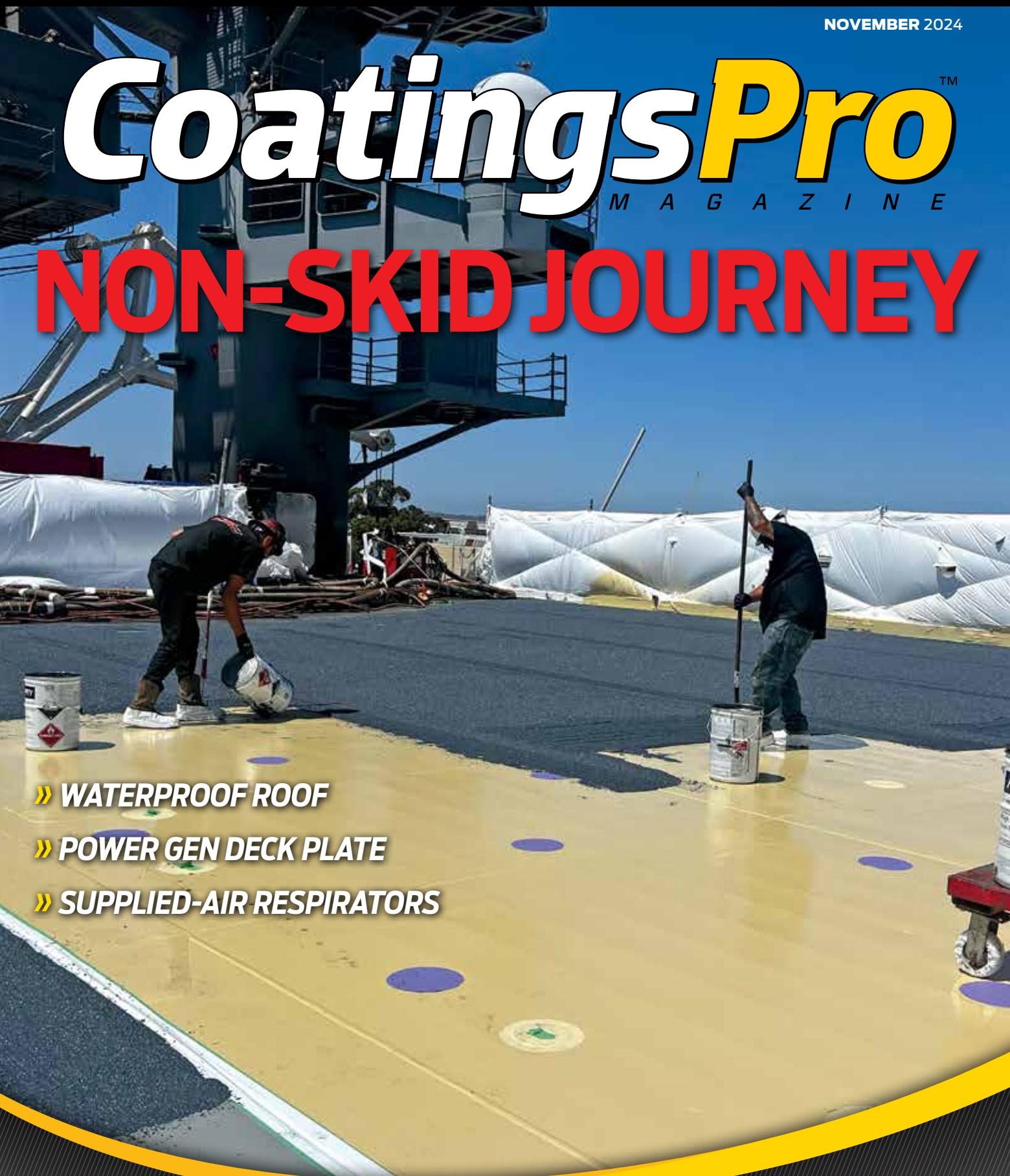


CoatingsProTM

M A G A Z I N E

NON-SKID JOURNEY



- » WATERPROOF ROOF
- » POWER GEN DECK PLATE
- » SUPPLIED-AIR RESPIRATORS



Figure 1. Observed rust staining of the roof surfaces below the snow fences.

