DESIGNER HANDBOOK

STAINLESS STEEL FOR COASTAL AND SALT CORROSION

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Stainless Steel The Value Option®
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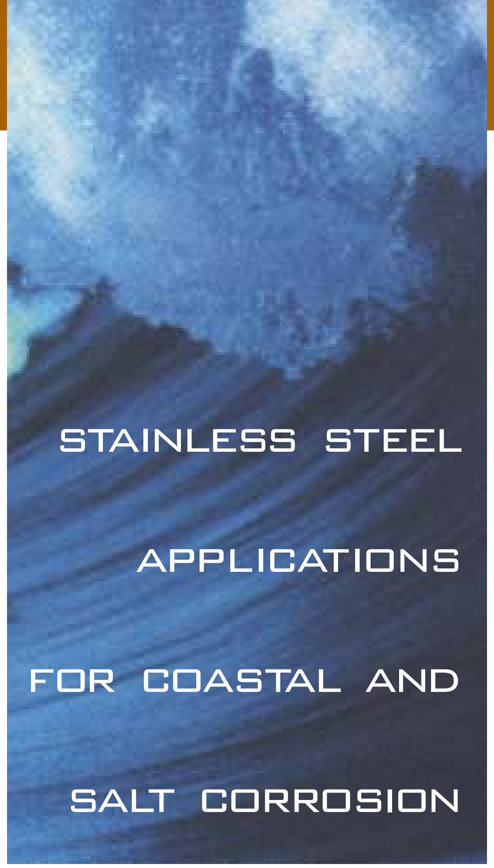
STAINLESS STEEL is not a single alloy, but rather the name applies to a group of iron based alloys containing a minimum 10.5% chromium. Other elements are added and the chromium content increased to improve corrosion resistance and other properties. There are over 50 stainless steel grades that were originally recognized by the American Iron and Steel Institute (AISI). Three general classifications are used to identify stainless steel. They are. . .

1. Metallurgical structure
2. The AISI numbering system (200, 300 & 400 series numbers)
3. The Unified Numbering System, which was developed by the American Society for Testing Materials (ASTM) and the Society of Automotive Engineers (SAE) to apply to all commercial metals and alloys.

The various types of stainless steels are detailed in a designer handbook “Design Guidelines for the Selection and Use of Stainless Steel” available online at ssina.com or from the Specialty Steel Industry of North America (SSINA) by calling the toll free number: 800.982.0355.

This handbook is designed to acquaint the reader with the 300 series stainless steels, particularly grades 304 and 316 and their applications in areas where coastal or salt corrosion is a factor in the life of a metal component.



STAINLESS STEEL APPLICATIONS FOR COASTAL AND SALT CORROSION

WHAT IS STAINLESS STEEL?

Stainless Steel is the generally accepted terminology applied to iron based alloys that contain at least 10.5% chromium. Many people are familiar with chromium as a corrosion-resistant coating on the surface of a chrome-plated part, such as an automobile bumper. In stainless steel, however, the chromium is added during the melting of the steel and forms a homogeneous mixture with the iron and other alloying elements, such as nickel and molybdenum, which enhance the metal's resistance to corrosion.

Grade 304 (UNS 30400), the basic "18-8" alloy (18% chromium, 8% nickel), is the most common of the 300 series and has excellent corrosion resistance in most applications. Grade 316 (UNS 31600), has an addition of at least 2% molybdenum, which significantly increases the metal's resistance to "salt" corrosion.

HOW IS STAINLESS STEEL DIFFERENT FROM CARBON STEEL?

Carbon steel contains at least 95% iron with up to 2% carbon. The higher the carbon content, the stronger the steel. Stainless steel also contains iron, but in addition it must contain at least 10.5% chromium and the carbon content is very low, usually 0.08% maximum. Stainless steel gets it strength from the metallurgical structure, rather than from the amount of carbon present. Carbon steel can be strengthened by heat treatment whereas the 300 series stainless steels cannot.

Stainless steel can be strengthened by work-hardening the structure. The 300 series stainless steel grades (304 and 316) contain nickel from 8 to 14% in addition to the chromium that must be present. 316 contains an additional element, molybdenum, from 2 to 3%. It is these alloying elements added to the iron base that makes stainless steel very different from carbon steel.

