Technical Report

Advanced Anticorrosion Coating Technologies in Steelworks Maintenance

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Abstract

In steel works, many cranes, conveyors, pipelines and gas holders are operating every day in severe corrosive environment such as marine environment and corrosive gas environment. We've been trying to investigate these corrosive conditions and apply our advanced anti-corrosion coating technologies, aiming to minimize the LCC (Life Cycle Cost) of these facilities. This report introduces these coating performance evaluation methods and application technologies.

1. Introduction

In steelworks, a number of equipment such as unloaders and belt conveyors that unload raw materials like iron ore and coal, wharf cranes for shipping iron and steel products and furthermore pipe lines of various energy, gas holders and so on are operating in severe corrosive environment such as marine environment and corrosive gas environment. In order to protect such infrastructure equipment in steelworks from corrosion, anticorrosion maintenance work like periodical recoating and the like are conducted. However, in the anticorrosion maintenance, several serious practical issues as following have to be faced always; how deterioration of coating film can be inspected to determine recoating schedule, how huge cost can be managed for recoating can be secured systematically, and so on.

On the other hand, to prevent the occurrence of equipment troubles and establish a relation of mutual trust with neighboring community is becoming increasingly important as corporate social responsibility. Therefore occurrence of any equipment troubles attributed to corrosion must be prevented by all means. Namely, it can be said that prevention of equipment troubles due to corrosion and maintenance management of equipment while securing stable operation of the equipment by means of application of appropriate anticorrosion technologies are the serious responsibilities imposed on the equipment maintenance division of steelworks.

With the above as a background, efforts are being made on day by day base to develop equipment management and coating technologies concerning anticorrosion maintenance for equipment in steelworks, aiming at reduction of the life cycle cost (LCC) by applying the most suitable anticorrosion coating while maintaining stable operation of the equipment. Namely, in Nippon Steel & Sumitomo Metal group, following have been practiced; installation of coating standard comprehensively applied to all steelworks, which is revised as necessary, educating maintenance people and technical staff about anticorrosion technologies and development of its own anticorrosion technologies. This report introduces the coating film diagnosis technologies and anticorrosion coating technologies.

2. Coating Film Diagnosis Technology

2.1 Three-dimensional surface configuration measurement

Normally, in the maintenance of steel high way bridges, visual inspection is applied to diagnose coating film deterioration in the first stage. In the Steel Structure Coating Film Investigation Manual,¹⁾ rust, separation, discoloring or fading, stains and so on are specified as visual inspection items and in particular, state of progress of rust is estimated with the area of rust generated (%). It means that progress of rust is judged with the area-wise coverage ratio of black spot rust. Also in the anticorrosion maintenance in steelworks, visual inspection is important. However, it's not easy to judge the necessity and timing of recoating based on inspection result and it's a matter of deep concern on the part of maintenance men. Therefore, education concerning corrosion and protection against corrosion is being rendered in order for maintenance men to understand the coating film deterioration phenomena correctly and utilize their inspection result for equipment management.

In the education of corrosion and anticorrosion technologies, in order to assist them understand the coating film deterioration phenomena, corrosion acceleration experiment on a coated test piece in a salt water spray test (termed as SST hereafter) was conducted and its three-dimensional surface configuration was mesured.²⁾ The measuring device shown in **Photo 1** is a laser range finder combined with an XY scanning table. **Figure 1** shows a result of measurement

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using the device. Figure 1 (a) shows the measurable range of a test piece and, (b) and (c) show the contour drawing and the topography of the coating film surface obtained by the three-dimensional surface profiler. It is known that spot rust, which looks black in (a), is a blister having a height of several hundred μ m.

