ALUMINUM PHOSPHATE TECHNOLOGY ANTI-CORROSION

APPLICATION DESCRIPTION

Worldwide, the direct cost of corrosion is estimated to be more than $1.8T, which amounts to 3-4% of the GDP of industrialized countries. This impact is even higher when accounting for indirect costs due to lost productivity, injuries and accidents. However, many studies claim that 25-30% of annual corrosion costs can be prevented with optimum corrosion management practices, demonstrating a serious, ongoing need for anti-corrosion products.

The Corrosion Prevention and Control Integrated Product Team estimated the current total cost of corrosion for the Department of Defense to be $22.5 billion. The vast majority of that total ($20.9 billion) is derived from maintenance records from the military services’ various databases; the remaining $1.6 billion is outside normal reporting. The corrosion cost for infrastructure and facilities is $1.8 billion. For weapon systems and equipment, the corrosion cost is $20.7 billion. The estimate for corrosion as a percentage of maintenance for the DoD is 23.0%. This includes both infrastructure and facilities (15.1%) and weapon systems and equipment (24.0%).

Bunge Amorphic™ has been successfully tested as a corrosion inhibiting pigment for a wide variety of paint uses, such as industrial protective coatings, coil coatings and automotive refinishing. As the corrosion inhibiting pigment market has been commercially neglected in recent years due to industry focus on binder systems and colorants, Amorphic™ offers an exciting opportunity to improve anti-corrosion properties of coatings and go beyond the typical pigments used today.

COMPARATIVE ANALYSIS

Several performance indicators demonstrate the value of a corrosion inhibiting pigment. These indicators include stability of the film, lack of under-film corrosion, and performance of the coating at a damaged site. Standard industry tests such as salt fog, prohesion, EIS and salt soak demonstrate high performance, though specific tests and requirements are dependent on the individual coating’s application.

TEST RESULTS

From salt fog test results, it is seen that the incorporation of Amorphic™ into the control formulation nearly triples the blistering resistance of an epoxy based 40% PVC formulation and doubles that of a 45% PVC formulation. Additionally, Amorphic™ significantly improves resistance to underfilm corrosion and scribe undercutting. These results are shown in the table below.

Table 2: Salt fog exposure testing Epoxy Salt fog exposure
<table>
<thead>
<tr>
<th>System</th>
<th>Blistering</th>
<th>Underfilm</th>
<th>Scribe</th>
<th>Total Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls - 40% PVC</td>
<td>3.2</td>
<td>6.7</td>
<td>5.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Amorphic™</td>
<td>9.0</td>
<td>9.1</td>
<td>6.1</td>
<td>24.2</td>
</tr>
<tr>
<td>Percent improvement</td>
<td>181.3%</td>
<td>35.8%</td>
<td>10.9%</td>
<td>56.1%</td>
</tr>
<tr>
<td>Controls - 45% PVC</td>
<td>4</td>
<td>6.5</td>
<td>5.9</td>
<td>16.4</td>
</tr>
<tr>
<td>Amorphic™</td>
<td>8.1</td>
<td>8.5</td>
<td>7.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Percent improvement</td>
<td>102.5%</td>
<td>30.8%</td>
<td>22.0%</td>
<td>42.7%</td>
</tr>
</tbody>
</table>

Note: All scores are on a 1-10 scale. Amorphic™ values are the averages of 12 triplicate test series. Variables included the level of phosphate release. Specification level established at 150 to 500 ppm.

Photographs from this test are shown below.

Figure 1: Epoxy Salt fog exposure testing, 3000 hours
Left to right: Amorphic™ 45% PVC, Amorphic™ 40% PVC, Control (no inhibitive pigment)

Similar results are seen from a number of Amorphic™ epoxy formulations below, where the combination of blistering, underfilm, and scribe performance are significantly better with the Amorphic™ technology relative to the control. The Amorphic™ technologies are highlighted in blue.

Figure 2: Salt spray test results relative to controls- 1996 hours, total score
This overall performance improvement is largely driven by Amorphic™’s exceptional ability to impart blistering resistance, as shown compared to the same control below.

