Environmental protection laws have obliged industries throughout the world to develop and use products with low toxicity levels. As a result, waterborne paints are becoming increasingly important in the protection of steel against atmospheric corrosion. However, many countries, mainly those that do not have specific legislation regarding paints and their effect on the environment, continue to be reluctant to use waterborne paints for the anticorrosive protection of steel surfaces. Part of this reluctance may be attributed to doubts about the anticorrosive performance of waterborne paints. Furthermore, technological changes are not an easy matter in any sector. These factors obviously tend to inhibit the large-scale adoption of this new painting technology.

Another important issue is cost. Many facility owners believe that waterborne paint systems ought to be cheaper than organic solvent-borne systems because they use water for the thinner. This rea-
soning is mistaken because waterborne anticorrosive paints are technologically more complex than organic solvent-borne paints.

In view of the above, this article presents the results of the authors’ research, which compares the anticorrosive performance of waterborne and solvent-borne paint systems on carbon steel plate in atmospheres of different corrosivity categories. In this article, a ‘waterborne coating’ is defined as one with a binder that is soluble or emulsifiable in water, and a ‘solvent-borne coating’ is defined as one with a binder that is soluble in organic solvents.

Experimental and Results
Specimens with dimensions of 250 x 125 mm were cut from 2-mm-thick carbon steel plate of a composition according to ISO 6301 (C ≤ 0.22%, P ≤ 0.06%, S ≤ 0.05%, and Cu ≤ 0.20%). The steel plate presented intact millscale, grade A of Swedish standard SIS 055900–1967.2

Surface preparation consisted of degreasing, followed by abrasive blast cleaning to grade Sa 2½ (near white metal) per ISO 8501 Part I.3 The abrasive used was G50 steel grit, which obtains an average surface profile of 30 µm. After surface preparation, the abrasive remaining on the surface was removed by solvent wiping and the specimens were coated with the corresponding paint systems in compliance with the manufacturers’ recommendations.

The Systems Tested
A complete description of the organic solvent-borne paints (S) is given in Table 1. With regard to these paint systems, it is important to note both of the following.

• The use of systems with different anticorrosive protection mechanisms: anodic passivation (S1), cathodic protection (S2), and barrier (S3)

• The inclusion of system S1, consisting of a red lead (Pb₃O₄) pigmented primer based on a long linseed oil alkyd resin, was simply for comparative purposes, in view of this system’s well-known anticorrosive properties. The red lead pigment is extremely harmful to human health.

Comparing Waterborne and Solvent-borne Paints for Protecting Steel in Atmospheric Exposures

Specifiers who do their homework on coatings and exposure environments can find many waterborne paints that provide satisfactory protection against corrosion.

Editor’s Note: This article was first published in the September 2006 issue of Surface Coatings International: Part B: Coatings Transactions, and is reprinted here with permission of the publisher, the Oil & Colour Chemists’ Association (OCCA).
and its use in paints should be avoided.

A description of the waterborne paints (W) is given in Table 2. With regard to these paint systems, it is important to note the participation of four leading Portuguese paint manufacturers, denominated A, B, C, and D, all with international recognition, each of which has provided two waterborne paint systems. Table 2 describes very similar paint systems, with only small differences in terms of thickness, but which incorporate paints from different manufacturers (e.g., systems W1 and W5, W2 and W3, and W4 and W8). System W6 is the only one with a zinc phosphate epoxy primer and an epoxy topcoat. Systems W2 and W3 have zinc phosphate epoxy primers and acrylic topcoats. System W7 has a primer pigmented with metallic zinc and differs from systems W4 and W8 in that its intermediate and topcoat paints are pigmented with micaceous iron oxide (MIO).

**Preparation and Placement of Coated Panels**

After a coating was applied to a specimen and allowed to cure, a scribe of 0.3 mm wide was cut in the lower zone, reaching the base steel. Two crossing scribes were done on panels exposed in Sines. The specimen edges were protected with an additional high-thickness coating to prevent premature coating in these critical areas.

A description of the waterborne paints (W) is given in Table 2. With regard to these paint systems, it is important to note the participation of four leading Portuguese paint manufacturers, denominated A, B, C, and D, all with international recognition, each of which has provided two waterborne paint systems. Table 2 describes very similar paint systems, with only small differences in terms of thickness, but which incorporate paints from different manufacturers (e.g., systems W1 and W5, W2 and W3, and W4 and W8). System W6 is the only one with a zinc phosphate epoxy primer and an epoxy topcoat. Systems W2 and W3 have zinc phosphate epoxy primers and acrylic topcoats. System W7 has a primer pigmented with metallic zinc and differs from systems W4 and W8 in that its intermediate and topcoat paints are pigmented with micaceous iron oxide (MIO).

**Preparation and Placement of Coated Panels**

After a coating was applied to a specimen and allowed to cure, a scribe of 0.3 mm wide was cut in the lower zone, reaching the base steel. Two crossing scribes were done on panels exposed in Sines. The specimen edges were protected with an additional high-thickness coating to prevent premature coating in these critical areas.