The Specialty Steel Industry of North America produces a handbook "Selection and Use of Stainless Steel" available from the web at **www.ssina.com**

HOW CARBON STEEL CORRODES

It is the iron in carbon steel that reacts with the oxygen in the atmosphere to produce "iron-oxides" which we can see as "red rust" on the steel surface. Rusting creates a layer of oxide on the surface that is several times thicker than the original iron present and often results in a spalling or flaking of the surface, reducing the steel thickness.

photograph courtesy of Nickel Development Institute

The functional pier in this photo was completed in 1941 and used 220 tons of Type 304 reinforcing bar. It is one of the oldest concrete structures in North America and is located in Progresso, Mexico. A casual visitor might assume that the remnants of the non-functional pier pre-date the functional pier, but they would be mistaken. The non-functional pier was completed about 30 years ago and used carbon steel rebar. Corrosion of the carbon steel caused the concrete to fail. It would have been much more cost effective to use stainless steel rebar.

APPLICATIONS

In the United States and Canada, the presence of salt laden mist from the oceans, chloride concentrations in rain water (see map on the following page) and the use of deicing salts in Northern or mountainous regions results in corrosion of steel in many applications. Upgrading the use of stainless steel from 304 to 316 has shown to be of significant help in reducing the effects of corrosion in several applications, some of which are shown in this brochure.

HOW STAINLESS STEEL RESISTS CORROSION

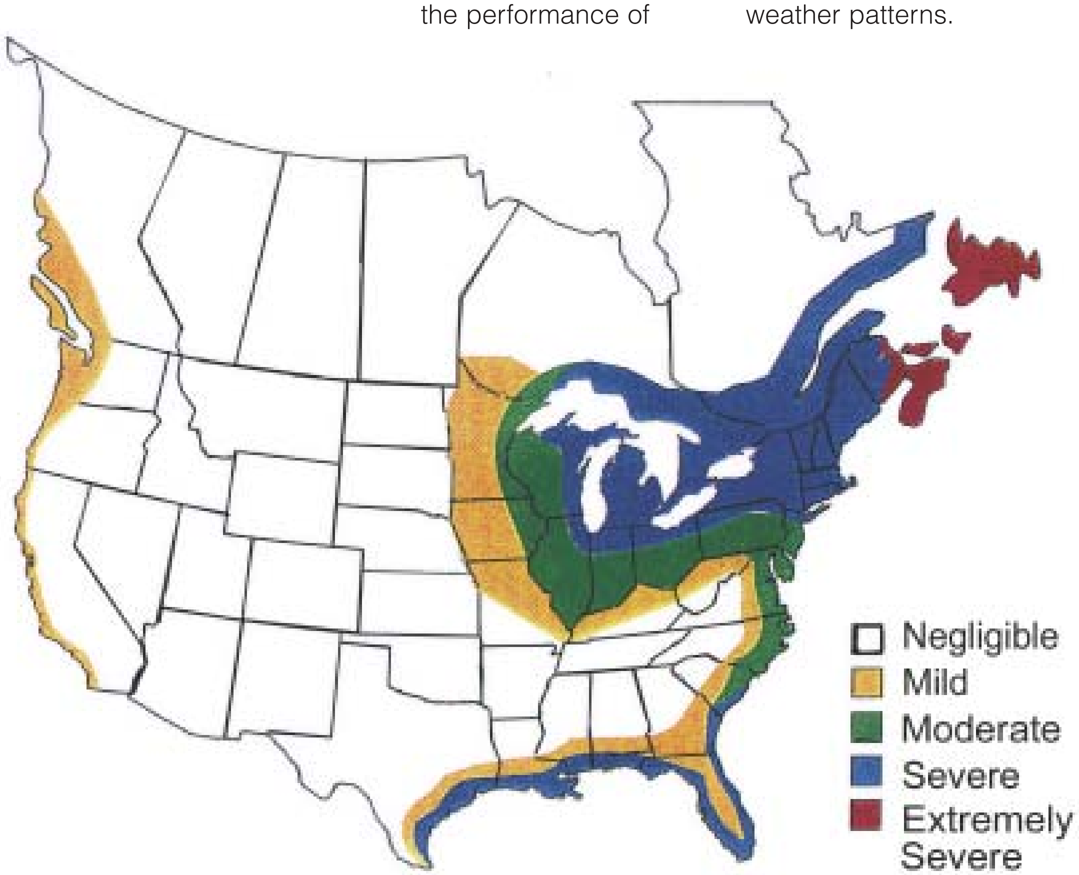
Because stainless steel contains at least 10.5% chromium, the oxidation of the iron is changed to produce a complex oxide that resists further oxidation and forms a passive layer on the surface. This is a very thin layer (microns in thickness) but very tenacious and will reform if it is removed by scratching or machining. The addition of nickel to the structure (8% minimum in 304 and 10% minimum in 316) broadens the range of passivity established by the chromium. The further addition of molybdenum (2% minimum in 316) further expands the passivity range and improves corrosion resistance, notable in acetic, sulfuric, and sulfurous acids and in neutral chloride solutions including sea water.

