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Deicing Salt – Recognizing The Corrosion Threat

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Worldwide, the use of deicing salt has been common since the 1960's in areas where snow or ice is a seasonal roadway safety hazard. Automobile and highway bridge corrosion and ecosystem changes caused by deicing salt are well documented and the focus of considerable study.

Unfortunately, the deterioration of building materials has largely been ignored due to the common misconception that deicing salt damage is limited to areas immediately adjoining roadways. Deicing salt poses a significant but often unrecognized corrosion threat to architectural metals and other construction materials.

Seasonal deicing salt accumulations have been documented up to 1.9 km (1.2 miles) from busy roadways and as high as the 59th floor of a high-rise building.[1,2] Whether a project is located in Asia, Europe, the Americas, or New Zealand, deicing salt exposure is a possibility.

Seasonal deicing salt exposure in 'snowbelt' cities (e.g. Düsseldorf, Germany, Chicago, Illinois, and Toronto, Canada) can be very high and corrosion can begin to appear quickly if the wrong metal is selected. Sometimes corrosion begins during warm periods in the first winter of the installation's first year. Inland cities with mild winters, like Beijing, China, or Nashville, Tennessee, also have at least localized salt exposure because deicing is used to combat freezing rain.

Inadequate understanding of deicing salt can lead to inappropriate metal selection and premature failure. Frank Gehry's Weisman Art Museum (Figure 1) illustrates that success is readily achievable, but specifiers must be aware of recent research on the severity of the deicing salt problem, corrosion principles, comparative metal corrosion rates, and common deicing myths.

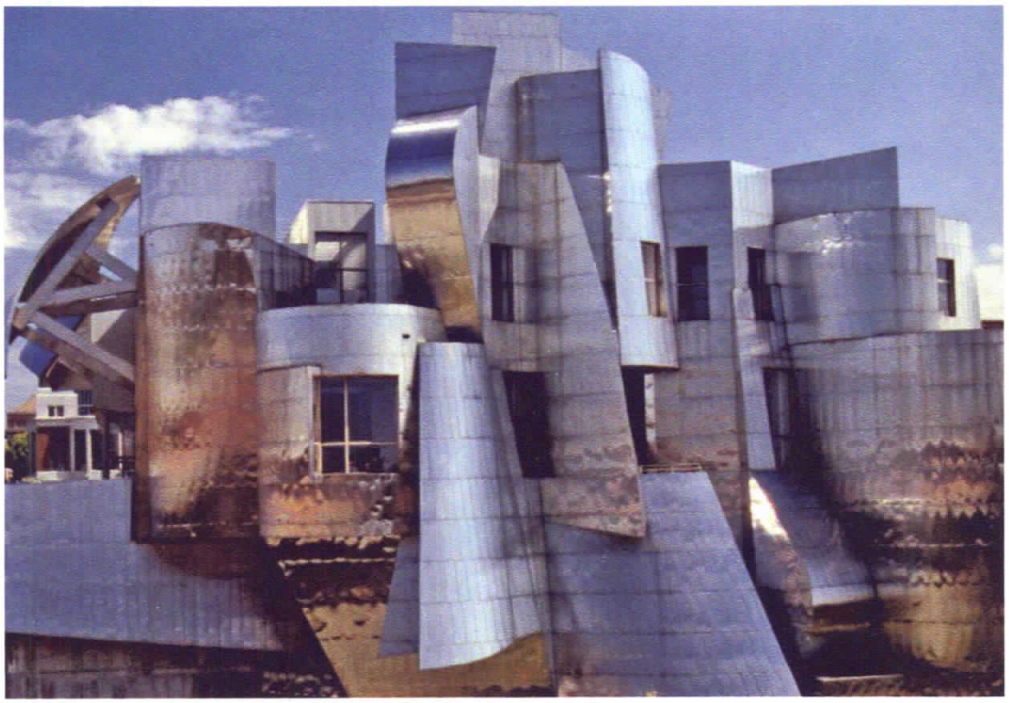

Figure 1: The Frederick R Weisman Art Museum has a smooth, fine No. 4 finish on its Type 316 stainless steel exterior and is easily rain-washed. It has performed well despite significant annual deicing salt exposure. No corrosion staining was evident on the exterior although there was some dirt accumulation.