In **Fig. 2**, state of growth of rust along the time in SST is shown by photos and three-dimensional topographies. From these results of



Photo 1 3D surface profiler

measurement, it is known that coating film deterioration phenomenon takes a process of developing blisters on a coating film surface that grow gradually, expand and yield rust flow from the tips of the blisters that stain the surrounding areas. As the coating film is separated from the steel surface inside the blister, coating film therein does not contribute to anticorrosion. Corrosion that grows inside of a blister is called sub-coating film corrosion wherein rust is generated, producing rust flow.

By this experiment, state of progress of coating film deterioration is clearly displayed, and it is understood that area-wise coverage ratio of generated rust (%) is the area-wise coverage ratio of blisters. It was shown that; based on this and by setting a threshold on the blister height and, by calculating the area corresponding to the height exceeding the threshold value in the three-dimensional surface configuration measurement device, area-wise coverage ratio of generated rust (%) can be calculated.²⁾ This method can be said to be an effective method to diagnose the coating film deterioration of a test piece on laboratory test base. However, it cannot help but stating that application of the three-dimensional surface configuration measurement to outdoor huge equipment coating film diagnosis is difficult, because of limitation of measurement range to about 20 mm square.



Fig. 1 Photo and 3D topography of a coated test specimen existing some blisters



Fig. 2 Photos and 3D topographies of alkid paint 70 µm coating sample (initial and after SST 1000 h, 2000 h, and 3000 h)

2.2 Ion permeation resistance measuring method

Although the above mentioned three-dimensional surface configuration measurement is helpful to the understanding of the coating film deterioration phenomenon, because of its limited measuring area and its substantial difficulty of carrying the device to outdoor equipment and further for other reasons, it's not applicable to outdoor coating film diagnosis. Therefore, in order to conduct outdoor diagnosis in an efficient manner, a device of measuring ion permeation for diagnosing rust developed on weathering steel has been improved and used (called RST hereafter).³⁾ Especially as points of improvement, maximum measurable coating film resistance was expanded from the maximum of $2G\Omega$ in the original device to the maximum of $20G\Omega$.⁴⁾ By this improvement, the device that was designed only for measuring the resistance value of weathering steel rust has become possible to measure the resistance value of anticorrosion coating film.

Photo 2 shows the actual practice of measuring coating film resistance using RST. **Figure 3** shows the sketch of the RST probe. Coating film resistance (R_R : called RST value hereafter) is shown in the equivalent circuit shown in **Fig. 4**. Principle of measurement is to let several mA alternating current of a certain frequency flow between two pistons filled with electrolytic solution and to calculate RST value (Ω). The RST value of anticorrosion coating film is higher than 20G Ω , exceeding the measurable maximum value, in a sound coating film condition immediately after coating, which will become several k Ω on the coating film where deterioration in coating film has developed and a number of blister have been generated.

As an example of actual measurements, the result of coating film



Photo 2 RST measurement



Fig. 3 RST probe

diagnosis for a harbor loading crane conducted in November of 2012 is explained. **Photo 3** shows the surveyed sections of a harbor loading crane in a steelworks. In **Table 1**, result of measurement at respective measured section and the photography of coating film



Fig. 4 Equivalent circuit of RST measurement



Photo 3 RST survey parts of a harbor loading crane

Table 1 RS	ST value and	photos of a	harbor	loading cr	ane
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Measured part	RST value	Surface condition	Remarks	
Leg frame (land side)	>20GΩ	5/ 8 40 (M	Height: 19 m Coating thickness: 477 μm Surface salinity*: 5 mg/m ²	
Leg frame (sea side)	442 MΩ		Height: 2 m Coating thickness: 458µm Surface salinity*: 194 mg/m ²	
Connection frame (upper part)	13.4 MΩ	angasta z o E og 196 kiste	Height: 30m Coating thickness: 747µm Surface salinity*: 81 mg/m ²	
Connection frame (upper part)	379 kΩ	-1374318 ## 831 \$	Height: 30m Coating thickness: 1613µm Surface salinity*: 263 mg/m ²	
Cantilever (lower part)	20 kΩ		Height: 30 m Coating thickness: 452 µm Surface salinity*: 380 mg/m ²	

