Atmospheric Corrosion of Stainless Steel
Which types of steel may be used in which environments?

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Stainless steel is unfortunately not always stainless. Depending upon the steel type and the environment, the steel may suffer from a number of different types of corrosion, and even though the conditions are normally worst when the steel is submerged in water, atmospheric conditions can produce all kinds of disasters, ranging from cosmetic discolorations to serious penetration.

Corrosion above water

Typically, the environment above water is characterized by the following “properties”: Small amount of water, close to neutral pH, short contact time, usually a low concentration of salts (i.e. chloride), a good supply of oxygen, and the possibility of evaporation – in particular in the case of hot equipment.

Normally, for stainless steel, the risk of severe corrosion above water is significantly smaller than below the waterline – in particular due the short contact time. In cold conditions, the main risk of corrosion is pitting corrosion; however, unlike immerged conditions, the reduced contact time and the absence of a large cathode only tend to produce superficial pitting corrosion, however, due to the reddish-brown color of the corrosion products, this may be very annoying from a cosmetic point of view.

Still, failure of stainless steel due to superficial pitting corrosion above water is very uncommon, unless the pitting corrosion develops into stress corrosion cracking (SCC, see below).

Superficial pitting corrosion in a glass holder of 4301 because of saltwater spray from the ocean. The risk on genuine failure is quite small, and even though it may look bad, the damages are mainly cosmetic (“Stainless steel and corrosion”, Chapter 7.2)
Crevice corrosion requires a large amount of electrolyte and is therefore very rare above the water-line. Narrow geometries, such as bolts and nuts, may collect water, however, technically such attacks are superficial pitting corrosion rather than crevice corrosion.

Due to the close-to-neutral pH and the small electrolyte, general corrosion and intergranular corrosion are uncommon, too. Instead, stress corrosion cracking (SCC, “Stainless steel and corrosion”, Chapter 7.4) is by far the most severe type of corrosion above water. In fact, SCC is the only type of corrosion which may be worse above water than when the steel is fully emerged, and break-down of equipment due to corrosion from the outside is not that uncommon.

The most vulnerable steel types are the austenitic 4301 types (the 18/8 group) and, to a lesser extent, the acid resistant 4401 class. Above a temperature of just 60 ºC, SCC is a serious risk for immersed 4301 while 4401 should last to 100-110 ºC, but evaporation combined with acid conditions may push these limits further down making the conditions much more serious. Above water, SCC in 4301 has been observed below room temperature, and in swimming pool conditions, SCC has been known to attack 4404 at temperatures of only 30 ºC.

Stress corrosion cracking (SCC) on the outside of a 4301 pipe. The corrosion was caused by a combination of heat from the inside (60-70 ºC) and chloride containing spray from the outside.
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Weather and construction

Above the water-line, the contact time is of utmost importance. The longer the time, the worse the corrosion, so ideally, the equipment should be designed in such a way that the contact time is minimized. Water and corrosive salts should be allowed to drain off, and for that purpose, a vertical surface is less vulnerable than a horizontal one.

For the same reason, and the exposure of inclusions, a roughly ground or glass blasted surface is less desirable than a smooth and bright one. A smooth surface tends to drain off the water much better than rough one, minimizing the risk of corrosion. This is often seen in the case of rails on boats. If corrosion occurs, it’s always in the roughest scratches.

Above water, the surface conditions are even more important than below due to the increased risk of collecting corrosive salts. The centre tube (4432, 2.5 % Mo) suffers badly from pitting corrosion, while the – on paper – less resistant steel behind (4404, 2.0 % Mo) does very well. The reason for this is the ground surface of the tube which is great for attracting salts and water.
Ground and glass-blasted surfaces are normally less corrosion resistant than a similar 2B, and the best results are obtained for polished or electro polished surfaces. This is closely linked to the increased contact time combined with the increased exposure of non-metallic impurities in the steel. In addition, horizontally ground steel sheets often perform poorer than vertically ground ones.

In contrast to common belief, stainless steel is perfectly able to cope with rain water. We get lots and lots of rain in Scandinavia (in particular in 2007, -11 and -12), so despite rumors of acid rain and "rural smells", rainwater is excellent for keeping the stainless steel clean and bright. The corrosive salts are removed effectively before they may initiate corrosion, and the more water, the better. Frequently, stainless steel in Denmark only stays free of corrosion because of the rain. This only applies for pure water. In coastal regions, sodium chloride (NaCl) is an all too common contamination, and so is corrosion of EN 1.4301 (and even 4404) in maritime environment. Similar conditions may apply inland at wintertime, when the roads are salted to prevent frosting. This salt is just as corrosive as seawater.

Due to the risk of salt from either maritime atmosphere or from road salting, common stainless steel (EN 1.4301, AISI 304) is not recommended for outdoor use in Denmark. The risk of discoloration is very real, indeed, and the 430 only works if it has a very fine surface (such as electro polished), if it is mounted vertically, and if there is no risk of long-term exposure. Despite this, 430i is still used widely for outdoor purposes, and frequently, it works – if the equipment gets lots of rain.

Due to its molybdenum content, the acid resistant 4401/4 along with the ferritic 4521 are much better than 430i for outdoor use. However, in severe conditions, it is neither immune nor fool-proof. Even the 440i (and 4521) class may suffer from superficial pitting corrosion in maritime conditions (see photo on page 1), but the risk is significantly smaller than for the lower alloyed 430i class.

For even better safety, steel with a higher pitting resistance equivalent (PREN) should be chosen, such as the duplex 4462, or the austenitic 4539 or 4529. The drawback is, of course, the higher price.
Indoor conditions

Indoors, the environment is much less corrosive than outdoors, and the risk of corrosion is equally lower. For that reason, most common types may be used indoors, including ground and glass blasted surfaces. Indoor environment is normally so dry and mild (and free of slats) that the risk of corrosion is about zero.

These days, the most widely used stainless steel is still the 4301 or the low-carbon 4307, and usually, these steels work without problems – also for ground or glass blasted equipment. Similarly, the ferritic parallel, 4509, is quite ok, and in most cases, the slightly lower alloyed 4016 can be used for indoor purposes. Acid resistant 4401/4 and the ferritic parallel, 4521, are even more corrosion resistant, and using these ones indoor is normally overshoot. The only disadvantage is, of course, the increased costs.

For equipment which may be used both indoors and outdoors, the steel should be chosen according to the demands of the most corrosive environment – normally, the outdoor one. In such cases, it makes sense to use 4401/4 and 4521 indoors, with a wide corrosion margin.

The table below shows the Damstahl recommendations for cool conditions above the water-line. The main risk of corrosion is superficial pitting corrosion. However, please note that the table is just a list of recommendations, and in no case the choice of material should be regarded as fool-proof. Ideally, each case should be evaluated separately.

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<tr>
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<th>Indoors</th>
<th>Outdoors, lots of rain</th>
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1 Normally no corrosion problems. The steel is sufficiently corrosion resistant to cope with the environment without suffering from corrosion.

2 Can sometimes be used. However, there may be a risk of corrosion. Pay attention to ground surfaces and sites with no cleaning rain.

3 Severe risk of corrosion and the steel type is not recommended.

None of the common steel types (4404, 4521 and below) are useful in maritime conditions without repeated cleansing (by rain). In such conditions, it is recommended than very corrosion resistant stainless steels are used, i.e. steels with a very high content of chromium (Cr) and molybdenum (Mo).

All references are with regards to “Stainless Steel and Corrosion” (Claus Qvist Jessen, Damstahl a/s, October 2011). The book can be ordered through www.damstahl.dk.