

Performance of Coating Systems in Industrial Atmospheres on the Arabian Gulf

J. Carew, A. Al-Hashem, and W.T. Riad

Materials Application Department, Kuwait Institute for Scientific Research, P.O. Box 24885, Safat 13109, Kuwait

M. Othman

Shuaiba Area Authority, P.O. Box 4690, Safat 13047, Kuwait

M. Islam

Cortest Columbus Technologies Inc., 2704 Sunbury Blvd., Columbus, OH 43235

The performance and durability of 11 industrial coating systems were studied for two and a half years at five weathering sites in the industrial belt of Shuaiba Area, Kuwait, in the Arabian Gulf. Coating performance was related to prevailing industrial atmospheric conditions and compared with their behavior in laboratory accelerated tests. Experience has shown that under conditions like those in Kuwaiti industrial areas, degradation of coatings has tended to be faster than in the Western countries for which most of these coating systems were developed.

The need to establish proper selection criteria for industrial coatings used in the industrial belt of Kuwait is growing. Many coating systems developed and manufactured for temperate regions have been used in hot and harsh climates, but they performed inadequately there. (It should be noted that some failures have been related to paints applied during difficult weather conditions.) However, little information is available on the performance or results from exposure tests of industrial coatings in the Arabian Gulf. What information is available has been based on tests conducted by individual companies on their own products, and specific results and

comparisons remained largely unpublished. One paper presented extensive data on the performance of several marine, industrial, and residential coatings under atmospheric conditions in Saudi Arabia over a 10-year period.¹ The paper also covered the service performance of aluminum alkyd, alkyd enamel, chlorinated rubber, epoxy, and vinyl mastic coating systems under mild, refinery, and marine atmospheres over a period of 20 years. All the coatings appeared to have performed well under the conditions of exposure. The paper concluded that the most critical factor affecting service performance of most of these coatings systems was the surface preparation.

Other studies have dealt with a range of building materials, including plastics, sealants, and surface coatings on concrete mortar exposed to weather conditions in Dubai, Saudi Arabia, for more than seven years.^{2,3} In the high mean and extreme temperatures at Dubai, most of the materials studied degraded more rapidly than when exposed at a site in the United Kingdom. However, no single factor of acceleration could be defined between the two sites.

The current test program was undertaken to fulfill the need for information and to provide guidance to decision makers in the local industries on paint selection for specific areas in the industrial belt. This article describes the performance results obtained for commercial coating systems exposed at different test sites for a period of two and a half years. Because of the long-term exposure required for the outdoor tests, the coating systems were evaluated first in accelerated laboratory tests.

TABLE 1
Coating Systems Studied

Paint System	Generic Type	Dry Film Thickness (μm)		Life Expectancy Under Severe Conditions (years)
		Individual	Total	
1	Inorganic zinc silicate	75	135	5 to 7
	epoxy polyamide	25		
	Acrylic enamel	35		
2	Zinc phosphate primer (based on long oil alkyd and urethane alkyd)	40	70	1 to 2
	Alkyd enamel	30		
3	Zinc-rich epoxy	50	250	8 to 10
	Epoxy polyamide/micaceous iron oxide	100		
	Epoxy polyamide/micaceous iron oxide	100		
4	Chlorinated rubber primer	75	190	2 to 3
	Chlorinated rubber undercoat	75		
	Chlorinated rubber topcoat	40		
5	Epoxy (two component)	50	200	3 to 4
	Polyurethane	150		
6	Zinc epoxy	50	225	5 to 7
	Epoxy polyamide sealer	25		
	Epoxy polyamide (high build)	100		
	Polyurethane	50		
7	Inorganic zinc silicate	50	200	10 to 12
	Epoxy polyamide	100		
	Polyurethane	50		
8	Acrylic water-based	40	70	Unknown (new system)
	Acrylic enamel water-based	30		
9	Zinc chromate (based on oil-modified alkyd)	80	60	2 to 3
	Alkyd undercoat	40		
	Alkyd gloss	40		
10	Zinc ethyl silicate	50	225	10 to 12
	Epoxy polyamide sealer	25		
	Epoxy polyamide (high build)	100		
	Polyurethane	50		
11	Zinc epoxy	50	225	5 to 7
	Epoxy polyamide (high build)	125		
	Polyurethane	50		