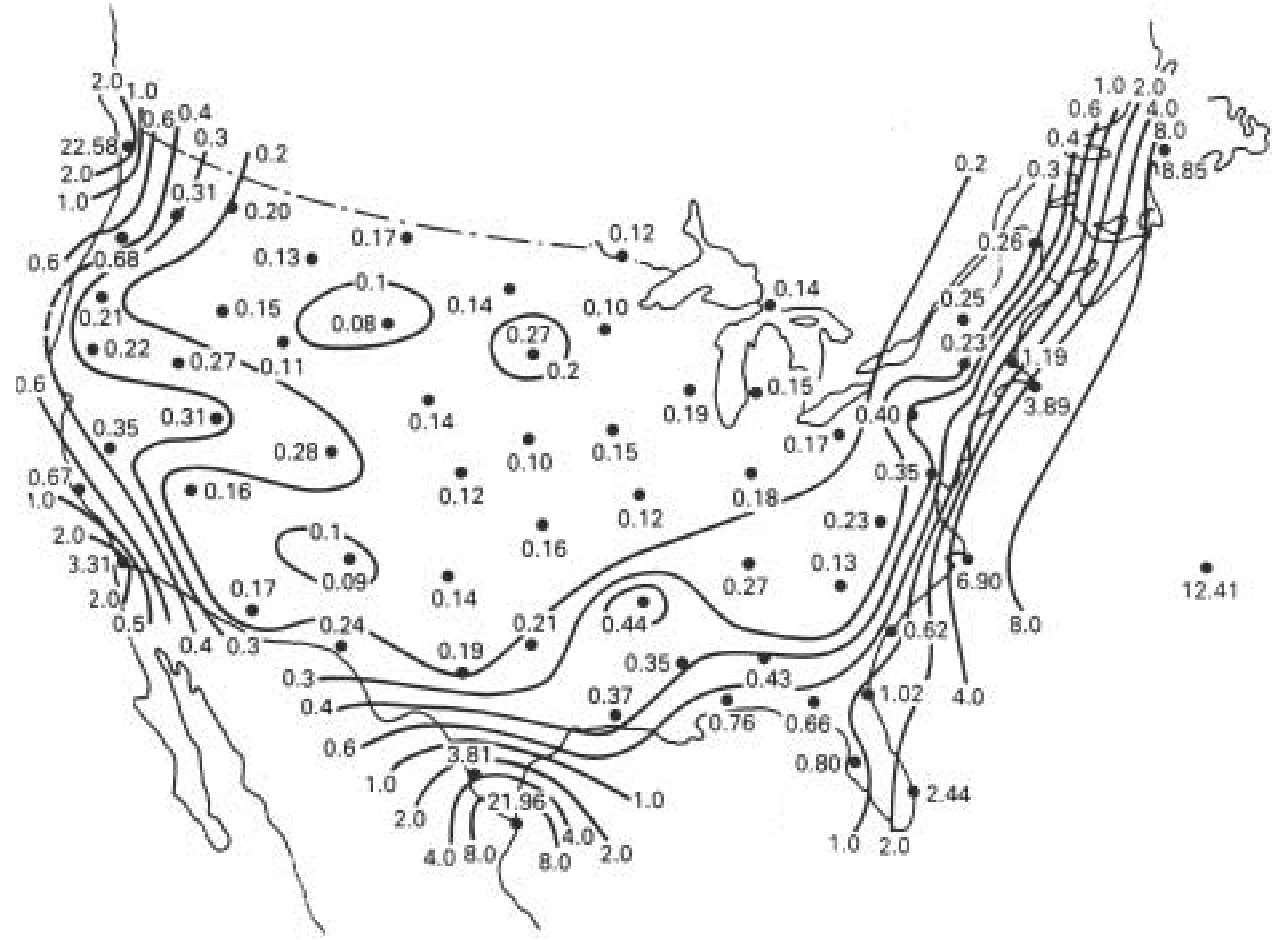
If stainless steel is properly selected and maintained it should not suffer any corrosion. Stainless steel will, however, corrode under certain conditions. It is not the same type of corrosion as experienced by carbon steel. There is no wholesale “rusting” of the surface and subsequent reduction of thickness. If stainless steel corrodes, the most likely form of corrosion is “pitting.” Pitting occurs when the environment overwhelms the stainless steel’s passive film and it cannot heal the interruption. It usually occurs in very tiny dark brown pits on the surface (hence the name pitting), and does not interfere with the mechanical properties of the stainless steel.

