Damage assessment of the corrosion-resistant performances for organic coating systems after accelerated tests using analytic hierarchy process

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A B S T R A C T

It is very significant to comprehensively evaluate corrosion-resistant levels of an organic coating system after accelerated tests or outdoor exposures. In this study, the comprehensive evaluation model of the tested or exposed organic coating systems was established with Analytic Hierarchy Process (AHP) based on their eight types of the often observable and measureable failure modes, and that this model was verified by the electrochemical impedance data based on their electrochemical impedances spectroscopies (EIS). The corrosion-resistant performance levels of the tested or exposed organic coating systems were defined based on the comprehensively evaluated values. The relationship of their comprehensively evaluated values with the electrochemical impedances of the tested or exposed organic coating systems was proposed. Finally, this model was used to assess the corrosion-resistant performances of the coated aluminum alloys with three types of availably commercial organic coatings after accelerated tests. The results showed that the comprehensive evaluation model was verified to be reasonable to straightforwardly and comprehensively assess the corrosion-resistant performance levels of the tested or exposed organic coating systems after accelerated tests in a laboratory which simulate different corrosive atmospheric environments.

1. Introduction

Material corrosion, which occurs spontaneously, has a significant impact on the word economy. There are many corrosion control methods, such as protective coatings, corrosion inhibitors, electrochemical protection etc.. Among these methods, organic coatings, the costs of which are up to 88.3% of the total costs of corrosion controlling measures and services [1], have been used much more efficiently and cheaply to protect materials from corrosion for a long time. It is a very primary task of the developers to research, develop a new kind of organic coating and to comprehensively evaluate its corrosion-resistant performances.

In general, the failure mechanism of an organic coating system is very complicated with many types of failure modes, such as cracking, blistering and fading etc. [2].Some researchers have paid their attentions to the failure mechanisms of organic coating systems [2,3];on the other hand, quickly and reliably accelerated tests to evaluate the corrosion-resistant performances and to predict the service life of an organic coating system have become the continuous demands of researchers, manufacturers and users. For this reason, outdoor exposures and accelerated tests in laboratory have been carried out for many years [4–9] and the relative standards have been issued [10 − 12]. Thus, a basis has been provided for selecting a type of organic coating for a specific application, and also for helping the researcher how to formulate a new organic coating.

In the recent years, the rapid, quantitative, discriminating techniques and experimental methods have been applied to assess the corrosion-resistant performances of an organic coating system [4, 8, 9].The low-frequency impedance and break point frequency data were often used to evaluate the corrosion-resistant performances of an organic coating system after outdoor exposures or accelerated tests [13,14]. At the same time, the accelerated tests in a laboratory, which simulate some atmospheric environments, are very importantly accelerated way to investigate the qualities and the failure characteristics of an organic coating system. These data which obtained through accelerated tests in a laboratory were only analysed based on the relative standards for one type of failure modes without the consideration of comprehensively or quantitatively assessing the corrosion-resistant performances of the tested or exposed organic coating systems, and of ranking different organic coating systems.

In fact, an organic coating system degrades in many types of failure modes, and that different failure modes reflect the different failure importance scales of the organic coating system with different failure mechanisms. Therefore, it is very necessary to comprehensively assess the impact of each failure mode on the corrosion- resistant performances based on the qualitative determination of the importance scales of the failure modes for an organic coating system. Recently, although K.McCallum, et al. [15] introduced that localised corrosion was assessed using Markov Analysis. F.Ayello et al. [16] described a Bayesian network approach to assess quantitively the internal and external corrosion probability of oil & gases pipelines. The comprehensive evaluation methodologies have been mainly used for risk assessment, including corrosion-induced risk assessment [15, 17–20]. However, few works attempted to more straightforwardly, quantitively and comprehensively assess the corrosion-resistant performance levels of an organic coating system based on the failure modes of the organic coating systems after accelerated tests or outdoor exposures.

The Analytic Hierarchy Process (AHP) is the most comprehensive system designed for multiple criteria decision making and has many industrial applications [18–19, 21–22]. In this study, an attempt was firstly made to establish the comprehensive evaluation model for the corrosion-resistant performance levels of an organic coating system after accelerated tests with AHP, and then to verify this model using its electrochemical impedance data. Finally, to further apply the comprehensive evaluation model to some case studies.

2. Materials and experimental methods

In this study, three types of commercially available two-component organic coatings were used. The sizes of the coated specimens were 150 mm × 75 mm × 2 mm. The organic coatings were applied by air spray on the substrates which were made of anodised Al-alloy, Aluminised and Phosphatised alloy steels, and cured at the room temperature for 7 days in accordance with their respective product data sheet. A brief description of three types of the coated specimens was listed in Table 1. At least three pieces of specimens were prepared for the each type of organic coating system. All of these coated specimens were subjected to the accelerated tests which simulated an ocean atmospheric environment (Fig. 1). Totally 8 Cycles of accelerated tests (UV A exposure and following immersing /drying test) were performed.

For a case study, 7050 Al-alloy was used for the substrates of the coated specimens in this study, sizes of which were 150 mm × 75 mm × 2 mm. The Al-alloy specimens were treated using sulfuric acid anodising process, and then were coated by air spray with the above three types of commercially available two-component organic coatings, respectively. The technical data of these specimens made of anodised Al-alloys were listed in Table 2.

Some of coated Al-alloy specimens were subjected to the accelerated tests which simulated an industrial atmospheric environment (Fig. 2). Totally 8 cycles of accelerated tests were performed. At the same time, as shown in Fig. 3, the accelerated tests simulating an urban atmospheric environment were conducted for the balance of the coated specimens. Similarly, totally 8 cycles of accelerated tests were performed.

After all of the coated specimens were subjected to totally 8 cycles of accelerated tests, some specimens were used for visual inspection and optical analysis, including SEM images; And then for the thickness test, the gloss test and the adhesive strength test in accordance with ISO, ASTM, JIS and Chinese standards (GB) [10–12, 23–32], respectively. Others were used for electrochemical impedance spectroscopy (EIS) measurements.

All of EIS measurements were performed in a 5% NaCl solution with Gamry 600 plus. In all cases, the area of the specimen exposure to investigation was 19.6 cm^2. EIS spectra were obtained using the classic three electrodes system with 10 mV of signal

Table 1
Brief descriptions of three types of specimens for the accelerated tests simulating an ocean atmospheric environment.

Items	Coating #1	Coating #2	Coating #3
Substrate	Al- alloy	alloy steel	alloy Steel
Surface treatment	Anodised	Aluminised	Phosphatised
Primer	HD-06* (Epoxy-polyamide)	HSD-1*(High-solid Epoxy-polyamide)	HD-06* (Epoxy-polyamide)
Top coating	H13–2*(Acrylic- polyurethane)	HST-1*(High-solid polyether-polyurethane)	H96–71*(Fluorine-modified polyurethane)
Pigment	TiO$_2$	TiO$_2$	TiO$_2$
Color	White	Grey	Light-grey
Thickness of organic coating (μm)	60.0–70.0	65.0–75.0	50.0–60.0

* : HD-06, H13-2, H96-71,HSD-1 and HST-1 are commercial brands.