Most accelerated aging tests for coatings make use of either a continuous wet test (for instance, the salt spray test), or a cyclic wet/dry environment. It has long been argued that cyclic exposures provide more realistic results because they more closely simulate outdoor weathering conditions and they create failure modes similar to those observed outdoors.⁴⁻¹¹ These workers concluded that a relationship does not exist between continuous wet and cyclic exposure results. However, a more recent publication concluded that for a medium-oil alkyd primer containing zinc hydroxyl phosphate and iron oxide pigments, continuous wet immersion was a more severe exposure than cyclic wet/dry immersion and that the failure mechanism in both exposures appeared to be identical.¹²

Nevertheless, for the present work, the laboratory tests made use

of factors of importance in coatings degradation such as a wet/dry cycle of salt spray, ultraviolet (UV)-light radiation/condensation cycling, and continuous UV-light/condensation. The wet/dry salt spray test used in this study is a variation on that described elsewhere.⁷ The present test used a higher concentration of sodium chloride plus sulfate. This test cycle represented a very severe service environment similar to that endured by industrial structures along the Arabian Gulf seashore of Kuwait.

Experimental

Panel Preparation

The test panels (150 by 100 by 1.6 mm) used for this study were prepared from a hot-rolled carbon steel. The surface of each panel was sand blasted to Swedish standard SA 2 1/2,¹³ cleaned with distilled water

and ethanol, and allowed to dry at 23°C and 45% relative humidity. The individual paints (primer, undercoat, and topcoat) making up the different coating systems (Table 1) were spray applied, and the coating thickness was measured after curing for two days. After the topcoat cured, the thickness of the coated panels was measured at the same locations primer and undercoat thicknesses were measured.

Accelerated Tests

Salt Spray/UV-Light Radiation/ Condensation Cycle (Wet/Dry Cycle)

In wet/dry cycle tests, coated panels were exposed inside a standard test chamber, supported at a 30-degree angle from the vertical. The panels were sprayed indirectly with an atomized salt spray based on 5 wt% sodium chloride dissolved in

TABLE 2
Performance Data and Defect Rating for Atmospheric Coating Systems Exposed to Continuous UV Radiation/Condensation Cycle

Paint System	Generic Type	% Gloss (60 degrees) Retention at Exposure Time (hours)					Defect Rating ^(A)
		250	500	1,000	3,000	4,000	
1	Acrylic enamel	95.8	65.3	53.6	47.0	31.4	Rust grade 8 (0.3%), yellowing, checking
2	Alkyd enamel	51.4	23.0	11.6	7.6	7.0	Rust grade 8, chalking, yellowing
3	Epoxy-micaceous-iron oxide	52.0	48.1	32.5	26.0	23.4	Slight chalking, fading
4	Chlorinated rubber	64.6	44.2	26.0	12.2	4.3	Orange-peel effect, chalking, rust grade 9
5	Polyurethane	73.2	70.3	39.9	31.2	24.6	Rust grade 7 to 9, high degree of chalking
6	Polyurethane	83.3	78.2	38.0	30.8	27.4	Rust grade 8 (0.1%), fading, chalking, crazing marks
7	Polyurethane	96.5	65.4	46.0	33.4	28.1	Rust grade 9 (0.1%), chalking
8	Acrylic water-based	97.5	94.6	64.9	63.7	58.3	High degree of chalking
9	Alkyd gloss	49.1	34.6	21.4	17.0	10.2	Rust grade 8 (0.3%), high degree of chalking
10	Polyurethane	91.6	63.6	48.3	36.7	29.7	Rust grade 9 (0.1%), chalking, crazing marks
11	Polyurethane	84.8	69.6	39.9	32.2	27.3	Rust grade 9 (0.1%), chalking, crazing marks

^(A)Rust grade rating is on a scale 10 to 0, where 10 = none.

TABLE 3
Performance Data and Defect Rating for Atmospheric Coating Systems Exposed to Salt Spray/UV Radiation/Condensation Cycle (Wet/Dry Cycle)

