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Further Investigation on the Corrosion of Coated Steel Using the Current Interrupter Technique

Hiroyuki Tanabe, Masanori Nagai, Tohru Taki,
Fundamental Research Laboratory, Dai Nippon Toryo Co., Ltd. 1382-12 Shimoisigami, Ohtawara-City, Tochigi-Pref. Japan
tanabe@star.dnt.co.jp

Abstract

A variety of electrochemical methods are available for the measurement of the under-film corrosion of coated steel. Each method has its own characteristics and is suitable to determine particular types of anti-corrosive mechanism of coatings. Of the many methods available, current interruption offers particular advantages in testing defect-free high resistance coatings that are difficult to evaluate by other methods such as impedance. An under-film corrosion tester (UCFT) has been developed based on the current interruption method and this paper discusses some experimental results on protective coating performance obtained by the UFCT.

Introduction

Corrosion protection by organic coatings is a common and important technology. Many high performance organic coatings have been developed for the protection of steel structures. However, in order to develop high performance coatings in a short timescale, it is necessary to utilise a rapid method for assessing coating performance. Over the last few years we have been experimenting with electrochemical methods that are able to measure protective coatings performance quantitatively in a relatively short measuring period [1-4]. As a result of this work, the current interrupter method was selected as the most appropriate and giving the best results and, consequently an under-film corrosion tester (UFCT) for coated steel was developed. Some of the advantages of the current interrupter method are:

1. It is possible to measure under-film corrosion on steel with a high performance coating having a film resistance of more than 10GΩ.

2. Five parameters: film resistance, film capacitance, polarization resistance, polarization capacitance and rest potential may be measured.

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3. The current interrupter method adopted corrosion tester for coated steel is easier to operate and takes a shorter period to measure electrochemical parameters compared to A.C. impedance method.

In this paper, the durability of coated steel, measured using the UFCT, is discussed.

Experimental Method

Principle of measurement

Polarization resistance and film resistance were measured using the current interrupter method with a current pulse generator having an accuracy of 10^{-10} A. The corresponding potential response was measured on application of the small current to the coated steel. Generally, the equivalent electrical circuit of coated steel has two different time constants. Thus, the time constant of the coating film (representing the coating resistance and capacitance) is around of the order of milliseconds. On the other hand, that of the steel surface under the coating film (representing any electrochemical double layer) is usually greater than a few seconds. The significant difference between these two figures makes it possible to separate them. Accordingly, the evaluation of protective performance of coated steel having high film resistance can be achieved non-destructively.

The potential decay of coated steel after charging using a small current is shown in Eq.(1).

$$V = iRe\ -t/\tau \quad \dots \quad (1)$$

Equation (2) is derived from Eq. (1)

$$\log V = \log iR - t\ /\ 2.3\tau \quad \dots \quad (2)$$

From Equation (2) the time constant, polarization resistance and polarization capacitance can be obtained. Thus, the film resistance and film capacitance can be obtained.

Test samples on steel

Blasted steel was prepared for coating with moisture cured polyurethane (MCU) and modified epoxy (EP). It was coated at two different dry film thicknesses of 50 μm and 100 μm, and dried at 5℃ for 3 days, and these coating were subjected to an impact resistance test at low temperature. JIS K 5400, DuPont Method, 1/2Φ×500g×50cm, with an atmospheric temperature of 5℃.

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In order to evaluate the degree of durability, coated steels were subjected to a standard 5% salt spray test. Other samples were measured electrochemically using the UFCT under immersion in 3 wt% sodium chloride solution.

Test samples on galvanized steel

Two kinds of coating system were applied to pre-treated galvanized steel, the specifications of which are shown in Table1. Two primers were used one containing chromate anti-corrosive pigment, another containing non-chromate anti-corrosive pigment. The coating system specifications were identical except for the primers.

Table 1: Specification of PCM coating system

No.	Substrate	Pre-treatment	Primer	Top coat
1	Galvanized steel	Chromate	Chromate primer (5μm)	Polyester resin top coat (15μm)
2	Galvanized steel	Chromate	Non-chromate primer (5μm)	Polyester resin top coat (15μm)

Results and Discussion

Measurement of dummy circuit using UFCT

The under-film corrosion tester apparatus is shown in Fig. 1 while the equivalent circuit model using fixed electrical elements is shown in Fig. 2. In this validation test, the ratio of the time constants for the different RC circuit elements in the equivalent circuit model were ten to thirty times as shown in Table 2. The results from the UHFCT, also in Table 2, indicate that the measured values were remarkably close to the nominal values. Thus, the measurement method is validated and the apparatus is reliable.

