ACCELERATED EXPOSURE TESTS OF PAINTED STEELS WITH DIFFERENT SURFACE PREPARATIONS OF STEEL SUBSTRATE

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ABSTRACT : This study examined corrosion characteristics of painted steels with different surface preparations. Accelerated corrosion tests were performed on the painted steels using A Combined Cyclic Corrosion Test Instrument. The combined cyclic test condition adopted in the research was the S6-cycle, which is applicable for simulating atmospheric exposure conditions. 9-mm thick 70×150 mm steel plates were made of two types of structural steels, Japan Industrial Standard (JIS) SM490A and SMA490AW. The surfaces of the steel plates were girt-blasted with No.50 grit specified in JIS S-G50. In each set, 9 of 12 plates were pre-corroded by the accelerated test, and then they were surface-treated mechanically by a disc grinder in three ways, i.e. complete removal, slight removal, and no removal of corrosion productions on the corroded surfaces. The 12 steel plates were painted with multilayer paint films except 20×70 mm rectangular substrate surface. Cross-scribed lines reaching the steel substrate were made in the painted surface.

The painted specimens were exposed into the S6-cycle corrosion environment for 251 days (about S6-1000 cycles). The surface geometry, gloss, and thickness of the paint films were measured at the exposure times of 0, 67, 141, and 251 days. After the accelerated tests, paint films and corrosion productions were removed mechanically and chemically, and then surface geometry and thickness loss of the steels were also measured. Based on blistering area of paint films and thickness loss of the steel substrates, the effect of the surface preparations on the durability of painted steels was discussed.

KEYWORDS: Corrosion, Painted Steels, Surface Preparation, Durability

1. INTRODUCTION

Corrosion is one of the most important causes of deterioration for steel structures. Organic and metallic coatings have been widely used to prevent corrosion attacks, and to maintain the functional ability of the steel structures to bear loads. In addition, coatings are also used to preserve cosmetic appearance, which is often a major concern for structures exposed to public view. The coatings in atmospheric environments are deteriorated, and periodic recoating is necessary for steel structures to prevent environmental attacks and to extend their service life. Because the recoating work lead to increase in lifecycle cost, durability evaluation of recoating becomes one of the most important issues in maintenance of old steel structures.

The durability of coating systems has been often evaluated by atmospheric exposure tests. Although they allow field examinations, it is takes long time to obtain any deterioration data of the coating systems. In addition, it is difficult to obtain fundamental information since various environmental factors, such as temperature, humidity, flying salt and carbon dioxide affect corrosion process in each

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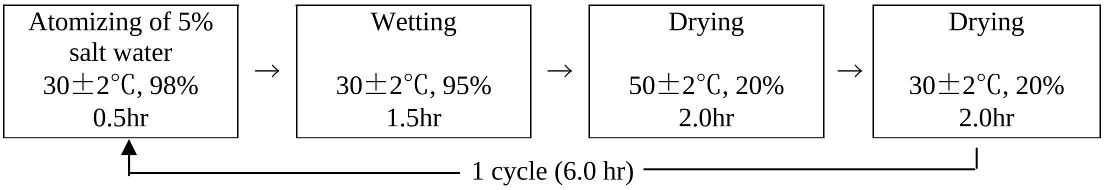


Figure 1. Condition of accelerated environment cycle (S6-cycle)

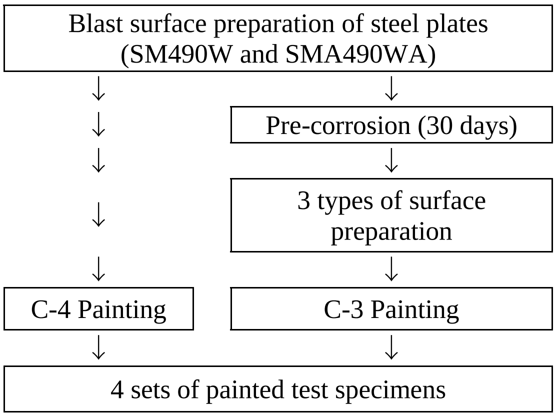


Figure 2. Process in fabrication of test specimens

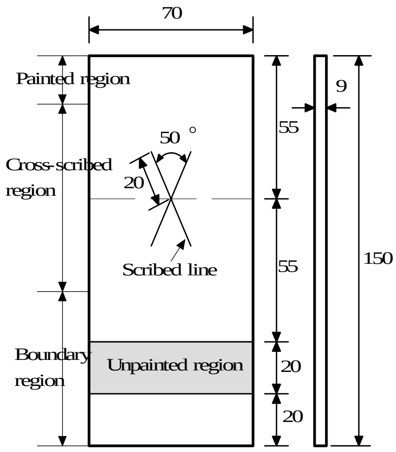


Figure 3. Dimension and configurations of test specimens (unit in mm)

test site. In these reasons, accelerated exposure tests in a laboratory are employed to obtain the fundamental data and to complement the data of the field exposure tests.