Figure 3: Salt spray test results relative to controls- 1996 hours, blistering resistance score

Compared to salt fog exposure, prohesion exposure is not sufficiently aggressive to demonstrate the blistering resistance of the test systems at 40% PVC. However, at 45% PVC, where the film is inherently less dense than at 40% PVC, the beneficial effect of Amorphic™ can be seen. It imparts an
18% improvement in blistering resistance compared to the control. At all levels, Amorphic™ incorporation improves performance, but especially at 45% PVC, as summarized in the table below.

Table 3: Prohesion exposure testing

<table>
<thead>
<tr>
<th>System</th>
<th>Blistering</th>
<th>Underfilm</th>
<th>Scribe</th>
<th>Total Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls - 40% PVC</td>
<td>9.9</td>
<td>9.2</td>
<td>5.8</td>
<td>24.8</td>
</tr>
<tr>
<td><em>Amorphic™</em></td>
<td>10.0</td>
<td>9.1</td>
<td>6.2</td>
<td>26.1</td>
</tr>
<tr>
<td>Percent improvement</td>
<td>1.0%</td>
<td>6.5%</td>
<td>6.9%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Controls - 45% PVC</td>
<td>7.7</td>
<td>8.7</td>
<td>4.5</td>
<td>20.9</td>
</tr>
<tr>
<td><em>Amorphic™</em></td>
<td>9.1</td>
<td>9.1</td>
<td>5.8</td>
<td>24.0</td>
</tr>
<tr>
<td>Percent improvement</td>
<td>18.2%</td>
<td>4.5%</td>
<td>28.9%</td>
<td>14.6%</td>
</tr>
</tbody>
</table>

Note: All scores are on a 1-10 scale. Amorphic™ values are the averages of 12 triplicate test series. Variables included the level of phosphate release. Specification level established at 150 to 500 ppm.

EIS testing demonstrates that the incorporation of Amorphic™ leads to coatings with impedance values in the range that indicates an effective barrier film. This performance does not decline through the test period. This is demonstrated below in Figure 4, where Average A is the control and the numbered products are variations of Amorphic™ with different loading levels.

This efficacy as a barrier film is driven by Amorphic™'s diffusion inhibition effect. By adsorbing water, Amorphic™ slows the diffusion of water into the film, thus slowing the rate of corrosion of the substrate.

Figure 4: Amorphic™ EIS results, 3500 hours
In OEM and product finishing applications, the substrates to be protected are different; thus, test methods and performance criteria vary. Salt soak testing demonstrates Amorphic™’s superior anti-corrosive and wet adhesion properties relative to competitors in automotive refinish coatings. Shown in Figure 5 below is the level of corrosion around a scribe on sanded cold rolled steel using (from left to right) no corrosion inhibiting pigment, Amorphic™ at 10% PVC, and zinc phosphate at 10% PVC.

Figure 5: Automotive refinish- 48 hours 5% salt soak at 100F, sanded cold rolled steel  
Left to right: Control, Amorphic™, zinc phosphate

In Figure 6 below, salt spray testing in automotive refinish shows the improved blistering resistance of Amorphic™ compared to zinc phosphate and the control without a corrosion inhibiting pigment. The panels shown from left to right are zinc phosphate, Amorphic™, and the control. Blisters are highlighted on the zinc phosphate and control panels in blue.

Figure 6: Automotive refinish- 200 hours salt spray, sanded cold rolled steel  
Left to right: Zinc phosphate, Amorphic™, control

As shown in figures 7 and 8 below, similar salt spray testing for coil coatings demonstrates Amorphic™’s superior performance in terms of cut edge corrosion resistance, scribe corrosion resistance, blistering resistance and wet adhesion.

Figure 7: Coil coatings- 400 hours salt spray, treated cold rolled steel  
Left to right: Zinc phosphate (10% of PVC), Amorphic™ (10% of PVC)
KEY ADVANTAGES OF AMORPHIC™

Amorphic™ offers a number of advantages as an anti-corrosive agent.

**Corrosion inhibition**

Amorphic™‘s primary advantage is the superior anti-corrosion protection it provides, as demonstrated by its performance in industry-standard testing.

The Amorphic™ chemistry provides more than just passivation; its unique diffusion inhibition property is key to improving corrosion resistance. The engineered aluminum phosphate slows both the degradation of the film by blistering and the consequential rate of corrosion. As a result, this diffusion inhibition property improves barrier properties and ultimately the overall life of the substrate.