The Case of the Rust-Stained Coated Snow Fences

By Leonard Phelps, PCS, Chemist and Associate Principal, and Kimberly Steiner, Chemist and Principal, WJE

Photos courtesy of the authors

Electroplated steel is often coated to provide a desired appearance and additional corrosion protection. While coating systems provide substantial corrosion protection from the effects of water, oxygen, salts, and other environmental factors, they cannot protect against all corrosion mechanisms.

Coated electroplated snow

fences, which are designed to restrict snow and ice from falling from roofs, were undergoing installation on a ski resort when rust staining of the roof surfaces below the snow fences was observed (see Figure 1). Studies were performed to determine the cause(s) of this premature coating/corrosion failure. Let's find out what went wrong.

Background

The snow fences consisted of an anchorage assembly and panels. The fence panels were typically constructed of $2 \times 2 \times \frac{3}{16}$ -inch ($5.1 \times 5.1 \times 0.5$ cm) hollow structural sections (HSS) (i.e., horizontal tubes) welded to vertical plates configured as intermediate spacers or endplates. Heavy gauge wire mesh was welded to the up-slope

face of the panels to prevent snow from extruding under or between the horizontal tubes, which were spaced approximately 6 to 8 inches (15.2–20.3 cm) from the center of each rail (see Figure 2).

These snow fence panels were fully assembled at the shop, and all welding was completed prior to zinc-electroplating. Preparation for electroplating included submersion in a series of tanks that contained chemical cleaners, hydrochloric acid, and air-agitated water. The electroplated fences were then treated with chromate and painted with a coating system at an average thickness of 8 mils (203 μm). The coating was made of an epoxy-based primer/aliphatic-polyurethane-based topcoat (EP/PU).

As the original installation was nearing completion, poor adhesion of the coating system to the electroplated steel was discovered. Consequently, the snow fence panels were uninstalled, shot-blasted, and recoated with an EP/PU system. The refurbished panels were reinstalled, and before completion of the reinstallation, rust staining of the roof surfaces below the snow fences was observed at 45 locations.

Laboratory Studies

Fence panels representing three lots and seven installed roof locations were removed and submitted to the laboratory. These were labeled S1–S7.

These fence panels exhibited minor coating damage — partially exposing the prime coat and steel substrate — due to handling, installation, dismantling, and transporting the samples to the laboratory. Typically, samples affected by rust stain appeared to originate from a roughly ¼-inch (0.6 cm) rust spot at the corner of a weld between the tube and endplate (see Figure 3).



Figure 2. Horizontal tubes were welded to vertical plates as spacers. Heavy gauge wire mesh was also welded to prevent snow from extruding under the tubes.

When the S1–S5 sections were cut open, between 15 and 80 mL (0.5–2.7 ounces) of greenish fluid was found on the interior of each tube (see Figure 4). These samples also exhibited rust staining on the exterior surfaces. To various degrees, corrosion was present on the interior of the tubes, but no appreciable section loss was observed. No fluid was observed when tubes of the S6 and S7 panels were opened.

Surface Observations

Two tube specimens were cut from the ends where each exhibited rust spots at the weld corners. The coating was removed from the weld area using a solvent-based stripper. Also removed was most of the corrosion to reveal mostly bright metal (see Figure 5), which suggested that the corrosion observed prior to stripping was rust stain on top of the coating.

The seal weld between the tube and endplate appeared to have been made in four separate passes: one on each face of the square tube.

The weld passes overlapped at the corners of the tube, which corresponds with where a ¼-inch spot of corrosion was typically observed on the samples.

Microscopical Observations

A microscopic examination of the stripped specimens revealed a shot-blast peened surface on the exposed portions of the weld, tube, and plate. A copper sulfate spot test indicated that zinc-electroplating was present on the surface.