Table 1: Road and bridge snow and ice control procedures in countries that participated in a 2002 European study of winter maintenance practices [3]

Country	Deicing Products Used	Metric Tons (1,000)	Deicing Period
Austria	NaCl, $CaCl_2$	NA	Nov. – March
Belgium	NaCl, $CaCl_2$	113	Oct. – April
Croatia	NaCl	NA	NA
Czech Republic	NaCl, $CaCl_2$, $MgCl_2$	215	Nov. – April
Denmark	NaCl	115	Oct. – April
Finland	NaCl	NA	Oct. – April
France	NaCl, $CaCl_2$	400 – 1,400	Nov. – March
Germany	NaCl, $CaCl_2$, $MgCl_2$	2,000	Nov. – March
Great Britain	NaCl, $CaCl_2$	2,200	
Hungary	NaCl, $CaCl_2$	NA	Nov. – March
Iceland	NaCl, $CaCl_2$	NA	Oct. – April
Ireland	NaCl	30-70	Nov. – April
Norway	NaCl	83	Oct. – April
Poland	No details	NA	NA
Romania	NaCl	108	Nov. – March
Slovenia	NaCl, $CaCl_2$, $MgCl_2$	NA	NA
Spain	NaCl, $CaCl_2$	80	Oct. – April
Sweden	NaCl	300	Oct. – April
Switzerland	NaCl, $CaCl_2$	NA	Oct. – April
The Netherlands	NaCl, $CaCl_2$	135	Oct. – April

NA – total tonnage data not available

Deicing Salt Use

Deicing is necessary because snow- and ice-related highway and business closures and accidents represent a significant economic cost. The United States, Canada, Japan, and Europe spend considerable sums on deicing. In recent years, the United States alone has used 13.6 to 18 million metric tons (15 to 20 million tons) of deicing salt per year and Canada has used another 3.6 to 4.5 million metric tons (4 to 5 million tons).[4]

In the US, about 70% of the roads and population are in areas that receive at least 13 cm (5 inches) of snow annually and additional sections of the country are affected by seasonal freezing rain, so deicing salt exposure is a potential factor in most prominent exterior design projects.[4]

European deicing salt use is similar to that in North America. Twenty countries participated in a 2002 European task group that studied road and bridge deicing practices. Table 1 summarizes the deicing methods used in each country, and, where available, the annual deicing salt tonnage. It is important to note that, like in North America, deicing salt is used in areas where either snow or freezing rain are a concern.

Although Table 1 only provides tonnage for twelve of the participating countries, it is evident that deicing is standard practice throughout Europe. Other European data sources document both widespread and growing use of deicing salts. The United Kingdom uses about 2 million metric tons (2.2 million tons) of deicing salt annually.[5] One supplier reported selling 6.4 million metric tons (7 million tons) of deicing salt annually in mainland Europe.[6]

Historical data shows that annual European deicing salt use is increasing. For example, the salt industry association, Verband der Kali- und Salzindustrie e.V., reported that over 3,000 metric tons of deicing salt were used on German roads during both 2005 and 2006, which is a 50% increase since 2002.[7]

Japan uses about 0.5 million metric tons (0.55 million tons) annually.[8] No data was available for the remainder of northern Asia, but deicing salt is being used where freezing rain and snow are a safety hazard. The use of deicing salt is growing in China and the country has recently become the largest producer in the world.

South America currently lags behind other parts of the world in deicing salt production and use. Internationally, approximately 240 million metric tons (265 million tons) of salt is produced every year.[9] The percentage used for deicing varies regionally, but it is possible that over 60 million metric tons (66 million tons) of deicing salt may be used annually worldwide.

Designers should also consider that some countries are undergoing rapid changes in their use of deicing salt. For example, China's infrastructure modernization and expansion has lead to increasingly liberal use of deicing salt.

Deicing Products

Despite environmental concerns that changing soil and water chemistries are harmful to plants, trees, and fish, the use of deicing salts has continued to grow and even 'sunbelt' cities are now stocking and spreading salt when freezing rain events occur.

