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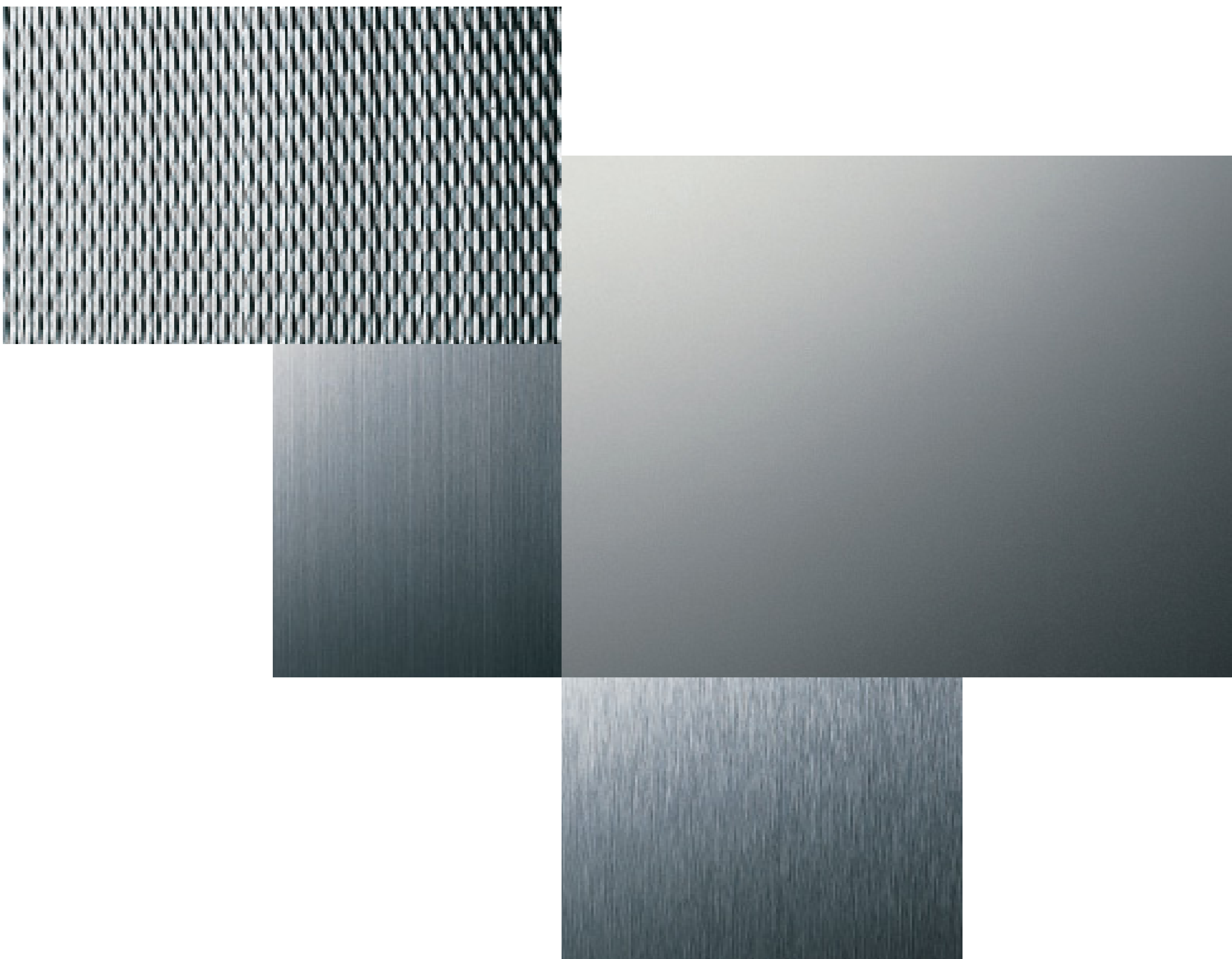
INTERNATIONAL MOLYBDENUM ASSOCIATION

Which Stainless Steel Should Be Specified for Exterior Applications?

Stainless steel is one of the most durable materials used in architecture. However, stainless steel is not just one material; there are many different types with different properties and, most importantly, different levels of corrosion resistance. If an appropriate stainless steel, surface finish, and design are selected and it is properly maintained, its appearance will remain virtually unchanged over the life of the building, even if that life is well over 100 years.

