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## WHITE PAPER: Stainless Steel Enclosures and Industrial Applications

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# Executive Summary

The need to place electrical equipment within corrosive environments necessitates protection beyond which painted carbon steel enclosures can provide. Enclosures made of stainless steel fill this void with superior strength and corrosion resistant properties, satisfying application requirements across a broad spectrum of industries. However, there are common criteria that must be considered to ensure that the proper stainless steel enclosure is chosen for a given application.

Here you'll find some of the technical aspects of stainless steel that are crucial to the selection of industrial enclosures including composition, distinguishing properties of different grades, chemical resistances, suitable applications and general benefits offered by stainless steel when compared to carbon steel enclosures.

# What Exactly Is Stainless Steel?

By definition, stainless steel is a metal alloy containing at least 10.5% chromium by mass. In a process known as passivation, the chromium within the metal forms a very thin layer of chromium oxide when exposed to the oxygen in our atmosphere. This layer continually protects the metal beneath and spontaneously regenerates if the surface is scratched — which is why stainless steel enclosures provide excellent corrosion resistance without the need for painting or any kind of surface treatment. Because of this passivation that stainless steel alloys do not display the gross surface rusting common in carbon steel alloys. If the passivation layer is destroyed beyond repair, however, corrosion will occur in the form of localized pitting.

**Grades**

The American Iron and Steel Institute (AISI) first classified certain types of stainless steel as standard compositions and designated each type with a 3-digit number. AISI no longer maintains these standards, but the Society of Automotive Engineers International (SAE) and ASTM International (the American Society for Testing and Materials) have since assumed this role. In addition, new designations were created utilizing the Unified Numbering System (UNS), which consists of one letter and five numerals and the DIN standard, established in Germany and common to Europe, which uses five numerals and no letters.

SAE grade 304 stainless steel is comprised of 18-20% chromium and 8-10.5% nickel. Somtetimes referred to as '18-8', this is the standard type of stainless steel used in the enclosure industry — filling the widest range of applications. Limitations of Type 304 stainless steel include use in outdoor applications near large bodies of saltwater where airborne salt can come into contact with the surface of the enclosure. A rule of thumb is that Type 304 stainless steel should not be used within 5 miles of the coast, but the true distance at which corrosion can occur is dependent upon local weather patterns. Cold climate regions where chlorides are used as de-icing agents may also cause significant pitting in Type 304 stainless steels. For these reasons, Type 304 stainless steel is not recommended in these situations without a regular cleaning regimen.

Fortunately, many of the limitations of Type 304 stainless steel are not apparent with the second most common stainless steel, SAE grade 316. Generally 25-35% costlier than Type 304, 316 stainless steel has a higher percentage of nickel and the addition of the alloy molybdenum (2-3%). The molybdenum provides better resistance to pitting and crevice corrosion, particularly in chloride-rich environments. Type 304 stainless steel can resist corrosion in waters containing up to about 100 ppm chloride while Type 316 stainless steel will exhibit this resistance up to 1000 ppm chloride. Often considered the standard marine grade steel, Type 316 stainless will not resist prolonged exposure to seawater (19,000 ppm chloride) but is acceptable in applications where exposure is limited to occasional salt spray. Severe conditions such as tight spaces with low airflow, lower pH, or higher temperatures may cause the need for more stringent standards.

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The 316L stainless steel commonly found in many enclosures has a lower carbon content (< .03%) than either 304 or 316, making it more resistant to sensitization (grain boundary carbide precipitation), a byproduct of welding. Due to the extreme heat, localized corrosion can occur in stainless steels in areas where the material has been welded, but the lower carbon content of Type 316L prevents the carbide precipitation that can lead to weld decay and possible structural failure.