In this article, a ‘waterborne coating’ is defined as one with a binder that is soluble or emulsifiable in water, and a ‘solvent-borne coating’ is defined as one with a binder that is soluble in organic solvents.

The anticorrosive performance of the paint systems described in Tables 1 and 2 was evaluated at atmospheric corrosion test sites covering a range of aggressive atmospheric exposures. The tests were conducted following the procedure established by standard ISO 8565\(^5\) at four sites (Table 3), which is well defined and classified in terms of type of atmosphere and corrosivity category.\(^6\) Testing was performed for 43 months in the rural, urban, and industrial atmospheres, and for 36 months in the marine atmosphere.

**Assessing Coating Performance**

Coating performance was assessed according to standard ISO 4628.\(^7\) The features evaluated were blistering (4628/2), corrosion (4628/3), cracking (4628/4, and flaking (4628/5), as seen in Table 4. Consideration was also given to coating performance in the scribe region, in this case measuring the advance of underfilm corrosion (Figs. 1 and 2).

Cracks in coatings may have various causes, but are basically due to the fact that the inner coats are more flexible than the outer coats. In the course of the natural expansion and contraction of the coatings, the least flexible part tends to crack.\(^8\) Type A cracking is very shallow and does not penetrate the topcoat. Type B cracking penetrates the topcoat, whereas Type C cracking penetrates the full paint system.

In the industrial atmosphere of Cubatao, the appearance of cracking was occasionally seen (Table 4), specifically, Type A cracks in paint systems S1, W6, and W8; and Type B cracks in paint systems S3. Although the Type A and B cracking observed on the above paint systems cannot be considered abnormal, it would be preferable if it did not occur. Certain paint systems tend to present Type A or B superficial cracking after a certain exposure time to natural weathering. This cracking usually goes unnoticed because in most cases it is visible only with the assistance of a magnifying glass or a microscope. Besides, Type A and B cracks are not problematic in terms of anticorrosive protection in the short- or mid-term because the substrate is not exposed to the corrosive medium. Thus, the cracking observed should not be

**Table 1: Solvent-borne Paint Systems**

<table>
<thead>
<tr>
<th>System code</th>
<th>Generic type</th>
<th>Primer</th>
<th>Intermediate</th>
<th>Topcoat</th>
<th>Total DFT (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Alkyd</td>
<td>B: Long linseed-oil alkyd (2c)</td>
<td>–</td>
<td>B: Long linseed-oil alkyd (2c)</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: Red lead (Pb₃O₄)</td>
<td></td>
<td>P: Titanium dioxide (TiO₂)</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>Zinc-rich epoxy/polyurethane</td>
<td>B: Epoxy polyamide (1c)</td>
<td>60</td>
<td>B: Epoxy polyamide (1c)</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: Zinc powder (88% metallic zinc in dry film)</td>
<td></td>
<td>P: Fe₂O₃ extenders</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>Epoxy/polyurethane</td>
<td>B: Epoxy polyamide (2c)</td>
<td>90</td>
<td>B: Aliphatic polyurethane (2c)</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: Fe₂O₃ extenders</td>
<td></td>
<td>P: TiO₂</td>
<td></td>
</tr>
</tbody>
</table>

B = binder; P = pigment; c = coat; DFT = dry film thickness; µm = micrometers; 1 µm ≈ 25.4 = 1 mil

In this article, a ‘waterborne coating’ is defined as one with a binder that is soluble or emulsifiable in water, and a ‘solvent-borne coating’ is defined as one with a binder that is soluble in organic solvents.
Color Consistency Made Easy

Ask any professional what matters most in paint, and consistency will always top the list. Whether it’s color or sheen, interior or exterior, our batch-to-batch consistency makes color matching easy—especially when you’re using multiple sheens or touching-up a wall. We offer ready-mixed colors in a variety of sheens, and our single-batch manufacturing capacity can produce up to 20,000 gallons of paint in any color you choose. With Kelly-Moore paint, consistency will not be a problem on your job.

Kelly-Moore’s 7100 Series is a premium quality, two component, low VOC, water reducible, gloss polyamide epoxy coating, designed for application on wall, trim, ceiling areas and concrete floors. It provides excellent chemical resistance, durability and washability when applied to properly prepared gypsum wallboard, plaster, concrete, masonry, ferrous metal, wood and hardboard. Available in white & clear and can be tinted to a wide variety of custom colors.

1.888.KM.COLOR • www.kellymoore.com
The Answer is ...

TBAc™ Solvent

- What SNAP-approved solvent was added to the EPA list of VOC-exempt compounds in 2004?

- What non-HAP solvent delivers broad solvency, an intermediate evaporation rate and low density?

- What VOC-exempt solvent can you use in coatings, inks, adhesives and cleaners?

- What versatile solvent can you use to comply with new VOC and NESHAP regulations?

The answer is ... TBAc solvent!

Who has the answer? Lyondell Chemical Company, the world’s premier producer of tertiary butyl acetate.