If an inappropriate stainless steel and/or finish are used, corrosion can be a problem. Although it may not adversely affect structural integrity, corrosion can be aesthetically undesirable and increase maintenance requirements. This brochure provides guidelines for evaluating a project and for determining which stainless steel should be specified.

It is instructive to examine nearby stainless steel installations and determine their maintenance history before using the *Site And Design Evaluation System* inside this brochure. It is prudent to confirm the predictions made with this evaluation system by exposing samples at the site, because some variables can be difficult to predict. It is suggested that the sample simulate the proposed design and be exposed for four to six months. It may be possible to reduce sample exposure to six weeks in severe marine or industrial locations. Case studies that illustrate the application of this evaluation system are available from IMOA.



Site and Design Evaluation System

Introduction

In architectural applications, aesthetic and performance requirements must be balanced against budget considerations for cost effective material specification. The guidelines in this brochure assume that corrosion staining of stainless steel is aesthetically unacceptable even if there is no structural deterioration.

Identifying a stainless steel that meets this aesthetic standard and is cost effective requires evaluation of the site environment, weather, finish, design and probable maintenance schedule. The *Site And Design Evaluation System* provides an initial evaluation of a project's susceptibility to corrosion and makes designers aware of factors that influence stainless steel selection

Instructions

The *Site And Design Evaluation System* was developed based on practical experience and atmospheric exposure studies. Evaluating a site and application can be complex. Nearby sites can have different requirements due to localized conditions or microclimates. The score should be viewed as a guideline that generates an initial evaluation of stainless steel requirements. It is not a precise scientific determination.

The *Evaluation System* has five sections. Read the background information for each section and then determine the section score using the adjoining point system. Sum all of the sections to obtain a Total Score. Compare the Total Score with *Stainless Steel Selection* on page 4.

If the design characteristics, maintenance schedules, or exposures of different components vary significantly, a score should be determined for each component.

If the presence of corrosive pollution or salt (chlorides) cannot be determined by site examination alone, a laboratory could test the surface of an unwashed sample from the site. The sample must have had long-term exposure without cleaning. Care must be taken during sample collection and handling to prevent removal of surface deposits.

When do I need a stainless steel corrosion expert?

If there is uncertainty about the project evaluation or if the location appears to be particularly corrosive, a stainless steel corrosion expert with architectural experience should evaluate the site and architect's drawings to recommend an appropriate stainless steel. The Nickel Development Institute (NiDI) or a stainless steel market development association can identify an expert (See page 6 for contact information). Particularly corrosive conditions include:

- Occasional or regular seawater or deicing salt splashing, immersion or salt spray
- High industrial or urban pollution levels
- Exposure to both coastal and deicing salt
- Hot, humid locations with salt or pollution exposure and very low or no rainfall
- Sites and designs producing a Total Score of 5 or higher

Evaluation System

Points		Score
	Section 1: Environment (Select the highest applicable score)	
	Rural	
0	Very low or no pollution	
	Urban Pollution (Light industry, automotive exhaust)	
0	Low	
2	Moderate	
3	High*	
	Industrial Pollution (Aggressive gases, iron oxides, chemicals, etc.)	
3	Low or moderate	
4	High *	
	Section 2: Coastal or Deicing Salt (Chloride) Exposure (Select the highest applicable score). If there is exposure to both coastal and deicing salt, obtain assistance from a stainless steel corrosion expert	
	Coastal or Marine Salt Exposure	
1	Low (>1.6 to 16 km (1 to 10 miles) from salt water) **	
3	Moderate (30 m to 1.6 km (100 ft to 1 mile) from salt water)	
4	High (<30 m (100 ft) from salt water)	
5	Marine (Some salt spray or occasional splashing) *	
8	Severe Marine (Continuous splashing) *	
10	Severe Marine (Continuous immersion) *	
	Deicing Salt Exposure (Distance from road or ground)	
0	No salt was detected on a sample from the site and no change in exposure conditions is expected	
0	Traffic levels on nearby roads are too low to generate road mist or wind levels are too low to carry chlorides to the site, and no deicing salt is used on sidewalks	
1	Very low salt exposure (≥180 m (600 ft) or 12 floors from salt source) **	
2	Low salt exposure (30 to 180 m (100 to 600 ft) or up to 12 floors from salt source)**	
3	Moderate salt exposure (<30 m (100 ft) or 3 floors from salt source) **	
4	High salt exposure (Direct application or splash zone) *	
	Section 3: Local Weather Pattern (Select only one)	
-1	Temperate or cold climates, regular heavy rain	
-1	Hot or cold climates with typical humidity below 50%	
0	Temperate or cold climate, occasional heavy rain	
0	Tropical or subtropical, wet, regular or seasonal very heavy rain	
1	Temperate climate, infrequent rain, humidity above 50%	
1	Regular very light rain or frequent fog	
2	Hot, humidity above 50%, very low or no rainfall ***	
	Section 4: Design Considerations (Select all that apply)	
0	Boldly exposed for easy rain cleaning	
0	Vertical surfaces with a vertical or no finish grain	
-2	Surface finish is pickled, electropolished, or roughness ≤ R_a 0.3 µm (12 µin)	
-1	Surface finish roughness R_a 0.3 µm (12 µin) < X ≤ R_a 0.5 µm (20 µin)	
1	Surface finish roughness R_a 0.5 µm (20 µin) < X ≤ R_a 1 µm (40 µin)	
2	Surface finish roughness > R_a 1 µm (40 µin)	
1	Sheltered location or unsealed crevices***	
1	Horizontal surfaces	
1	Horizontal finish grain orientation	
	Section 5: Maintenance Schedule (Select only one)	
0	Not washed	
-1	Washed at least annually	
-2	Washed four or more times per year	
-3	Washed at least monthly	
	Total Score	Total Score