S1–S5 each had a rust spot at the weld corner and rust stain on adjacent coating. A transverse section was prepared from one sample for microscopical observation. Inadequate fusion was revealed between the tube wall and weld bead and in a crevice between the endplate and the tube (see Figure 6).

Coating Thickness Measurements

The thicknesses were measured microscopically on cross-sections of fence samples.¹ The system typically had three layers:



Figure 3. Rust stain appeared to originate on most affected samples from a ¼-inch spot at the corner of the weld.

a zinc-electroplated layer at 0.6 mil (15.2 μ m), a primer at 5.0 mils (127.0 μ m), and a topcoat at 2.9 mils (73.7 μ m). The average thicknesses indicated complied with the manufacturer's recommendations. Other items of note: zinc-electroplating thickness was unspecified, and no substrate corrosion was observed on the examined cross-sections.

Leakage Testing

Prior to cutting, S6 and S7 were placed in a chamber under heat lamps for 72 hours, resulting in surface temperatures of 104–115 °F (40–46 °C). S8 welds indicated the formation of “new corrosion” made of several crusted bubbles with underlying fluid (see Figure 7).

Chemical Composition Studies

A series of chemical tests were performed to characterize the trapped fluid of tube interiors, corrosion, rust-stained, and non-rust-stained surface areas.

- Surface Chloride Analysis: S8 and S9 exhibited rust at the welds as well as streaks of rust staining on the endplates to which the tubes were welded. The surfaces were analyzed for chloride content using the latex sleeve method.² Each sample was tested over rust-stained areas of the endplate below the weld and on the tube at the bottom of the fence where rust stains or corrosion were not apparent. On each sample, the rust-stained areas indicated surface chloride concentrations

in excess of 60 μ g/cm² (the maximum detection limit). Areas with no rust stains indicated no surface chloride.

- Scanning Electron Microscopy/Energy Dispersive X-ray Spectroscopy (SEM/EDS): External surface deposits from S4 and S5, and the interior portions of tubes from all samples, were examined by SEM/EDS for high magnification imaging and elemental analysis.

The corrosion products generally indicated traces of chlorine and sometimes potassium. Compounds used for the processing of the snow fences, namely hydrochloric acid, potassium chloride, ammonium chloride, and



Figure 4. Greenish fluid was found on the interior of each tube on sections S1–S5.

potassium hydroxide, all include the elements chlorine and/or potassium. Samples that did not contain trapped fluids had no visible corrosion product on the areas analyzed. They also did not contain potassium or chlorine in their interiors.

A distinct zinc layer was not observed on the interior of any of the tubes sampled; however, zinc was apparent in the EDS spectra in areas of some samples. This indicates that zinc from the plating baths penetrated to the interior of the tubes. Likewise, while a chromate conversion layer wasn't observed on any interior, chromium was detected in areas on some interior surfaces. This suggests penetration of the chromate conversion bath chemicals into the tubes.

- X-ray Diffraction (XRD): Various materials were analyzed using XRD. Solid samples were collected from a given substrate; fluid samples were prepared by evaporating a representative portion at room temperature.

Iron chloride hydrate, potassium chloride, zinc carbonate, iron oxide, potassium zinc chloride, and sodium chloride were detected in the evaporation residue of the fluids. Sodium chloride, potassium chloride, and potassium zinc chloride were detected in the corrosion/

stain on the exteriors. Analysis of the non-rust-stained areas of the exterior tubes detected sodium chloride, along with quartz, mica, and feldspar, which are typical ingredients of painted coatings.

- Chloride Measurements: The chloride contents were found on the interior surfaces of selected tubes by rinsing the tube interiors with a known amount of deionized water and analysis by potentiometric titration.³ Chloride concentrations between 419.7 and 1,012.9 $\mu\text{g}/\text{cm}^2$ were detected on the tube interiors from which fluid was removed, while negligible surface chloride concentrations of 0.23 to 0.37 $\mu\text{g}/\text{cm}^2$ were detected on the S6 and S7 interiors. The greenish fluid removed from a tube contained 141,370 mg chloride/liter (nearly 10 times that of seawater).
- Fourier Transform Infrared Spectroscopy (FTIR): FTIR indicated that the primer was epoxy-based, and the topcoat was based on a styrenated-acrylic-polyurethane, both consistent with the requirements.

