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Degradation of Coatings under Atmospheric Tropical Conditions

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The weather resistance of five coatings systems based on alkyd, chlorinated rubber, epoxy, polyurethane and fluoropolymer were studied by natural exposure test and accelerated test. The coatings were exposed at Hanoi station with urban industry atmosphere and at Baichay station with marine atmosphere. The degradation of coatings was evaluated by gloss measurement and surface analysis by scanning electronic microscopy. The results obtained show that among coatings tested the gloss of polyurethane and fluoropolymer coatings remained highly and those of alkyd, chlorinated rubber and epoxy coatings were very low after two years of atmospheric exposure. Under accelerating conditions the gloss of fluoropolymer coatings remained highly after 80 cycles of testing. By comparison with accelerating test in UV-condensation chamber the conditions at atmospheric stations are more aggressive.

Keywords *: coatings, weather resistance, gloss retention, atmospheric test, accelerating test.*

1. Introduction

The top coating plays an important role in the coating system. The main factors of environment which cause the weathering, or degradation, of coatings are sunlight (in particular UV radiation), temperature, oxygen, water and pollutants. Among these factors the UV- radiation plays a significant part for coating degradation.[1] The degradation of organic coatings presents as a result of weathering can manifest itself in many ways, for example by lost of gloss, discoloration, chalking and embattlement [2),3),4)].

Table 1. Coating systems used for the test

Coatings types	Primer coating	Undercoating	Intermediate coating	Top coating
Alkyd coating	-	Anti corrosive under coating (35 μmxtwice)	Alkyd Intermediate coating (30 μm)	Alkyd Top coating (30 μm)
Chlorinated rubber coating	Epoxy zinc-rich primer (75 μm)	chlorinated rubber	chlorinated rubber Intermediate coating (35 μmxtwice)	chlorinated rubber Top coating (30 μm)
Epoxy coating	Inorganic zinc-rich primer (75 μm)	Epoxy resin under coating (60 μmxtwice)	Epoxy resin Intermediate coating (35 μm)	Epoxy resin Top coating (30 μm)
Polyurethane coating	Inorganic zinc-rich primer (75 μm)	Epoxy resin under coating (60 μmxtwice)	Epoxy resin Intermediate coating (35 μm)	Polyurethane Top coating (30 μm)
Fluoropolymer coating	Inorganic zinc-rich primer (75 μm)	Epoxy resin under coating (60 μmxtwice)	Epoxy resin Intermediate coating (35 μm)	Fluoropolymer Top coating (30 μm)

In this paper we present some results of coating degradation of 5 coating systems under tropical atmospheric conditions and in UV- Condensation chamber. The degradation of coatings was evaluated by gloss measurement and electrochemical impedance and coating surface was analyzed by scanning electronic microscopy.

2. Experiment

2.1 Preparation of coated steel used

Five coating systems of alkyd, chlorinated rubber, epoxy, polyurethane and fluoropolymer were applied to sandblasted steel (see Table 1).

2.2 Gloss measurement

The coatings were exposed at 2 atmospheric stations (Hanoi, Bai chay). The Hanoi station has the urban industry atmosphere and the Bai chay station has the marine atmosphere. The meteorological dates of this stations are presented in the Table 2.[5] The gloss of coatings was measured after 6 months, 1 year and 2 years of exposure.

Table 2. Meteorological dates of two stations

Station	Hanoi	Bay chay
Air average temperature ℃	23.9	26.7
Air average relative humidity, %	83	87
Sunshine total time (h/year)	1624	1800
Average wind velocity (m/s)	1.7	4.2

Beside atmospheric exposure the coating systems were tested in the UV-condensation chamber ATLAS UVCON UC-327-2 according to ASTM standard G53 - 96 (4 h UV at 70 ℃ + 8 h of condensation at 50 ℃). The gloss of coatings was measured during the test.

2.3 Electrochemical impedance measurement

A classical three-electrode cell was used: the working electrode is the coating after testing for 80 cycles in UV-condensation chamber, Saturated Calomel reference Electrode (SCE) and a platinum auxiliary electrode. The test solution was a 3 % NaCl solution. The electrochemical impedance measurements were performed by using AUTOLAB 30.

2.4 Electron-probe microanalysis

Coating surface after one year of exposure at atmospheric stations and after 80-cycles testing in UV-condensation chamber was analyzed by JSM-5300 spectrometer.