Any other questions? For technical information or to request a sample, visit www.tbac.com or contact us:
North America: 713-309-2623
Europe: 33-3-44-24-9204
Email: tbac@lyondell.com

1 The U.S. EPA has published a rule excluding tertiary butyl acetate from the Federal definition of a VOC (40 C.F.R. § 51.100(s)(5); see also 69 FR 69304).
taken as the sole decision-making factor for the selection of a paint system.
Tests were performed before and after atmospheric exposure to explain the behavior observed with the waterborne paints and to assess paint system adhesion to the metallic substrate and water absorption rates.

The adhesion characteristics were evaluated according to standards ISO 46249 and ISO 2409.10 The results observed are shown in Fig. 3 and Table 5, respectively.

Water absorption rates were measured according to the procedure described by E. Almeida et al.,11 yielding the results shown in Fig. 4.

Discussion

General Analysis of Waterborne Coating Behavior

Table 4 and Figs. 1 and 2 summarize the results obtained in the different atmospheric conditions.

In general terms, the anticorrosive results for the waterborne paints show the superior behavior of paint systems W4, W7, and W8, while the worst behavior was obtained with systems W1 and W5.

Combined analysis of this information with the results of the adhesion tests (Fig. 3 and Table 5) indicates a lack of correlation between the natural exposure results and the pull-off adhesion results. The fact that the three waterborne paint systems with the best overall anticorrosive behavior (W4, W7, and W8) have a total thickness of more than 250 µm made it impossible to validate cross-cut adhesion measurements in these cases. Nevertheless, the best adhesion results (systems W1, W3, and W5) do not correspond with good anticorrosion behavior results in aggressive environments.

Overall Analysis of Waterborne Results in Natural Environments

Overall analysis of the results obtained with the waterborne coatings in natural exposure conditions shows the worst anticorrosive behavior with systems W1 and W5, both comprised of homogenous acrylic paints with a total thickness of 225 and 220 µm respectively. Although the use of zinc phosphate pigments, either alone (W3, W5, and W6) or in combination with titanium dioxide, iron oxide, or other pigments (W1 and W2), can provide particularly good anticorrosive behavior, the incorporation of these pigments in primers 1 and 5 was insufficient to prevent the formation of filiform corrosion and subsequent blistering in the natural marine atmosphere (Sines). It is well known that the anticorrosive behavior of these pigments varies with the choice of the resin and additives included in the paint formulation.12 A particularly interesting aspect seems to be the water absorption rate of the complete paint system, which presents the highest values with systems W1 and W5 (Fig. 4).

In turn, the homogenous acrylic paint systems incorporating zinc phosphate primers (W1 and W5), which presented the worst anticorrosive behavior in the chloride-rich marine environment,
showed the best anticorrosive behavior in the natural exposure in the Cubatao industrial atmosphere. This is most likely due to the fact that this atmosphere does not have a chloride level high enough to initiate filiform corrosion and its transformation into more and larger blisters—as occurs in the marine atmosphere. This differentiation of the corrosion mechanisms that operate in industrial atmospheres, practically free of the influence of chlorides, suggests the suitability of this type of waterborne acrylic coating for exposure in industrial atmospheres of a relatively high corrosivity category but where chloride pollution is practically nonexistent.

Meanwhile, although useful for interpreting some of the resulting anticorrosive behavior of the different coatings, the results obtained in the adhesion tests were not adequate to classify the relative anticorrosive behavior of these coatings. It was also clearly seen that the best anticorrosive protection results were presented by paint systems W4, W7, and W8. All of these are epoxy systems with zinc powder pigments in their respective primers, and were applied at a total film thickness of at least 250 µm. As shown in Fig. 4, all of these systems present relatively low water absorption rates.

Paint systems W2, W3, and W6 presented intermediate results. Although these systems include an epoxy primer, their composition varies significantly. Paint system W2, consisting of an epoxy primer pigmented with zinc phosphate, an epoxy intermediate layer, and a gloss acrylic topcoat, presented worse water absorption characteristics than the best waterborne systems. Paint system W3, consisting of two coats of epoxy pigmented with zinc phosphate and one coat of an acrylic enamel, presented the lowest thickness of all the waterborne paint systems (180 µm) and a relatively high water absorption rate, consequently offering poor barrier protection.

Finally, paint system W6, consisting of four coats of epoxy-amine paints (including a primer pigmented with zinc phosphate), presented good behavior in undamaged areas, but had severe blistering and delamination close to the scribes. Because these defects were only encountered close to the scribes, they suggest an absence of correlation with the primer’s epoxy-amine binder.

Normally the excellent emulsifying properties of epoxy emulsions allow the incorporation of cross-linking agents containing low viscosity hydrophilic polyamines in an aqueous medium. The selection of the most suitable curing agent depends on the application techniques, the required mix life, the curing conditions, and other desired properties. Determining either the type of chemical bonds formed or the degree of cross-linking, a curing agent affects the chemical resistance and mechanical strength properties of a coating, such as its adhesion and resistance to atmospheric exposure.