Stainless steel can also become subject to crevice corrosion when the deposits or other material (like a washer) creates a “crevice” on the surface. It is similar to pitting but over a larger area where again the environment has overwhelmed the ability of the passive layer to heal itself when deprived of oxygen. It is not attractive, but in most cases it should not affect the mechanical properties of the stainless steel. Good design to eliminate sharp corners or seal them will minimize this type of corrosion.

SALT IN RAINWATER

Chlorides in airborne sea spray, rain, and dry salt particles carried by wind may cause pitting and rusting of stainless steels, unless a sufficiently corrosion resistant grade is chosen. The distance airborne salt is carried can vary significantly with local wind patterns. Generally, locations within five to ten miles (9 to 18 km) of salt water are considered at risk for chloride-related corrosion, but local weather patterns and the performance of metals near the site should be evaluated prior to material selection. In some locations, marine salt accumulations are only a factor within the first 0.9 miles or 1.5 km from the shore. In other locations, salt may be carried much further inland. The map below shows the average chloride concentration (mg/1) in rainfall across the United States. The chlorides in rainwater are primarily marine salts carried inland by weather patterns.





The above map shows the influence of deicing and marine salts, corrosive pollutants (SO_2, NO_X, H_2S and NH_4), and particulate on North American vehicle corrosion. SO_2 and NO_X can form sulfuric and nitric acid in the atmosphere and become acid rain.

This research is relevant for all metals and other types of street-level applications. Please note, this is a general guideline and there may be areas characterized as low or high corrosion areas where localized corrosion levels are different from the level indicated.

WEATHER DAMAGE EFFECTS

Case Studies

SSINA would like to thank the International Molybdenum Association (IMOA) for providing the following case studies and guidelines for stainless steel selection in demanding exterior environments with chloride exposure. Additional case studies will be added to the website as they become available. Hard copes of these case studies can be ordered from SSINA or IMOA.

IMOA coordinates promotional, statistical and technical activities for the worldwide molybdenum industry. Promotion of molybdenum includes educating users about its benefits and by organizing meetings and conferences. One current focus of IMOA's educational activities is selection of appropriate grades of stainless steel for demanding architectural applications. In addition to these case studies, IMOA is providing architectural decision makers with workshops and industry conference presentations. Membership is broad based and includes producers, consumers, converters, traders and assayers. Additional technical information can be found at IMOA's website.

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photographs courtesy of TMR Stainless

STREET LEVEL APPLICATIONS

There is no corrosion on this Type 316 bench and railings in downtown Chicago after five years of service. A smooth polished finish was used.

These Type 304 railings were corroding after one winter in Pittsburgh. They are uphill from a busy highway and salt-laden road mist is blown on to them. The rough surface finish holds the salt on the railing making corrosion worse.

Deicing Salt (Moderate/High)

Urban Pollution (Low/Moderate)

DEICING SALT EXPOSURE

In many colder climates, deicing salt is used to prevent accidents. Unfortunately, salt accumulates over time and makes the environment around roads and walkways much more corrosive for all metals. Typically, deicing salt (sodium chloride and calcium chloride) deposits in cold climates can be heavier than the sea salt deposits found in coastal areas. Both of these salts are corrosive to architectural metals. Salt begins to absorb water from the air and forms a concentrated corrosive chloride solution above specific humidity and temperature levels. Calcium chloride becomes corrosive at 0°C (32°F) and 45% humidity and sodium chloride becomes corrosive at 10°C (50°F) and 76% humidity.

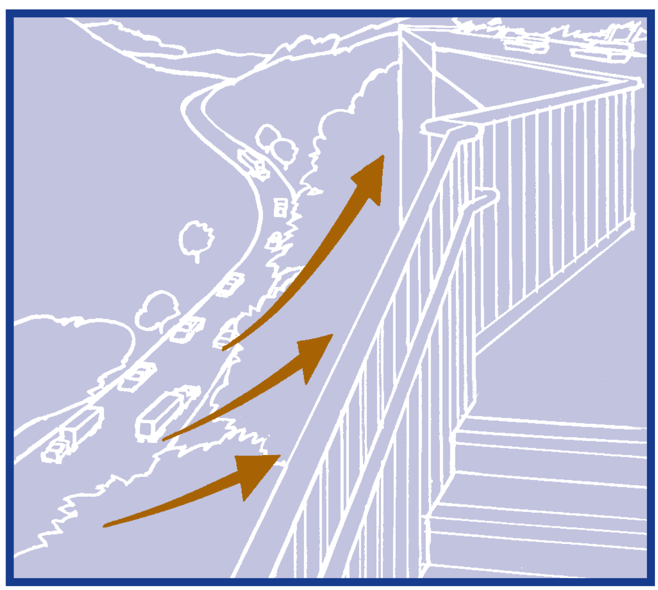
Surface contamination with salt is not limited to sites immediately beside roads. Road mist and salt contaminated airborne dust can carry deicing salt significant distances from busy highways, and as high as the 12th or 13th floor of adjacent closely spaced buildings. Once added to the environment, salt is present throughout the year. On building exteriors, salt concentrations and corrosion are usually greatest between street level and the third floor but this can vary with the location.