A variety of anti-icing products are used, including sodium chloride (NaCl), calcium chloride ($CaCl_2$) magnesium chloride ($MgCl_2$), potassium acetate (CH_3COOK), and calcium magnesium acetate (CMA). Sodium chloride (i.e. rock salt) continues to be the most popular deicing product used around the world, followed by calcium and magnesium chlorides. Roadways are most commonly deiced with a premixed salt and water formula. Sodium chloride is effective in temperatures as low as -21°C (-6°F), and calcium and magnesium chloride are used individually or as part of a salt mixture when lower temperatures are anticipated.[10]

While some deicing products claim to be environmentally responsible or non-corrosive, they should be evaluated carefully. For example, while neither calcium magnesium acetate (CMA) nor molasses are corrosive, other deicing salt alternatives like fertilizer (e.g. potassium chloride [KCl] and urea [$NH_2CO\ NH_2$]) can be corrosive and over-fertilization can kill plant life. Fertilizer can also cause concrete deterioration.

All salts (chlorides) used for deicing are corrosive. Several states (e.g. Montana and Michigan) decreased their use of sodium chloride in favor of magnesium chloride with added corrosion inhibitors, because it was promoted as a non-corrosive deicing option. However, this may not be the case.

The American Trucking Association Foundation (ATAF) has reported a direct correlation between increased magnesium chloride use and a significant escalation in truck corrosion and electrical system damage.[11] Road concrete deterioration and electrical outages and pole fires are also being attributed to magnesium chloride use.

Road Salt Mists

Road salt mists or aerosols are formed as the tires of moving vehicles spray tiny particles of salt water or dry salt particles into the air. The turbulence caused by moving vehicles creates a vertical column of wet or dry salt particles and the wind transports those particles away from the road. Wind and vehicle speed, vehicle type, and the density of traffic all influence how much salt mist is formed and how far it is carried from roadways.

Large saltwater droplets land relatively close to roads, generally within 15 m (49 ft) in what is referred to as the 'splash zone.' Smaller wet droplets and dry particles can travel much further away from roads.

Hundreds of deicing salt studies have been done on roads of all sizes but most have focused on areas close to roadways. New research released by the Illinois Department of Transportation (DOT) in collaboration with Argonne National Laboratory (ANL) and the U.S. National Atmospheric Deposition Program/National Trends Network (NADP/NTN) documented seasonal deicing salt accumulations as much as 1.9 km (1.2 miles) downwind from a major highway outside of Chicago. In most locations, the deicing salt accumulations stopped within 1 km (0.6 mi) of the highway.

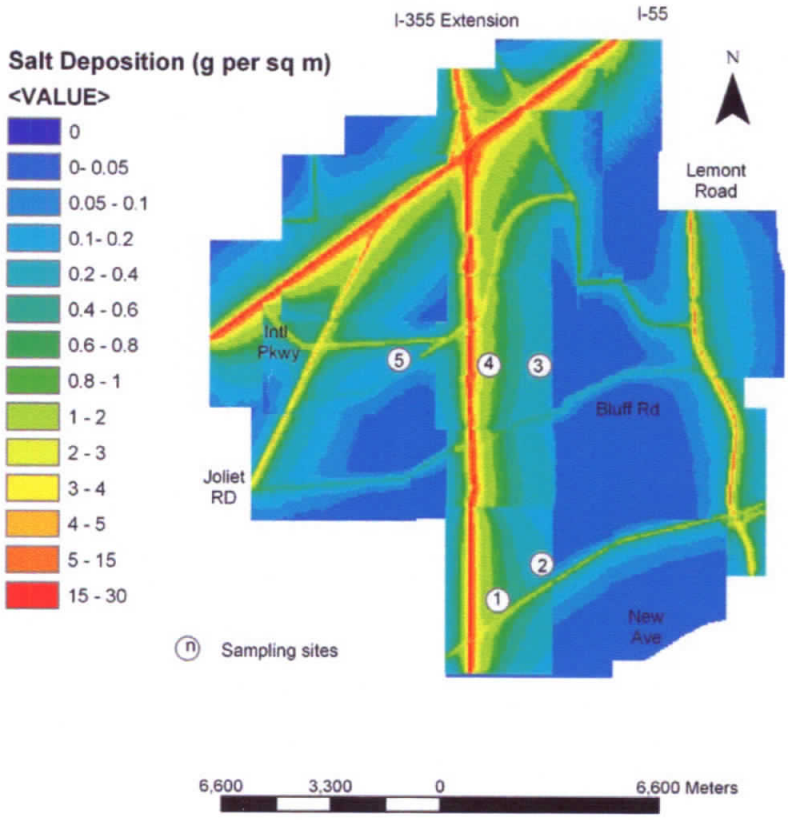

Figure 2: Model projection of annual deicing salt deposition around highways I-55 and I-355 and small surface roads with the spacing of some test sites shown (Courtesy of the Illinois Department of Transportation).