Fig.1 Photograph of under-film corrosion tester (HL201)

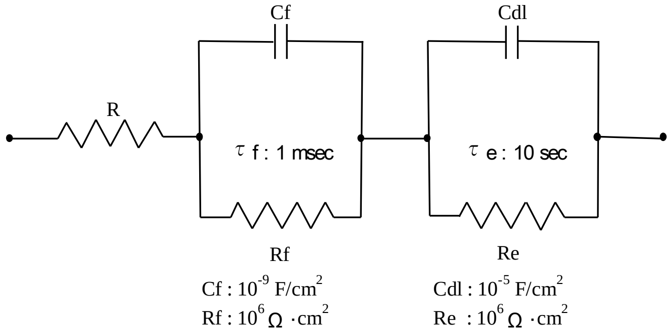

Fig.2 Equivalent circuit of coated steel.

Table 2: Comparison of nominal values and measured values of fixed elements

Model circuits	Nominal Values				Measured Values			
	R_f	C_f	R_e	C_{dl}	R_f	C_f	R_e	C_{dl}
No.1	95MΩ	330pF	105MΩ	0.01μF	95.9MΩ	320pF	105.9MΩ	0.01μF
No.2	100MΩ	1000pF	100MΩ	0.01μF	102MΩ	980pF	98.4MΩ	0.012μF

Measurement of coated steel using UFCT

Electrochemical parameters of painted steel were measured using the UFCT method. Generally, heavy duty coatings (for example epoxies) have been used for the protection of steel structures. However, two pack paints such as epoxy do not cure sufficiently at the temperature lower than 5℃ and so a good protective performance is not expected here. On the other hand, moisture-cured polyurethane paint has been used often as good performance paint even if it was cured at low temperature. The results for the epoxy (EP) and polyurethane (MCU) systems are shown in Fig. 3. The coated panels were then subjected to an impact resistance test at low temperature. After which the electrochemical parameters were again measured using UFCT under immersion in 3% NaCl solution at 23℃. The change in polarization resistance with time is shown in Fig. 3 and the change in polarization capacitance with time is shown in Fig. 4.

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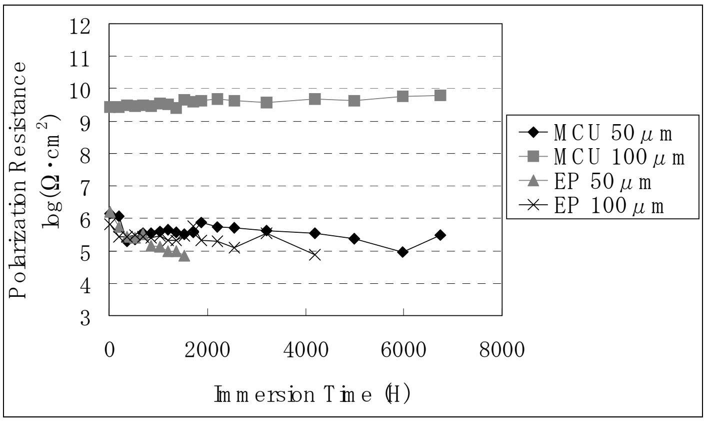

Fig 3. Change in Polarization Resistance after impact resistance test.
(Drying : 5°C×3days, impact resistance : 5°C 1/2φ ×500g×50cm)

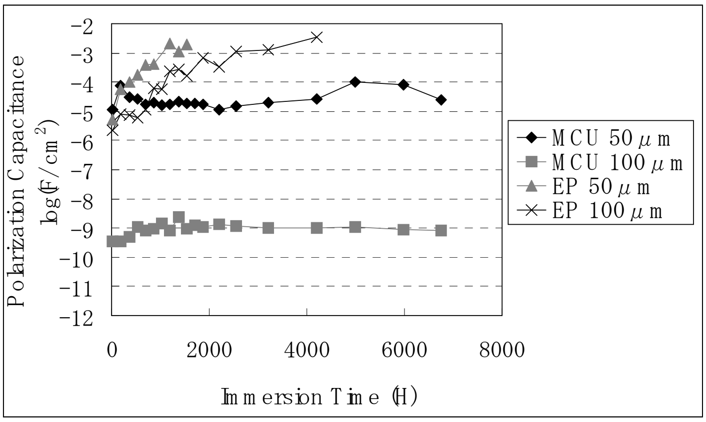

Fig 4. Change in Polarization Capacitance after impact resistance test.
(Drying : 5°C×3days, impact resistance : 5°C 1/2φ ×500g×50cm)

In the case of MCU (film thickness is 100μm), the polarization resistance was very high and polarization capacitance was very low for a long time. This is evidence of excellent anti-corrosive properties. However, for the MCU with film thickness 50μm, the polarization resistance after the impact resistance test was low from the start of the immersion.

On the other hand, the electrochemical measurement clearly shows that the anti-corrosive property of the EP system was not good enough with the low temperature drying regime and after impact testing. The coated panels were tested for impact resistance after that they were subjected to salt spray test in order to evaluate the correlation between results of electrochemical results and anti-corrosive property. The film appearance after 560 hours

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salt spray test is shown in Figure 5. As the result, the correlation between electrochemical method and salt spray test was confirmed.

