Products and Priorities

Corrosion Resistance and Environmental Considerations for Architectural Metal Coatings

Executive Summary

The coil and extrusion coatings industry is at a crossroads. Certification and testing bodies such as the American Architectural Manufacturers Association (AAMA) and the American Society for Testing and Materials (ASTM) have introduced more stringent corrosion testing to better reflect real-world difficult industrial and seacoast environments. There are further discussions about raising industry standards for corrosion resistance in these environments.

At the same time these organizations are increasing the demand for corrosion resistance; architects, governments, municipalities and environmental organizations are demanding the elimination of *Living Building Challenge* "Red List" materials such as chromium and lead, which are both well-known and traditionally used corrosion inhibitors. This strategy, while well-intentioned, has the potential to significantly reduce corrosion performance for coated metal building components in hot, humid, salt-laden seacoast areas and industrial environments.

The coil and extrusion coatings industry is committed to developing coatings that answer the need for increased corrosion performance with coatings that do not contain "Red List" materials. While a comprehensive and cost-effective solution remains elusive, coatings industry innovation is well on the way toward resolving these issues.

The purpose of this document is two-fold: The first is to educate architects, building owners, specifiers and applicators about the types of corrosion and geographic areas vulnerable to premature failures, current industry standards and market conditions. The second is to address the potential problems that may arise when new coatings technologies – such as primer-less, single-layer liquid and powder coating systems – are substituted in place of more robust corrosion-resistant coating technologies.

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Corrosion and Causes

The definition of corrosion is "the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties."

There are multiple factors that can accelerate corrosion. Such factors include, but are not limited to, the following:

- Salt-saturated air and salt spray from oceans
- High humidity
- Condensation (dew)
- Sunlight
- Impact, freeze/thaw
- Time of wetness

Industrialization

- Salt from de-icing roads
- Acid rain/smokestack emissions
- Vehicle exhaust

Miscellaneous Stresses (Natural and Man-Made)

- Dew, rain, floods, salty air, salt spray
- Birds, insects
- Fungus, bacteria, microbes, plant sap, mildew
- Temperature and sunlight variation
- Dust, hail, lightning, gravel impact, abrasion, high-pressure spray
- Poor surface preparation
- Insufficient maintenance
- Perspiration

Types of Corrosion

Filiform Corrosion

There are many forms of corrosion associated with the building market. One of the most prevalent is ***filiform corrosion***, which occurs most commonly on aluminum substrates. This type of corrosion begins when a substrate metal is exposed by a deep scratch, or a cut edge enables moisture to penetrate beneath a metal coating.

Filiform corrosion requires relative humidity measuring between 40 and 90 percent. It typically spreads in streaks and creeps along the surface of the metal, causing the coating to lose adhesion and its aesthetic appeal. Filiform corrosion accelerates in warm temperatures, high humidity, elevated salt environments and when metal is exposed by a raw or cut edge.

Example of filiform corrosion creepage away from a horizontal exposed scribe

Aluminum extrusions and coil-coated materials are both susceptible to filiform corrosion because their metal edges are frequently exposed. Most aluminum extrusions are fabricated after coatings are applied, so when window frames are mitered, or fastener holes are drilled during installation, exposed edges may be left unprotected by the coating.

The vulnerability of exposed edges also is an issue for manufacturers applying paint to coil-coated stock. When paint is roll-coated onto the flat surface of the coil, edges are left uncoated. The same phenomenon occurs when painted coils are cut and fabricated into sheets. Fabrication bends in these applications also may cause slight micro-cracking on the paint surface, opening another potential site for moisture penetration.

Galvanic Corrosion

Another type of corrosion is called ***galvanic corrosion***. This occurs when electrochemically dissimilar metals share an electrically conductive path, enabling the ions from one of the metals to attack and oxidize the other. Applying a continuous paint film (coating) or inserting a gasket that eliminates contact between two or more incompatible metals helps prevent this type of premature corrosion.