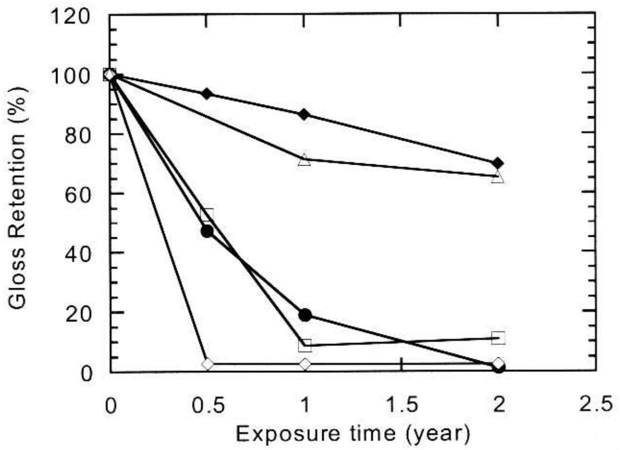

Fig. 1. Gloss retention of alkyd coating (●); epoxy coating (◇); chlorinated rubber ( ); polyurethane coating (△) and fluoropolymer coating (◆) exposed at Hanoi station

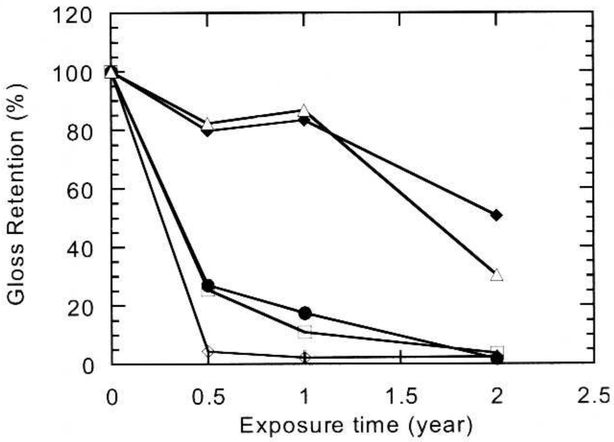

Fig. 2. Gloss retention of alkyd coating (●); epoxy coating (◇); chlorinated rubber ( ); polyurethane coating (△) and fluoropolymer coating (◆) exposed at Bai chay station

3. Results and discussion

Coating systems were exposed at Hanoi and Baichay station for two years. The gloss of coatings were measured during exposure time: after 6 months, one year and two years of exposure. The gloss retention of coatings exposed at Hanoi station was shown on the Fig. 1 and the gloss retention of coatings exposed at Bai chay station was shown on the Fig. 2.

After two years of exposure for the coating systems exposed at two stations, the gloss of fluoropolymer and polyurethane coatings remains highly. The gloss retention determinated were 69.6 % and 50.6 % for fluoropolyme coatings and 65.3 % and 30.2 % for polyurethane coatings exposed at Hanoi and Baichay station. By comparison with fluoropolymer and polyurethane coatings the gloss retention of chlorinated rubber coatings were lower (10.9 % and 3.6 % at Hanoi and Baichay station respectively). The gloss retention of alkyd and epoxy coatings are very low (lower than 2.5 %).

Comparing the gloss retention of coatings exposed at Hanoi and Baichay stations we can see that the gloss of coatings at Bai chay station decreased more rapidly than the one of coatings at Hanoi station. This difference can be explained by the aggressivity at Bai chay station: higher humidity, higher sunshine time and the presence of ions Cl^-. Among five coating systems the Fluoropolymer coatings are the best resistant at atmospheric conditions. The polyurethane coatings are also resistant at urban atmospheric conditions, but it is less resistant under marine atmospheric conditions. The coatings may be ranked in the following order of increasing of gloss retention:

fluoropolymer > polyurethane > chlorinated rubber > alkyd > epoxy

Beside exposure at two atmospheric stations coating systems were tested in UV-condesnation chamber. The gloss retention of coatings during accelerating test is presented in the Fig. 3.

The gloss of fluoropolymer coating did not decrease and it remained very highly. The gloss of alkyd and epoxy coating decreased significantly after 7 cycles of exposure and after 20 cycles it did not change very much with exposure time. The gloss of polyurethane and chlorinated rubber coatings decreased significantly after 21 cycles of exposure. After 80 cycles of exposure the gloss retention of epoxy coating was lowest (13,7 %), the gloss retention

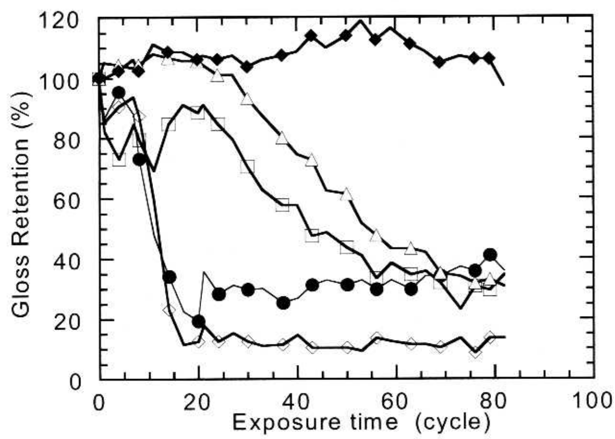

Fig. 3. Gloss retention of alkyd coating (●); epoxy coating (◇); chlorinated rubber ( ); polyurethane coating (△) and fluoropolymer coating (◆) exposed in UV-condensation chamber during test