Additionally, the ability to optimize the phosphate release levels of the Amorphic™ technology as compared to its competitors enhances under-film corrosion resistance.

**Synthesis flexibility**
The Amorphic™ technology can be customized to control its performance. Characteristics such as phosphate release rate, surface area, porosity, and form can be controlled depending on the customer's need.

**Environmental impact**

An additional consideration beyond performance is that of environmental impact. This is a more recent concern as traditional anti-corrosion pigments made from heavy metals, like chromates, have been found to have toxic and carcinogenic characteristics. Thus, corrosion inhibiting pigments have transitioned away from traditional chromates, encouraged by near-global regulations. In 2006, OSHA set permissible exposure limits for hexavalent chromium, which is carcinogenic. Given concerns about such heavy metals combined with growing awareness of the adverse effects of volatile organic compounds (VOCs), greener corrosion inhibitors are becoming increasingly important.

Amorphic™ does not contain hexavalent chrome-based pigments, avoiding the use of heavy metals while offering similar corrosion protection. Amorphic™’s lower density compared to heavy metals also provides resistance to hard settling or packing during dispersion, which can limit efficacy in corrosion inhibition.

- OTHER APPLICATIONS

**EXTENDER**

Certain Amorphic™ pigments are especially useful as extender pigments for titanium dioxide in coating and paint compositions. For paints formulated below the critical pigment volume concentration (CPVC), Amorphic™ may be used to replace up to 40% of the titanium dioxide contained in the formulation (provided that approximately 10% TiO₂-PVC remains). At this level, testing has shown that less than 1% reduction in opacity occurs compared to the control formulation with a full level of titanium dioxide. The substitution is effective for both water-based and solvent-based compositions.

The benefits of Amorphic™ as an extender pigment include: (1) ease of incorporation into paint formulations using typical compounding and manufacturing procedures; (2) good dispersion in typical paint compositions including acrylic latex based systems; (3) good rheology (less thickener is required compared to other extenders); (4) excellent sheen control; (5) excellent color development (superior to calcined clay, a typical extender pigment); (6) no interference with formula color acceptance; and (7) improved film integrity (higher scrub resistance compared to other extenders).

The use of Amorphic™ as an extender pigment offers the architectural and decorative paint formulator an opportunity for cost reduction without performance compromise.

**ANTIMICROBIAL**

Hygienic coatings have major potential in the decorative, or architectural, segment of the market. They are intended to prevent collateral effects of illness or product spoilage from surface contact in sensitive environments like hospitals or public areas. These include photo-activated biocidal surfaces, biocide release, or the nano-silver approach. The latter is the least toxic and most acceptable with the broadest possible usage.
The Amorphic™ product follows the nano-silver approach. Amorphic™'s silver aluminum phosphate provides a source of biologically active chemicals that can give antimicrobial properties to a surface. Definitive testing has established the anti-microbial efficacy of the prototypes against competitive approaches in representative latex architectural coating formulations.

As an example of the performance potential of the Amorphic™ product, the anti-microbial properties of dry films (paint) containing Amorphic™ silver complex were tested. The paints were dosed with the Amorphic™ silver complex and compared to two reference control paints containing commercial biocides. The tests were conducted in accordance with JIS Z2801 using two bacteria, Staphylococcus aureus and Escherichia coli. Bunge's Amorphic™ silver biocide showed good activity against the controls and exhibited >6 log reduction in bacterial population on the paint surface (high kill rate). It performed as well as two commercial silver based biocides and a formulated product used as controls.

**INK JET**

Demand has grown for coated ink jet media with high quality intermediate and high gloss finishes that resemble photographic images. As quality and speed improve, ink jet printing will continue to expand into more printing markets and could challenge electrophotography in many high-end applications.

To avoid the formation of puddles that lead to graininess, the ink vehicle or solvent must be quickly absorbed into the coating layer. Conventional coating pigments do not provide the void volume and pore diameter necessary for fluid uptake, and most ink jet coatings are silica-based due to its high internal porosity and large surface area. Silica, however, does not flow well at solids level above 15% to 20% because of its particle size distribution, and silica pigments also require a high binder level. A pigment that flows well at a solids level above 30% represents the target technology.