A salt deposition computer model was developed using the data gathered between 1997 and 2004. The map generated by this model (Figure 2) covers a 5 x 5-km (3.1 x 3.1-mi) site around the junction of highways I–55 and I–80.[12] The model assumes that deicing salt is applied 17 times per year on average.

Sites within 100 m (328 ft) from busy roadways are most likely to have salt accumulations comparable to moderate to severe coastal areas. In some locations, this higher salt exposure zone extends further. Most of the salt that traveled further from the roadway was in the form of dry salt particles, which rise from the pavement between snow events. The authors theorized that, in urban areas with many busy roadways and deicing salt use (e.g. Chicago), a regional salt plume or mist might exist for several days after a snow event. This increases salt exposure and the distance that it may travel.

The vertical distance that deicing salt is carried from roadways by wind has never been formally studied, but cleaning contractors and forensic consultants report regularly finding salt deposits and corrosion on buildings. This happens when thermals carry salt aerosols from roadways up buildings and air turbulence keeps them aloft.

In major downtown areas with moderate wind levels, deicing salt deposits generally stop around the 12th floor of closely spaced high-rise buildings. However, in cities with higher winter wind levels, it travels higher. In Chicago, deicing salt-related metal corrosion stopped between the 59th and 60th floors of one tall building and regularly stops between the 20th and 30th floors of moderately sized high-rises bordering busy roads. On side streets bordered by low-rise buildings, deicing salt accumulation may stop between the first and third floor.[13]

salt mists to the 12th floor!

Salt Corrosion

For corrosion to occur, a material's surface must be dampened by an electrolyte, which is a water solution that can conduct an electric current. There is a direct correlation between regular surface dampening of corrosive surface deposits and the corrosiveness of the environment. Moisture can come from rain, fog, or even humidity. Heavier rains or thunderstorms dilute the electrolyte and help to remove potentially harmful deposits. Conversely, regular light, misty rains may deposit additional corrosive deposits and encourage corrosion. The most significant corrosive constituents in coastal salt are sodium chloride, calcium chloride, and magnesium chloride, which are the same salts (chlorides) used for deicing.

Salts influence corrosion rates in several ways. First, salt is hygroscopic, meaning it absorbs water from the air. This makes it possible for corrosion to occur at lower relative humidity levels and for longer periods of time than otherwise expected. Second, salt increases water's ability to carry a current and speeds up the corrosion process. Third, the chloride ions in salt can break down the protective oxide layer that forms on the surface of some metals. For example, aluminum's otherwise protective oxide layer is damaged by salt exposure.

Salt gradually begins to absorb water and forms a corrosive concentrated chloride solution when critical humidity and temperature level combinations are reached (See Table 2.)[14] It is at approximately these humidity levels that corrosion is most severe because the corrosive solution is most highly concentrated. When several salts with different critical humidity levels are combined, the temperature and humidity range at which corrosion can occur is broadened.

With the exception of highway bridges and vehicles, long-term testing of metal performance in environments containing salts (chlorides) has focused on coastal or marine applications. Average annual salt accumulations near roadways can be similar to or even higher than typical annual coastal salt surface deposits. Since sodium, calcium, and magnesium chlorides cause both coastal and deicing salt corrosion, coastal corrosion data can be used to help predict the relative corrosion resistance of architectural metals.

It does not matter whether the corrosion test site is near your project site or in another part of the world as long as the conditions that influence corrosion are similar [e.g. pollution, acid rain, moisture, temperature, humidity, and salt exposure].

Table 3 provides comparative corrosion data for some common construction metals from several coastal corrosion test sites.[15] These sites were selected because the conditions are similar to those in U.S. and European cities with seasonal ice or snow events. A location with no salt exposure and low levels of pollution was included to provide a comparison to locations with varying levels of salt, pollution, and moisture exposure.