Table 3. The exposure times at atmospheric stations correspond to exposure times to UV-condensation

Coating	Exposure time at atmospheric station (year)	Exposure time to UV-condensation (cycle)
Polyurethane	2	50-55
Chlorinated rubber	1	60-65
Epoxy coating	1	20-25
Alkyd	1	20-25

of alkyd coating, chlorinated rubber coating and polyurethane coating were higher then the one of epoxy coating but very much lower then fluoropolymer coating.

The coatings may be ranked in the following order of increasing of gloss retention in UV-condensation chamber:

fluoropolymer > polyurethane > chlorinated rubber > alkyd > epoxy

This order is the same order obtained by atmospheric test. But the gloss retention of coatings exposed to UV-condensation was higher than the gloss retention of coating exposed to atmospheric conditions. Comparing the gloss retention of coatings in atmospheric test and in accelerating test it is shown that for fluoropolymer coating it is difficult to compare two types of test for the other coatings it is possible to compare the time of exposure to atmospheric conditions and the time of exposure to UV-condensation. The exposure times at atmospheric stations correspond to exposure times to UV-condensation are presented in Table 3. It is shown that for each coating the relation between atmospheric test and accelerating test is different.

In order to study the degradation of coatings in UV-condensation chamber the electrochemical impedance measurement of coatings exposed for 80 cycles was carried out. The coating capacitance was determinated from impedance diagrams and the of water absorbed by coating has been calculated as:

$$\%\ \text{water uptake} = 100(\log(C_c/C_o)/\log 80)$$

where C_c is the coating capacitance, C_o is the coating capacitance at t = 0, 80 corresponds to the dielectric constant of water.[6)]

The variation of water absorption for coatings exposed in UV-condensation chamber during immersion time in NaCl 3 % solution are presented in the Fig. 5.

It is observed that for alkyd and epoxy coatings the water absorption increased rapidly with immersion time during first 3 hours, after that it was stable at high values (9.1 % and 5 .5% for alkyd and epoxy coating respec

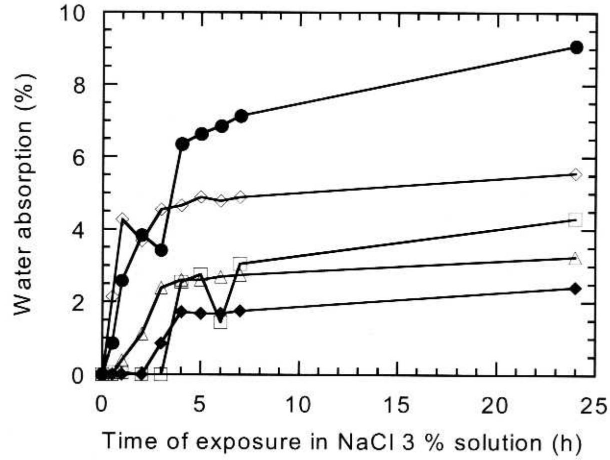

Fig. 5. Variation of water absorption of alkyd coating (●); epoxy coating (◇); chlorinated rubber ( ); polyurethane coating (△) and fluoropolymer coating (◆) during immersion time in 3 % NaCl solution

tively). For fluoropolymer coatings and polyurethane coatings water absorption increased slowly and after that it were stable at low values (2.4 % and 3.2 % for fluoropolymer and polyurethane coating respectively). The water absorption is related to the porosity of coating, which. corresponds to coating degradation. The coatings may be ranked in the following order of decreasing of coating degradation after testing in UV-condensation chamber:

fluoropolymer > polyurethane > chlorinated rubber > epoxy > alkyd

3.1 Surface analyze by SEM

In order to study the degradation of coatings, the change of coating surface was analyzed by SEM. The SEM photographs of coatings before and after testing are presented in the Fig. 6.