Paint System	Generic Type	% Gloss (60 degrees) Retention at Exposure Time (hours)					Defect Rating ^(A)
		200	400	1,000	2,000	3,000	
1	Acrylic enamel	79.9	77.7	30.1	24.8	14.7	Rust grade 7 to 8, undercutting scab-like freckled defect (MD)
2	Alkyd enamel	82.4	54.8	12.0	6.6	5.1	Rust grade 7 (0.1%), severe edge rusting, undercutting, blister size 2, frequency 8 (F)
3	Epoxy-micaceous-iron oxide	49.2	35.8	31.7	13.3	10.8	Chalking, slight undercutting, few rust spots less than grade 9
4	Chlorinated rubber	63.2	54.8	34.4	15.5	6.6	Severe undercutting, rust grade 9 (0.3%) associated with freckled areas
5	Polyurethane	61.1	53.1	37.7	20.4	16.1	Rust grade 7 to 8, frequency 2 (D), slight undercutting
6	Polyurethane	72.4	56.7	44.8	23.5	20.3	Rust grade 8 (0.1%), frequency 4 (MD)
7	Polyurethane	83.5	75.5	52.1	27.5	25.6	Rust grade 8 (0.3%), undercutting, staining
8	Acrylic water-based	94.2	78.5	42.4	14.1	10.5	Rust grade 7 (0.3%), loss of adhesion, blister size 4, frequency 2 (D)
9	Alkyd gloss	62.0	44.7	17.3	13.0	8.2	Rust grade 7 (0.1%), loss of adhesion, blister size 2, frequency 2 (D)
10	Polyurethane	70.7	64.4	52.6	30.9	28.0	Rust grade 8 (0.1%), frequency 6 (M), no undercutting
11	Polyurethane	61.9	59.3	44.8	20.0	16.7	Rust grade 8 (0.1%), frequency 6 (M), no undercutting

^(A)Rust grade, blister, and frequency ratings are on a scale 10 to 0, where 10 = none. D = dense; MD = medium dense; M = medium; F = few.

potable water containing 3,000 ppm sulfate. Salt spray tests based on sodium chloride spray alone have been reported to be unreliable tests for corrosion in an industrial atmosphere.^{4,14,15} The observed unreliability has been attributed to the absence of ammonium and sulfate species as well as the effects of wet/dry cycling. UV-light radiation and condensation cycle were incorporated into the wet/dry salt spray cycle corrosion test, as by other workers.⁷

The spraying rate of the salt mist was 5.4 mL/hour, and all coated panels received a similar quantity of electrolyte when located around the periphery of the chamber. The wet/dry cycle (100 hours of salt spray at 35 ± 2°C followed by drying for 16 hours under ambient conditions) was followed by exposure of the coated panels to a UV-light radiation/condensation cycle in test apparatus operating to ASTM G 53-84 specifications.¹⁶ The conditions used were: 12

hours of radiation at 60°C followed by 12 hours of condensation (using deionized water) at 40°C.

The coated panels were exposed to the wet/dry cycle corrosion test for 200 hours, then cycled through the UV/condensation test chamber for 200 hours on a rotating basis for a total of 3,000 hours. One of each duplicate test panel was cross-scribed.

The tests panels were inspected visually and microscopically for evidence of coating breakdown every

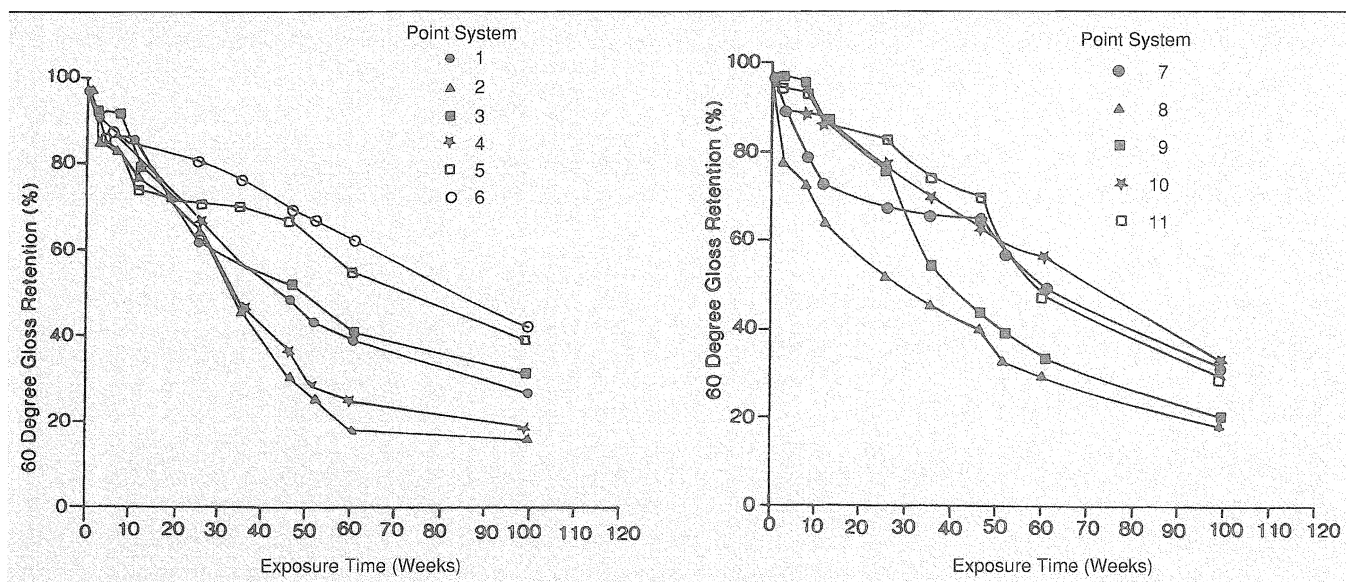


FIGURE 1
Coatings at test site A.