Although it was designed to provide assistance with stainless steel selection, the International Molybdenum Association's (IMOA's) Site and Design Evaluation System can be very helpful in identifying the factors that influence metal corrosion.[16]

Table 2: Temperature and humidity levels at which marine and deicing salts begin to absorb water and form a corrosive chloride solution

Temperature		Critical Humidity Level		
°F	°C	Sodium Chloride	Calcium Chloride	Magnesium Chloride
77	25	76%	30%	50%
50	10	76%	41%	50%
32	0	–	45%	50%

Table 3: Average annual metal corrosion rates after long-term exposure for various climates and pollution levels

Environment				
Salt exposure	None	Moderate	Moderate	High
Pollution	Low	Low	Moderate	Moderate
Fog days/year	10	160	79	10
Thunderstorms/year	43	59	3	28
Avg. rainfall/year mm (inches)	700 (29)	1,370 (54)	515 (20)	1,050 (42)
Relative humidity %	57	69	76	78
Avg. temp. °C (°F)	16 (61)	11 (53)	17 (62)	21 (70)
Annual Corrosion Rate mm/year (mils/year)				
Type 316 stainless	<0.000025 (<0.001)	<0.000025 (<0.001)	<0.000025 (<0.001)	0.00028 (0.01)
Type 304 stainless	<0.000025 (<0.001)	<0.000025 (<0.001)	0.000127 (0.005)	0.0004 (0.02)
Aluminum	0.0003 (0.01)	0.009 (0.3)	0.004 (0.17)	0.0194 (0.77)
Copper	0.0056 (0.22)	NA	0.007 (0.28)	0.0246 (0.97)
Zinc	0.003 (0.13)	0.002 (0.08)	0.03 (1.14)	0.111 (4.37)
Weathering steel	0.023 (0.9)	NA	0.09 (3.6)	0.810 (31.89)
Carbon steel	0.04 (1.70)	0.147 (5.8)	0.26 (10.12)	2.19 (86.22)

NA indicates data on this metal was not available for this test site

Aluminum

Aluminum can provide excellent corrosion resistance in many applications, but salts (i.e. chlorides) break down this material's protective oxide film, causing corrosion. There is no significant difference in the corrosion rate of common aluminum alloys when exposed to salt. Salt (chloride) corrosion of aluminum is accelerated when sulfur compounds (e.g. atmospheric sulfur dioxide) are also present in the environment. Protective sacrificial carbon steel coatings containing aluminum will also have higher corrosion rates under these conditions.

When aluminum corrodes, it is through pitting, rather than uniform surface corrosion, producing a white to grayish white powder. Anodizing improves corrosion resistance, but it does not provide adequate long-term protection in environments where corrosion of unprotected aluminum is likely. For aluminum to perform well in these environments, regular maintenance cleaning is needed to remove corrosive deposits.[17]

Figure 3: Severe deicing salt corrosion of an aluminum door threshold

Figure 3 shows corrosion in Pittsburgh, Pennsylvania, caused by a combination of sulfur dioxide and deicing salt. The aluminum door threshold is perforated due to severe corrosion. The adjacent sidewalk is regularly deiced during the winter and salt was allowed to accumulate on the threshold.

Figure 4, shows anodized aluminum panels on the second floor of an adjoining building. The panels were originally anodized to a charcoal gray color. The white and lighter gray areas indicate where deicing salt accumulated on the surface and caused surface pitting corrosion, which removed the original anodized finish.

Figure 4: Deicing salt corrosion of anodized aluminum panels on the second floor of an office building

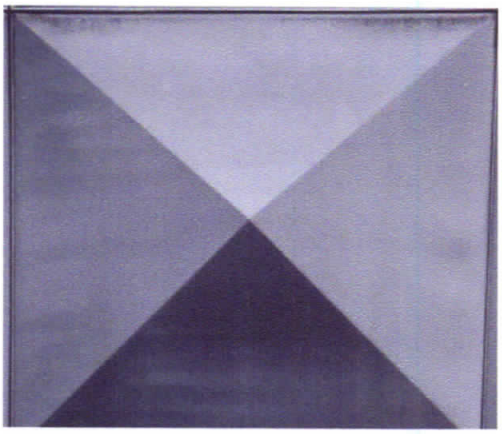

Figure 5: Exterior anodized aluminum panels that had regular cleaning to remove deicing salt and pollutants.