In recent years, Fujiwara (Hiroshi et al. 1997) performed on accelerated exposure tests of 7 sets of accelerated test conditions, called SS, S6, DS, JASO, NS, seawater-NS, and ASTM-cycles. Based on the results of painted steels filed exposure tests in 5 sites in Japan, he presented the correlation between laboratory and field tests and proposed that S6-cycle test conditions is applicable for simulating the field exposure tests. The S6-cycle was proposed by the Ministry of International Trade and Industry and was specified in JIS. Itoh (Yoshito et al. 2002) performed on laboratory accelerated tests of unpainted steel plates, and proposed accelerating factors of the S6-cycles against field exposure tests using weight of flying salt.

This study performed laboratory accelerated tests conforming to the S6-cycle test condition to examine corrosion characteristics and durability evaluation of painted steels with different surface preparations of steel substrate. Four sets of surface preparations, grit-blast cleaning and hand-tool cleaning of complete, slight, and no removal of rusts, were used in the experiment. Comparing blistering area of paint films and thickness loss of steel substrate, the effect of the surface preparation on the durability of the painted steels is discussed.

2. EXPERIMENT PROCEDURE

2.1 Equipment of Experiment

A Combined Cyclic Corrosion Test Instrument made by SUGA TEST INSTRUMENTS Co., Ltd. was used in the research. This equipment can operate automatically the conditions of atomizing of salt water, temperature, and humidity in arbitrary order and combination. This has an environmental chamber of 2000 × 1000 × 500 mm, in which 188 test specimens of 70 × 150 mm can be arranged. The S6-cycle test condition adopted in the experiment is shown in **Figure 1**.

2.2 Test Specimen Preparation

The fabrication process of test specimens and the geometry of the specimen are shown in **Figure 2** and

Table 1. Details of test specimens

Symbol	Number	Surface preparation degree*	Pre-corrosion	Steel type
NL4	3	Grit blast cleaning (**L**evel**4**)	×	**N**ormal structural steel (SM 490A)
NL3	3	Hand tool cleaning (**L**evel**3**)	○	
NL2	3	Hand tool cleaning (**L**evel**2**)	○	
NL1	3	No cleaning (**L**evel**1**)	○	
WL4	3	Grit blast cleaning (**L**evel**4**)	×	**W**eathering structural steel (SMA 490AW)
WL3	3	Hand tool cleaning (**L**evel**3**)	○	
WL2	3	Hand tool cleaning (**L**evel**2**)	○	
WL1	3	No cleaning (**L**evel**1**)	○	

* Level 3, 2, and 1 indicate the surface conditions that removal all visible corrosion productions, that slight removal of rust, remaining tight residues of rust in the bottoms of corrosion pits, and no removal corrosion productions, respectively.

3, respectively. Two types of steel plates, called normal structural steel plates and weathering structural steel plates, were made of Japan Industrial Standard (JIS) SM490A and SMA490AW steels, respectively. In each type, 12 steel plates of 70×150×9 mm were prepared. They were grit-blasted by No.50 grit specified in JIS S-G50. 9 of 12 steel plates in each type were pre-corroded by the S6-cycle corrosion tests for 30 days, and then they were treated mechanically by a disc grinder in three ways, i.e. complete removal of all visual rusts, slight removal of rusts, which remains tight residues of rusts in the bottoms of corrosion pits, and no removal of rusts in each for 3 corroded plates.

All steel plates were painted with multilayer paint films having different functions, called C-3 or C-4 painting systems, except 20×70 mm rectangular region of steel substrate. Total thickness of paint films is between 0.3 to 0.4 mm. Cross-scribed lines of 0.3mm width, which reached the steel substrate, were made in the painted surface using a cutter knife. The specimen edges were protected with an extra thickness of paint films in order to prevent corrosion attack in these parts. The details of the test specimens are summarized in **Table 1**.