* It was measured after 3 fine days



surface condition of the section are shown. RST value obtained on the actual equipment corresponds well to the state of deterioration judged through visual inspection and external view photos of coating film. Namely, RST values exceed $20 G\Omega$ at the upper back side section of the crane where salt of sea water splash adheres, however, easily washed away by rain fall. On the other hand however, the RST values were very low of about $20 k\Omega$ on the coating film on the inner side of the front end of the cantilever where the amount of adhering salt is large and the salt is not easily washed away by rain fall and, progress of corrosion was observed. As above, it is found that RST values are very useful for coating film diagnosis of practical equipment and quantitative maintenance data in a form of RST value is characteristically made available. Furthermore, it was confirmed that coating films on all parts of an equipment do not deteriorate evenly and equally. The coating films exposed to severe corrosive environment deteriorate antecedently. Therefore, some difference exists in the extent of deterioration in the whole equipment.

Hereafter, based on the findings thus obtained, authors will attempt methods of establishing anticorrosion maintenance program and so on aiming at reduction of recoating cost, for instance, changing coating specification depending on partial condition, recoating only the part where the deterioration have remarkably progressed.

3. Anticorrosion Coating Technologies

3.1 Thick film coating

For coating of steel structures, primary coating with oil paint that contains lead as a rust-inhibiting pigment (red lead rust inhibiting paint) and intermediate coating and final coating with synthetic resin paint (alkid paint) have been conventionally and widely applied. Since around 1990, a coating system of applying modified epoxy resin paint excellent in long durability to primary coating and applying poly-urethane resin paint to intermediate coating and final coating has come to be used. This means the shift from Coating System A (light anticorrosion coating) to Coating System C (heavy duty anticorrosion coating) in Steel Highway Bridge Coating Handbook⁵⁾ from the viewpoint of prioritizing long term durability.⁶⁾ Pursuant to the technical trend of the steel highway bridge coating, incompany coating technical manuals of Nippon Steel & Sumitomo Metal Corporation were revised to realize long life of coating in iron- and steel-making equipment. It means that the coating system of the primary coating with the modified epoxy resin paint was added. However, as the Coating System C of steel highway bridge is a very expensive coating specification, stipulating six layers coating excluding shop primary coating, inexpensive thick anticorrosion coating aimed to be specified for application to iron- and steel-mak-



Photo 4 Cross-section of developed high-build paint

ing equipment has been developed.

Figure 5(c) shows the specification of the developed thick film coating. As compared to the C5-M specification for ISO12944-7⁷) marine environment (Fig. 5 (d)) and the Coating System C (Fig. 5 (b)) and, the coating is of economical specification having thicker film and less number of coating layers. Furthermore, modified epoxy resin paint used in thick film coating is the improved type of modified epoxy resin paint having excellent anticorrosion performance to fit thick film type and coating thickness of 300 μ m is obtained with three under coating layers. As a whole, total coating film thickness of 330 μ m is built up with one layer of top coating of polyurethane.

Outline of the improved thick film type modified epoxy resin paint^{8,9)} is stated hereunder. In order to enable thick coating of more than 100 μ m with one time brush painting, as **Photo 4** shows, the paint is designed to enable thick film coating by brush repainting in wet paint condition with addition of optimum amount of squamous pigment having a specific aspect ratio. **Photo 5** shows the comparison of anticorrosion performance of the one layered thick film coating film peeled off at the cross-cut section of the thick film coating after 2000 hours in SST is 2.5 mm, Photo 5 (a). It is confirmed that the thick film coating is highly excellent anticorrosion performance comparing with the Coating System A.

Presently, the abovementioned thick film coating is specified as standard coating for outdoor equipment steelworks where use of thick film coating is recommended.

3.2 Internal coating of energy pipeline

In steelworks, several energy pipelines, for example, coke oven gas (COG) and converter furnace gas (LDG), are installed for the distance over several tens of kilometers. These pipe lines supply energy as several fuel gases and the like to each plant in steelworks.