The white to grayish white color of aluminum corrosion may not bring attention to the problem until permanent aesthetic damage has been done. Wall panels accumulate much less salt than thresholds making perforation less likely but this damage cannot be repaired.

Corrosion could have been minimized through regular cleaning to remove salt and pollution deposits. The old Alcoa headquarters in Pittsburgh (Figure 5) had the same anodized aluminum finish, but it has only minor wall panel deterioration thanks to a regular maintenance cleaning program.

Zinc and Zinc Coatings

Corrosion or oxidation of zinc produces a gray patina designers find attractive. In locations that are non-corrosive to zinc, corrosion rates are low and the protective patina can decrease corrosion rates over time.

Exposure to sulfur compounds (e.g. sulfur dioxide) has the most significant influence on increasing zinc's corrosion rate. Salts (chlorides) and nitrous oxides also increase zinc's corrosion rates, but to a lesser extent. The highest corrosion rates are found in locations where both pollution and chlorides are present. The acidity of rain is also a significant factor in zinc corrosion if the pH is below 5.[18] The corrosion rate of galvanized steel and other zinc-containing coatings, is accelerated by the same factors that increase zinc alloy corrosion rates.

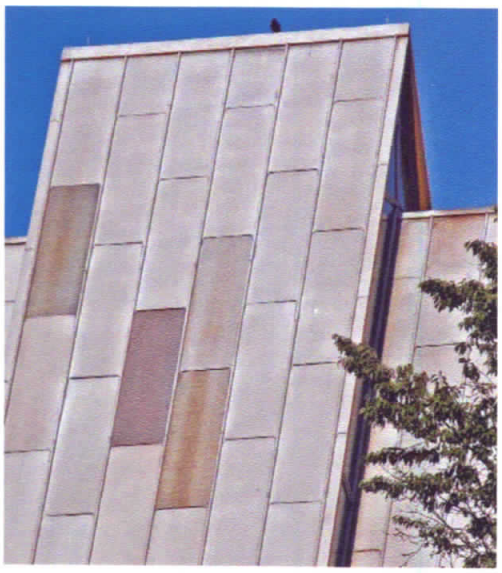

Figure 6: Corroding galvanized steel roof panels on a church near a suburban four-lane road.

Figure 6 shows the galvanized steel roof of a church near a busy suburban four-lane roadway where deicing salt is used during the winter. Despite regular rainfall in the warmer months, which helps to remove corrosive deposits, the side facing the road is exhibiting much more corrosion than the side facing the church parking lot because of its higher salt exposure.

This location has limited salt exposure because it is a slower moving roadway and the church is several hundred feet away. Pollution levels are moderate and corrosion has been gradual. More significant salt exposure and/or pollution levels would produce higher corrosion rates. Applications that are more readily rain-washed, like this roof, will retain fewer corrosive compounds and have lower corrosion rates than less boldly exposed applications.

Carbon and Weathering Steel

Carbon steel is incapable of forming its own protective coating, and paint or sacrificial metallic coatings are necessary to limit corrosion. Salt (chlorides) and pollutants (e.g. sulfur dioxides and nitrous oxides) are very corrosive to bare carbon steel. They are also corrosive to the sacrificial metallic coatings made from zinc and aluminum that are commonly applied to carbon steel. A protective metallic coating combined with a multi-layer paint system usually provides the best protection.

If an application is near a roadway where deicing salt is used, specifiers should follow coating manufacturers' recommendations for coastal areas. The highest rates of corrosion for carbon steel occur where both salt and sulfur compounds are present. This combination of atmospheric conditions is common in industrial, snow-belt cities.

Figure 8: Weathering steel with deicing salt damage on a building exterior.

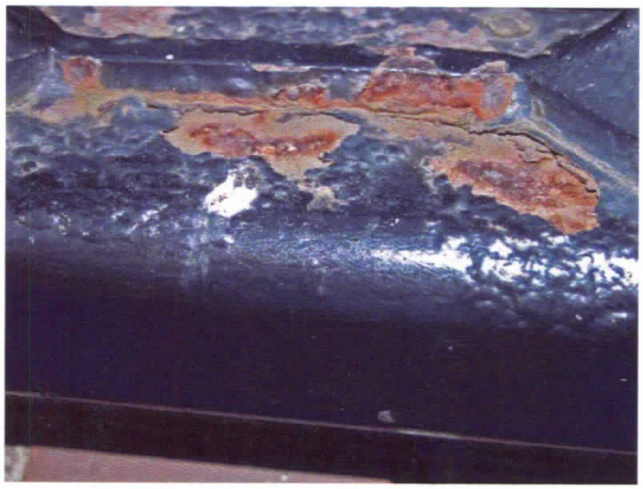

Figure 7: As evidenced by the surface "bubbling" of the paint, this carbon steel coating failure is accelerating the corrosion rate. Moisture and corrosive substances are getting under the coating edges creating crevice corrosion. More frequent paint removal and repainting are necessary to extend service life.

