

A Quantification Method for Coating Degradation due to Outdoor Environmental Factors

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ABSTRACT

Three accelerated aging tests including the cyclic corrosion, intermittent condensation, and ultraviolet irradiation as well as an outdoor exposure test are performed on polyurethane coatings to investigate a quantification method for assessing the life of coatings. Rust did not occur in the 6-months accelerated test and the 12-months outdoor exposure test. However, the urethane bond of the coating surface was decomposed by the ultraviolet irradiation, and this behavior consisted with the outdoor exposure test. The ultraviolet irradiation primarily accounts for coating degradation in the environment. It was also found that decrease in contact angles are associated with that molecular changes on the surface. The contact angle showed a better correlation with the decomposition of urethane bonds on the surface than the specular gloss. An EIS measurement model for capturing degradation in the coating is also examined. Future work will involve heavily degraded samples to assess data reproducibility and to establish a degradation quantification method capable of reproducing the behaviors of different environments.

Keywords: polyurethane coating, accelerated test, outdoor exposure test, FT-IR, EIS, contact angle

INTRODUCTION

Buildings and structures are generally coated with paint for corrosion protection and scenery preservation. Since metals are shielded from corrosion by coatings, choosing a long-life coating is important for effective maintenance. In order to determine long-life coatings in different environments, accelerated aging tests are conducted. However, simulating degradation in used environments through aging tests is challenging because the coatings are applied to varied places, with exposure to varying degradation factors. Moreover, no effective quantitative evaluation method for coating degradation exists, with the most widespread assessment by visual check. An accelerated test method suitable for the service environment and a quantitative method for evaluating coating degradation will facilitate choosing a long-life coating.

The degradation behaviors of coatings such as polyurethane, fluorine resin and others, and accelerated test methods for simulating a real environment are reported in several studies. For example, G. Cai, H. Wang, D. Jiang, and Z. Dong investigated the corrosion resistance, morphology, molecular

structure, and depth profile of fluorinated polyurethane coating aged under a UVA and a salt spray. ^{(1), (2)} However, the study for the relationship between the coating degradation rate and the corrosion condition remains not enough.

The present study focuses on an accelerated test method and a quantitative degradation evaluation method for coatings. An anticorrosion coating on a carbon steel plate is aged using the cyclic corrosion (CCT), intermittent condensation, and ultraviolet irradiation tests. These allow separate investigations of the effects of common environmental factors including salt, water, temperature, and ultraviolet rays. Then, we classify the coating degradation on rust-free carbon steel into three stages displayed in Figure 1. Since environmental factors such as salt, water, and ultraviolet rays are initially exposed to the surface of the coating, the first degradation stage occurs on the surface. In the second stage, as the coating on the surface deteriorates, environmental factors invade the coating interior, with degradation progressing. During the third stage, the environmental factors breach the coating, reaching the carbon steel, and initiating corrosion. The first stage degradation was examined using a stereo microscope, scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FT-IR). For quantitative evaluation, the contact angle and gloss ratio were measured. The second and third degradation stages were investigated using electrochemical impedance spectroscopy (EIS).

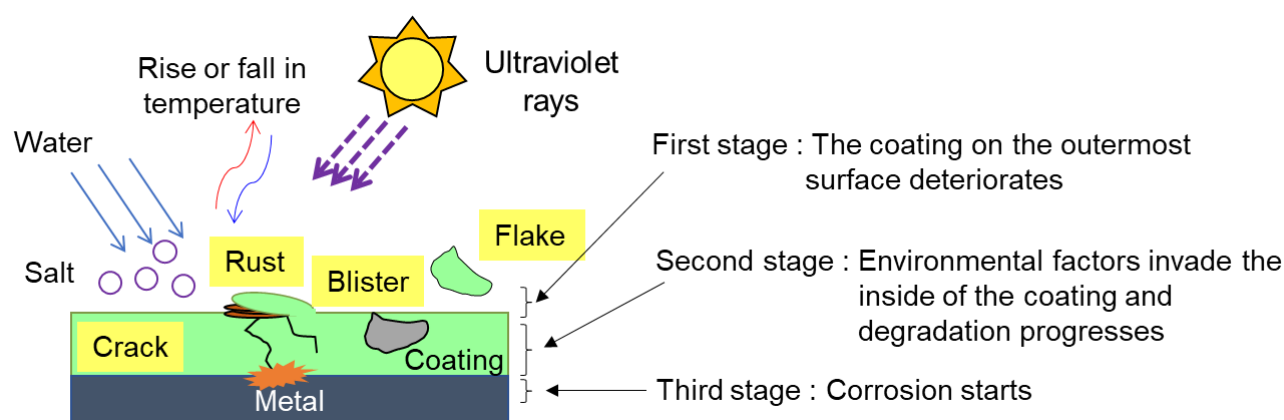


Figure 1: Illustration of environmental factors, coating degradation types, and three coating degradation stages.