**Chemical Analysis (Weight %)**

| SAE | UNS | DIN | % Cr | % Ni | % C | % Mn | % Si | % P | % S | % N | % Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 304 | S30400 | 1.4301 | 18–20 | 8–10.50 | 0.08 | 2 | 0.75 | 0.045 | 0.03 | 0.1 | -- |
| 316L | S31603 | 1.4404 | 16–18 | 10–14 | 0.03 | 2 | 0.75 | 0.045 | 0.03 | 0.1 | 2.0–3.0 |

# Finishes for Stainless Steel

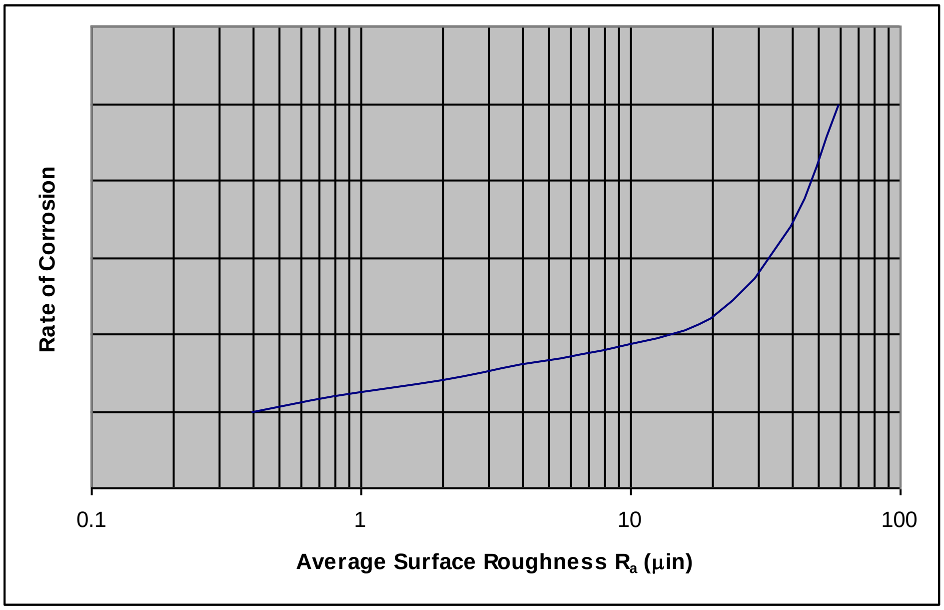
Metals are finished not only for aesthetic purposes, but also to improve their corrosion resistant properties. The ASTM A480 standard provides a framework for different metal finishes based on certain criteria. Sheet steel finishes are designated by a system of numbers ranging from a No. 1 finish to a No. 8 finish. Additional global standards that apply to metal finishes include BS EN 10088-2 and ISO 1302.

**Surface Finish Specifications**

| | ASTM A480 | ASTM A480 Description | Roughness Ra (μin) | Roughness Ra (μm) | BS EN 10088-2 | ISO 1302 |
|---|---|---|---|---|---|---|
| **Mill Finish** | **-** | - | - | - | **1U** | **-** |
| | **-** | - | - | - | **1C** | **-** |
| | **No. 1** | Hot-rolled, annealed, and de-scaled. | 157 to 276 | 4.0 to 7.0 | **1E, 1D** | **N8, N9** |
| | **-** | - | - | - | **2H** | **-** |
| | **-** | - | - | - | **2C** | **-** |
| | **-** | - | 16 to 39 | 0.4 to 1.0 | **2E** | **N5, N6** |
| | **No. 2D** | Cold-rolled, dull finish. | 16 to 39 | 0.4 to 1.0 | **2D** | **N5, N6** |
| | **No. 2B** | Cold-rolled, bright finish. | 3.9 to 20 | 0.1 to 0.5 | **2B** | **N3 to N5** |
| | **No. BA** | A bright cold-rolled finish retained by final annealing in a controlled atmosphere furnace. | 2.0 to 3.9 | 0.05 to 0.1 | **2R** | **N2, N3** |
| | **-** | - | - | - | **2Q** | **-** |
| **Special Finish** | **-** | - | 79 to 98 | 2.0 to 2.5 | **1G, 2G** | **N7** |
| | **No. 3** | Intermediate polished finish, one or both sides. | 28 to 47 | 0.7 to 1.2 | **1J, 2J** | **N6, N7** |
| | **No. 4** | General purpose polished finish, one or both sides. | 12 to 25 | 0.3 to 0.6 | **1J, 2J** | **N4, N5** |
| | **No. 6** | Dull satin finish, Tampico brushed, one or both sides. | 10 to 20 | 0.25 to 0.50 | **1K, 2K** | **N5** |
| | **No. 7** | Light luster finish. | 2.4 to 7.9 | 0.06 to 0.20 | **-** | **N3, N4** |
| | **No. 8** | Mirror finish. | 0.8 to 3.9 | 0.02 to 0.10 | **1P, 2P** | **N1 to N3** |
| | **-** | - | - | - | **2F** | **-** |
| | **-** | - | - | - | **1M, 2M** | **-** |
| | **-** | - | - | - | **2W** | **-** |
| | **-** | - | - | - | **2L** | **-** |
| | **-** | - | - | - | **1S, 2S** | **-** |