Weathering steels are low-alloy structural steels that can develop an adherent dense oxide film, which reduces the metal's corrosion rate as it thickens. In locations where the wet and dry cycles are such that this stable film can form, they are used without protective coatings.

Salt (chlorides) and industrial pollutants disrupt this film on weathering steel, resulting in a much higher corrosion rate. Figure 8 shows deicing salt accumulation on weathering steel used on a building exterior. Without a protective coating, weathering steel wall panels can perforate in deicing salt laden and/or polluted environments, particularly if they are sheltered and not regularly rain-washed.

Stainless Steel

There are significant differences in the corrosion rates of different types of stainless steel. Some can be immersed in seawater without corroding, while others will corrode when exposed to coastal and deicing salts. Sulfur dioxide has a minor influence on corrosion rates.

The two most common stainless steels are Types 304 and 316. While their forming characteristics and properties are essentially identical, the addition of molybdenum to Type 316 gives it superior performance in environments containing salt. As can be seen in Table 3, both stainless steels have very low corrosion rates relative to other architectural metals – making structural or perforation failure unlikely.

Under typical coastal and deicing salt exposure conditions, Type 304 will exhibit surface staining unless there is regular maintenance cleaning. For example, the Inland Steel Building in Chicago has exterior panels made of Type 304, and there is corrosion staining every Spring before the building is cleaned. The light corrosion staining is superficial and the stainless steel's appearance is restored after cleaning.

Type 316 is preferred for most applications exposed to coastal or deicing salts, since it can often provide many years of corrosion-free performance between cleanings, particularly when a smooth finish is applied. Figure 1 shows the smooth Type 316 skin on the Frederick R. Weisman Museum in Minneapolis. It had not been cleaned for five years when this photo was taken and there has been no corrosion.

Figure 9 shows Type 304 (left) and Type 316 (right) panels on the second floor of buildings that are in close proximity to one another and have similar levels of deicing salt exposure. Neither has been cleaned regularly. Light deicing salt corrosion staining is evident on the Type 304 panel but no staining is visible on the Type 316.

Even Type 316 may not provide adequate corrosion resistance in applications with very high salt exposure levels such as embedded sidewalk lighting, entrance gratings and the bottom of panels where piles of salt are allowed to accumulate. Areas regularly exposed to salt water splashing are also susceptible. Cleaning could remove this staining, but, in some instances, a more corrosion resistant stainless steel than Type 316 is necessary. There are many possible options including Types 2205, 317LMN, and 904L.

Free information on stainless steel selection is available from IMOA and the Nickel Institute.[19] Surface finish, design, weather conditions and probable maintenance cleaning frequency also influence stainless steel selection.