200 hours. Gloss values and weight changes were also measured.

UV-Light Radiation/Condensation Cycle

The continuous wetting test involved the exposure of the coated panels to continuous UV light radiation/condensation in a weathering chamber operating to ASTM G 53-84 specifications. Coated panels were exposed to 12 hours of illumination under UV light at 60°C followed by 12 hours of condensation (using deionized water) at 40°C for 180 cycles according to ASTM D 3361-81.¹⁷ This test procedure is intended to simulate deterioration caused by dew and the effect of natural UV radiation. The test panels were inspected and rated for performance as described earlier.

Outdoor Exposure Test

Triplicate test panels coated with each of the 11 systems were exposed at five test sites, in racks facing south at an angle of 45 degrees, in the Shuaiba industrial area.

The location of five test sites are as follows:

- Site A (0.2 km from the sea)—Heavy pollution (downwind from refinery and chlor-soda [chlorine-sodium hydroxide] plant).
- Site B (0.55 km from the sea)—

Heavy pollution (next to refinery, desalination plant, and electricity plant).

- Site C (1.5 km from the sea)—Heavy pollution (upwind from refinery, next to cement clinker factory).
- Site D (3 km from the sea)—Mild pollution (rural area).
- Site E (15 km from sea)—Mild pollution (rural area).

The exposure period at the time of this report was two and a half years. The panels were examined every month for defects such as rusting, cracking, chalking, and general appearance, and the gloss retention was measured at a 60-degree angle. Panels were rated in accordance with ASTM D 610-43.¹⁸

Results and Discussion

Accelerated Tests

The performance of the various coating systems exposed under accelerated test conditions are summarized in Tables 2 and 3. The tables reveal that the modes of degradation and types of defects produced by the various coating systems depended fundamentally on the test conditions to which the coatings were subjected.

The alkyd (enamel and gloss) and chlorinated rubber coating systems exhibited significant degradation in gloss and protective properties, re-

gardless of the test cycle, after 3,000 hours of exposure. The differences in performance of these coatings under the two accelerated test conditions appear to be very marginal. However, the degradation on the alkyd systems (enamel and gloss coatings) in the wet/dry cyclic test centered on and emanated from the scribe, and was marked by corrosion creep, under-rusting, and rust creep. Similar results have been recorded for a medium-oil alkyd in the wet/dry cyclic test.^{5,12} Continuous UV radiation/condensation cycling degraded the surface layer, leaving crazing marks. An obvious result (Table 2) was a reduction in gloss and yellowing of the paint. Such changes in the surface condition of paint can cause subsequent interactions with the environment to which it is exposed.¹⁹ This may allow longer moisture retention by the paint and lead to rusting of the substrate.

The polyurethane coatings appeared to be in good condition with no blisters and very little or no rusting visible on the surfaces. However, the alkyds (enamel and gloss) showed a relatively rapid decline in gloss; chalking and yellowing were observed, as was evidence of blisters and rusting under the coating. These findings suggest that the barrier property of this coating system became