As metals are worked to obtain finer finishes, the average surface roughness decreases, thereby improving the corrosion resistance of the metal. The following graph illustrates the general relationship between the average surface roughness and corresponding rate of corrosion.

**Average Surface Roughness vs. Rate of Corrosion**




On a logarithmic scale, the corrosion rate maintains a consistent relationship with surface roughness up until about 20 microinches (~0.5 micrometers). Any increase in surface roughness beyond 20 μin will greatly affect the corrosion resistance. Given this information it is clear why the two most common stainless steel finishes for industrial components, including enclosures, are No. 2B and No. 4. Both of these low-cost, general-purpose finishes have surface roughness characteristics to maintain acceptable corrosion resistance capabilities.

In addition to surface finish quality, the grain orientation of a stainless steel enclosure can have a significant impact on corrosion resistance. A vertical grain orientation can help to provide an easier, more thorough cleaning since rainwater and gravity fed hose water will run parallel to the grains. By contrast, horizontal grain lines may retain corrosive contaminates, thereby expediting the corrosion process.

# Applications

One of the most common applications for Type 304 stainless steel is in the food and beverage industry because it gives users the ability to frequently wash the enclosure and surrounding environment without fear of rust. The ability to withstand the corrosive properties of the various acids found in meats, milk, fruits and vegetables makes Type 304 stainless steel enclosures ideal for housing controls used to operate the machinery found in food and beverage processing plants. Although Type 304 stainless steel is effective in many food and beverage settings, if the environment is overly chloride-rich or cleaning procedures involve the use of highly corrosive solvents, a switch to a stronger grade of stainless steel may be necessary.

As a general rule, Type 316 stainless steel enclosures are more reliable in harsh chemical environments than other grades. The primary exception to this rule is exposure to nitric acids, which are principally used in the production of fertilizer, pharmaceuticals, fungicides, and explosives. It can also be used for the manufacture of synthetic fibers and polymers as well as for the treatment of water. All stainless steel has some resistance to nitric acids, but in industries where nitric acids are prevalent, SAE 304 enclosures are usually preferred because of their superior resistance to this specific substance. Even though stainless steel will naturally self-passivate, the strong oxidizing nature of nitric acid is often used to encourage this process, thereby increasing the corrosion resistance of stainless steels.

Applications such as the treatments of waste and potable water are ideal for stainless steels. Type 304 stainless steel is sufficient in most areas, however some treatment plants use chlorine gas to disinfect water and use sulfur dioxide to then remove residual chlorine. Combined with the naturally humid environment of the plant, these gases are highly corrosive to stainless steels so the increased resistance of Type 316L is required. In some cases, through an effort to be more environmentally friendly and reduce chemical usage, municipalities are turning to ultraviolet (UV) treatment to purify water. Type 304 stainless can be used in this application since there are no chemicals introduced to the surrounding environment of the enclosure.

Because Type 316 stainless steels are considerably more resistant to sulfuric acid solutions (<10%) and sulfur bearing gases, enclosures constructed of them are often found in industries where these substances are regularly found. For example, this makes Type 316 stainless steel enclosures a wise choice for use in many pulp and paper mills.