URBAN POLLUTION

Both sites are exposed to moderate levels of urban pollution, which does not have an impact on the corrosiveness of the sites.

THE PITTSBURGH RAILINGS

These railings are Type 304L with a rough finish. The contractor used pipe with a mill finish and applied a rough polish over it. The round bar has a smoother finish and was not as badly corroded. Type 304L will corrode if exposed to deicing salt and can require annual



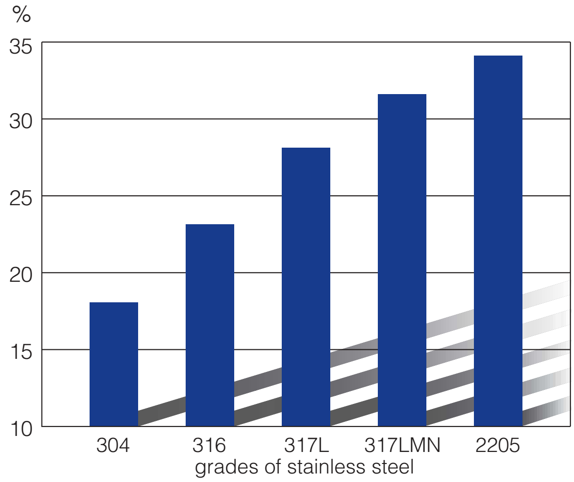
Illustrated diagram of airborne road mist and contaminants being carried a significant distance from a busy highway.

remedial cleaning to restore its appearance. The pictured Type 304 railings are approximately 300 feet (91 meters) uphill from a busy highway. Wind blows deicing salt mist up the hill and deposits it on the railings. Unfortunately, this was not an isolated incident and salt accumulation and the resulting corrosion are usually worse closer to where salt is applied.

THE CHICAGO RAILINGS

The bench and railings are adjacent to a sidewalk and within a few feet of a busy road where deicing salt is used. They are Type 316L with a smooth finish. Unlike Type 304, Type 316L contains molybdenum, which improves resistance to pitting and crevice corrosion and is particularly helpful in preventing salt damage. Type 316L is usually suitable for street level applications where deicing salt is used, particularly if a smooth surface finish is used and salt deposits are washed

Index of Corrosion Resistance



off after the last snowfall of the season. The use of Type 316, the specification of a smooth finish, rain cleaning, and maintenance keep the bench and railings attractive.

STAINLESS STEEL SELECTION

In applications with moderate deicing salt exposure and urban pollution, Type 316 is usually adequate if smooth surface finishes (<Ra 20 micro-inches or 0.5 microns) are specified, horizontal surfaces that collect salty deposits are avoided, and the finish grain is vertical. Designs that encourage natural rain-washing by avoiding sheltered areas are also beneficial in reducing risk of corrosion. If there will be regular maintenance, Type 316 with rougher surface finishes, sheltered applications, or horizontal surfaces can be used. If there will not be regular maintenance, a more corrosion resistant stainless steel should be considered.