Film Erosion

Film erosion is most commonly associated with coatings that are not UV-durable and, therefore, susceptible to chalking. Severe chalking causes paint film to deteriorate or erode at a high rate, ultimately exposing the metal substrate underneath the paint to moisture and other hazards that initiate the corrosion process.

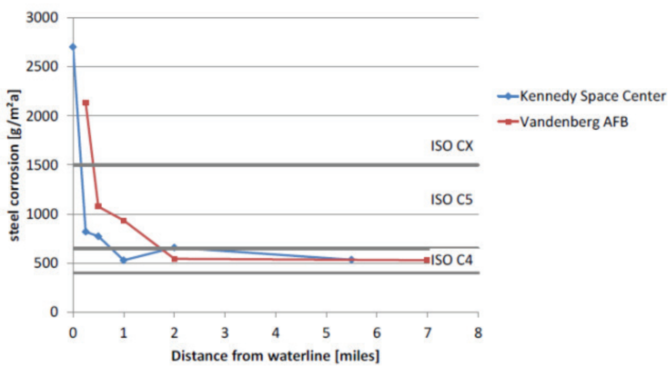
Aluminum extrusions are coated and cut into sections to build products such as window frames. This process also leaves edges of metal uncoated and unprotected from moisture, salt and other hazards that cause corrosion.

Coil coatings are applied to the surface of metal building products by roll-coating, which leaves edges unpainted and vulnerable to corrosion when the product is transported, stored outdoors or installed on a building.

The Geography of Corrosion

As the maps below illustrate, buildings and metal structures along the U.S. Gulf Coast and Eastern Seaboard are especially susceptible to corrosion failure due to the preponderance of heat, humidity, salt and wind.

According to most architectural metal coatings manufacturer warranties, a seacoast region is defined as an area from 1,500 feet up to one mile inland from an ocean coast. As the chart indicates, salt concentration drops significantly after one mile inland from the coast, as defined by the level of sodium and chloride ions in the atmosphere. However, moist salt-air from the sea can carry well beyond those distances. In fact, wind (and, at times, hurricanes) have been known to carry sea salt several hundred miles inland from coastal areas.

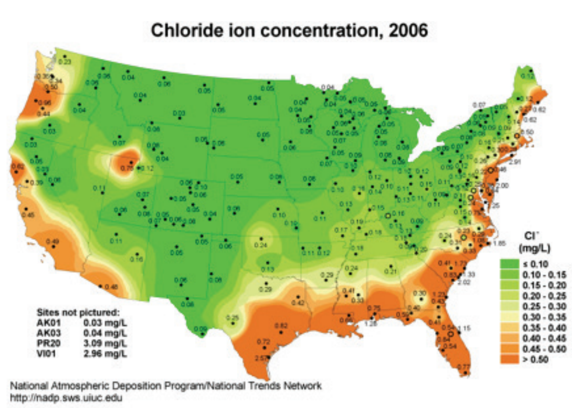


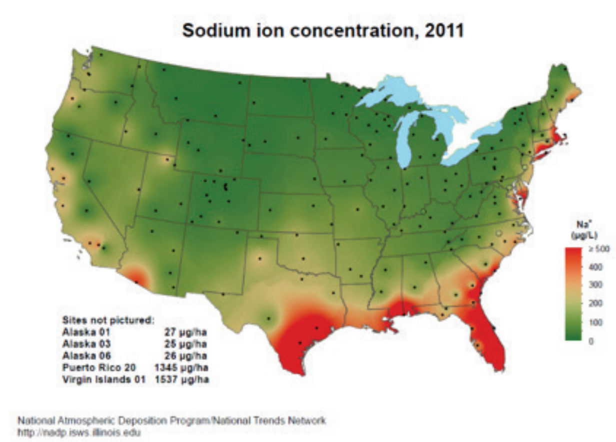
This chart, which illustrates corrosion levels at The Kennedy Space Center in Florida and Vandenberg Air Force Base in California, demonstrates how dramatically corrosion levels diminish when steel surfaces are located at least two miles from the coastline.