2.3 Test Procedure and Measurement

The test specimens were exposed in the environmental chamber of the S6-cycle corrosion conditions during 251 day (about S6-1000 cycles). The thickness, gloss, and blistering area of paint films were measured at exposure times of 0, 67, 147, and 251 days. After the accelerated tests, corrosion productions and paint films on the steel substrates were removed by boiling with ammonium citric and thioureas, and then the geometry of steel surface under paint films was also measured by A Laser Focus Measuring Instrument.

3. EXPERIMENTAL RESULTS

3.1 Classification of Specimen Surface

In the research, paint films were scribed to create a well-defined defect, and resistance is judged by the degree of corrosion attack at the scribe lines. An unpainted region was also prepared to determine the degree of corrosion attack at the boundary of painted and unpainted regions. As shown in **Figure 3**, the test surface was divided into three regions, painted region($0 \leqq X \leqq 20$ mm), cross-scribed region ($20 \leqq X \leqq 90$ mm), and boundary region ($90 \leqq X \leqq 150$ mm). In the painted region, deterioration of the paint films was invisible to the naked eye.

3.2 Cross-scribed Region

1) Blistering of the paint film

Corrosion originated at the scribed lines, undercut the paint film/steel substrate interface, and moved out from the lines. As a result of this process, blistering of paint film was produced. Typical surfaces of the cross-scribed regions at 251 days are shown in **Table 2.** Blistering of the paint films in the NL4 specimen is observed near the scribe lines. On the other hand, corrosion in the other specimens moved out from the lines, and then the blistering is widened far away from the lines.

Table 2. Blistering in the cross-scribed region

No corrosion	NL4	NL3	NL2	NL1
				

The geometry of the painted surfaces was measured at 0.5-mm interval in both width and length direction on the surface using a Laser Focus Measuring Instrument. From these data, blistering area was calculated, and its mean is plotted against to the testing time in **Figure 4.** When the testing time increases, the blistering area also increases gradually, while the increase in the NL4 and WL4 specimens are little. The difference in the blistering area due to the surface preparation degree becomes clear as the testing time increases.

Mean and mean±s data of the area for 251 days is shown in **Figure 5**. The blistering area increases in this order of Level 4 (NL4 or WL4), 3 (NL3 or WL3), 2 (NL2 or WL2) and 1 (NL1 or WL1). Comparing the blistering area, it is observed that the blistering of paint films depends on the surface preparation degree: corrosion initiation and propagation in blast-cleaned painted steels is limited near the defects, and that in hand-tool cleaned steels drastically increases.

2) Deterioration of the painted steels

The corrosion resistance in painted steels is usually characterized by the degree of corrosion attack at