It observed that there are not big difference between

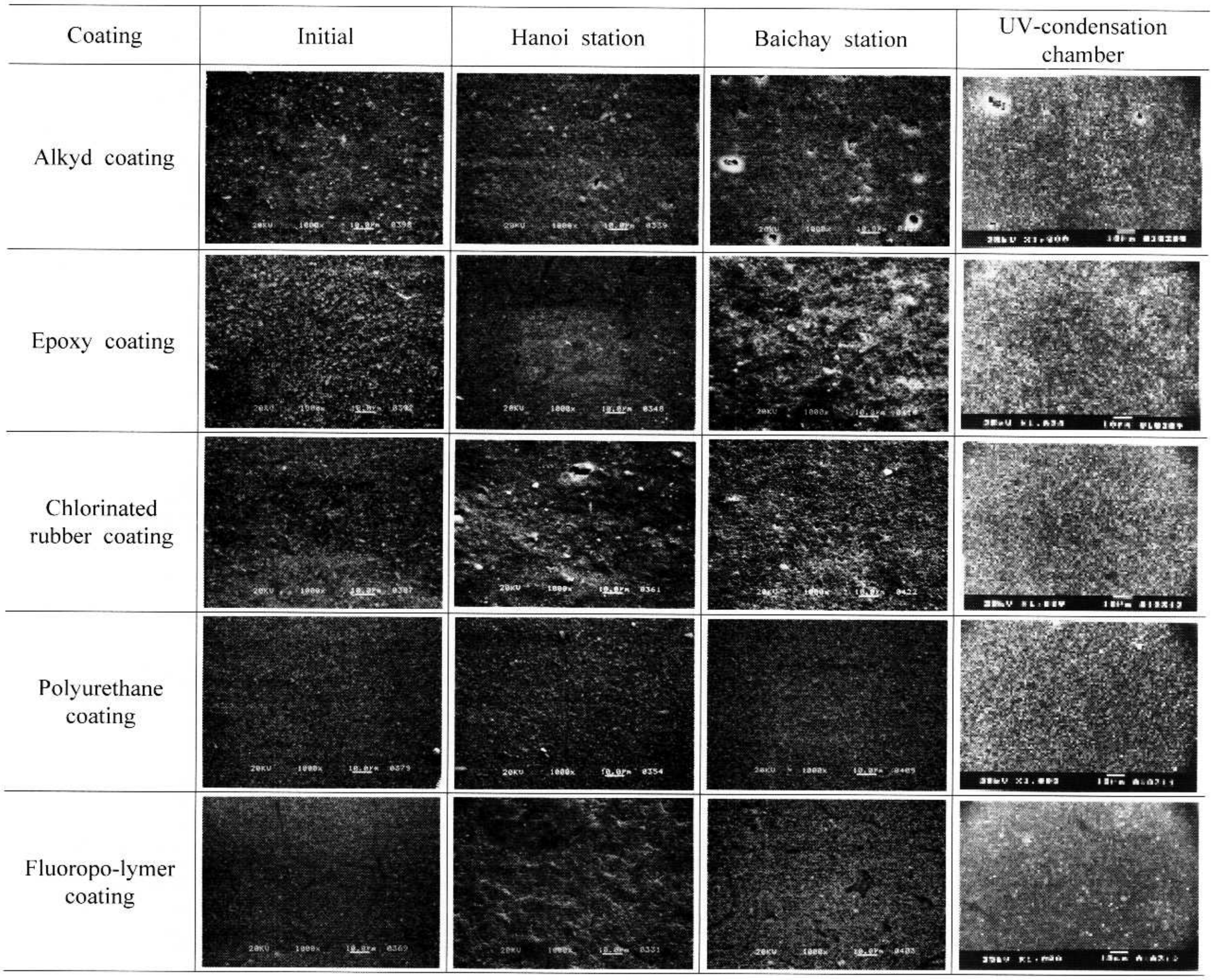

Fig. 6. SEM photographs of coating after one year of exposure at Hanoi and Bai chay station and after 80 cycles of testing in UV-condensation chamber

coatings before testing. After testing the coating surface was changed due to degradation. For alkyd coatings we can see the holes and micro-crack in coating surface after accelerating test and atmospheric exposure. The formation of holes explains the gloss decrease and high water uptake of this coatings. For epoxy, chlorinated rubber coating it is observed also micro-cracks after testing. For polyurethane and fluoropolymer coatings it is observed micro-cracks after atmospheric exposure but after 80 cycles of testing in UV-condensation chamber the fluoropolymer coating shows no degradation.

4. Conclusion

Degradation of five coating systems based on alkyd, chlorinated rubber, epoxy, polyurethane and fluoropolymer exposed to atmospheric exposure and accelerating test. were studied by gloss measurement, electrochemical impedance and SEM analyze.

Among five coating systems the Fluoropolymer coatings are the best resistant both at atmospheric conditions and UV-condensation chamber. The polyurethane coatings are also resistant at urban atmospheric conditions, but it is less resistant under marine atmospheric conditions. The coatings may be ranked in the following order of increasing of weather and UV-condensation resistance : fluoropolymer > polyurethane > chlorinated rubber > alkyd > epoxy.

The atmospheric test was compared with the test in UV-condensation chamber and it was shown that for each coating the relation between atmospheric test and test in UV-condensation chamber is different.

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