

High-Performance Water-Based Coating Enhanced with Nano-Vapor Corrosion Inhibitors

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The use of single-component water-based coatings for protection of military metal substrates continues to grow due to their low odor, health and safety advantages, easy cleanup, and environmental friendliness. Nevertheless, the challenge remains to find alternatives to the traditional chromate, zinc, or similar heavy metal-type corrosion inhibitors that tend to rely on passivation or sacrificial cathodic protection. Additionally, ongoing regulatory developments, which require lower volatile organic compounds and elimination of carcinogenic materials, continue to tighten the use of products containing these heavy metals, thus forcing the need for alternative technologies. The use of nano-vapor phase corrosion inhibitors provides an attractive alternative by adsorbing onto the metal substrate

and filling the voids or micro-crevices of the substrate and preventing corrosion from starting or growing once the surface of the coating has been damaged. This technology has been proven effective in single-component water-based coatings at a dry film thickness of 1 mil (25 μm).

In a 2002 study by NACE International,¹ the cost of corrosion for the U.S. Department of Defense (DoD) was estimated to be in excess of \$20 billion. Traditional corrosion control methods for protecting metal substrates in the military include chromate, zinc, and other heavy metals in inhibitors working in conjunction with passivation or cathodic protection.² An environmentally friendly, effective alternative involves the use of nano-vapor phase corrosion inhibitors (VCIs) in coatings used to protect these assets.³⁻⁴

VCIs and Coatings

How VCIs Work in a Coating

VCIs are formulated into a coating through a complex development process that involves determining chemical compatibility of the VCIs with the other components of the coating, such as the resin, solvents, pigments, and other additives used for a variety of reasons. VCIs work by adsorbing onto the metal surface in a nonreactive attractive capacity; in other words, they are

attracted to the metal through the particle charge.⁵

How VCIs Compare to Traditional Inhibitors

VCIs compare with traditional inhibitor systems by using smaller particles as well as relying not only on contact inhibition but also vapor phase inhibition, providing more complete coverage and protection of the surface. This is illustrated in Figure 1.

The larger platelets are representative of traditional inhibitors that are unable to fill the micro-crevices, leaving gaps where corrosion can start and/or grow.⁶

Types of Coating Systems that Use VCIs

VCIs can be used with most coating systems. There are many variations of VCIs and the key is to choose the correct VCI for the corresponding coating system by checking compatibility, effectiveness, and processability.

Environmental Advantages of VCIs over Traditional Inhibitors

Traditional inhibitors containing heavy metals are becoming increasingly more regulated and often are no longer allowed to be used due to the negative impact they have on the environment and as carcinogens for workers exposed to them. The environmental advantages of using VCIs are that they are nontoxic, do not contain heavy metals, and have no adverse effect due to their low usage concentrations. VCIs have long been used in other products

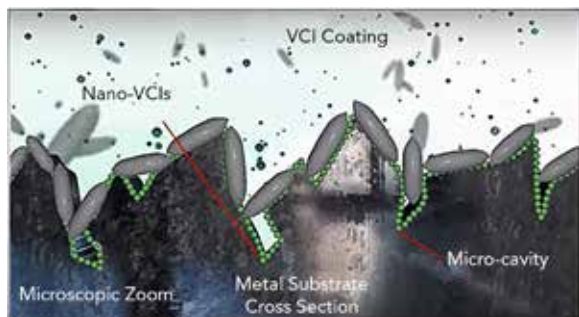


FIGURE 1 Use of traditional inhibitors with larger platelets can leave gaps in which corrosion can occur.

such as polyethylene films, foams, powders, and liquids to provide a vapor phase of corrosion protection without impacting the environment.

Experimental Procedures

This study examines the effectiveness of various types of corrosion inhibitors in a waterborne styrenated acrylic coating, based on salt fog results (ASTM B117⁷). All of the samples were made using high-speed dispersion.

Each coating was applied in triplicate on 4 by 12-in cold-rolled steel (CRS) panels (SAE 1010), using a 40 RDS[†] draw down bar. This produced a dry film thickness (DFT) of 1.0 mils +/- 0.2 mils. Tables 1 and 2 show the list of prepared samples.

Testing Procedures

Panels were prepared according to ASTM B117 and allowed to cure at ambient temperature for seven days. After the curing cycle, the panels were scribed with a single diagonal scribe per ASTM D1654.⁸ All of the edges and backs of the panels were taped to prevent any corrosion creep from uncoated surfaces. Panels were then placed in a 5% sodium chloride (NaCl) salt fog chamber, per ASTM B117. The test panels were checked periodically for blisters, creep from scribe, and degree of rusting.

Results

The purpose of this experiment was to investigate the effectiveness of nano-VCIs when added to waterborne acrylics. The ultimate goal was to achieve 1,000 h in a salt fog chamber (ASTM B117), on CRS, with a high gloss clearcoat of less than 2.0 mils DFT. Normally this kind of performance can only be achieved with highly pigmented coatings using corrosion inhibitors that are toxic, or at the very least not environmentally friendly.

The control panels failed at approximately 168 h in the salt fog cabinet, as can be seen in Figure 2 and Table 3.

Figure 3 and Table 4 show the results of the 700-h salt fog test; Figure 4 and Table 5 show the results at 1,000 h.

[†]Trade name.