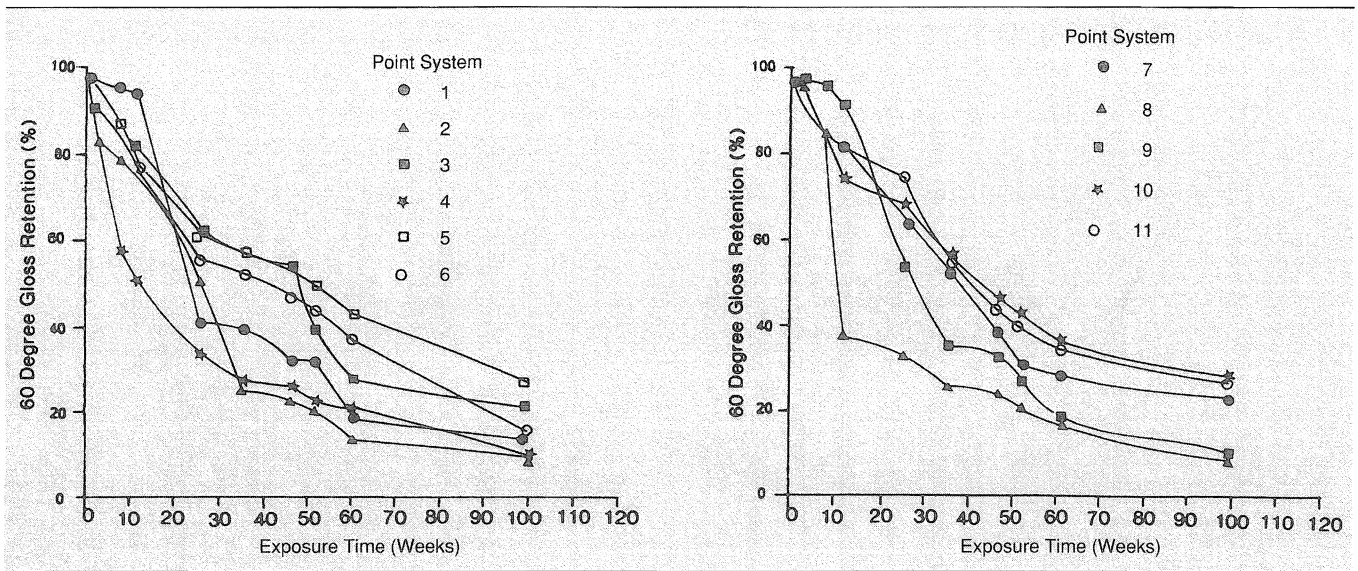


FIGURE 2
Coatings at test site B.

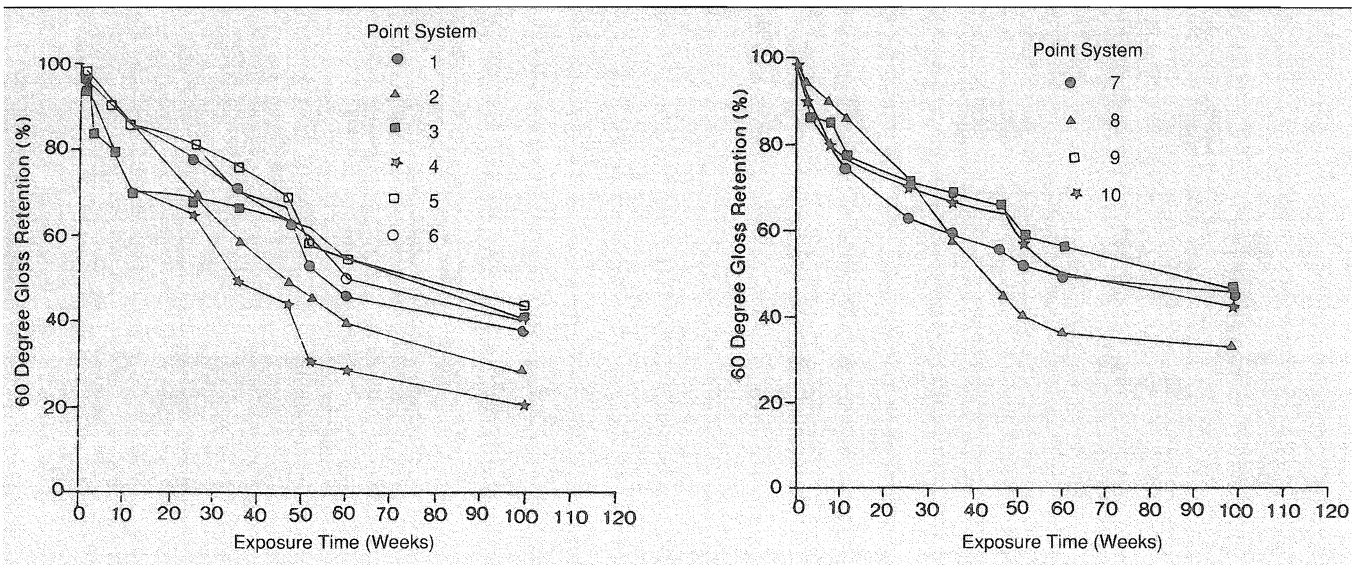


FIGURE 3
Coatings at test site D.

ineffective after 500 hours of exposure.

In contrast, the addition of salt spray exposure to the UV/condensation test (Table 3) fundamentally altered the nature of the corrosion/degradation processes. The results produced by the three-factor combination did not appear to be closely representative of the degradation (in terms of gloss retention and rust spot grade and frequency) observed for the alkyd and chlorinated rubber paint systems in natural atmospheric service environments at test sites A, B, D, and E (Figures 1 through 4). The

gloss retention observed for alkyd (enamel and gloss) and chlorinated rubber after 3,000 hours of exposure in the accelerated tests were quite similar to that observed for the paint systems exposed at site C (Figure 5). Test site C is located in the vicinity of a refinery. For the polyurethanes, epoxy micaceous iron oxide, and acrylic water-based systems, the wet/dry cycle exposure test gave a more realistic deterioration effect, with some rusting in the scribe lines, as well as loss of gloss.