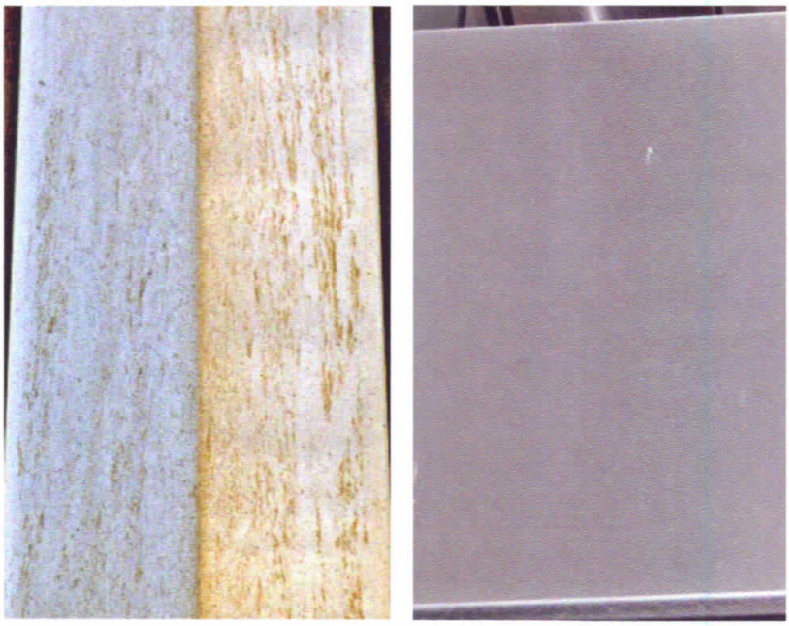

Figure 9: Both stainless steel panels are on the second floor of nearby buildings and are exposed to deicing salt. Neither has been cleaned and dirt and some residual salt was visible. The Type 304 panel (left) is exhibiting superficial corrosion staining while the Type 316 panel (right) remains corrosion free.

Case Study: German Stainless Steel Bollards

Surface finish can have a significant influence on the corrosion performance of materials, because rougher finishes retain more corrosive salts (chlorides), pollutants, dirt, and other debris. In addition, their higher surface tension retains moisture for the longer periods of time necessary to initiate corrosion. This combination of higher surface contaminant concentrations and longer periods of surface wetness can lead to higher than expected corrosion rates. Even materials that would normally perform well in an environment can fail if an inappropriate finish is selected.

Type 316 stainless steel has significantly lower corrosion rates than other common architectural metals in applications with salt (coastal or deicing) and pollution exposure. For that reason, it is an ideal choice for security bollards in demanding environments. Low sulfur content (0.005% or less), type 316 bollards with a smooth, well applied surface finish can provide excellent long-term structural and aesthetic performance in salt laden environments as long as they are not regularly immersed, splashed or sprayed with salt water.

Figure 10 shows, a Type 316 stainless steel bollard in Düsseldorf, Germany along a major city roadway where deicing salt is used during the winter months. The bollard is downwind of the roadway and the heavy, fast moving traffic generates road salt mists which are blown onto it. The top of the bollard has a smooth No. 4 polish and is performing well except for a recessed groove with a rougher finish that is not easily rain-washed.

The bottom section of the bollard has a very rough mill finish with numerous small indentations, which encourages retention of high concentrations of deicing salt (white areas), which can be seen in the image. Because Type 316 has a high level of corrosion resistance, the corrosion staining is superficial and could be easily removed by cleaning, but it will reappear again during subsequent winters because a rough finish was specified.

The Type 316 bollards upwind of this roadway and on side streets with slow moving traffic have minimal or no visible corrosion. In those locations, the deicing salt exposure is minimal and the corrosion resistance of the stainless steel is sufficient to withstand the surface salt concentrations. It is important to note that corrosion on the most severely affected bollards is superficial and, with Type 316's low corrosion rates, structural failure could take hundreds of years. But, this is an aesthetic failure, which could have been avoided by specifying a smooth finish. Specification of low sulfur (0.005% or less) content and a surface roughness of less than R_a 0.5 microns (20 micro-inches) would have improved performance. A surface roughness of R_a 0.3 microns (12 micro-inches) or less is preferred for applications with high levels of salt exposure like these bollards.

Figure 10: Type 316 stainless steel bollard adjoining a Düsseldorf, Germany roadway. Image courtesy of the International Molybdenum Association, Nicole Kinsman photographer

Conclusions

Deicing salt corrosion can cause unexpected problems that are easy to avoid. The first step is to determine whether deicing salt is being used in the vicinity of the project and how frequently salt is applied. Air pollution levels and rain acidity should also be assessed since they can combine with salt (chlorides) to substantially increase the corrosion rates of some metals.

Examination of nearby buildings, discussions with cleaning contractors, and simple non-destructive surface tests can determine whether chlorides are a problem and how far they are traveling. Regular cleaning to remove deicing salts quickly can substantially improve corrosion performance, as can coating maintenance.

If little or no maintenance is preferred and/or long-term structural integrity is critical, it is important to select metals with very low corrosion rates such as Type 316 or another appropriate stainless steel. The International Molybdenum Association (IMOA) provides free literature and software to assist with stainless steel and finish selection on the architecture section of their website http://www.imoa.info.

Acknowledgement

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