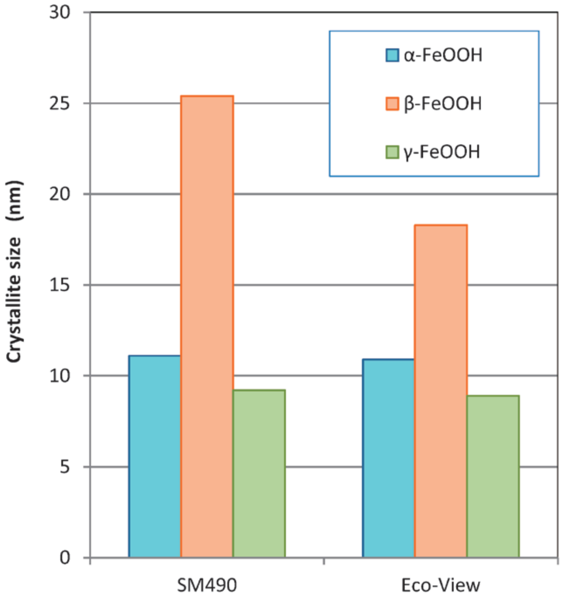


Fig. 8 Crystallite size of SM490 and Eco-View

formed in chloride environments and adversely affects the corrosion resistance. The Eco-View has approximately half the amount of β-FeOOH, compared with the ordinary steel.

To quantitatively evaluate the crystallinity, the crystallite sizes were determined on the basis of Scherrer's equation using the half-peak width of the XRD peaks. The results are shown in **Fig. 8**. The Eco-View has β-FeOOH with a crystallite size that is approximately 30% finer, indicating that the addition of Ti can effectively refine β-FeOOH.

3. Discussions

A chloride environment leads to the formation of a significant amount of β-FeOOH, known as detrimental rust. Titanium (Ti) is an element considered to be effective in interrupting the formation of β-FeOOH and improving the corrosion resistance through its refinement.[8)] The current testing of small samples exposed to an actual environment has confirmed the advantage, in terms of blister width, of the Eco-View. The results show that the optimized composition, including no addition of Cr and the addition of Ti, Cu and Ni, inhibits the corrosion at the tip of the under-film corrosion and densifies the rust formed, so as to inhibit the penetration of corrosion factors. This is considered to verify the validity of the mechanism originally assumed.

In a past experiment, the post-coating corrosion resistance of the Eco-View was evaluated for different coating systems. The results showed that, for the A-coating system, which is used for the general environment, the Eco-View exhibited a greatly inhibited progression of rust from defects in the paint film, as well as a significantly reduced blister width in the paint film, compared with conventional steel. For the C-coating system (a heavy corrosion-protection coating system), used for harsh coastal environments, the results showed a reduced blister width and confirmed the effectiveness of sacrificial protection by zinc.[4)]

The corrosion protection of road bridges made of steel used to be provided by the A-coating system, consisting of rust-inhibiting red lead primer and phthalic resin coating. The coating system is being changed to a heavy corrosion-protection system including a zinc-rich primer and a final coating of polyfulorocarbon for atmospheric isolation. Yet, however excellent the coating system may be in its anti-corrosion function, corrosion may occur and spread from the corners of parts, where the films are not thick enough, or from scratches and defects. Once the sacrificial protection effect of zinc disappears after a long period of time, the corrosion of the base iron may occur and spread from such portions. Here, the mechanism shown in Fig. 1 is considered to apply in the same manner. The 10-year exposure test conducted this time was performed on the I-coating system (a thin-film type, heavy corrosion-protection coating system) in a mild environment. Therefore, there was not much difference between the different steels. In the future, however, when corrosion has progressed further, the effect of alloying elements, as described above, will become clearer, accentuating the difference between different steels.[4)]

Considering the experimental results this time, the Eco-View is expected to lengthen the cycles of re-painting and reduce the life-cycle cost of bridges for which the re-painting cycles are regulated due to damage in the paint films.

Conclusions

A 10-year exposure test was conducted on an actual bridge. The results show that the "Eco-View", a steel plate for bridges with long-life coating, exhibits excellent resistance against coating corrosion compared with ordinary steel. The results, including the results of rust analysis, indicate that the mechanism of inhibiting under-film corrosion is working as expected. The Eco-View is expected to enable re-painting cycles to be lengthened and reduce the life-cycle cost of steel bridges. Kobe Steel will continue to accumulate more data on corrosion resistance for an extended period of time and data on corrosion occurring in different environments.

Finally, our special thanks are due to West

Nippon Expressway Company, Kansai Office and Hanna Highway Office for their cooperation in the long-term exposure test.

References

1) S. Takagi. *KYOURYOU-TO-KISO (Bridges and Foundations)*. 2014, No.9, p.33.
2) T. Tamakoshi et al. *Report of General Studies on Land and Infrastructure Management*. Ministry of Land, Infrastructure, Transport and Tourism. 2006, No.294, p.1.
3) H. Kawano et al. *R&D Kobe Steel Engineering Reports*. 2002, Vol.52, No.1, p.25.
4) S. OKANO et al. *R&D Kobe Steel Engineering Reports*. 2002, Vol.52, No.1, p.39.
5) F. Yuse et al. *The 55th annual conference of the Japan Society of Civil Engineers*. 2001, I-A234.
6) A. Takahashi et al. *The 69th annual conference of the Japan Society of Civil Engineers*. 2014, V-459.
7) N. Furukawa et al. *R&D Kobe Steel Engineering Reports*. 2003, Vol.53, No.1, p.47.
8) T. Ishikawa et al. *Zairyo-to-Kankyo*. 2003, Vol.52, No.3, p.140.