* Potentially a highly corrosive location. Have a stainless steel corrosion expert evaluate the site.

** A sample from the site should be tested to determine if chlorides are present. Some locations of this type are exposed to chlorides but others are not.

*** If there is also salt or pollution exposure, have a stainless steel corrosion expert evaluate the site.

Section 1: Environment

If you are uncertain about the pollution levels for a region, data can usually be obtained through the Internet or by telephone from local or national governments. The data in the table was issued by the World Bank in 1998 and compares two pollution factors in a sampling of cities. If pollution levels are suspected to be high, a stainless steel corrosion expert with architecture experience should be consulted.

City	Suspended Particulate $\mu g/m^3$	Sulfur Dioxide $\mu g/m^3$
Beijing	377	90
Calcutta	375	49
Helsinki	40	4
Los Angeles	46	9
Moscow	100	109
New York	23	26
Paris	14	14
Rio de Janeiro	139	129
Sydney	54	28
Tokyo	49	18
Toronto	36	17

1998 Urban Pollution Levels

Rural

Rural or suburban areas with low population densities and light, non-polluting industry are included in this category. Migrant air pollution from industry upwind of the site could change this classification.

Urban sites

Urban sites include residential, commercial, and light industrial locations with low to moderate pollution from vehicular traffic. High urban pollution levels are generally found in areas with little or no air pollution controls or are caused by localized conditions that concentrate pollution.

Industrial sites

Sulfur and nitrogen oxides from coal combustion, and gases released from chemical and process industry plants are typical in industrial sites. Airborne particles, such as soot from incompletely burned fuel or iron oxides, increase the site's corrosiveness. High industrial pollution levels are generally found in areas with little or no air pollution controls or are caused by localized conditions that concentrate pollution.

Section 2: Coastal or Deicing Salt Exposure

Salt can corrode architectural metals, including some stainless steels. If the humidity and temperature are high enough or if there is regular light rain or fog, salt deposits on the surface will absorb moisture and form a highly concentrated and corrosive salt solution[1].

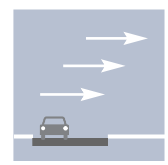
A stainless steel corrosion expert should be consulted if a component is splashed, sprayed or immersed on an occasional or regular basis with seawater or a deicing salt. An expert should also be consulted if a location is exposed to both deicing and coastal salt, because the combined salt exposure can make the location more corrosive than exposure to only one salt source.

Coastal and marine exposure

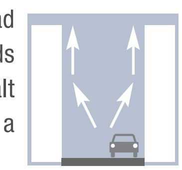
Local wind patterns determine how far sea salts are carried inland. Generally, locations within 8 to 16 kilometers (5 to 10 miles) of salt water are considered coastal. In some locations, salt is carried a relatively short distance inland, and, in others, it can be carried much farther than 16 kilometers (10 miles). A sample from the site can be tested for salt deposits. Applications that will be immersed in seawater or regularly splashed require a super duplex, super ferritic, or 6% molybdenum super austenitic stainless steel.