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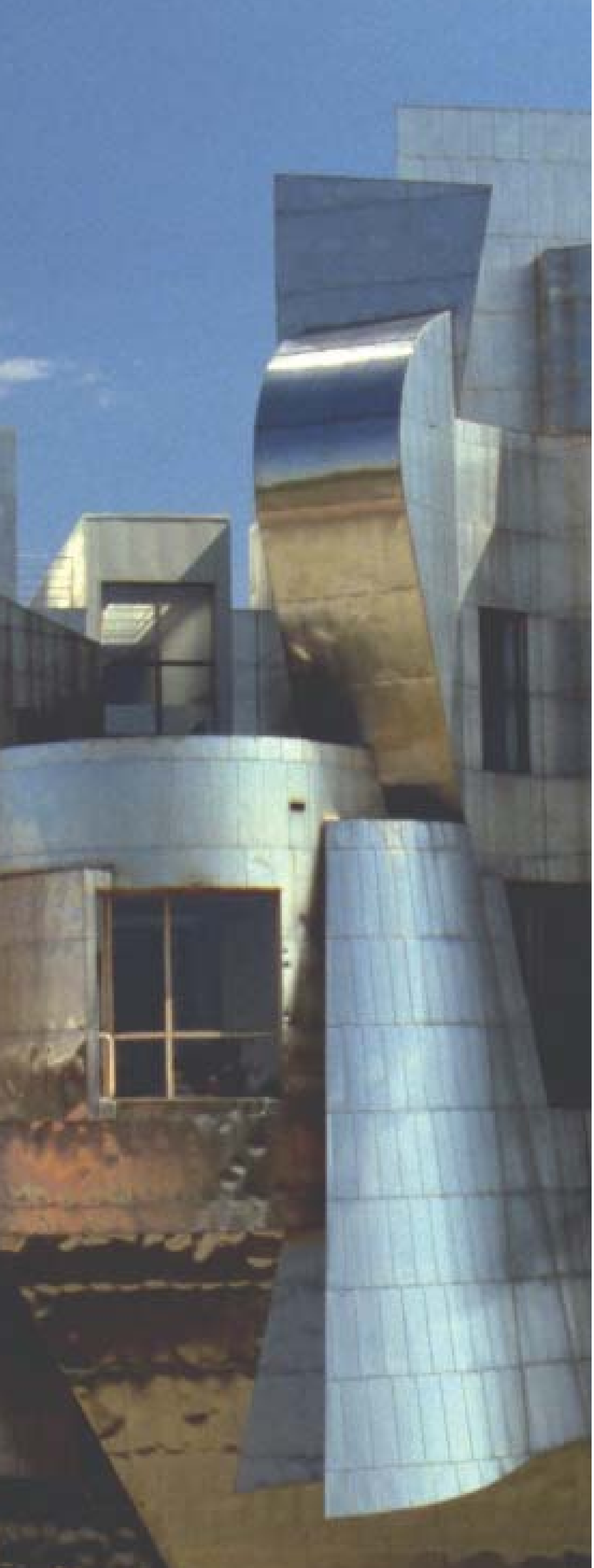
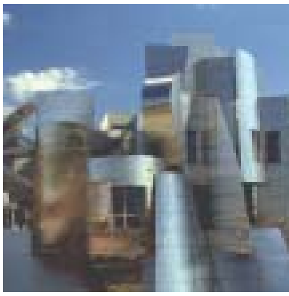


EXTERIOR WALL PANELS AND WINDOW FRAMES

When these photos were taken, it had been five years since both the Type 304 window frame (right, middle) and the Type 316 wall panel (right, bottom) had been washed. Both have a smooth No. 4 finish and are on the second floor of neaby buildings exposed to deicing salt in Minneapolis, Minnesota. The wall panel is from the Frederick R. Weissman Art Museum (right, top). The Weissman is exposed to higher levels of deicing salt than the window frame.

Deicing Salt (Moderate)

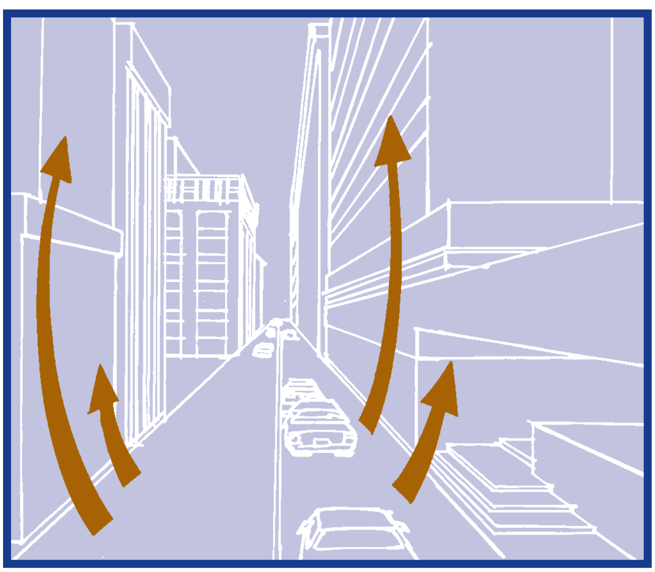
Urban Pollution (Moderate)



DEICING SALT EXPOSURE

Minneapolis has long, cold winters with significant snowfall. Large quantities of deicing salt are used on roads and sidewalks to prevent accidents. Deicing salt accumulates over time and makes the environment around roads and walkways corrosive for all metals. Road mist and salt contaminated airborne dust can carry deicing salt as high as the 12th or 13th floor of adjacent closely spaced buildings. Sodium chloride and calcium chloride are used for deicing and are both corrosive. Salt begins to absorb water from the air and form a concentrated corrosive chloride solution above specific humidity and temperature levels. Calcium chloride becomes corrosive at 0ºC (32ºF) and 45% humidity and sodium chloride becomes corrosive at 10ºC (50ºF) and 76% humidity.