EXPERIMENTAL PROCEDURE

Sample Preparation

Carbon steel was used as the sample material. In the accelerated aging tests, the samples were 150 mm × 70 mm (t = 4.5 mm), while samples for the outdoor exposure test measured 200 mm × 150 mm (t = 4.5 mm). The carbon steel plates were blasted according to the ISO Sa2 1/2 grade and painted according to the specifications shown in Table 1. After drying, the coating thickness of each piece was measured at its center using a thickness gauge. The external appearance of a sample is exhibited in Figure 2.

Table 1: Summary of the specification of coatings applied on samples.

Coatings		Dry film thickness (μm)	Total thickness (μm)
Primer	Epoxy resin zinc primer	20	210
Under coat	Modified epoxy resin anticorrosive paint	140	
Top coat	Thick film polyurethane resin paint	50	

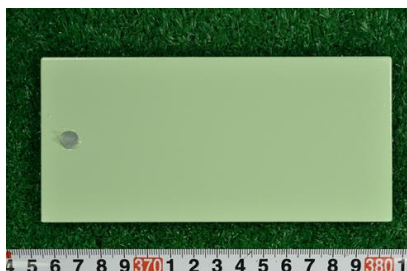


Figure 2: Photo of the typical appearance of a sample after coating.

Accelerated Aging Tests

The main degradation factors in many used environments are salt, water, temperature, and ultraviolet rays. Three types of accelerated tests including the cyclic corrosion (CCT), intermittent condensation, and ultraviolet irradiation test (Table 2) were performed to evaluate the effects of various factors. The CCT was conducted according to the Japan Industrial Standard (JIS) K 5600-7-9 standard using a cyclic corrosion test instrument, with a cycle comprising four steps.⁽³⁾ The first step known as salt spray involved exposing the samples to a 5 wt.% NaCl solution for 30 minutes, with the chamber temperature maintained at 30 ± 2 °C. The second step described as a humid environment in which the samples were exposed to pure water for 90 minutes, with the chamber temperature held at 30 ± 2 °C at $95 \pm 3\%$ RH. In the third step referred as the high temperature drying, the samples were dried for 120 minutes at a chamber temperature of 50 ± 2 °C. The final step termed intermediate temperature drying involved drying samples for 120 minutes at a chamber temperature of 30 ± 2 °C, and the cycle then restarts. The intermittent condensation test was performed according to JIS K 5600-7-3 standard using a temperature and humidity test chamber, while the ultraviolet irradiation test was conducted according to the JIS K 5600-7-7 standard at 63°C and 50% RH using a xenon weather meter.^{(4), (5)} Each test was conducted for periods of 1, 3, and 6 months.

Table 2: Accelerated aging tests and the main degradation factors.

The accelerated test	The main degradation factor
Cyclic Corrosion Test (CCT)	salt, water, temperature
Intermittent condensation test	water, temperature
Ultraviolet irradiation test	ultraviolet, temperature

Outdoor Exposure Test

To obtain data on coating degradation in an actual environment, an outdoor exposure test was performed in Miyakojima, Japan. Miyakojima is characterized by a hot and humid environment, with an average temperature of 24.4°C and an average humidity of 81%. It is known in Japan as an area rich in natural degradation factors such as solar radiation and sea salt particles. The samples were mounted southward at 45° and exposed for a year from March 2019 to March 2020.

Analysis

The surface observation was conducted using a digital single lens reflex camera and a stereo microscope, while the surface morphologies were examined by scanning electron microscopy (SEM) at an acceleration voltage of 10 kV and magnifications of $\times 200$ and $\times 20,000$.

Fourier transform infrared spectroscopy (FT-IR) was used to investigate changes in the molecular structure of the coatings through an attenuated total reflection technique with a diamond prism. The wavenumber range was 500–4000 cm^{-1} .

Electrochemical impedance spectroscopy (EIS) measurement was performed to determine the resistance of the coatings, and the measurement cell is shown in Figure 4. The exposed sample area was 1 cm^2 , with platinum mesh as the counter electrode and silver-silver chloride as the reference electrode, and a 5.0 wt.% NaCl solution as the electrolyte. First, the sample was immersed for 1800