Nevertheless, in the case of system W6, the lack of resistance in the marine atmosphere (Sines) was barely observed close to the scribes, proving not to be a consequence of the nature of the primer binder. Meanwhile, the similarity of the paint defects close to the scribes observed with systems W6 and W3 (the latter with a significantly lower thickness) during exposure in the Sines atmosphere suggests the inefficiency of the primer pigments in highly aggressive saline environments. (The latter environments present a significant amount of chloride ions and frequent humid and dry exposure cycles.)

Possible Effects of Zinc Phosphate Pigment

The main pigment in these paint systems is zinc phosphate, as in systems W1 and W5. However, the former systems presented relatively better initial pull-off adhesion than the latter, and during the

Table 3: Characteristics of Atmospheric Corrosion Test Sites

<table>
<thead>
<tr>
<th>Test site (atmosphere)</th>
<th>Country</th>
<th>Time of wetness (annual fraction)</th>
<th>Deposition rate (mg/m²/day)</th>
<th>1st year steel corrosion rate (µm)/ISO corrosivity category</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Pardo (rural)</td>
<td>Spain</td>
<td>0.366</td>
<td>3.9</td>
<td>6.4</td>
</tr>
<tr>
<td>Lumiar (urban)</td>
<td>Portugal</td>
<td>0.135</td>
<td>19.6</td>
<td>22.6</td>
</tr>
<tr>
<td>Cubatao (industrial)</td>
<td>Brazil</td>
<td>0.579</td>
<td>8.1</td>
<td>54.5</td>
</tr>
<tr>
<td>Sines (marine)</td>
<td>Portugal</td>
<td>0.509</td>
<td>203.0</td>
<td>27.0</td>
</tr>
</tbody>
</table>

1 mm x 25.4 = 1 inch
B: Blistering
(a): Delamination due to the formation of some blisters close to the scribe
(b): Corrosion (even perforation) in the scribe area
FC: Delamination due to filiform corrosion

Fig. 1: Extent of paint coating delamination in scribe area at end of atmospheric exposure time. Figures courtesy of the authors.
PPG introduces its new waterborne acrylic, Pitt-Tech Plus

Formulated for direct-to-metal application and primer use on multiple substrates. With a nearly unlimited color catalog, you can pursue your most demanding jobs successfully.

And Pitt-Tech Plus has <100 g/L VOC in gloss, semi-gloss and satin sheens.

Available through the PPG distribution network or contact your PPG representative directly.
The Most Complete Line of Blast Cleaning Products

1. Complete Line Of Silica Free Abrasives

- Aluminum Oxide
- Blackblast - Coal Slag
- Corn Cobs
- Crushed Glass
- Chilled Iron Grit
- Ebonygrit - Copper Slag
- Glass Beads
- Garnet
- Stainless Steel Shot & Grit
- Steel Shot & Grit
- Ultrablast - Nickel Slag
- Plastic Media
- Powerblast - Nickel Slag
- Walnut Shells
- Blast Cleaning Equipment

2. QPL approved products Black Blast & IG Garnet

15 Locations Including 3 Blastox (One Step Lead Abatement) Blending Plants

OPTA MINERALS has production and warehouse facilities in the following locations: Brantford, ON; Waterdown, ON; Lachine, QC; Laval, QC; St-Bruno-de-Guiges, QC; St-Germain-de-Grantham, QC; Norfolk, VA; New Orleans, LA; Los Angeles, CA; Hardeeville, SC; Attica, NY; Baltimore, MD; Keeseville, NY; Walkerton, IN; Milan, MI; Richfield, OH

For more information or to order please call:
1-888-689-6661 Ext. 234 or 261, Email: info@optaminerals.com or visit
www.optaminerals.com

Click our Reader e-Card at paintsquare.com/ric
The cutting operation showed more intense delamination at the cuts, which consequently led to areas of differential aeration of the substrate in the vicinity of the scribes. In these conditions, when the electrolyte medium entered the scribed areas, some ferrous phosphate may have formed as a consequence of the reaction between the soluble fraction of the pigment and the substrate, in the presence of the electrolyte. However, the slight solubility of the ferrous phosphate did not allow the formation of a continuous protective film of iron phosphate, as occurs in phosphating. Thus, complete control of the corrosion reaction close to the scribes cannot be achieved, especially in areas with poor aeration, such as at the coating delamination fronts next to the scribes.

The inhibition of zinc phosphate seems to be due to the formation of a fine $\gamma Fe_2O_3$ film maintained and constantly repaired by oxygen. In poor oxygenation conditions, such maintenance cannot occur. Consequently, in these exposure conditions, corrosion advances under the coating from the scribes, leading to the significant formation of blisters, which increase in size with exposure time. However, the zinc phosphate may exert some effect because it is possible to identify $\gamma Fe_2O_3$ as one of the main components of the corrosion products formed close to the scribes when these were analyzed by FTIR (Fourier transform infrared) and Mössbauer spectroscopy. This iron oxide has been mentioned by various authors as a component of the protective film formed under the inhibiting action of zinc phosphate, whose constant repair by oxygen from the electrolyte assures the protection mechanisms conferred by this pigment. However, besides $\gamma Fe_2O_3$, $FeOOH$ and $ß-FeOOH$ were identified as the main components of the corrosion products included in the blisters next to the scribes in paint systems W3 and W6. The latter of these corrosion products is characteristic of chloride-rich environments.