In concurrence with reported observations for coatings exposed to

wet/dry salt spray/UV radiation/condensation environments,¹⁹ the test appears to produce results that are more comparable to natural exposure degradation processes than results from tests in a continuous UV radiation/condensation environment.

Outdoor Exposure

Five sites with the different environment parameters of the industrial area (Table 4) and at various distances from the Arabian Gulf were selected for outdoor panel exposures. From Table 5, it can be seen that the polyurethane (systems 5, 6, 7, 10, and

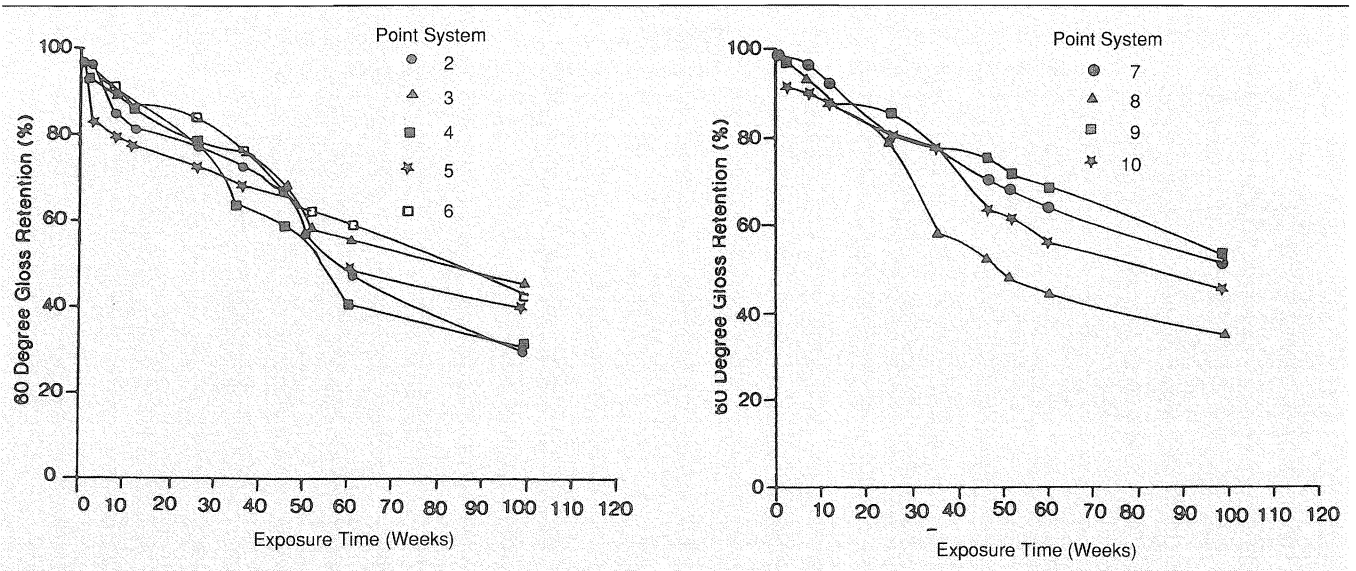


FIGURE 4
Coatings at test site E.