Surface contamination with salt is not limited to sites immediately beside roads. Road mist and salt contaminated airborne dust can carry deicing salt significant distances from busy highways, and as high as the 12th or 13th floor of adjacent closely spaced buildings. Once added to the environment, salt is present throughout the year. On building exteriors, salt concentrations and corrosion are usually greatest between street level and the third floor but this can vary with the location.



Illustrated diagram of airborne road mist and salt contamination being swept as high as the 12th or 13th floor of closely spaced adjacent buildings.

URBAN POLLUTION

Both sites are exposed to moderate levels of urban pollution, which does not have an impact on the corrosiveness of the sites.

THE FREDERICK R. WEISSMAN MUSEUM

The museum is adjacent to a busy major road and bridge. Road mists, laden with deicing salt rise from the road and are blown onto the building throughout the winter. The architect, Frank O. Gehry, recognized that the deicing salt would create a corrosive environment and selected Type 316 for the building. Type 316L contains molybdenum, which improves resistance to pitting caused by salt and crevice corrosion. The museum panels have a smooth No. 4 finish (average Ra 0.3 microns) and vertical grain orientation. The building has some horizontal surfaces but generally encourages natural rain-washing. Some dirt accumulation was observed on the building but there is no evidence of corrosion.

THE WINDOW FRAME

The Type 304 stainless steel window frame is on a nearby building and has a smooth No. 4 finish and is approximately the same height above the sidewalk as the wall panels on the Weissman. It is on a smaller street with less traffic, so less salt-laden road mist is generated. The window frame is badly stained by corrosion. Type 304 does not provide sufficient protection from salt corrosion for this application and annual remedial cleaning after the last snowfall would be required to keep these window frames attractive. Cleaning quarterly would provide the most attractive appearance.

STAINLESS STEEL SELECTION

In applications with moderate deicing salt exposure and urban pollution, Type 316 is usually adequate if smooth surface finishes (<Ra 20 micro-inches or 0.5 microns) are specified, horizontal surfaces that collect salty deposits are avoided, and the finish grain is vertical. Designs that encourage natural rain-washing by avoiding sheltered areas are also beneficial in reducing risk of corrosion. If there will be regular maintenance, Type 316 with rougher surface finishes, sheltered applications, or horizontal surfaces can be used. If there will not be regular maintenance, a more corrosion resistant stainless steel should be considered.

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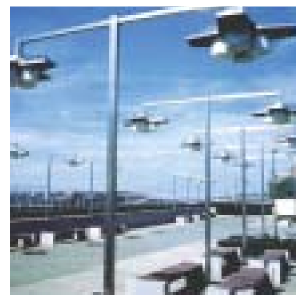
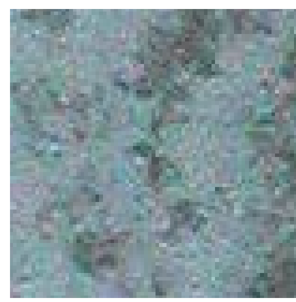
LIGHT STANDARDS

These Type 316 light poles were installed at Jones Beach, New York in 1967 with a smooth No. 4 finish. Although they are in the parking area immediately adjoining the beach and are exposed to coastal salt, there is no sign of corrosion. A similar light pole of Type 304, shown in close-up view, (right, middle) was installed in a sheltered location a few blocks from Miami Beach, Florida. After one year, chloride corrosion is visible.

Coastal (Medium)

Urban (Medium)





Samples of Type 304 and 316 with a smooth 2B finish were installed 250 meters (820 feet) from mean high tide at Kure Beach, North Carolina. When this photo was taken, they had been in place for 56 years with only rain cleaning. Like the Jones Beach light poles, they illustrate the performance advantage of Type 316 in a coastal location.

photographs courtesy of Nickel Development Institute

COASTAL SALT EXPOSURE

Sea salt contains a mixture of salts including sodium chloride, calcium chloride, and magnesium chloride. It is carried inland by wind, rain and fog. The distance salt is carried can vary significantly with local weather patterns. Generally, locations within five to ten miles (9 to 18 km) of salt water are at risk for corrosion by sea salts. In some locations, marine salt accumulations are only a factor within 0.9 miles or 1.5 km from the shore. In others, salt deposits have been measured 27 miles (50 km) or more inland. Sea spray and deposits of dry salt particles can lead to pitting and unsightly rusting of some stainless steels.