While that reality makes buildings throughout the state of Florida vulnerable to corrosion failure, the structures most susceptible to such damage are those located in areas that also experience high levels of crashing surf and salt mist. Luckily, abundant rainfall in the Sunshine State helps mitigate corrosion by rinsing salt residue from buildings (although any metal building parts located under an eve or shielded from rainfall remain extremely vulnerable to corrosion).

Buildings in the northeastern U.S. are less exposed to the corrosive warm and humid conditions than those in Florida and the southeastern U.S., yet the proliferation of winter road salt can yield comparable results. In large cities such as New York, Boston and Philadelphia, road salt has been shown to reach surfaces as high as 20 stories from the ground, due to the wind tunnels created between tall buildings.

While all coastal locations are susceptible to salt air corrosion, the West Coast is not as severely affected due to the dryness of the air. Filiform corrosion requires humidity in excess of 40 percent to develop. Even so, corrosion maps show that salt can travel from the Sea of Cortez in the Baja Peninsula to non-coastal areas as far inland as southern Arizona.





Corrosion – Current Industry Standards

The International Standards Organization (ISO) has developed standards that rate interior and exterior environments according to their respective degrees of risk for corrosion. The ISO 9223 standard is for the *Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, determination and estimation.* Ratings within this standard are determined by weighing a steel panel, exposing it to a specific environment for one year; then re-weighing the panel again to measure the degree of weight loss that occurred during that time.

For example, an exterior environment designated as C2 (C stands for corrosion) represents a rural area with low levels of pollution, while an exterior environment with a C5-M designation identifies a harsh coastal environment with high levels of salt air.

The table to the right describes these ratings in detail.

Accelerated Corrosion Testing and AAMA standards

AAMA also has developed industry standards for various levels of corrosion performance, commonly referred to as AAMA 2603, AAMA 2604, and AAMA 2605. Each standard contains laboratory-based accelerated test methods that were adopted to mimic, as closely as possible, corrosive conditions in the real world.

Historically, the primary test method had been the ASTM B117 Salt Spray Fog Test. During this test, coated panels are exposed in a chamber to a constant mist cloud containing a 5-percent sodium-chloride solution at a sustained temperature of 95°F. The test requirement to meet the AAMA 2605 specification, the industry's most rigorous performance standard for weathering performance, was 4,000 hours.

Recently, AAMA eliminated the 4,000-hour salt spray specification, determining that a new accelerated corrosion test method better mimics real-world corrosion conditions. The organization now mandates the use of a new 2,000-hour G85 Annex 5 (A5) Dilute Electrolyte Cyclic Fog/Dry corrosion test.

Other AAMA committees have been formed to define corrosive environments and examine various filiform corrosion test methods that may be added to the AAMA 2605 specification. The goal of these changes is to streamline and shorten the corrosion-testing cycle. The organization also is considering amendments to the AAMA 2605 specification to include a new section on severe environmental conditions.

By implementing these changes and considering others, AAMA and ASTM are clearly focused on helping their members and the industries they serve more accurately assess the corrosion resistance of materials in the real world.

Corrosivity Category	**Type of Environment or Location** (ISO 9223 atmospheric-corrosivity categories)	
	Interior	**Exterior**
		Residential
C1 Very low	Heated buildings with clean atmospheres, *(e.g. offices, shops, schools, hotels)*	Not applicable
C2 Low	Unheated buildings where condensation may occur, *(e.g. depots, sport halls)*	Atmospheres with low level of pollution Mostly rural areas
C3 Medium	Production rooms with high humidity and some air pollution, *(e.g. food processing plants, laundries, breweries, dairies)*	Urban and industrial atmospheres, moderate sulfur dioxide pollution Coastal areas with low salinity
		Industrial
C4 High	Chemical plants, swimming pools, coastal ship, boatyards	Industrial areas and coastal areas with moderate salinity
C5 Very high	Buildings or areas with almost permanent condensation with high pollution	Industrial areas with high humidity and aggressive atmosphere
		Severe Marine
C5 M Very high	Buildings or areas with almost permanent condensation and with high pollution	Coastal and offshore areas with high salinity
CX		Buildings on water

Comparing Aluminum and Steel

Aluminum is the preferred metal substrate for coastal applications. When testing for corrosion in South Florida, coatings manufacturers commonly remove steel panels from panel farms after five years of exposure because they are likely to rust away before they are seven years old. While high-build primers over steel have demonstrated the ability to extend steel panel life to 12 years, they cannot match the weathering and corrosion performance of aluminum, which delivers performance advantages that do not require the use of such primers.