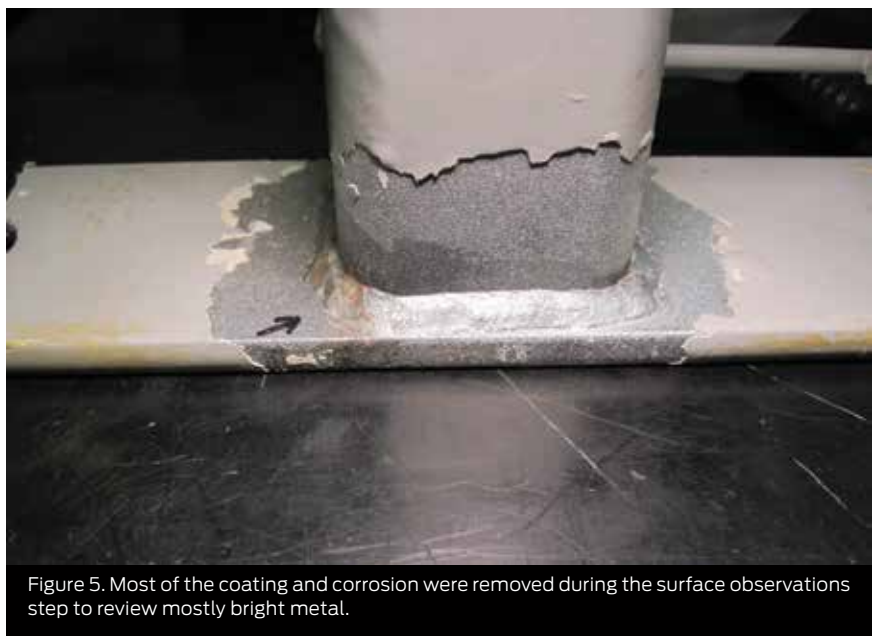


Figure 5. Most of the coating and corrosion were removed during the surface observations step to review mostly bright metal.

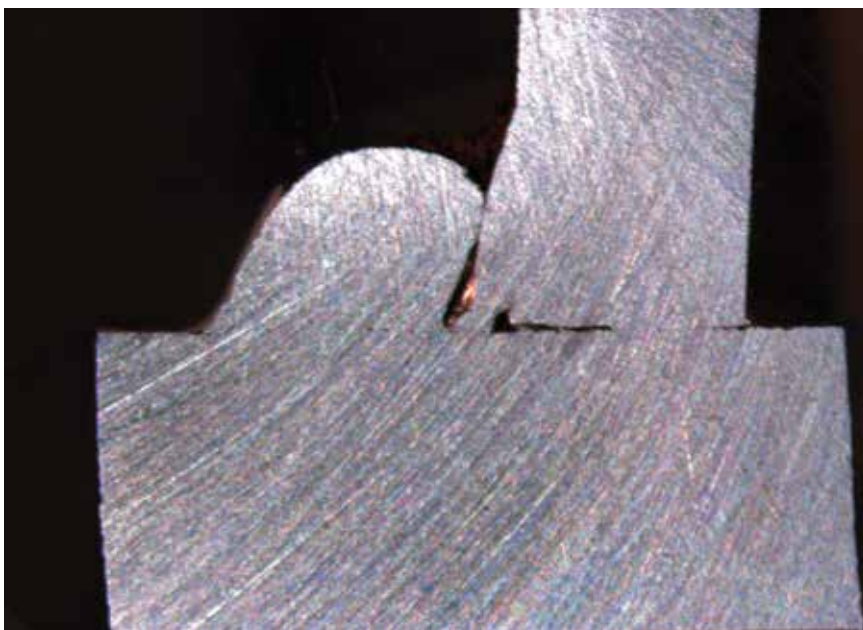


Figure 6. When a transverse section was prepared from a sample, inadequate fusion was revealed between the tube wall and the weld bead and between the endplate and tube.

welding process, a previously placed weld metal must remain molten between passes, or be sufficiently reheated, as the subsequent weld is placed. Without this, a lack of fusion between weld segments can create discontinuities in the welds, resulting in a path between the interior and exterior of the tube.

