Stainless Steel: How Problems Arise and How to Avoid Them

Stainless steel—widely used in drinking water, wastewater, and water reuse systems—can fail from corrosion. Careful attention should be paid to specification, handling, and installation of stainless steel piping and components.

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**Table 1. Common Types of Stainless Steel**

<table>
<thead>
<tr>
<th></th>
<th>Martensitic</th>
<th>Ferritic</th>
<th>Austenitic</th>
<th>Duplex</th>
<th>Lean Duplex</th>
<th>Precipitation</th>
<th>Hardening</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Grade</strong></td>
<td>Type 410</td>
<td>Type 430</td>
<td>Type 304</td>
<td>Type 316</td>
<td>Alloy 2205</td>
<td>LDX 2101</td>
<td>Grade 17–4Ph</td>
</tr>
<tr>
<td><strong>Percent Chromium</strong></td>
<td>11.5–14.5%</td>
<td>16–18%</td>
<td>18–20%</td>
<td>16–18%</td>
<td>21–23%</td>
<td>15–17.5%</td>
<td>15–17.5%</td>
</tr>
<tr>
<td><strong>Typical Application</strong></td>
<td>Bolting and pump shafts</td>
<td>Cooking utensils</td>
<td>Aqueous corrosion-resistant materials</td>
<td>Aqueous corrosion-resistant materials with low nickel fraction</td>
<td>Shafting and fasteners</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Industry</strong></td>
<td>General purpose</td>
<td>Appliances and automotive</td>
<td>Water industry</td>
<td>Storage tanks</td>
<td>Aerospace and marine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stainless steel is a chromium alloy steel that’s resistant to rusting and corrosion. The particular application for which stainless steel will be used determines the type and grade of stainless steel.

**WHAT IS STAINLESS STEEL?**

An alloy is a mixture of metals and other elements and is generally considered to be “stainless” when it’s iron based and the chromium content is greater than 12 percent by weight. Chromium provides alloys with corrosion resistance by forming a thin, adherent, corrosion-resistant oxide film on clean alloy surfaces. When exposed to oxygen-rich conditions such as air, this layer helps prevent dissolution of the underlying stainless steel. The effectiveness of this protective oxide layer can become compromised if the original oxide surface layer is damaged or scratched, but the protective film can rapidly reform in the presence of oxygen. Table 1 shows the most common types of stainless steel materials and their applications. In water
Stainless steel offers a wide range of capabilities for handling potable water and wastewater. However, potential changes to water chemistry and operations can affect the correct choice of stainless steel.

### HOW CORROSION OCCURS

Corrosion occurs when an electrochemical cell establishes anodic and cathodic reactions on a metal surface, with one of the reactions being at a weak point. Corrosion can be caused by a range of conditions, including using steel that isn’t sufficiently corrosion-resistant for the environment or the material’s protective outer chromium oxide surface is compromised or exposed to damaging conditions. Pitting and crevice attacks are the two most common corrosion types.

**Pitting.** A cell is formed between two nearby points on a metal surface. Adjacent anodes and cathodes are created, and, in the presence of chloride ions, metal oxide breakdown begins (Figure 1). The pH environment is more acidic at the pit bottom, the anode, than at the top of the pit, because the anodic environment (the active pit bottom) attracts negative chloride ions that react and release metal ions to form metal chlorides. This causes the pit to grow quickly.

**Crevice Attack.** A cell is created between two halves of a tight metal-to-metal (or metal to a nonporous material) joint when immersed in an aqueous chloride-containing solution (Figure 2). Oxygen is consumed within the crevice, but the gap’s tightness prevents dissolved oxygen in the bulk solution from penetrating the crevice. However, because smaller chloride ions can penetrate the crevice, the chloride ions concentrate there.

### COMMON CAUSES OF CORROSION

Environmental factors and material-handling practices can significantly affect steel’s corrosion resistance.

**Microbiologically Induced Corrosion (MIC).** MIC often occurs in stagnant and slow-flowing water. Bacteria attach to crevices and rough surfaces and form a biofilm on the steel’s surface, which leads to formation of a biomound and eventually results in a hardened shell (tubercle) forming, which interfaces with the internal metal surface. Anodic and cathodic sites develop, and a corrosion cell is formed. Tubercles are microenvironments in which aggressive chemical compounds can accumulate and accelerate the rate of oxidation (corrosion). When a tubercle is formed, it can quickly cause bulbous cav-erns to form in the submerged or buried

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**Figure 1. Pitting Corrosion**

Pitting corrosion results in deep penetration at only a few spots.

![Figure 1. Pitting Corrosion](Image)
stainless steel piping, plate, or containment vessel.

Mismatch of Steel and Environment. Lower pH, higher temperatures, and concentrations of chloride and free chlorine contribute to higher corrosion rates. Water that's warm and has high chloride and/or free chlorine concentrations or low pH is aggressive.

Next to oxygen, chlorine is the primary oxidant present in cooling water, potable water, and wastewater. Free chlorine is corrosive. Chloramine solutions are alkaline in nature and, in doses used in water treatment, can be handled by stainless steel without major concern for pitting or crevice corrosion. Freshwater with 2–3 mg/L Cl₂ as free chlorine supports widespread use of austenitic stainless steels for constructing potable water treatment plants, freshwater-cooled condensers, and heat exchangers (Table 2). At elevated concentrations of free chlorine, higher alloyed materials should be considered.

Chloride is also a significant corrosion catalyst and acts synergistically with free chlorine and higher temperatures to create a highly aggressive environment. For example, at a crevice gap, chlorides and pH are the principal factors influencing corrosion initiation. In waters of normal pH (6.5–8), crevice corrosion of 304/304L stainless steel is rare up to 200 mg/L chlorides and equally rare for 316/316L stainless steel up to 1,000 mg/L chlorides.