However, on the inner surface of these pipe lines, corrosion is slowly developed by corrosiveness of gases and drain, and some problematic conditions like perforation or the like occurs after about thirty years operation.¹⁰ In case of COG pipe lines, such phenomenon has been confirmed with, for instance, laminar corrosion product as shown in **Photo 6** formed by the effect of hydrogen sulfide in COG and sulfite ion and the like in drain.¹⁰ Furthermore, in LDG pipe lines, corrosion is developed by carbon dioxide gas contained in a gas and or drain. For these reasons, anticorrosion technology that can control the internal corrosion of energy pipe lines has become necessary in steelworks.

Then, the corrosion prevention for inner surface of pipe lines by means of coating was studied. In this case, the anticorrosion coating is required long term durability against the various chemical materi-





 $125 \,\mu$ m (4 layers)

(a) Developed high-build paint 200 μ m (1 layer)

Photo 5 Anti-corrosion performance comparing developed high-build paint with alkid paint system (after SST 2000 h)



(b) EPMA image of S distribution

Photo 6 Photo and EPMA S distribution of corrosion product in COG pipe

als contained in gases and drain (chemical resistance) and barrier properties against environment. Then, a non-solvent type epoxy resin paint that has a strong molecular structure, hardened at normal temperature and has high glass transition temperature (Tg), allowing easy handling on site was developed.^{10, 11)} In order to confirm the anticorrosion performance of the developed paint, some exposure tests for comparing its anticorrosion performance with those of various coatings have been conducted. In Photo 7, a result of analysis of coating film cross-section of a coated specimen after six month dipping test in drain in a COG pipe line is shown. When a solvent type chemical resistant paint and developed non-solvent type paint are compared based on the cross section photos and the results of observation of sulfur penetration distribution taken by an electron probe microanalyzer, it is found that the developed paint suppresses the penetration of sulfur from coating surface remarkably. Presently, the developed paint is employed as anticorrosion paint for inner surfaces of various energy pipe lines and steel smoke stacks. Photo 8 shows the actual internal coating work for COG pipe line. 3.3 Corrosion prevention of pipe supporter

5.5 Corrosion prevention of pipe supporter

It has been already stated that various energy pipe lines are installed in steelworks and the pipe lines are supported by pipe supporters each installed on a support column. The pipe supporter con-



(a) Cross-section of solvent resin paint film (left photo) and S distribution (right photo)



(b)Cross-section of developed non-solvent epoxy resin paint film (left photo) and S distribution (right photo)

Photo 7 Cross-section of coating films after 6 months dipping test in COG drain



Photo 8 Internal coating application of developed non-solvent paint to COG pipeline

sists of a steel holder below and a steel band on it and crevices are formed while the holder maintains the pipe line. To be specific, a crevice exists between the pipe and the holder and between the pipe and the steel band, so sometimes corrosion is generated in these crevices.

Photo 9 shows the rust grown on the pipe surface under the band at the crevice observed after the band is loosened. This phenomenon is considered to be attributed to the wet and hard-to-dry condition brought forth by the penetration of rain water. Ultimately it reaches perforation sometime and an anticorrosion measure is necessary when the situation cannot be ignored. As a method of anticorrosion measures, although a method of removing of the pipe from the pipe supporter and recoat the crevice section is conceivable, the method is impractical as; not only it requires big expense but also has a possibility of causing gas leakage at the time of removing the pipe and therefore the method cannot be implemented without shut down of the gas supply. In steelworks, which is operating around the clock, since even a temporal shut down of gas supply results in a great influence in the steel production schedule, a method of providing anticorrosion performance without removing the pipe from a pipe supporter was seriously required.