Process chemicals on this project included chlorine-based compounds, such as hydrochloric acid, potassium chloride, and ammonium chloride. Chlorine-based compounds were detected in corrosion stains on the exteriors of most samples. Where corrosion stains were present on the exterior, fluid was detected in the interiors of tubes along with chlorine-containing compounds. Of the two samples without corrosion stains on the exteriors, neither fluid nor chlorine-containing compounds were observed on the tube interiors.

Process fluids not only migrated into the fence tubes during processing through weld discontinuities; they also migrated

Findings and Conclusions

Stripping the coating from the weld areas revealed mostly bright, peened metal beneath the coating system rather than any substantial rust. This indicates that the applied coating system is protecting the substrate.

Observations and testing indicate that rust staining of the snow fences and roof surfaces did not originate at the exterior surfaces but came from within the fences' tubes, where greenish process fluid was found in five of seven samples tested. Observed corrosion at welds on the exterior coated surfaces of the fences was primarily due to accumulated deposits and stain from rust and process chemicals exuding through weld discontinuities.

We concluded that during the cleaning, electroplating, and chromating processes, chemicals penetrated through discontinuities in the weld metal and into the tubes. Microscopical observation of a corroded/stained weld clearly showed that the interior of the

tube was connected to the exterior through gaps between the weld and tube caused by a lack of fusion during welding.

To establish continuous fusion of the weld segments in a start-stop

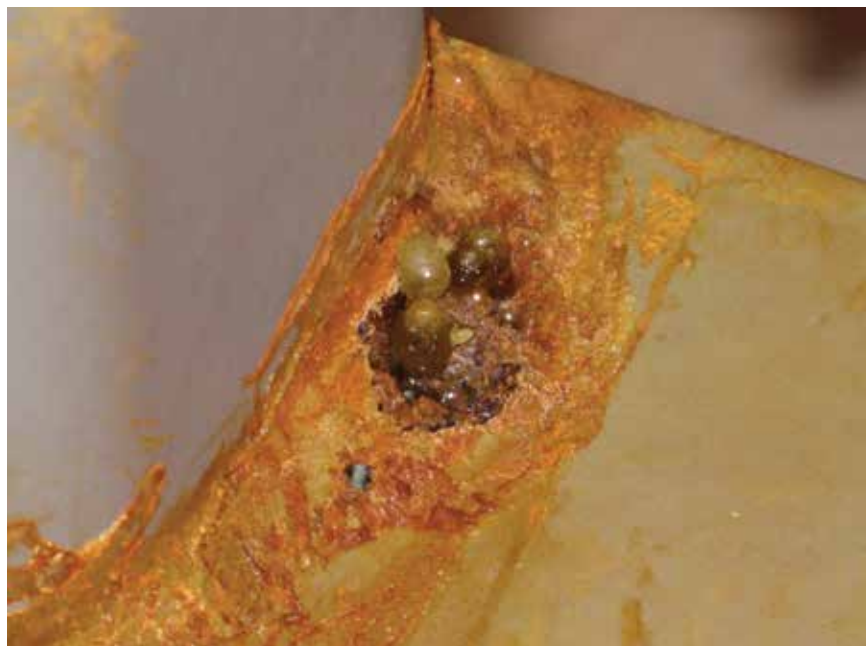


Figure 7. Leakage testing indicated that "new corrosion" formed. This was made of crusted bubbles with underlying fluid.

out during service when the interior temperature and pressure increased due to exposure to sunlight, as demonstrated by the leakage testing. Trapped fluids flowed out, staining the fence and roof surfaces with chemicals and corrosion byproducts. This happened because electroplating and applied coatings are not designed to withstand the backside pressure from trapped chemical fluids and will eventually succumb to the effects of the trapped fluids leaking from the tubes until exhausted.