Together, chlorine and chloride cause stainless steel failures that wouldn't occur by exposure to chlorine or chloride alone. Some data indicate 304/304L stainless steel can corrode significantly in even moderately brackish water environments. This explains, in part, why crevices, surface pits, and tubercles are common sites of corrosion problems; they provide prime locations in which high-chloride/low pH microenvironments that foster corrosion can be established. Similarly, elevated temperatures (e.g., > 40°C) are associated with faster rates of corrosion.

Wrong Material Combination. When two metals are connected while immersed in an aqueous environment, an electric cell can be created and galvanic corrosion may occur. The potential for this corrosion mechanism is expressed in terms of electrochemical potential (measured in volts). The metal with the highest voltage is the cathode (most noble and corrosion protected), and the other becomes the sacrificial anode. Generally, the greater the voltage difference, the greater the potential for galvanic attack. For example, copper and stainless steel should be separated by dielectric unions, because copper has a lower voltage potential than stainless steel. Such dielectric unions are commonly used in plumbing piping.

Improper Welding. Corrosion associated with improper weld fabrication usually occurs as a result of inexperience in welding stainless steel. Even if welds are made properly, corrosion problems may follow if the heat tint isn't removed from the heat-affected weld area.

When stainless steel is mechanically ground or polished, it's important to remove oxide scale around the welded area. After welding, a light straw color for a heat tint at the weld area may have acceptable corrosion resistance. If it's significantly darker in color, it should be removed mechanically or by pickling, so the stainless steel surface can be returned to optimum corrosion resistance.

Failure through the fabrication wall is caused by pitting or crevice corrosion and is evident as weepage. Depending on the severity of the problem, this requires replacing the part, draining and drying the line, grinding the area of attack, and repairing the weld.

TIPS FOR AVOIDING CORROSION

When corrosion starts, it can be difficult to stop. The key to corrosion control is reducing the likelihood of its initiation.

Preparing and Handling Steel. Flaws in fabrication or damage during transport and installation that weaken or breach the protective chromium oxide layer are common problems at corrosion initiation sites. Ensuring proper shipping and storing of material can head off many potential problems:

- Ship the piping material on pallets and cap the ends with nonmetallic covers.
- Foam and shrink-wrap surfaces to protect them, especially during shipping.
- Don’t allow piping materials to rub against each other or other nonstainless steel surfaces.
Maintaining clean conditions during stainless steel handling and component fabrication is important, especially when these materials are welded.

- Store components on pallets, not on the ground.
- Lift components with nylon straps, not metallic chains.

**Ensure Steel Is Clean.** Dirt, glue, and metal contaminants can weaken the protective chromium oxide layer. Iron contaminants (grinding or weld slag) shouldn’t come in contact with piping. Stainless steel should be protected from wind-blown grinding dust and welding spatter. Grinding wheels and hand grinders dedicated for stainless steel use should be used to avoid cross contamination from iron. Any glue or other contaminants should be removed from the surface. Passivation (chemical treatment of stainless steel surfaces to achieve different chrome-to-iron ratios in the protective oxide film) where chromium predominates in the surface layers is often warranted to help ensure a strong, clean protective layer remains on the surface. Pickling, which uses more aggressive chemicals, is also a possible treatment.

**Eliminate/Minimize Field Welding.** Use of certified welders, along with greater fabrication control, increases weld quality. When welding is performed in the field, purge the pipe’s interior with an inert gas (e.g., argon) and passivate the welded area (inside and out) to minimize the potential for weakening the chromium oxide surface.

**Dissimilar Metals.** Don’t put dissimilar metals next to each other. These connections may be protected by using dielectric unions, generally a plastic liner that separates two dissimilar metallic materials. Dielectric unions may include flange isolation kits that also contain isolators to ensure the flange bolts aren’t contacting the dissimilar metals.

**Surface Finishing.** Use surface finishing to remove impurities and smooth out the surface. Electropolishing and iron-free glass-bead blasting are surface finishing processes that are sometimes applied to stainless steel pipes, vessels, and tanks. Properly performed finishing removes heat tint or iron impurities from the surface, may change crevice depth and geometry, and creates a smoother surface that makes it more difficult for MIC bacteria to attach to the metal. Both electropolish and glass-bead blasting methods are cost-effective alternatives to mechanical polishing for water treatment applications that remove a minimal amount of metal surface (i.e., usually 5–25 µm).

**Water Chemistry.** Don’t allow stagnant water to remain for long periods of time in stainless steel. Drain and dry lines immediately after hydrostatic testing, or place immediately into service. Use treated potable water for hydrostatic testing.

Potential changes to the water chemistry, or changes in the environment because of operational changes, can affect the correct choice of stainless steel. For example, different well waters may have significantly different microbes or amounts that can cause microbial corrosion and result in MIC in one system but not another.

**CLEANING CORRODED AREAS**

When corrosion is noticeable, it can be difficult to stop and repair. Here are a few things you can do to address the problem.

If the corrosion is microbiologically induced, first remove the microorganisms. Clean the pipes thoroughly of all deposits and chlorinate and flush the pipes. To repair surface damage:

- Clean and strip the corroded area.
- Remove as much of the corrosion as practicable.
- Neutralize any residual materials remaining in pits and crevices.
- Restore protective surface film.
- Apply temporary or permanent coatings or paint finishes.
- Attempt repairs if the damage involves a small area of corrosion. (This method isn’t often used when corrosion covers an extensive area.)

**VERSATILE MATERIAL**

Stainless steel offers a wide range of capabilities for handling potable water and wastewater. Maintaining clean conditions during stainless steel handling and component fabrication is important, especially when these materials are welded.

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