### Technical Considerations on the Use of Waterborne Paint Systems

As previously mentioned, the main objective of this article is to give a general overview on the use of waterborne paint systems for the anticorrosive protection of steel surfaces exposed in atmospheres with different corrosivity categories, mainly in comparison with traditional solvent-borne paint systems.

The considerations presented here are based on the performance of products that were commercially available when the studies were conducted and which were supplied by four important paint manufacturers with international recognition in this area. Research and development in waterborne paints continues, and obviously new products offering better performance are continually appearing on the market.

### Industrial and Marine Atmospheres

It can be seen in Table 3 that two of the atmospheric exposure sites (Cubato and Sines) have very high corrosivity categories. Nevertheless, the organic coating degradation mechanisms were different in these two atmospheres, especially in the scribe area (Figs. 1 and 2). With regard to the anticorrosive performance of the various paint systems, the following considerations should be made.

- In terms of anticorrosive protection, differences between the various paint systems were basically found in the

### Table 4: Results of Atmospheric Corrosion Tests at the End of Exposure

<table>
<thead>
<tr>
<th>Paint system</th>
<th>El Pardo (rural)</th>
<th>Lumiar (urban)</th>
<th>Cubatao (industrial)</th>
<th>Sines (marine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint system</td>
<td>B C Cr F</td>
<td>B C Cr F</td>
<td>B C Cr F</td>
<td>B C Cr F</td>
</tr>
<tr>
<td>S1</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 3(SO) a WPO</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>S2</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>S3</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 4(SO) b WPO</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W1</td>
<td>0 RiO 0 0</td>
<td>2(S3) RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>4(S5) RiO 0 0</td>
</tr>
<tr>
<td>W2</td>
<td>0 RiO 0 0</td>
<td>2(S3) RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>5(S5) RiO 0 0</td>
</tr>
<tr>
<td>W3</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W4</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W5</td>
<td>0 RiO 0 0</td>
<td>2(S3) RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W6</td>
<td>0 RiO 0 0</td>
<td>2(S5) RiO 0 0</td>
<td>0 RiO 5(SO) a WPO</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W7</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
</tr>
<tr>
<td>W8</td>
<td>0 RiO 0 0</td>
<td>0 RiO 0 0</td>
<td>0 RiO 5(SO) a WPO</td>
<td>0 RiO 0 0</td>
</tr>
</tbody>
</table>

B = blistering; C = corrosion; Cr = cracking; F = flaking; WPO = with preferential orientation; WOPO = without preferential orientation; Ri = degree of rusting (ISO 4628-3)
scribe area because time of atmospheric exposure was insufficient to obtain differential information in undamaged areas (Table 4).

- The results of advanced corrosion in the scribe area (Figs. 1 and 2) in both atmospheres (but mainly in the marine atmosphere), show that the paint systems with zinc-rich primers (S2, W4, and W7) presented the best anticorrosive performance, irrespective of the type of paint technology (waterborne or organic solvent-borne). System W8 had the same zinc-rich primer as W7, but presented poorer performance in the industrial atmosphere—a fact that should be attributed to other components in these paint systems. Table 2 indicates that, in system W7, the intermediate and topcoat paints were pigmented with micaceous iron oxide (MIO), which has excellent anticorrosive barrier properties. Furthermore, system W7 had a slightly greater thickness than W8. All of this shows how important it is to correctly specify the paint system, not only in terms of thickness, but also the type of paint included in the overall paint system.

- With regard to paint systems in the marine atmosphere that did not have zinc-rich primers, great degradation was observed in the scribe region. In the addition to advanced corrosion, the waterborne acrylic systems (W1 and W5) and the solvent-borne alkyd system (S1) presented highly accentuated filiform corrosion starting at the scribe.

- For the paint systems without zinc-rich primers exposed to the industrial atmosphere, it is possible to see very different behavior than that observed in the marine atmosphere. For instance, the waterborne acrylic systems (W1 and W5) presented very little advance of corrosion, as was also the case with system W2 (epoxy/acrylic), and performed better than solvent-borne system S3.

- Of the results shown in Figs. 1 and 2, it is significant to highlight systems W2 and W3, which are both epoxy/ acrylic in nature (the latter with a significantly lower thickness) but were supplied by different manufacturers. Both systems did not perform in the same way—in the tests, W2 was found to perform better than W3. This shows that the formulation technology, the manufacturing techniques for waterborne paints, and the total dry film thickness had a significant influence on the performance of the paint systems.