Most of the pulp in the US is produced using either mechanical or chemical methods. The mechanical method (used to produce lower grades of paper such as newsprint) utilizes steam, pressure and high temperatures to break wood chips down into fiber. Type 304 stainless steel is often sufficient in pulp mills employing these processes. Higher quality pulp is produced using chemical processes such as the Kraft (sulfate) or sulfite processes where concentrated solutions of highly corrosive chemicals are used, necessitating the use of Type 316 stainless steel. If the pulp is going to be used to make white colored paper, it is then bleached with chlorine solutions, making the choice of Type 316 stainless steel even more imperative.

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The use of sulfur-based compounds is not limited to pulp and paper processing. They are also very prevalent in other industrial operations including the vulcanization process in the production of rubber, as well as the production of dyes, gunpowder, insecticides, disinfectants, and plastics. Type 316 stainless steel enclosures are ideal for applications in these industries as well.

Due to an increased resistance to chlorides, Type 316 stainless steel is the preferred material of choice for food processing plants where enclosures could come into contact with highly acidic chemicals and concentrated chloride salts. Type 316 stainless steel enclosures are also recommended for marine applications such as shipping and offshore drilling and, not surprisingly, in salt mines. Basically, any application where high chloride levels are present or the corrosive environment will continually attack the surface of the enclosure, Type 316 stainless steel is the metal of choice.

### Industries Using Stainless Steel Enclosures

| Industry | Sub-Industry | Typical Stainless Steel |
|---|---|---|
| **Food & Beverage** | General Food Processing | 304 or 316 SS |
| | Milk & Dairy | 304 or 316 SS |
| | Brewery and Wine | 304 or 316 SS |
| | Bottling | 304 or 316 SS |
| | Bakeries | 304 or 316 SS |
| **Chemical** | Pharmaceutical | 316 SS |
| | Petrochemical | 316 SS |
| **Marine** | Offshore Drilling | 316 SS |
| | Shipping | 316 SS |
| **Water** | Waste Water Treatment | 304 or 316 SS |
| | Potable Water Treatment | 304 or 316 SS |
| | Desalination | 316 SS |
| | Distribution | 304 or 316 SS |
| **Materials** | Pulp | 316 SS |
| | Paper | 304 or 316 SS |
| | Rubber | 316 SS |
| | Plastic | 304 or 316 SS |
| **Mining** | Ore | 304 or 316 SS |
| | Salt | 316 SS |
| | Coal | 304 or 316 SS |

## Stainless Steel Enclosures and Industrial Applications

It is important to note that neither Type 304 nor Type 316 stainless steel will resist the chemical corrosion caused by hydrochloric acid. The acid will destroy the passivity, leaving the surface of the metal defenseless. The following chart shows how Type 304 and Type 316 stainless steels react with some of the chemicals present in common application environments.

**Chemical Resistance Table (Room Temperature)**

| Group | Compound | 304 | 316 |
|---|---|---|---|
| **Inorganic Acids** | Hydrochloric Acid | Poor | Poor |
| | Sulfuric Acid (<10%) | Poor | Good |
| | Nitric Acid | Excellent | Good |
| | Phosphoric Acid (<40%) | Poor | Fair |
| | Sulfurous Acid | Good | Good |
| | Carbonic Acid | Good | Good |
| **Organic Acids** | Acetic Acid | Poor | Good |
| | Formic Acid | Good | Excellent |
| | Lactic Acid | Good | Good |
| | Citric Acid | Good | Excellent |
| | Fatty Acids | Good | Excellent |
| **Bases** | Ammonium Hydroxide | Excellent | Excellent |
| | Sodium Hydroxide (50%) | Good | Good |
| | Potassium Hydroxide | Good | Excellent |
| **Misc** | Fresh Water | Excellent | Excellent |
| | Sea Water | Poor | Fair |

# Variables Affecting Corrosion

Exactly how a metal will corrode in a given environment is often difficult to predict. Variables that can affect corrosion include the concentration and pH of the corrosive material and the temperature of the environment. The pH measurement scale is used to describe the strength of an acid or base. A pH of 7 is considered neutral while chemicals with pH values less than 7 are acidic and chemicals with pH values greater than 7 are basic or alkaline. Generally speaking, stainless steels will corrode when exposed to strong acids or alkalis but the overall effect of this corrosion is dependent upon the temperature at which the corrosive attack takes place.