Zinc-coated steel offers better weather protection than standard cold-rolled steel in coastal areas; nevertheless, history demonstrates that any form of treated steel with cut edges remains extremely prone to edge corrosion.

South Florida exposure testing proves that, when protected with a viable chrome pretreatment and primer system, aluminum is the best substrate for coastal areas, even for parts that are installed with exposed edges.

Corrosion-Resistant Pretreatment Technologies

For the past 50 years, the building industry has relied on zinc-coated steel and/or chromium pretreatments in combination with chromium primers to protect steel and aluminum building components, especially from corrosion, in industrial and seacoast environments. Chrome also enables coatings to adhere more strongly to the metal surface.

Chrome pretreatment, combined with a strong-adhering chrome primer, is one of the most effective coating solutions for preventing the proliferation of filiform corrosion on aluminum substrates. Although chrome pretreatments and primers will not stop filiform corrosion from occurring, they do prevent it from proliferating.

Three pretreatment options are most commonly used for aluminum substrates:

- Hexavalent Chrome
- Trivalent Chrome
- Chrome Alternatives

Hexavalent Chrome

Hexavalent chromium also is referred to as "hexavalent chrome Cr(VI)," "Cr6" or "chrome-six." It has a gold, yellow or green appearance and offers the most robust corrosion protection resistance. It has been used in the industry for 50 years.

While hexavalent chrome is the most robust option for corrosion protection, it also is the least safe for the environment and human health, as it is both toxic and carcinogenic. Due to its toxicity, hexavalent chromium has been placed on the "Red List" of products to avoid by administrators of the *Living Building Challenge*, one of the world's most rigorous green building certification systems. Other environmental organizations often reference the *Living Building Challenge* "Red List" when creating their own restricted substance lists.

A major performance benefit associated with this material is its wide operating window. AAMA specifications require minimum coating weights of 40 mg/ft^2 for this type of pretreatment system, although many applicators apply up to 100 mg/ft^2 to optimize protection. It is essential for applicators to find the coating weights that best suit the performance demands of their product or application. If the pretreatment is applied too thinly, it is vulnerable to corrosion; if it is applied too heavily, it can turn to powder and cause a loss of adhesion between the pretreatment and the paint surface.

Trivalent Chrome

Trivalent chrome is referred to as "Cr3" or "chrome-three" and features a lower concentration of chrome than hexavalent chrome. Trivalent chrome (chrome-three) has proven to be an effective corrosion-prevention solution, but it still does not facilitate the goal of fully eliminating heavy metals from the waste stream. Although it is not currently considered carcinogenic, trivalent chrome is still a heavy metal and likely to be placed on the "Red List" in the future.

Its appearance is clear, though additives often are used to indicate the presence of a coating. Trivalent chrome does not have the same level of corrosion protection or self-healing properties as hexavalent chrome, but it can be a very effective corrosion deterrent if applied within the correct parameters.

Chrome, Not Intentionally Added (NIA)*

Pretreatments specifically formulated without intentionally added "chrome three" or "chrome six" have been developed and commercialized in recent years. While they offer excellent corrosion resistance, they are not as robust as legacy chrome alternatives.

In the applicator's process, chrome (NIA)-containing pretreatment products have much tighter operating tolerances. When these materials are run, they demand much shorter test intervals to assure the chemicals are being applied at optimum performance levels. Operating outside of these rigorous tolerances can significantly diminish the corrosion protection performance of the finished product. Failure to maintain tight operating conditions can lead to process failures and negative results. For this reason, it is important to test these pretreatment systems at frequent intervals during the application process to make sure the chemicals remain within specification.