- System W6 (epoxy/epoxy) presented the worst performance in the scribe region in both atmospheres. This was obviously due to many factors, but it is important to note that the barrier protection mechanisms of epoxy systems provide weak resistance to corrosion in highly aggressive environments when the coatings are damaged. The anticorrosive

\[ \text{Paint System} \quad \text{Industrial Atmosphere (Cubatao)} \quad \text{Marine Atmosphere (Sines)} \]

\[
\begin{array}{c}
\text{W1} \\
\text{W3} \\
\text{W5} \\
\text{W6} \\
\text{W8}
\end{array}
\]

\[ \text{Fig. 2: State of scribe area after two years of exposure of waterborne systems in test sites with the most aggressive atmospheres.} \]
Harness the Proven Power of Polyurethane Coatings

Built on Bayer Technology

Bayer technology puts the power in polyurethane coatings:

- Speed-to-cure high-film build coatings for productivity that just can’t be touched by polysiloxanes or epoxies
- Polyaspartic resin technology for coatings that offer a 1-hour recoat time and 1- to 2-hour walk-on time, and can be applied and cure at temperatures as low as 30°F
- EPA award-winning waterborne coating technology that meets the quality of proven, solventborne polyurethane coatings while meeting today’s health and environmental needs
- Odorless, ultra-low VOC coatings that reduce environmental impact

These are just a few examples of the proven power of polyurethane coatings built on Bayer technology.

For more than 50 years, Bayer technology has been the foundation of resins and polyisocyanates used in the formulation of high-performance polyurethane coatings for a wide range of applications—from metal and concrete to wood, plastics, and composite substrates.

Learn more about how polyurethane coatings built on Bayer technology can work for you. See examples of applications where polyurethane coatings are providing enduring protection and exceptional, long-term great looks. And how easy they are to apply. Call 800-662-2927 and get your copy of The Proven Power of Polyurethane Coatings.
ITW Devcon Futura Coatings corrosion control technology has been used successfully in FGD applications including absorber vessels, ductwork, chimney flues, clarifiers and water treatment tanks throughout the world for over 25 years.

Our VE9300 series lining system provides better chemical resistance than alloys and better abrasion resistance and water permeation protection than rubber in the highly aggressive FGD environment. This series can withstand temperatures as high as 265°F (130°C) wet and 390°F (200°C) dry.

ITW Devcon Futura Coatings offers FGD owners a winning combination of the best dollar per dollar value combined with long term trouble free performance backed by the industry’s best warranty.

When it's time to choose the materials of construction for your FGD system, choose THE PROVEN LEADER, ITW DEVCON FUTURA COATINGS.

1685 Galt Industrial Boulevard
St. Louis, MO 63132-1021
314-733-1110 • FAX: 314-733-1164
877-347-5730
www.futuracoatings.com
Click our Reader e-Card at paintsquare.com/ric
Reducing Solvent Levels in Coatings in the U.S.

The trend away from solvent-borne coatings in the U.S. has been driven in part by the demand for coatings with low levels of volatile solvents, or volatile organic compounds (VOC), which contribute to smog. Currently, a Federal Environmental Protection Agency (EPA) rule on architectural and industrial maintenance (AIM) coatings is in place, but some regions and states— notably, several air quality districts in California and states that belong to the Ozone Transport Commission (OTC)—have adopted lower limits in the past few years.

The OTC is a voluntary organization of states in the Northeast and Mid-Atlantic area. It was set up as a response to the 1990 Clean Air Act Amendments (CAA), which called for the establishment of an ozone transport region (OTR) consisting of “Connecticut, Delaware, Maine, Maryland, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and the consolidated Metropolitan Statistical Area that includes the District of Columbia” (Section 184 of the 1990 CAA). The OTR is intended to help states with heavy industry and heavy traffic manage air quality with measures more stringent if necessary than the national rule. The OTC established a model rule in 2001 for its member states to adopt or adapt as needed. The OTC rule was based on the model rule of the California Air Resources Board (CARB), which serves a similar model-rule-making role for the air quality districts in California. The CARB and OTC rules are more stringent than the national rule, and at least one district in California—the South Coast Air Quality Management District (SCAQMD)—has an AIM rule more stringent than EPA’s rule and CARB’s model rule (Kapsanis and Goldie, JPCR, October 2005, pp. 36-42).

A comparison of the several agencies’ current rules for various AIM coatings, drawn from federal, state, and regional regulations on-line, is given below. As seen in the table, VOCs in coatings have been regulated in terms of grams of VOC per liter of paint (g/L).

Because smog is formed from the reaction of VOCs and nitrogen oxide in the presence of sunlight, the reactivity of particular VOCs vary. EPA and most states allow companies to petition for a solvent to be exempted from VOC regulation if its reactivity, and therefore its contribution to ozone, are considered negligible. The two most important solvents for use in paint and coatings that have been exempted by the U.S. EPA are Acetone and Oxsol 100 (parachlorobenzotrifluorine). These solvents are not regulated as VOCs: they are exempt solvents, and therefore do not contribute to the VOC content of paint and coatings. There is interest among regulators as well as solvent and coating manufacturers in changing the way VOCs from AIM coatings are regulated—from mass to reactivity. This change could lead to increased flexibility for paint formulators and possibly reduced emissions of smog-forming VOCs. This would be a major change in the way that coatings are formulated and regulated, but more research is needed before such a major change could be undertaken.