Deicing salt exposure

Deicing salt is sodium chloride or calcium chloride or a mixture of both. Salt accumulates over time and can make the environment near roads and walkways corrosive. Salt deposits are usually greater closer to where the salt is applied. Unfortunately, salt contamination is not always limited to sites immediately next to roads. Vehicle and wind speeds and traffic levels are the most important factors in determining how far deicing salt laden road mist will travel.



If traffic and wind levels are high, deicing salt laden road mist can be carried as high as the 12th floor of buildings and as far as 200 meters (650 feet) from busy highways[2]. If the adjoining road has too low a traffic volume to generate road mist or if the prevailing wind blows in the opposite direction, salt deposits are generally only found immediately beside the road or sidewalk. The distances provided in the Evaluation System assume the worst possible conditions. That is a site near a busy road with vehicles moving at sufficient speed to generate salt laden road mist and prevailing winds that blow the mist towards the site. If there is uncertainty about the level of salt exposure, a sample from the site could be tested by a laboratory to determine if there are salt deposits.



Section 3: Local Weather Pattern

Information on typical temperatures, humidity, total snow and rainfall levels, and fog days is usually collected by national governments and can be obtained on the Internet or by telephone. This information should be supplemented with local observations for accurate interpretation. The moisture in fog, light misty rain or high humidity can combine with corrosive compounds on a surface to activate them and make corrosion possible. Higher temperatures will increase the corrosion rate. The most corrosive environments are areas with very little or no rain, high temperatures, salt (chloride) or aggressive pollution exposure that also have moderate to high humidity or regular fog.

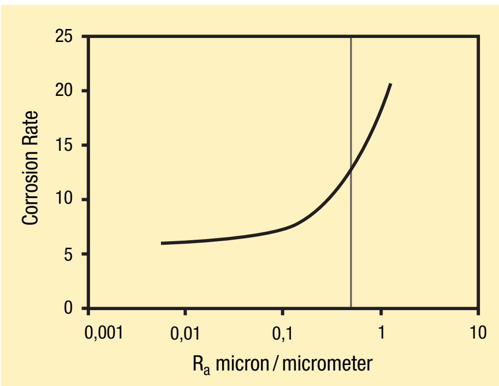
It is important to look at both annual rainfall levels and the type of rainstorms that occur. Light rain will not remove surface contaminants. Storms with high rainfall rates or wind driven rain, like thunderstorms, can remove corrosive deposits from exposed surfaces. If they are frequent enough to prevent significant deposit or dirt accumulation on surfaces, they can reduce the risk of corrosion. For example, much of eastern North America and Northern Europe get enough heavy rain to minimize surface deposits and would have a -1 rating.

Surface roughness

Corrosion cannot occur unless corrosive substances adhere to a surface. A smooth surface finish makes it difficult for contaminants to adhere and makes manual and heavy rain-washing more effective. A rough surface accumulates more contaminants and is less easily cleaned. Therefore, a smooth surface finish reduces the risk of corrosion staining, and a rough surface finish promotes corrosion staining. A finish is considered smooth if the surface roughness is R_a 0.5 µm (microns or micrometers) or 20 µin (micro inches) or less. The typical surface roughness associated with a specific finish can vary from supplier to supplier and around the world. Ask the surface finish supplier to provide the typical surface roughness when samples are requested and include surface roughness requirements in project specifications.

Finish grain orientation

Finish orientation is important if there is an obvious grain line (like No.4, embossed and similar finishes). Vertical finish grain orientation makes it easier for rain to wash the surface and for water and contaminants to drain away. A horizontal grain orientation tends to retain contaminants on the surface. Better corrosion protection is achieved by installing directional finishes so that the grain orientation is vertical.



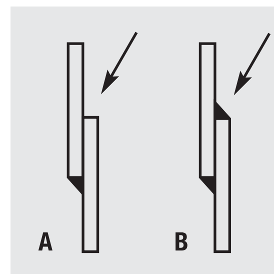
The chart above shows the relationship between corrosion rate and surface roughness. The line represents a surface roughness of R_a 0.5 µm or 20 µin. Corrosion rate accelerated rapidly above this surface roughness level.[3]

Sheltered and horizontal surfaces

There is more dirt and contaminant accumulation on sheltered components or horizontal surfaces because rain may not be able to remove the contaminants. Leaving corrosive contaminants on the stainless steel for an extended period of time can lead to corrosion staining. Horizontal or sheltered surfaces should be avoided unless rain or manual cleaning is likely. Alternatively, a more corrosion resistant stainless steel could be used.