One proof of this phenomena was evidenced years ago in the coil industry. Responding to demand for more flexible pretreatment options to help fabricators improve their post-forming operations, the coil industry began converting to complex oxide pretreatment systems. Before long, corrosion failures on metal roofing resulting from acid rain fallout became a widespread problem in the "rust belt" areas of the United States.

*Chrome NIA (which some people refer to as "chrome free"), is intended to indicate that chromium is not intentionally used within the formulation or manufacturing process.

Continued Rise of Chrome Pretreatment Alternatives

With environmental regulations becoming stricter around the globe, there is growing demand to fully eliminate not only chrome pretreatment, but also chrome primers and chrome-containing multi-layer coatings systems from industrial and architectural coatings systems. This is especially true in the European Union, where legislators have mandated the elimination of several hexavalent chrome compounds from most paint systems by 2019.

Most U.S. pretreatment systems use chrome phosphate, which has excellent adhesion but less throw protection on the edges of a metal surface. Chrome chromate, which is not often used in the U.S., has less adhesion strength but more throw power and can be considered self-healing.

In Europe, manufacturers are pursuing two different pretreatment alternatives. The first is improved etching with acid cleaners to remove more oxide from aluminum surfaces. While cleaning a metal surface is probably the most important step in preparing it for painting; removing aluminum impurities—along with oxides and oils—may be the most important step in coating it. Acid-etching has proven to enhance the ability of coatings to adhere to aluminum surfaces and thereby improve their corrosion protection.

The second alternative is flash anodizing, which imparts a fine layer of protection to the surface of the metal to prevent the formation of filiform corrosion. Filiform corrosion cannot form on an anodized layer.

Corrosion-Resistant Coatings Systems

The need to protect metal from corrosion is not restricted to the substrate and pretreatment layer. This section summarizes the advantages and disadvantages of four major corrosion protection layers and/or systems and components for building products:

- Pretreatments
- Primers
- Clearcoats
- One-coat systems

Pretreatment

Real-world results and South Florida accelerated exposure testing have clearly demonstrated that coatings systems containing one layer of chrome in the pretreatment or primer will perform to expectations.

Recent history and accelerated exposure testing also have clearly demonstrated that coatings systems that do not contain chrome in the pretreatment or primer may also perform to expectations, provided there is tight control on operating parameters. Recent experience also has shown that non-chrome-containing systems that are not properly applied can lead to serious corrosion and safety issues on buildings.

Primers

Primers are as important as pretreatment methods in protecting metal substrates from corrosion because they make coatings adhere more readily to metal surfaces and provide an excellent barrier against moisture penetration. While primers are formulated to adhere to metal and thereby enhance corrosion protection, topcoats are engineered to emphasize UV protection, which may limit their ability to achieve optimum adhesion.

Clearcoats

Clearcoats aid directly in the prevention of corrosion by functioning as an extra protective barrier against salt penetration. In addition, clearcoats tend to rinse and clean more easily than color coats, which, due to the presence of pigmentation in the film, feature a rough surface that can trap and hold dirt and salt residue. Because clearcoats have exceptionally smooth surface profiles, rain is generally effective in removing external contaminants from their surfaces.

Clearcoats are mandatory over metallic flake-containing paint systems because they prevent the aluminum flake from tarnishing and discoloring, but they also can be layered over solid and mica coatings to enhance UV protection.

As the photos to the right illustrate, panels finished with clearcoats placed in South Florida testing farms have demonstrated virtually no change in chalking or color fade after 35 years of continuous weather exposure. Clearcoats effectively eliminate chalking because they contain no pigments. Pigments lose their chemical bond with coatings film during exposure to UV light. This is the primary condition that leads to the formation of chalk.

One-Coat Systems

Single-layer powder and liquid coatings are becoming increasingly popular for less-rigorous AAMA 2604 architectural and building-product applications, where they frequently displace two-coat, 50-percent PVDF coatings that have dominated this performance category for more than 50 years.