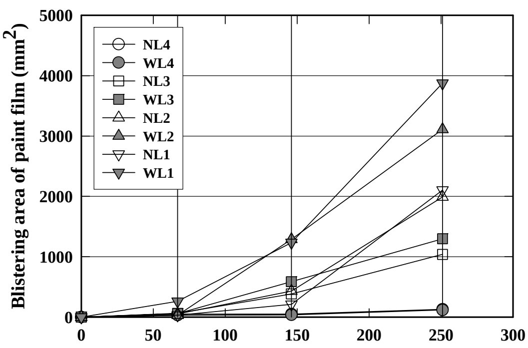


Figure 4. Increase in blistering area

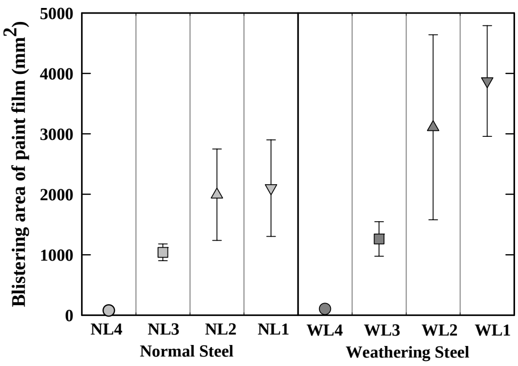
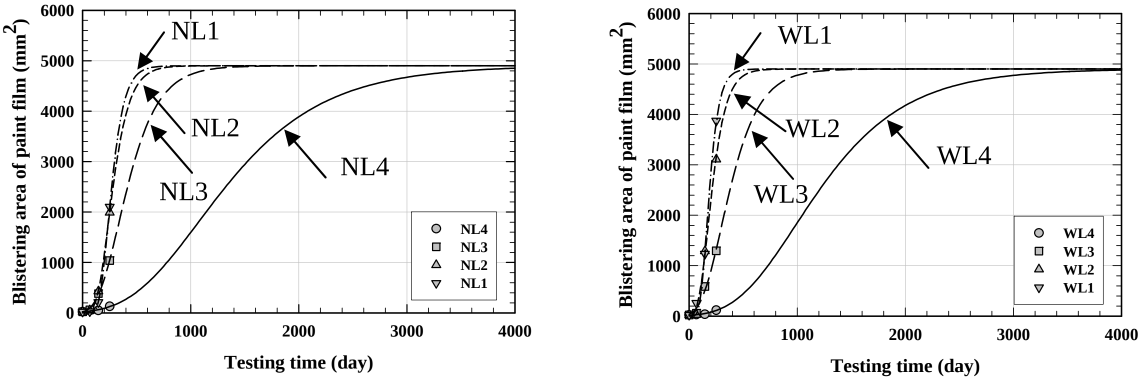


Figure 5. Blistering area at 251 days



(a) Normal steels (SM490A)

(b) Weathering steels (SMA490WA)

Figure 6. Deterioration curves of painted steels

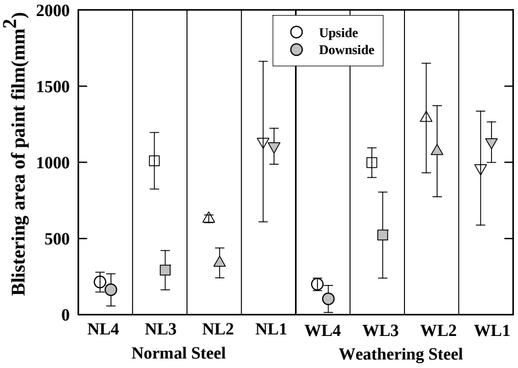


Figure 7. Blistering area in boundary region

scribed lines. In addition, adhesion between paint films and steel substrates is the most important property of organic painting because if it fails, all other paint properties become worthless. Herein, based on the blistering area of paint films resulted from loss of the adhesion, deterioration degree of the painted steels is evaluated. The data of the blistering area were fitted by Gompertz's growth regression curves, $y = ab^{c^t}$, as shown in **Figure 6**, where 4900 mm^2 is the area of the cross-scribed region. The application of the Gompertz's curve for evaluating deterioration of paint films was theoretically confirmed by Nishimura (Akira et al. 1985). He presented that long-time deterioration of paint films can be estimated using corroded area under the films in early stage of the deterioration process.

The testing time for the same blistering area tends to shorten in the order of Level 4, 3, 2 and 1 specimens, respectively, while those for the Level 2 and Level 1 are almost equal. For example, when the blistering area is 2000 mm^2, the testing time is 250 days for the NL2 and NL1 specimens, 350 days for the NL3 specimens, and 1200 days for NL4 specimens. From comparison of the regression curves obtained from the present data, it is observed that blistering area of painted steels depends on the degree of the surface preparations, while it is almost same when the rusts remained on the substrate after the surface preparation.

3) Thickness loss

After removal of paint films and rusts, the geometry of the surfaces was measured. From these data, corrosion depth (thickness loss) in the three regions, painted region, cross-scribed region, and boundary region, were calculated. In this calculation, average thickness of the paint region, where no corrosion attack was observed, was taken as the thickness of each specimen. Based on the thickness in each specimen, thickness loss in the cross scribe region was calculated. Mean thickness loss tend to increase in the order of Level 4, 3, 2, and 1. However it is below 0.06 mm for the normal steels, N-series specimens, and below 0.25 mm for the weathering steels, W-series specimens. In maximum thickness loss, the NL4 and WL4 specimens show the smallest thickness loss in each set, and the other specimens in each set show almost the same mean values. It is noted that mean thickness loss in unpainted steel plates is 0.2 to 0.25 mm (Kainuma et al. 2002).

3.3 Boundary Region of Painted and unpainted regions

1) Blistering area

Blistering area at 251 days in the boundary region is plotted in **Figure 7**. It tends to increase in the order of Level 4, 3, 2, and 1 similar to that in the cross-scribed region.