Crevices

Crevice corrosion can occur when water and corrosive contaminants remain trapped in narrow gaps and salt (chloride) is present in the environment **(A)**. Problems can be avoided by eliminating narrow crevices that can accumulate moisture or by sealing them with a weld or sealant **(B)**. Alternatively, specify a more highly alloyed stainless steel that is not subject to crevice corrosion. For example, woven stainless steel has tiny crevices where the wires overlap and corrosion can occur at each crevice if there is salt (chloride) exposure. Welded mesh is a good alternative, because it does not have crevices.



Section 5: Maintenance Schedule

If a stainless steel is susceptible to corrosion by salt (chlorides) or pollution, they have to remain on the surface of the stainless steel long enough and in sufficient concentration for corrosion to start. Frequent cleaning by heavy rain or manual washing prevents corrosive deposit accumulation and corrosion. The manual cleaning frequency necessary for a pristine appearance depends on the site environment, surface finish, design, stainless steel selected, and potential for rain cleaning. More frequent cleaning will be required if the stainless steel does not provide adequate corrosion resistance or if there is a rough finish, horizontal or sheltered surfaces, or crevices. If Type 304 is exposed to more corrosive environments, it may be necessary to clean it four or more times per year to maintain an attractive appearance.

Stainless Steel Selection

Total Score

0 to 2	**Type 304/304L (UNS S30400, EN 1.4301, SUS 304) is generally the most cost-effective choice.**
3	**Type 316/316L (UNS S31600, EN 1.4401, SUS 316) is generally the most cost-effective choice.**
4	**Type 317L (UNS 31703, EN 1.4438, SUS 317L) or a more corrosion resistant stainless steel is suggested.**
≥ 5	**A more corrosion resistant stainless steel such as 2205 (UNS S32205, EN 1.4462, SUS 329J3L), 904L (UNS N08904, EN 1.4539, SUS 890L), 317LMN (UNS S31726, EN 1.4439, SUS 317LN), super duplex, super ferritic, or a 6% molybdenum super austenitic stainless steel may be needed. These stainless steels provide different levels of corrosion resistance as shown in Figure 1. If you obtain a score of 5 or above, a stainless steel corrosion expert with architectural experience should evaluate the site and design and suggest an appropriate stainless steel.**

How can I reduce the score?

Some design changes that can improve performance and possibly change material requirements are:

- Boldly expose components for better rain washing
- Select smooth surface finishes
- Use a vertical surface finish grain orientation
- Eliminate horizontal surfaces
- Eliminate or seal crevices
- Design to facilitate manual washing
- Encourage a regular washing schedule
- Add natural or artificial barriers to reduce deicing salt road mist exposure.

Stainless Steel Corrosion, Fabrication and Resources

Corrosion Resistance of Stainless Steels

In architectural applications, corrosive environments are defined as locations with deicing or coastal salt exposure and/or areas with industrial or urban pollution. The constituents that make these environments corrosive include sea or deicing salts (sodium, potassium and calcium chlorides) and acid rain from exhaust gas condensates generated by power or chemical plants and motor vehicles.