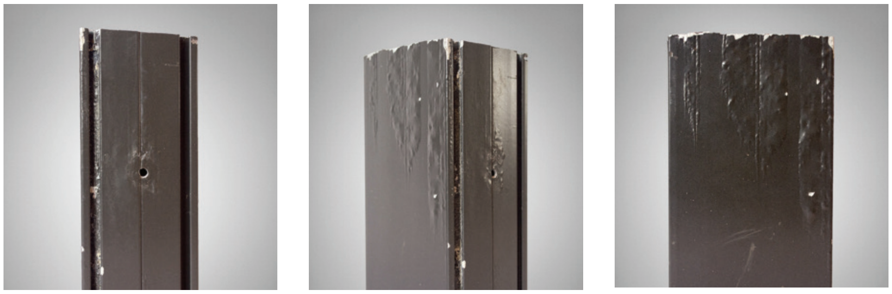
UV-durable fluoropolymer coatings are less susceptible to film erosion than standard polyester- and acrylic-based coatings because they have powerful molecular bonds that limit film loss to less than 10 percent every 20 years.

One-coat liquid and powder coatings for aluminum extrusions began entering the building market in the early 2000s to lower cost and meet environmental mandates. While most applications were limited at first to residential and light building projects, architects eventually began to specify them for monumental buildings requiring compliance with AAMA 2604 and 2605 standards for weathering and corrosion resistance.

One-coat liquid products also are marketed for aluminum applications in the coil industry. Typically applied as clearcoats or tinted clearcoats over natural or brushed aluminum surfaces, one-coat liquid finishes accentuate the metallic appearance of aluminum and provide an anodized look to the coated part.

While one-coat liquid and powder systems are viable products for normal building environments, they can be susceptible to premature corrosion in seacoast environments when not applied over a robust base primer or if they are not manufactured under the proper operating conditions.

Three-Coat System with Clear - 35 Years, South Florida
Clearcoats improve chalk-, fade- and corrosion-resistance, enhance cleanability and provide graffiti resistance.



Powder-Coated Aluminum Extrusions - Two Years, South Florida
Powder-coated aluminum extrusions exposed on a building for two years in a coastal region in South Florida. Corrosion sites formed on cut edges, recesses and punched fastener holes

Other Methods to Reduce Corrosion

Rainfall and Fresh-Water Rinsing

Even in Florida, where rainfall contributes substantially to removing salt residue from building surfaces, fresh-water flushing is recommended for eaves, overhangs and other metal building components not regularly exposed to weather. Countless cases of pitting and corrosion on metal building surfaces have been documented, with many failures traced to the release of sulfur gas from sealants and gaskets that have not been rinsed regularly. For this reason, coating manufacturer warranties typically recommend fresh-water rinsing on a regular basis to keep such areas free from salt build-up. (For additional recommendations on keeping buildings free of corrosive materials, reference AAMA 609 and 610-15 *Cleaning and Maintenance Guide for Architecturally Finished Aluminum*.)

Market Warranties

Warranties from paint suppliers cover film integrity, chalk and color fade, but do not, as a rule, cover corrosion protection. Film integrity should not be confused with loss of adhesion due to corrosion failures; it refers exclusively to good adhesion to the metal substrate and intercoat adhesion between paint layers.

Many buyers mistakenly assume that paint companies cover corrosion based on the claim that their products meet AAMA specifications. In truth, multiple application and processing factors can contribute to the onset of corrosion and not all are related to paint failure. Poor cleaning, lack of proper chrome film weights, under-cured paint and low film thicknesses are other circumstances that may contribute to premature corrosion failures.

Summary

Legacy coating systems have demonstrated their ability to last more than 50 years on landmark buildings, and in harsh industrial and seacoast environments, since their introduction in the 1960s. Despite their proven effectiveness, there is growing demand in the United States to eliminate harmful ingredients such as hexavalent chrome, trivalent chrome and chrome primers from these legacy coatings systems. Abolishing some or all these materials may have an adverse effect on long-term corrosion resistance and raise overall cost.

As they move into the future, it will be important for pretreatment chemical and coatings companies to innovate and improve corrosion resistance with new alternative materials. Over the months and years ahead, it is likely that new technologies will continue to emerge, and that they will set new standards of performance for the coatings industry and the commercial building market.

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