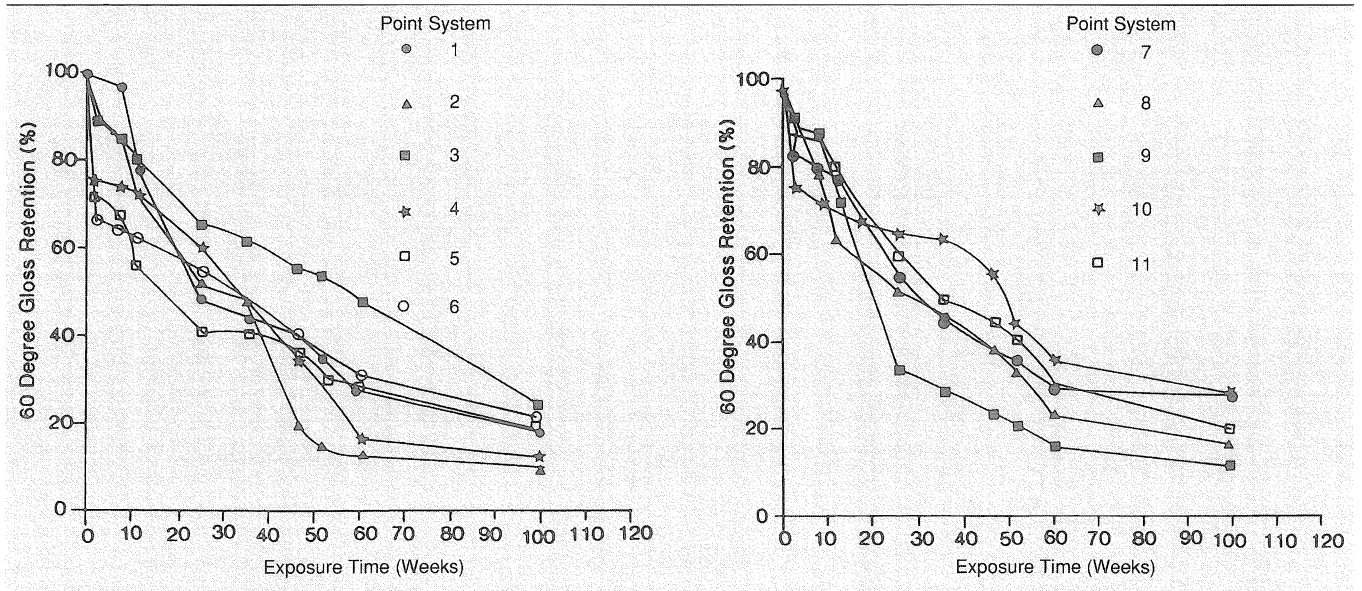


FIGURE 5
Coatings at test site C.

11) epoxy-micaceous-iron oxide (system 3) and acrylic water-based (system 8) paint systems outperformed the other paint systems, even in the heavily polluted environment of site B. This trend in performance was also apparent in the results of the accelerated laboratory tests.

In the course of outdoor weathering, most coatings failed to retain their gloss values, at all test sites; exceptions were systems 3, 5, 7, 10, and 11 exposed at sites D and E. In general, a comparison of gloss retention

as a function of time curves (Figures 1 to 5) for the polyurethane systems (5, 6, 7, 10, and 11) and micaceous-iron-oxide epoxy system (3) showed that these paints retained their gloss better than the other coating systems (acrylics [2 and 9] and chlorinated rubber [4]) exposed at the test sites. Visual observations of the coated test panels after two and half years of exposure detected rust spots on the coated test panels to be limited to between grade 10 for the polyurethane and epoxy-micaceous-iron oxide

systems at sites D and E and grade 7 for most of the systems at sites A and B.

The chlorinated rubber (system 4) and the alkyd gloss (system 9) coating systems showed checking defects (fine cracks which did not penetrate the topcoat) after exposure at all test sites. It has been reported that in oil-based paints, such as the alkyd gloss system, water and aging can gradually leach out the plasticizing elements making the film become brittle with age.²⁰ Also, in chlorinated

TABLE 4
Annual Averages of Atmospheric Parameters Obtained at the Five Test Sites

	Site A		Site B		Site C		Site D		Site E	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Sulfur dioxide (ppm)	0.39	0.11	1.3	0.07	0.31	0.01	0.21	0.01	0.029	0.002
Ammonia	0.60	0.24	0.73	0.2	0.32	0.13	N.D.	N.D.	0.048	0.006
Total sulfur (ppm)	0.56	0.07	1.66	0.1	0.091	0.03	0.22	0.02	0.037	0.003
Hydrogen sulfide (ppm)	0.35	0.01	0.38	0.02	0.07	0.01	0.01	0.02	0.54	0.001
Nitric oxides (ppm)	0.11	0.03	1.29	0.25	1.42	0.09	0.36	0.006	0.075	0.006
Total suspended particulate (µg/m ³)	1,097.68	1,102.23	1,102.23	263.19	1,913.62	254.14	1,370.10	412.79	N.D.	N.D.
Ammonia (in particulate)	4.79	1.52	2.70	1.07	2.66	1.04	2.03	1.31	N.D.	N.D.
Chlorine (in particulate)	21.93	5.8	24.41	4.85	18.08	4.71	15.66	13.65	N.D.	N.D.
Air wind speed (m/s)										
Horizontal	5.8	3.13	5.57	3.13	5.81	3.13	5.81	3.13	5.81	3.13
Vertical	0.67	0.2	0.67	0.20	0.67	0.20	0.67	0.20	0.67	0.20
Air wind direction	NW	NW	NW	NW	NW	SW	NW	SW	NW	SE
49.02	4.9	49.02	4.9	49.02	4.9	49.0	6.2	49.0	6.16	
Temperature (°C)	49.05	20.5	49.05	20.5	49.05	20.5	49.05	20.5	49.05	20.5
Relative humidity (%)	95.7	44.6	95.69	44.59	93.69	44.59	91.7	44.6	90.2	44.6

N.D. = not detected.