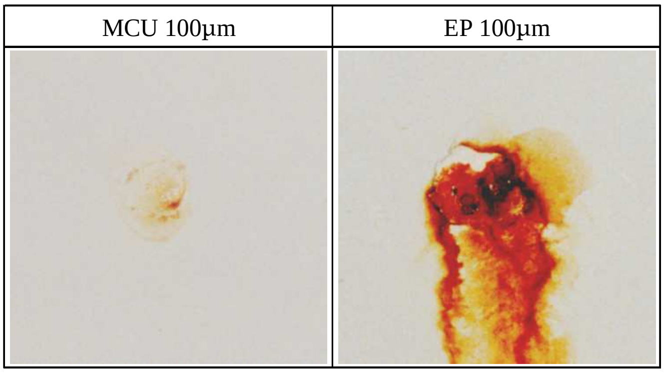

Fig.5 Film appearance after impact resistance test and SST 528H

Measurement of coated galvanized steel using UFCT

The change in polarization resistance, measured by UFCT, is shown in Fig. 6.The polarization resistance of both coating systems was very high after 2500 hours immersion in 3% NaCl. Since the anti-corrosive property of the two coating systems (chromate and non-chromate) was nearly the same, the non-chromate system was considered practical to use.

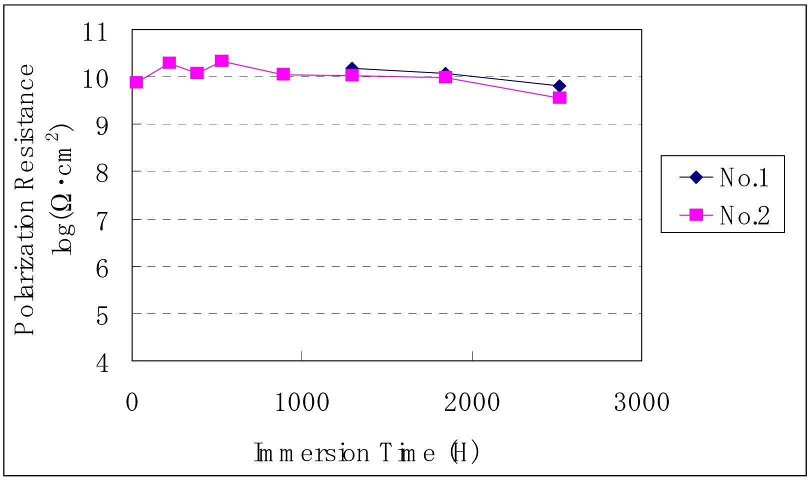

Fig 6. Change in Polarization Resistance after 3%NaCl immersion.

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Influence of oxygen on coated steel

Influence of oxygen on coated steel was investigated using UFCT. In case of an acrylic emulsion, the polarization resistance under de-aeration was larger than that under aeration as shown in Fig 7. The variation in potential of the coated steel (shown in Fig. 8) also indicates the influence of oxygen as well as non-coated steel.

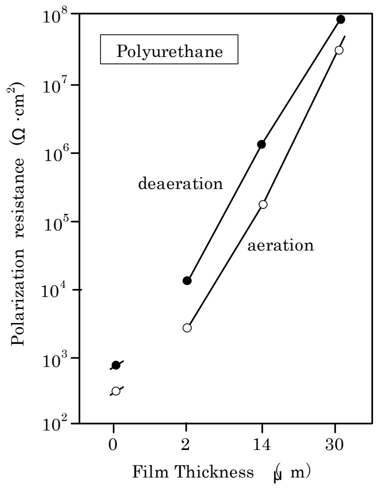

Fig.7 The effect of dissolved oxygen on polarization resistance and film thickness

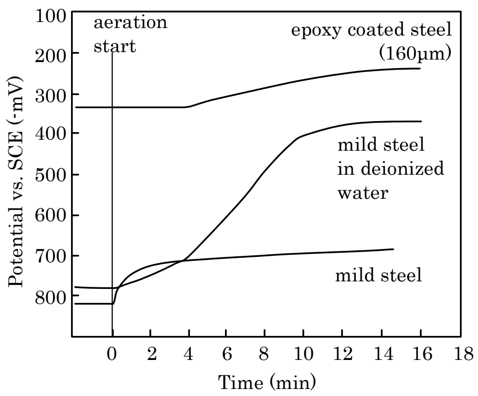

Fig.8 The potential change of coated steel and uncoated steel with time. (3 wt% sodium chloride solution)

Conclusions

1. Under-film corrosion tester using current interrupter method was developed. The advantages were found as follows.

2. Coated steel having high resistance of 10GΩ was measured successfully.

3. The measurement operation was easy and took less time to measure by adopting current interrupter method. It is good for test samples and save time for measurement.

4. The correlation both electrochemical method and salt spray test was appeared.

5. UFCT is useful to evaluate the durability of coated panels.

6. Influence of oxygen was observed according to experimental results of protective coating performance obtained by UFCT.

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