Chloride compounds in contact with bare metal of the tube interior can markedly increase the corrosion rate of the steel. The threshold needed for chloride concentrations to cause corrosion is usually very small; however, the rate and the degree of corrosion of the steel tubes can increase as the levels of chloride increase. Iron chloride complexes are often soluble and can result in a continued corrosive attack of the steel. Pitting and crevice corrosion are examples of the more severe damage that can be done to the tubes over time.

Additionally, rust staining on exterior surfaces of the fences was more than an aesthetic issue. Exterior surface chloride analysis at the rust-stained areas revealed chloride concentrations in excess of 60 $\mu\text{g}/\text{cm}^2$, substantially exceeding surface chloride threshold limits typically reported in coatings literature⁴ before problems with coating application or corrosion of coated steel are encountered. This investigation was performed after only three months of service for the snow fences, and eventually these high chloride concentrations will accelerate the corrosion of the zinc-electroplating and the steel substrate and will undercut the coating system. If left as is, the contamination is also expected to migrate to other architectural surfaces and accelerate corrosion of

associated architectural metals.

Key Takeaways

- Corrosion and rust staining on fences and roof surfaces were not due to a failure to protect the fences' steel substrate electrochemically with the zinc electroplating or as a barrier with the EP/PU coating system. Instead, rust staining, and to a lesser extent corrosion, occurred primarily at welds because electroplating processing fluids trapped on the tube interior leaked through weld discontinuities. As the fluid leaked out, it led to the rust staining of coated fence tube welds, other coated fence surfaces, and roof surfaces.
- Analysis of the trapped fluid, interiors of selected tubes, and exterior tube surfaces exhibiting staining indicated high-chloride levels exceeding known thresholds for chloride-induced corrosion of metals.⁵
- The origin of the trapped fluids was the manufacturing processes that introduced chloride-based chemicals (a fluid) into the HSS tubes through gaps between the weld and the tube due to a lack of welding fusion.
- The EP/PU coating system was not designed to bridge the gaps in the welds nor to withstand the backside pressure exerted by the trapped fluid. Therefore, it did not effectively impede the leakage of the trapped fluids.

Final Thoughts

Coating failures are not always what they seem. The premature corrosion of these snow fences was not due to poor coating performance; instead, the root cause of the corrosive-staining was due to the gaps in the seal welds, which were allowing chloride-laden fluids in and out of fence tubes. Although

remedial drain holes may allow the chloride-laden fluids to drain, rinsing through drain holes may not adequately eliminate chloride and prevent future corrosion. The remedy would be to refurbish or make new fences with functional seal welds to prevent entry of chloride-laden fluids into the tubes in the first place. **CP**

References

- 1 ASTM B487, "Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section," Nov. 9, 2020.
- 2 SSPC Technology Guide 15, "Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Nonporous Substrates."
- 3 ASTM D512, "Standard Test Methods for Chloride Ion in Water," Apr. 14, 2023.
- 4 Corbett, B., *Let's Talk About Surface Soluble Salt Remediation Practices Surface Soluble Salt Testing*, KTA Certified Coating Inspector Forum Volume 3, Issue No. 4-April 2024.
- 5 Matsushima, I. 2000. "Carbon Steel — Corrosion in Fresh Waters." In *Uhlig's Corrosion Handbook*, by R. Winston Revie, 529–544. New York: John Wiley & Sons, Inc.

LEONARD PHELPS, PCS, is a chemist and



an associate principal with Wiss, Janney, Elstner Associates (WJE). He has 47 years of experience in the coatings

consulting industry.

KIMBERLY STEINER is a chemist and a



principal with WJE. She has 25 years of experience in materials analyses, including the evaluation of coatings.

For more information, contact: Len Phelps, lphelps@wje.com, or Kim Steiner, ksteiner@wje.com.