TABLE 1. LIST OF COATING FORMULATIONS

| Sample No. | Description | Corrosion Inhibitor | Percent of total formula weight (%) | Coating thickness (mils) |
|------------|-------------|---------------------|-------------------------------------|--------------------------|
| 1 | Control | D | 0 | 0.9-1.2 |
| 2 | Exp. 1 | A | 3 | 0.9-1.2 |
| 3 | Exp. 3 | A+C | 5 | 0.9-1.2 |
| 4 | Exp. 2 | B | 3 | 0.9-1.2 |
| 5 | Exp. 4 | B+C | 3 | 0.9-1.2 |

TABLE 2. CORROSION INHIBITOR DETAIL

| Corrosion Inhibitor | Description |
|---------------------|---|
| D | Organic/inorganic corrosion inhibitor |
| A | Amino carboxylate salt |
| A+C | Amino carboxylate salt + nano-inhibitor |
| B | Liquid sol gel |
| B+C | Liquid sol gel + nano-inhibitor |

TABLE 3. ASTM B117, 168 H SALT FOG RESISTANCE

| Sample No. | Film Thickness (mils) | Corrosion Rating ^(A) | Scribe Rust ^(B) |
|------------|-----------------------|---------------------------------|----------------------------|
| 1 | 0.9-1.2 | 5 | 5 |
| 2 | 0.9-1.2 | 8 | 5 |
| 3 | 0.9-1.2 | 9 | 9 |
| 4 | 0.9-1.2 | 8 | 8 |
| 5 | 0.9-1.2 | 10 | 10 |

^(A)ASTM D1654, Procedure B rating of unscribed areas: 10 = no corrosion, 5 = 11 to 20% corrosion, 0 = 75%+ corrosion.

^(B)ASTM D1654, Procedure A rating of failure at scribe: 10 = no creepage, 5 = 0.125-0.1875 in., 0 = 0.625+ in.

Coatings

With the DoD estimating that corrosion costs in the military are in excess of \$20 billion, there is a need for environmentally friendly, low volatile organic compounds, waterborne coatings that can be applied at a thin film thickness (1.0 mils)



FIGURE 2 Control panels failed after 168 h in the salt fog cabinet.

TABLE 4. ASTM B117, 700 H SALT FOG RESISTANCE

| Sample No. | Film Thickness (mils) | Corrosion Rating ^(A) | Scribe Rust ^(B) |
|------------|-----------------------|---------------------------------|----------------------------|
| 1 | 0.9-1.2 | 5 | 5 |
| 2 | 0.9-1.2 | 8 | 5 |
| 3 | 0.9-1.2 | 9 | 9 |
| 4 | 0.9-1.2 | 8 | 8 |
| 5 | 0.9-1.2 | 10 | 10 |

^(A)ASTM D1654, Procedure B rating of unscribed areas: 10 = no corrosion, 5 = 11to 20% corrosion, 0 = 75%+ corrosion.

^(B)ASTM D1654, Procedure A rating of failure at scribe: 10 = no creepage, 5 = 0.125-0.1875 in., 0 = 0.625+ in.

TABLE 5. ASTM B117, 1,000 H SALT FOG RESISTANCE

| Sample No. | Film Thickness (mils) | Corrosion Rating ^(A) | Scribe Rust ^(B) |
|------------|-----------------------|---------------------------------|----------------------------|
| 1 | 0.9-1.2 | 0 | 0 |
| 2 | 0.9-1.2 | 5 | 2 |
| 3 | 0.9-1.2 | 3 | 4 |
| 4 | 0.9-1.2 | 3 | 4 |
| 5 | 0.9-1.2 | 9 | 9 |

^(A)ASTM D1654, Procedure B rating of unscribed areas: 10 = no corrosion, 5 = 11to 20% corrosion, 0 = 75%+ corrosion.

^(B)ASTM D1654, Procedure A rating of failure at scribe: 10 = no creepage, 5 = 0.125-0.1875 in., 0 = 0.625+ in.

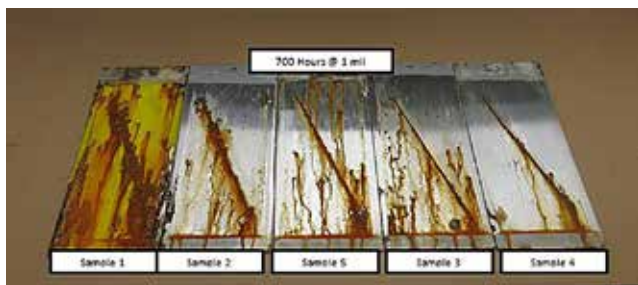


FIGURE 3 Control panels after 700 h in the salt fog cabinet.

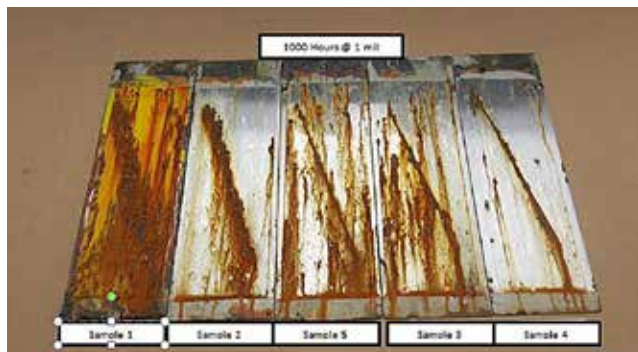


FIGURE 4 Control panels after 1,000 h in the salt fog cabinet.

and provide excellent corrosion protection.

This article shows, through research, that the combination of nano-VCI and nontoxic metal complex inhibitors form a synergistic effect that now allows for water-based acrylics to reach 1,000 h of salt fog testing at less than 1.5 mils (ASTM B117). The direct to metal aspects of these coatings results in direct cost savings by reducing the amount of material needed, reducing the application time

and labor due to fewer coats, and finally, reducing the time and expense of equipment cleanup due to the environmentally friendly nature of the waterborne systems. Applications range widely from equipment to vehicles to infrastructure where chemical agent-resistant coatings are not specified or required.

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