### Table 1: Comparison of Current VOC Limits for Select AIM Coatings in U.S. in g/L

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>EPA</th>
<th>OTC</th>
<th>CARB</th>
<th>SCAQMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Maintenance</td>
<td>450</td>
<td>340</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Zinc-Rich IM Primer(^1)</td>
<td></td>
<td></td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Antifouling</td>
<td>450</td>
<td>400</td>
<td>400</td>
<td>100(^6)</td>
</tr>
<tr>
<td>Fire-Resistive(^2)</td>
<td></td>
<td>350</td>
<td>350</td>
<td>—</td>
</tr>
<tr>
<td>Fire-Retardant</td>
<td>850</td>
<td>650</td>
<td>650</td>
<td>—</td>
</tr>
<tr>
<td>Clear</td>
<td>450</td>
<td>350</td>
<td>350</td>
<td>—</td>
</tr>
<tr>
<td>Opaque</td>
<td>450</td>
<td>350</td>
<td>350</td>
<td>—</td>
</tr>
<tr>
<td>Heat- Reactive(^3)</td>
<td>420</td>
<td></td>
<td>—</td>
<td>100(^6)</td>
</tr>
<tr>
<td>High-Temperature</td>
<td>650</td>
<td>420</td>
<td>420</td>
<td>420(^6)</td>
</tr>
</tbody>
</table>

Notes:
1. Used only in SCAQMD and is a subcategory of Industrial Maintenance
2. Included in the “Fire-retardant” category in the EPA rule
3. In EPA rule only; 4. Adopted by CT, DE, DC, ME, MD, NH, NJ, NY, PA, VA; implementation dates vary.
5. CARB has proposed a new model rule for 2010. Shown here is the existing CARB rule.
6. Included under Industrial Maintenance; 7. Subsumed under coating category for which they are formulated

pigment and the type of epoxy resin and hardener used in the primers are other factors that may also influence the performance of these paint systems.

- On the basis of these considerations, it is recommended in atmospheres with very high corrosivity categories, especially in marine atmospheres, to use correctly specified paint systems with zinc-rich primers. In this respect, paint systems W4 and W7, both waterborne paints, can provide good anticorrosive protection to steel surfaces, similar to that of solvent-borne system S2.

However, it is always important to bear in mind that the quality of the paints used is fundamental for the success of the paint system. In other words, the performance of paint systems cannot be generalized.

### Rural and Urban Atmospheres

In rural and urban atmospheres, which are classified, respectively, in low and medium corrosivity categories, it is common to use cheaper paint systems for the anticorrosive protection of steel surfaces, with the aim of achieving a satisfactory cost/benefit ratio. In this respect, for instance, solvent-borne alkyd systems have been used successfully. When other properties are desired, such as impact, abrasion, or UV resistance, mixed epoxy/polyurethane or epoxy/acrylic systems are used, but with lower thicknesses than are employed in atmospheres with higher corrosivity categories.

In the rural atmosphere, as expected, all the studied paint systems—with or without zinc-rich primers and irrespective of the type of paint technology (waterborne or solvent-borne)—presented excellent performance. Thus, with regard to the cost/benefit ratio, it is not justified to use paint systems with zinc-rich primers in this type of atmosphere because there are waterborne paint systems that provide satisfactory anticorrosive protection without using such
The Incorez 140 Series Epoxy Curing Agents

Incorez is your ideal partner for waterborne and high solids systems. Our Incorez 140 series of waterborne reactive polyamine curing agents can be used with both liquid and emulsified solid epoxy resins, yielding tough, durable polymers in the range of zero VOC with freeze/thaw stability and no free amines. Ideal applications include:

- **Wall or floor coatings**: chemical-resistant and hygiene coatings
- **Epoxy cements**, repair mortars, and self-levelling systems
- **Anti-corrosion coatings** for steel protection

To learn more about Incorez or our line of polyurethane and oxazolidine technology, contact us at 1-860-613-1613.

Table 5: Results of Cross-cutting Test (ISO 2409)*

<table>
<thead>
<tr>
<th>Waterborne System</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>0</td>
</tr>
<tr>
<td>W2</td>
<td>5</td>
</tr>
<tr>
<td>W3</td>
<td>0</td>
</tr>
<tr>
<td>W4</td>
<td>-</td>
</tr>
<tr>
<td>W5</td>
<td>0</td>
</tr>
<tr>
<td>W6</td>
<td>1</td>
</tr>
<tr>
<td>W7</td>
<td>-</td>
</tr>
<tr>
<td>W8</td>
<td>-</td>
</tr>
</tbody>
</table>

*Scale of 0 to 5 (best to worst)
EPOTUF® 37-685 waterborne epoxy curing agent from Reichhold provides the corrosion protection of solventborne coatings with waterborne chemistry.

Coatings based on this new curing agent and EPOTUF 37-143 epoxy dispersion provide excellent corrosion resistance equivalent to many solventborne systems. Where other waterborne epoxy systems tend to exhibit blistering and/or delamination when exposed to moisture, EPOTUF 37-685 produces coatings with exceptional adhesion to steel.