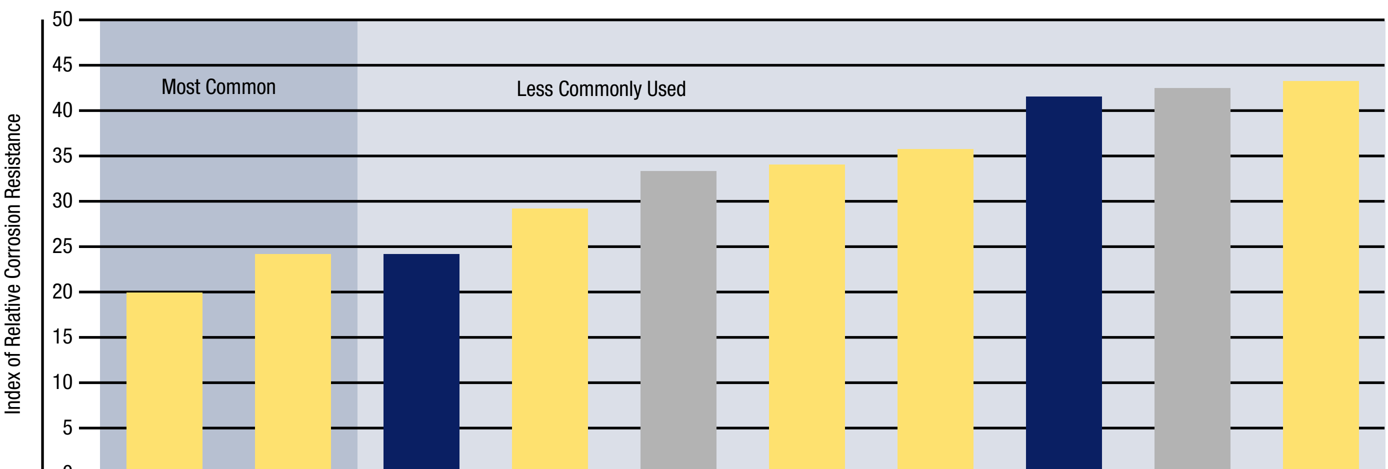
Most stainless steels are classified as austenitic, ferritic or duplex. These stainless steels can generally be hardened by “cold work” but not by heat-treatment. Austenitic stainless steels such as Types 304 (UNS S30400, EN 1.4301, JIS SUS 304) and 316 (UNS S31600, EN 1.4401, SUS 316) contain iron, chromium and nickel. They are non-magnetic and provide very good formability. Ferritic stainless steels, such as 444 (UNS S44400, EN 1.4521, SUS 444), contain iron and chromium. They are magnetic and have limited formability. Duplex stainless steels such as 2205 (UNS 32205, EN 1.4462, SUS 329J3L) contain iron, chromium and an intermediate amount of nickel. They provide higher strength levels than ferritic or austenitic stainless steels, are magnetic, and have intermediate formability. There are also proprietary “lean” duplex stainless steels, which have the corrosion resistance and cost of Types 316 and 317L and the higher strength levels associated with duplex stainless steels. The most corrosion resistant stainless steels shown in Figure 1 are examples from the stainless steel families known as super ferritic 447 (UNS 44700, SUS 447J1), super duplex 2507 (UNS S32750, EN 1.4410) and 6% molybdenum super austenitic (UNS S31254, N08926, N08367; EN 1.4547, 1.4529; or SUS 312L), which are resistant to pitting when immersed in seawater. In addition to the basic alloying elements mentioned, molybdenum is added to all of the stainless steels in Figure 1 expect Type 304 to improve corrosion resistance, particularly resistance to salt (chloride) corrosion.

Figure 1 compares the relative pitting resistance of different stainless steels using a formula to predict relative corrosion resistance, Pitting Resistance Equivalent (PRE) number [4]. This formula is based on the improvement in stainless steel corrosion resistance associated with increasing chromium, molybdenum and nitrogen content.

Cold rolling, embossing, and forming operations such as bending or deep drawing change the shape of a metal and thereby “cold work” or strengthen it. All three families of stainless steel can be shaped by common architectural forming techniques, however only austenitic stainless steels are sometimes deliberately strengthened by cold working.

The dominant stainless steels used in architecture are Types 304 and 316. Type 304 is suitable for most interior and exterior applications with low corrosion risk, even with minimal or no maintenance. In moderately corrosive environments, Type 304 may be acceptable if a smooth finish is specified and there is regular cleaning. Type 316 or 444 with an appropriate finish can remain attractive in most corrosive applications with little or no manual cleaning. In very corrosive applications, Type 316 or 444 may require regular cleaning or a more corrosion resistant stainless steel may be necessary.

If the design includes welded sections that are heavier than about 6 millimeters (0.25 inch), use the low carbon “L” version of the stainless steel (e.g. 304L, 316L) to maintain corrosion resistance. Pitting corrosion resistance is improved by specifying that sulfur content should not exceed 0.005.