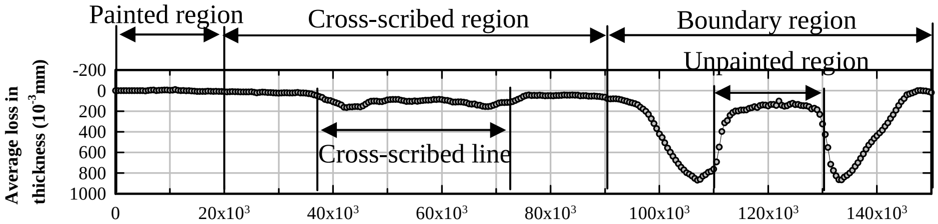


Figure 8. Average thickness loss in an AP2 specimen

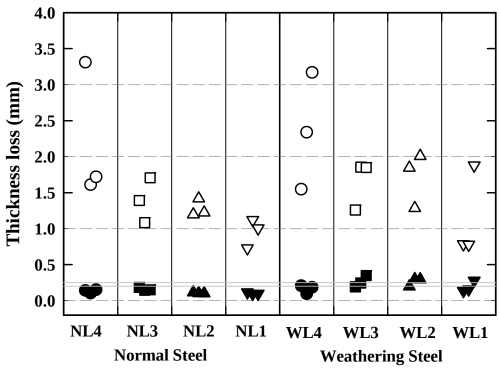


Figure 9. Thickness loss in boundary region

2) Thickness loss

Mean and mean ± s corrosion depths in each specimen were measured. The mean thickness loss in the width direction is plotted in **Figure 8**. Thickness loss under paint film is occurred in the cross-scribed region and the boundary region. It is invisible in the painted region. The mean thickness loss maximizes at the side of paint films along the boundary-lines of paint and upside/ bottom side of the unpainted region.

The maximum and mean thickness loss in the boundary region of each specimen is shown in **Figure 9**. Difference in the average thickness due to the surface preparation is not clear, while the maximum thickness loss tends to reduce in the order of Level 4, 3, 2, and 1. The maximum loss in the NL4 and WL4 is 1.5 to 3.5 mm, and that of the others is 0.7 to 2.0 mm.

4. SUMMARY

This study performed the corrosion characteristics of painted steels with different surface preparations of steel substrate. The surfaces of the steel plates were surface-treated in four ways, and they were painted with multilayer paint films. In this procedure, unpainted region and cross-scribed lines were made in the painted surface. The painted steels were exposed in the S6-cycle accelerated test condition during 251days.

From blistering area of paint films and thickness loss in steel substrate, the effect of the degree of surface preparations on deterioration of paint discontinuities, cross-scribed lines and boundary of painting and unpainting regions was discussed. Deterioration curves of four sets of test specimens were also presented.

5. REFERENCES

Fujiwara, H. and Tahara, Y. (1997), “Research on the correlativity of outdoor exposure test of painting test piece with corrosion test for steel bridge painting”, *Journal of Structural Mechanics and Earthquake Engineering*, No. 570/I-40, 129-140.

Itoh, Y., Iwata, A., and Kainuma, S. (2002), “Accelerated exposure tests of environmental durability for steels and the estimation of acceleration coefficient”, *Journal of Structural Engineering, JSCE*,Vol. 48A, 1021-1029.

Kainuma, S., Hoshomi, N., Kim, I.T., and Itoh, Y. (2002), “Fatigue behavior of corroded out-of-plane gusset welded joints”, *Proceedings of 2th International Conference on Advances in Structural Engineering and Mechanics (ASEM’02)*, Busan.

Funke, W. (1981), “Blistering of paint films and filiform corrosion”, *Progress in Organic coatings*, Vol. 9, 29-46.

Denny, A.J. (1992), Principles and prevention of corrosion, Prentice Hall International, Inc., Singapore.

Funke, W. (1997), “Problems and progress in organic coatings science and technology”, *Progress in Organic coatings*, Vol. 31, 5-9.

Masuko, N. (1981), “Corrosion initiation and propagation under paint films”, *Anticorrosion Engineering (Bousyoku Gizyutsu)*, Vol. 30, 699-704.

Nishimura, S. and Shimada, K. (1985), “Theoretical analysis of deterioration behavior of paint film in steel structures”, *Bridge and foundation engineering*, No.5, 17-21.