Applications
- Medium-Heavy Duty Industrial Maintenance Primers
- Light Duty, Direct-to-Metal Coatings
- Rail & Transportation Coatings
- Concrete Sealers, Primers & Topcoats

Primers based on EPOTUF 37-685 and 37-143 have VOC levels below 100 grams per liter meeting the new SCAQMD regulations in California.

For more on Reichhold’s coatings industry products, visit our website at www.Reichhold.com/Coatings or call (800) 431-1920.
Conclusions
On the basis of the studies carried out, and taking into account the technological state of the paints used in this research and the technical considerations explained in this paper, the following conclusions may be drawn.

- A prior knowledge of the atmospheric corrosivity, not only the corrosivity category, but also the corrosive agents present (e.g., presence of chlorides), is essential for the correct specification of paint system.
- Among the studied paint systems, there are many waterborne paints that can provide satisfactory anticorrosive protection when correctly specified in accordance with the atmospheric corrosivity category and formulated with paints of sufficient quality. The studies performed clearly demonstrate that waterborne coatings are available that can very efficiently protect steel surfaces exposed to aggressive conditions such as those at Sines (marine industrial atmosphere of corrosivity > C5) or Cubato (industrial atmosphere of corrosivity C5). Mention may be made of the waterborne paint systems W4, W7, and W8, each of which is of a homogenous epoxy/polyamide nature and comprised of medium dry film thicknesses of 250 µm or more. This group of efficient paint systems also includes the waterborne acrylic systems W1 and W5, but only in industrial atmospheres without chloride pollution or other ions that promote filiform corrosion and blistering, such as the Cubato atmosphere.
- Paint manufacturing technology, especially in the case of waterborne paints, may influence the anticorrosive perfor-

Continued on page 59
Setting the Standard for

Surface Cleaning Equipment all over the World

Abrasives transport and recovery equipment.
Vacuum and/or mechanical.

Ventilation systems.
Portable and stationary.

Dehumidifiers.
Adsorption or refrigerated.

Blast room design & installation.
Equipment for complete blast and paint room installations.

Call us and benefit from more than 3 decades of experience...

MUNKEBO
PRODUCTION A/S
www.munkebo.com
AVANSE™ MV-100

THE NEW STANDARD IN WATERBORNE TECHNOLOGY

HIGHER PERFORMANCE

ENHANCED GLOSS, BETTER HIDE, IMPROVED CORROSION PROTECTION, LOWER VOC

From the leader in coatings innovation comes Rohm and Haas’s AVANSE™ MV-100 resin. This high-performance waterborne acrylic binder is designed for use in low-VOC industrial maintenance coatings for metal and concrete surfaces. Now you can formulate at levels below 100 g/L and offer a more environmentally-advanced choice compared to traditional solventborne materials, such as alkyls, epoxies, and polyurethanes. AVANSE™ MV-100 resin enables paint manufacturers to offer state-of-the-art products and systems that have an advanced environmental profile with the performance attributes to match.

FOR MORE INFORMATION OR TO CONTACT US, PLEASE VISIT www.avanseresins.com
The authors would like to express their special gratitude: in Brazil, to Roberto Mariano, Celso Gnecco, and Pedro A. Liza (Sherwin Williams) for their great help in the evaluation of results obtained from the industrial atmosphere corrosion site at Cubatao and their consistent opinions and information in this research, and to Eng Nelson Capiotto (COSIPA) for allowing the use of the atmospheric test site in this study; and in Portugal, to all the members of the LTR/INETI team who participated in the study, and to the Portuguese paint manufacturers CIN, Hempel, Robbialac, and Sika, and to SLM as paint applicator.

References

Acknowledgements
The authors would like to express their special gratitude: in Brazil, to Roberto Mariano, Celso Gnecco, and Pedro A. Liza (Sherwin Williams) for their great help in the evaluation of results obtained from the industrial atmosphere corrosion site at Cubatao and their consistent opinions and information in this research, and to Eng Nelson Capiotto (COSIPA) for allowing the use of the atmospheric test site in this study; and in Portugal, to all the members of the LTR/INETI team who participated in the study, and to the Portuguese paint manufacturers CIN, Hempel, Robbialac, and Sika, and to SLM as paint applicator.
New DuPont™ Imron® 2.1
Go Green...Faster!

Our Imron® 2.1 Polyurethane is reaching new lows: lower VOC, lower HAPs and lower dry time* (dry to recoat in just 2 hours**).

This high performance, highly productive, fast-drying topcoat is available in four gloss levels, plus clear.

Contact your local authorized DuPont Industrial Coatings distributor to go green faster!

1-800-GET DUPONT www.performancecoatings.dupont.com

*Compared with Imron® 2.8 HG    ** with accelerator

Copyright © 2007 DuPont. The DuPont Oval Logo, DuPont™, The miracles of science®, DuPont Industrial Coatings and Imron® are trademarks or registered trademarks of E.I. du Pont de Nemours and Company or its affiliates. All rights reserved.

Click our Reader e-Card at paintsquare.com/ric