	304/304L	316/316L	444	317L	2205	317LMN	904L	447	2507	6% Mo
UNS	S30400 S30403	S31600 S31603	S44400	S31703	S32205 S31803	S31726	N08904	S44700 S44735	S32750	S31254 N08926 N08367
EN	≈1.4301 ≈1.4307	≈1.4401 ≈1.4404	≈1.4521	≈1.4438	≈1.4462	≈1.4439	≈1.4539	–	≈1.4410	≈1.4547 ≈1.4529
JIS	SUS 304	SUS 316	SUS 444	SUS 317L	≈SUS 329J3L	SUS 317LN	SUS 890L	SUS 447J1	–	SUS 312L

Figure 1 This chart of relative pitting resistance is based on the Pitting Resistance Equivalent or PRE number. Austenitic stainless steels are shown in yellow, ferritics in blue, and duplex in gray. The UNS (Unified Numbering System), EN (European Number), and JIS (Japanese Industrial Standard) designations identify the specific stainless steel chemistries associated with the common names shown in the bar chart.

Fabrication and Installation

Corrosion appearing within a few months of installation is usually the result of improper handling, fabrication, storage or cleaning. If corrosion staining occurs, it may be possible to restore the finish with cleaning. The cleaning product ingredients should be checked before use even if they are labeled "stainless steel cleaner". Cleaning products that contain chlorides should be avoided or thoroughly washed off surfaces after use to prevent corrosion. Cleaning products containing Muriatic or hydrochloric acid will cause rapid corrosion of stainless steel and should never be used on or near it. These products are sometimes used to clean concrete, masonry or tile.

If the surface of the stainless steel has been contaminated with carbon steel or iron, corrosion is rapid and may appear within a few days of exposure to outside air. Contamination can occur at the job site or during fabrication. Sources include contaminated tools or abrasive media, steel wool or brushes, airborne steel particles, scratching, and improper shipping or storage. Sometimes the finish can be restored, but it is best to avoid contamination by using good handling practices.

The corrosion resistance of a weld should be similar to the surrounding material. Often the weld can be blended so that it matches the surrounding finish and becomes invisible. The surface roughness of the weld should not be greater than that of the surrounding finish.

If a stainless steel with a sulfur level above 0.005 has been used, the surface of the finished component should be passivated with phosphoric or nitric acid to improve pitting resistance after finishing and fabrication is completed. If the sulfur level is 0.005 or less, this is not necessary.

Where Can I Get More Information?

The International Molybdenum Association (IMOA) has developed case studies on specific architectural applications and environments that can provide more insight into selecting the correct stainless steel (www.imoa.info, or telephone: +44 20 8742 2274). Each case study illustrates the use of the evaluation system introduced in this brochure.

Additional information about the subjects covered in this brochure is available from IMOA, NiDI, stainless steel market development associations, and stainless steel producers around the world. These organizations can provide contact information for stainless steel corrosion experts who are familiar with architectural applications. Links to stainless steel market development associations can be found at the IMOA (www.imoa.info) or NiDI websites (www.stainlessarchitecture.org or by calling: +1-416-591-7999).

NiDI publication No. 11 024, *Stainless Steels in Architecture, Building and Construction: Guidelines for Corrosion Prevention* provides detailed information about evaluating the environment and selecting an appropriate stainless steel. If a stainless steel with more corrosion resistance than Type 316 is needed, request the IMOA publication *Practical Guidelines for Fabrication of Duplex Stainless Steels* and NiDI publication 11 021 *High Performance Stainless Steels*. Examples of buildings and structures that have performed well over time can be found in the NiDI publication 11 023, *Timeless Stainless Architecture* and the Euro Inox publication, *Stainless Steel Facades*, Building Series, Volume 2 (info@euro-inox.org or www.euro-inox.org). Information on welding, cleaning stainless steel, and post fabrication cleaning is available from NiDI, Euro Inox, stainless steel market development associations, and stainless steel producers.

1 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. Both are found in coastal and deicing salts.

2 A series of scientific studies on deicing salt aerosols at the Royal Military College of Canada found measurable chloride corrosion on metal samples as far as 200 meters (656 feet) from Highway 401. Under certain conditions, salt may be carried even farther.

3 Surface finishes of stainless steels, Bulletin of the International Dairy Federation No 189, 1985, p3 - 12.

4 Expressed through their Pitting Resistance Equivalent number, $PRE = \%Cr + 3.3 * \%Mo + 16 * \%N$ for austenitic and duplex stainless steels and $PRE = \%Cr + 3.3 * \%Mo$ for ferritic stainless steels.

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