The climate of a particular region can have a large impact on corrosion characteristics. As previously mentioned, coastal areas can be affected by airborne salts carried over long distances by strong winds. Special attention must also be given to not only the general climate of the region where the enclosure will be installed but also to potential microclimates of the specific enclosure location. Nowhere is this more evident than cold regions where de-icing is a regular occurrence. Just as prevailing winds carry salt from the sea, urban areas with a large volume of highway traffic can lift and carry these contaminants significant distances.

The first priority for industrial enclosures is to protect the electronics inside. Therefore it would seem that placement of an enclosure into an area where it won't get wet would be a good idea. For instance, one may think that covering the enclosure with a shield or placing it under an eve will prevent water and/or ice damage. However, the microclimate created by doing this makes it such that rainwater is unable to wash contaminates away. Higher humidity and lack of ventilation may also be factors. Without regular cleaning, significant corrosion may occur. In most situations it is more beneficial to rely on the enclosure NEMA rating for the electronics protection, while exposing the enclosure to a more open environment to get cleansed by occasional rainfall.

It is also important to differentiate the ability of a material to resist corrosion following prolonged contact and the ability of a material to resist corrosion resulting from occasional or possible accidental contact. For instance, the production of chloride-rich foods in direct contact with stainless steel will require the use of a stronger grade when compared to the requirements of an electrical enclosure, which may be unlikely to ever have direct contact with the corrosive material. Another possible issue, corrosive gases, poses a different set of challenges because the gases expand, continually corroding everything in the surrounding environment.

Each application will have unique circumstances requiring different levels of protection, but in the event of a corrosive attack, it is always better to have too much protection than too little.

# Further Benefits

In addition to better corrosion resistance, stainless steel enclosures possess superior hygienic qualities when compared to their carbon steel counterparts. Bacteria and germs have difficulty adhering to and growing on stainless steel (provided that a sufficient finish is maintained) and the smooth, hard surface of stainless steel allows for a much easier, more thorough cleaning. Other material properties of stainless steel enclosures offer advantages when compared to carbon steel models as well. A greater strength-to-weight ratio results in increased rigidity in larger enclosures, plus, stainless steels' superior hardness provides an increased ability to withstand damage.

When total life cycle costs are taken into consideration, stainless steel enclosure costs may be equal to, or in some cases, less than that of carbon steel. Although the acquisition cost of stainless steel is usually greater than that of carbon steel, this is often offset by lower maintenance costs and a longer life expectancy. Once the serviceable life of the enclosure is over, stainless steel also delivers yet another benefit versus carbon steel — a better return as scrap metal.

# Conclusion

Stainless steel has proven to be a relatively low-cost material that can protect electrical equipment in a variety of different industries and application settings. The durability of stainless steel depends greatly on the steel grade, surrounding environment and surface finish. Type 304 stainless steel is the common solution for most environments where mild corrosion is a concern. Harsher environments will require the use of costlier Type 316 stainless steel, but the chemical concentration and subsequent rate of attack should be carefully determined and monitored. A smooth finish with a vertical grain orientation and a regular cleaning regimen are vital to maintaining stainless steels' anti-corrosive and hygienic properties.

When specifying a stainless steel enclosure for any project, all of the factors covered here should be carefully considered to ensure that the appropriate levels of protection are provided for installed equipment and the overall success of the application.

**About the Author:** *Nathan Xavier* has worked at Rittal Corporation since 2007 as both an Application Engineer and Assistant Product Manager. He holds a Bachelor of Science degree in Mechanical Engineering and provides product management and customer-specific applications support relating to Rittal industrial enclosure and power distribution solutions.

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