The performance of metals near the site should be evaluated prior to material selection. If possible, determine if there are salt (chloride) deposits on surfaces around the site. Portable chloride test kits can be used or a laboratory can provide a more accurate assessment. If a laboratory is used, they will need a sample that has been near the test site and has not been washed. Care must be taken, so that chlorides are not inadvertently removed from the surface before testing. If there is industrial or urban pollution, the level must be determined to assess corrosion potential.

Evaporation and infrequent rain increase salt concentrations on exterior surfaces and corrosion rates. Sheltered locations generally have heavier salt deposits because the salt is not removed by rain. Humidity, fog and light rain can dampen the deposited salt and create a concentrated, very corrosive salt solution on the surface. Salt solutions begin to form at temperatures above 0ºC (32ºF) and humidity levels above 45%. The most aggressive conditions are created by high salt concentrations combined with high ambient temperatures and moderate humidity.

JONES BEACH AND MIAMI BEACH LIGHT POLES

The Jones Beach Type 316 light poles were installed at Jones Beach, New York in 1967. They have a very smooth No. 4 finish. Although they are in the parking area immediately adjoining the beach, there is no corrosion. They are not cleaned but are well washed by rain. Urban pollution levels are moderate.

A Type 304 light pole was installed within a few blocks of Miami Beach, Florida in a sheltered location. It has a rough mill finish, which was abrasive blasted. Higher levels of salt collect on the rough finish and, in a sheltered location, they are not washed away by rain. There is no maintenance cleaning. A close-up view is shown. After one year, chloride corrosion is visible.

KURE BEACH SAMPLES

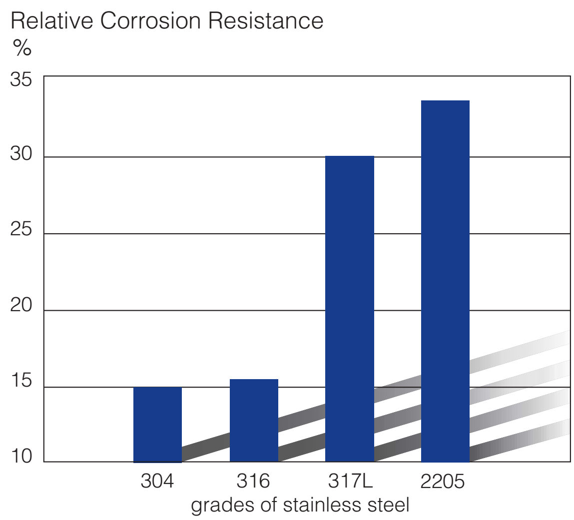
Samples of Type 304 and 316, with a smooth 2B finish, were installed 250 meters (820 feet) from mean high tide at Kure Beach, North Carolina. When this photo was taken, they had been in place for 56 years with only rain cleaning. Like the Jones Beach light poles, they illustrate the performance advantage of boldly exposed Type 316 with a smooth finish in a coastal location.

STAINLESS STEEL SELECTION

A very smooth surface finish should be used and frequent washing assumed if Type 304 is used in a moderate coastal location. Type 316/316L is preferred for most coastal architectural applications, because it contains molybdenum, which increases resistance to pitting caused by salt exposure. In moderate coastal locations, a pristine appearance can usually be maintained by selecting a smooth surface finish and washing to remove contaminants. If unwashed, some discoloration may occur after long-term exposure.

Higher levels of molybdenum and chromium increase corrosion resistance. If the location appears more aggressive, a more corrosion resistant stainless may be required. Chart 1 shows the relative corrosion resistance of Type 304, 316, and two common and more corrosion resistant stainless steels, 317L and 2205. The advice of a stainless steel corrosion expert is suggested if the conditions appear severe.

Rough surfaces and horizontal grain lines retain more salt and usually have higher corrosion rates. In coastal locations, surface finish roughness should not exceed Ra 20 micro-inches (0.5 microns) unless a more highly alloyed stainless steel is used or regular washing is planned. Sheltered applications are more corrosive and require a higher grade of stainless unless regular cleaning is planned. Crevices should be sealed to avoid crevice corrosion.



Note: Determined using ASTM G48 (24hrs.)

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