TABLE 5
Percentage Gloss (60 degrees) Retention of Coating Systems After Two Years' Exposure at the Five Test Sites

Coating System	Site A		Site B		Site C		Site D		Site E	
	% Gloss	Defect Rating (A)	% Gloss	Defect Rating	% Gloss	Defect Rating	% Gloss	Defect Rating	% Gloss	Defect Rating
1	31.5	7D	14.0	7D	8.6	8M	38.0	8F	29.0	8F
2	15.7	7D	10.0	6D	9.1	8M	18.2	8M	29.0	8F
3	30.8	8M	11.2	7M	23.8	8F	41.3	9F	43.6	10
4	16.7	6M	10.2	6D	2.0	7M	20.4	8M	31.6	9F
5	31.2	7M	27.5	7M	8.3	8M	44.1	9F	45.8	10
6	32.1	8D	15.7	7M	9.1	8M	33.7	9F	41.5	9F
7	32.1	8MD	23.4	7F	8.4	8M	45.5	9F	51.0	10
8	18.4	7F	4.6	7F	10.7	8M	N/A	—	N/A	—
9	30.9	8D	11.1	7MD	8.2	8D	33.1	9F	36.9	9F
10	33.5	8MD	15.7	7F	18.8	8M	40.2	9F	47.1	10
11	30.0	8M	17.1	7F	8.0	8M	41.1	9F	48.3	10

^(A)Defect rating is on a scale of 10 to 0, where 10 = no rust spots. D = dense; F = few; M = medium; MD = medium dense; N/A = not available.

rubber paints, the plasticizer elements can migrate under the influence of heat. These two systems proved unsuitable for outdoor application under these test conditions. Furthermore, the alkyd systems suffered from severe chalking compared with the other systems tested. Chalking is the formation of a friable, powdery coating on the surface of a paint film caused by disintegration of the binder by weathering, particularly as a consequence of exposure to the photochemically active rays of the sun and condensate from dew.

Different binders react at different rates; for example, epoxies (system 3) react quite rapidly; acrylics and polyurethanes can remain unchanged for long periods.

Chalking of epoxies, however, is generally considered to be a surface phenomenon only, and therefore is not harmful, except to the appearance.

In all cases, chalking is generally considered the most acceptable form of failure because surface preparation for subsequent maintenance generally consists only of removing the loose powdery material.

Furthermore, the alkyd systems are not expected to survive more than one to three years under severe atmospheric conditions such as those at test sites A, B, and to some extent C, before maintenance coating is necessary.

In terms of corrosion protection of the underlying steel, all the coat-

ing systems tested have provided varying protection levels depending on the predominant atmospheric conditions of the site. The annual average (1988 to 1989) atmospheric data collected for the five exposure sites are given in Table 4. The exposure conditions at sites A and B appear to be the most severe, with higher concentrations of sulfur dioxide, ammonia, hydrogen sulfide, and nitrogen oxide species in the atmosphere. Furthermore, the concentrations of ammonium and chloride ions in the suspended particulates in the site A and B atmospheres are much higher than those observed for the other sites. The nearness of sites A and B to the seashore, with the slightly higher relative humidity, would result in a

prolonged time of wetness on the panel surfaces. Degradation, as reflected by gloss loss, of coatings exposed at site C was faster than expected. This can be attributed to the nearby cement clinker factory. Over the two years of exposure, significant amounts of clinker dust have been removed periodically from the surface of the coatings. Analysis of the dust showed the presence of 38% calcium oxide, 20% silica, and 6.55% sulfate.

Conclusions

The projected ability of a coating to protect a steel substrate under conditions prevalent in Kuwaiti industrial areas can be largely duplicated in the laboratory by exposure to a salt spray/UV radiation/condensation test environment.

The polyurethane and epoxy-micaeous-iron oxide-based systems performed better (both aesthetically and in corrosion resistance) at all test locations in the Shuaiba area than the other coating systems studied.

Systems topcoated with polyurethane offer extremely good corrosion protection for steel. Although they are expensive initially, their effective life is long.

The conventional coating systems based on alkyd, acrylic, and chlorinated rubber performed moderately compared with the polyurethane systems.

Acknowledgments

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More information may be available in paper no. 445, presented at CORROSION/94, Baltimore, Maryland.