Then, a method of supplying anticorrosion performance to the pipe on the pipe supporter was developed. This is a method of pressing an easy-to-penetrate low-viscosity urethane resin paint into the crevice between the pipe and the pipe supporter or between the pipe and the steel band.¹²⁾ Figure 6 shows the outline of the method. Upon pressing the low-viscosity urethane resin paint, except the pressing-in section and the discharging section, the crevices between the pipe and the steel band edge and, the pipe supporter and the pipe are sealed and hardened so that the paint is penetrated into the entire crevice. The low-viscosity urethane resin paint has the characteristics of arresting water existing in the crevice during the process of



Photo 9 Crevice corrosion under pipe supporting bands



Fig. 6 Anti-corrosion coating into the gap under pipe supporter and bands

hardening after penetration. For this, water exiting inside the crevice is absorbed by the paint and made harmless, securing anticorrosion effect. Photo 10 shows the actual application work of the pipe supporter anticorrosion method.

As for the method, in addition to the application to pipe supporters in steelworks, there are examples of applications for anticorrosion to the gap between a leg part and a base plate of a rolling mill housing and for anticorrosion of a narrow gap of steel bridge girders and, application to other equipment for anticorrosion is expanding. 3.4 Coating with light tool cleaning

For surface preparation before coating, Category I cleaning (with blasting) or Category II cleaning (with power tool) is applied for rust removing. To be specific, the surface to be coated is cleaned either as per Sa21/2 or St3 specified in ISO 8501-1 as standard procedure. However, in case of external coating of gas piping and gas holders where corrosion has progressed remarkably, there's a possibility of causing gas leak through a perforated hole by normal cleaning. Therefore basically, the supply of the gas should be shut down and residual gas inside should be replaced by nitrogen gas and purged and discharged to open air. But, if the external pipe coating can be done without any shut down of the gas supply, the anticorrosion work can be done with great ease, safety and much reduced cost. Therefore, a coating specification was studied that can secure anticorrosion of a certain degree even with the cleaning of the surface that leaves a residual rust of a thin layer (hereafter called light cleaning).

Light cleaning is defined as a rust removing work leaving a rust layer of about 100 μ m and as shown in Table 2, comparison tests of anticorrosion performance of coating up to SST 3000 hours were conducted. It is confirmed that; below 100 μ m of residual rust layer, anticorrosion performance up to 3000 hours can be secured with the coating of the special type primer paint having penetration ability to rust, further coated by normal thick film coating. As observed in Photo 11 showing the coating film section, the sufficient penetration of the special type primer into the thin rust layer of less than 100 μ m and suppressing effect to corrosion in residual rust are considered to be the major reason.

Coating with light tool cleaning is applied only when coating work of energy pipelines and gasholders without purging the gas inside is needed. Still, through these experiments, it is confirmed that the anticorrosion performance as shown in No.1 in Table 2 cannot be obtained in cases of no special primer (in No.2 in Table 2). Further, the developed light tool cleaning coating (No.1 in Table 2) has almost same performance as Category II cleaning (in No.3 in Table 2).

Furthermore, upon application of the method to an actual coat-



Photo 10 Anti-corrosion coating into the gap under pipe supporter and bands

Experimental easting system	SST exprosure time			Domorito	
Experimental coating system	500 h	1 000 h	3 000 h	Keinarks	
No. 1: Developed coating				Disbonding width from the cut is	
• Light tool cleaning	1 /	> 1		about 1mm after SST 3000 h.	
Residual rust $<100 \mu m$	X		X	Anti-corrosion performance is	
• Special primer 25 µm		1		almost equal to No. 3.	
• Modified epoxy resin paint		()	No.7		
200µm	No.1	No.3	110.7		
No.2:				Remarkable disbonding occurred,	
 Light tool cleaning 	Contract of			because of no special primer.	
Residual rust $<100 \mu m$					
• Modified epoxy resin paint	12 4 R		_		
200 <i>µ</i> m					
	No.18				
No.3:	1			St.3 is standard surface cleaning	
• Standard tool cleaning St.3		No. 1	~ /*	method according to ISO 8501-1.	
(ISO 8501-1)	X	3			
• Modified epoxy resin paint					
200 <i>µ</i> m	No.9		No. 15		
	1.0.9	No.11	C1.0VI		

Table 2 Anti-corrosion performance of developed light tool cleaning method using special rust-penetration primer



Photo 11 Cross-section of developed light tool cleaning coating



Photo 12 Rust thickness measurement in developed light tool cleaning coating

ing work as shown in **Photo 12**, the residual rust film thickness is checked during light tool cleaning to be maintained below $100 \,\mu\text{m}$. Furthermore as shown in **Photo 13**, there are cases of cleaning work in which water jet sand blasting is applied. This example shows the case of coating the external surface of a gas holder. Water jet sand blasting has been employed as a method that can clean a large area in a very effective way and inexpensively without dangerous possibility of igniting as the method does not cause sparks. However, since long term durability of the coating with light tool cleaning



Photo 13 Water-jet-sand-blasting method applying to a gas holder

longer than 3 000 hours has not yet been confirmed, therefore the method is applied only when normal surface preparation cannot be employed due to some restricting conditions.

4. Conclusion

Coating film diagnosis technologies and anticorrosion coating technologies applicable to many infrastructure equipment operating in steelworks have been introduced. Individual technology was introduced based on the examples of application to a harbor loading crane, energy pipes, pipe supporters and gasholders.

The technologies are summarized below.

- (1) As one of the coating film diagnosis methods, the method of measuring the 3D surface configuration by using a 3D surface profiler was shown and it was confirmed that coating film deterioration is the generation, growth and increase in number of blisters.
- (2) As a quantitative coating film diagnosis method applicable to on-line equipment, a method of measuring coating film resistance with a permeation resistance measuring device (RST) was shown. As an example of application, measured RST values of coating film of a harbor loading crane was shown and it was confirmed that a difference in the extent of film deterioration



Fig. 7 Infrastracture-equipment examples that should be maintained from corrosion in steel works

exists between the one in the section where adhering salt is easily washed away by rain water and the one in the section opposite.

- (3) Thick film coating on the base of thick film type modified epoxy resin primer was shown as the anticorrosion coating specification that is expected to provide sufficient durability in the application to open air equipment in steelworks situated on a sea coastal area.
- (4) As anticorrosion coating effective for prevention of internal corrosion of energy piping in steelworks, application of nonsolvent type high Tg epoxy resin paint was shown.
- (5) As countermeasures for crevice corrosion that develops on the energy pipe supporter, a method of pressing a low-viscosity urethane resin paint into the crevice was shown.
- (6) In the coating work of the external surface energy piping and or gasholders, a method of coating with light tool cleaning with use of water jet sand blasting as a method of applying coating without developing the danger of causing sparks without purging the gas inside was introduced.

As mentioned above, several coating film diagnosis technologies and anticorrosion coating technologies were introduced. However, as Fig. 7 shows, a large number of huge infrastructure equipment needing anticorrosion maintenance exist in steelworks, which imply unsolved and or unclarified problems or areas where application of developed technologies are expected. They are, for instance, corrosion under high temperature environment like inside of a smoke stack, corrosion prevention of equipment in marine environment and or in earth and, corrosion prevention and reinforcing of underwater concrete structures. Furthermore, establishment of a system that preserves record of inspection for projecting to equipment maintenance and managing plan is also required. As the above shows, corrosion prevention maintenance is the field wherein coordinated work of a number of divisions in vast technological arena is necessary with respective division fulfilling its own work and, incessant efforts must be maintained. Hereafter, Nippon Steel & Sumitomo Metal and Nippon Steel & Sumikin Anti-Corrosion Co., Ltd. continue to make efforts aiming at more securer and higher level anticorrosion maintenance in steelworks under the cooperation between divisions in charge and related companies.

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