Corrosion of stainless steels

Corrosion resistance

Stainless steels are defined as being characterized by particularly high resistance to chemical attack by aqueous media. In general, they contain at least 12 % by weight of chrome and a maximum of 1.2 % carbon.

The reason for their high resistance to corrosion is a passive layer that forms on the surface. This consists of a metal oxide or hydroxide layer, rich in chrome, only a few Ångstrom units thick, separating the actual metal from the attacking medium.

The passive layer of a stainless steel is not something that never changes; however, after sufficient time has passed, its composition and structure achieve a state of equilibrium with the surrounding medium. Once formed, a passive layer cannot therefore be transferred to another medium. Following any mechanical damage of the surface, a new layer can generally be expected to form spontaneously at that point.

Corrosion can occur if a satisfactory passive layer cannot form in some medium, or if an existing layer is locally damaged or completely destroyed.

The decisive alloy responsible for the formation of a passive layer is chrome. A chrome content above the quoted value of some 12 % inhibits rusting under normal atmospheric conditions. Further increases in the chrome content and, depending on the application, the addition of molybdenum and other alloys permit corrosion resistance to be extended to much more aggressive conditions.

Only those alloy contents dissolved in the metal are effective in achieving passivation. The highest resistance to corrosion is thus given with a segregation-free matrix whose chrome or molybdenum contents are not reduced by precipitations or the formation of intermetallic phases.

The right heat treatment for achieving an ideal structure is described in the particular material sheets.

Stainless steels can suffer from wear corrosion at the surface and various forms of local corrosion. Surface-wear corrosion is to be expected mostly in acids and strong alkalis. In practice, however, the various forms of local corrosion are generally of greater significance and they will therefore be discussed in more detail below.

Information on the corrosion resistance of our stainless steels in many different media is to be found in our publication „Chemical Resistance of NIROSTA® Steels".

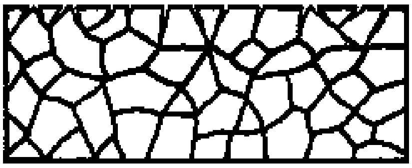
Surface finish

The steel surface exposed to chemical attack must be as smooth as possible and free of any impurities. Foreign materials, such as residues from grinding pastes or tool shavings, pressed into the surface reduce corrosion resistance considerably. Non-metallic impurities, above all sulphide precipitations, promote local corrosion if they reach the surface.

Intercrystalline corrosion

Intercrystalline corrosion is defined as an attack along the grain boundaries, while the grains themselves are not or hardly worn away. An attack at the grain boundaries can be so extensive that individual grains can be removed from the grain structure so that the steel can lose its cohesion.

The cause of intercrystalline corrosion of stainless steels lies in the precipitation of high-chrome carbides at the grain boundaries, resulting in a reduction in chrome content in the areas near to the grain boundaries.


Intercrystalline corrosion

The low-chrome zones thus formed at the grain boundaries are not resistant enough to most attacking media and are easily dissolved.

Chrome carbide precipitations only occur given a certain carbon content and at temperatures between 500 and 800 °C, e.g. when carrying out heat treatment or welding processes.

Chrome carbide precipitations can be avoided in stainless steels by reducing the carbon content to under 0.03 % or by fixing the available carbon with so-called stabilising elements such as titanium or niobium that have a greater affinity for carbon than chrome does. Ferritic steels can also be stabilised against intercrystalline corrosion by alloying with titanium or niobium.

If chrome carbide precipitations have occurred, they can be redissolved by solution annealing at temperatures above 1050 °C. With unstabilised ferritic steels, susceptibility to intercrystalline corrosion can be eliminated by annealing at 800 – 850 °C.

Low-chrome areas near grain boundaries are then enriched with chrome diffusing from the inside of the grains.

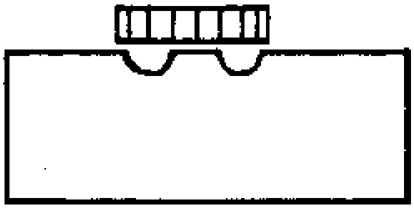
Pitting and crevice corrosion

In practice, pitting and crevice corrosion are generally caused by chloride ions. However, the more unusual halogen ions, bromides and iodides, can also initiate this type of corrosion if they occur.

Pitting is initiated by interaction between the halogen ions and the passive layer, the layer being locally punctured, forming pinholes that grow into pit sites of varying severity. The danger of pitting increases with

- increasing concentration of halogen ions,
- increasing temperature,
- increase in the electrochemical potential of the steel in the particular electrolytes due, for example, to the effect of an oxidising agent.

Pitting

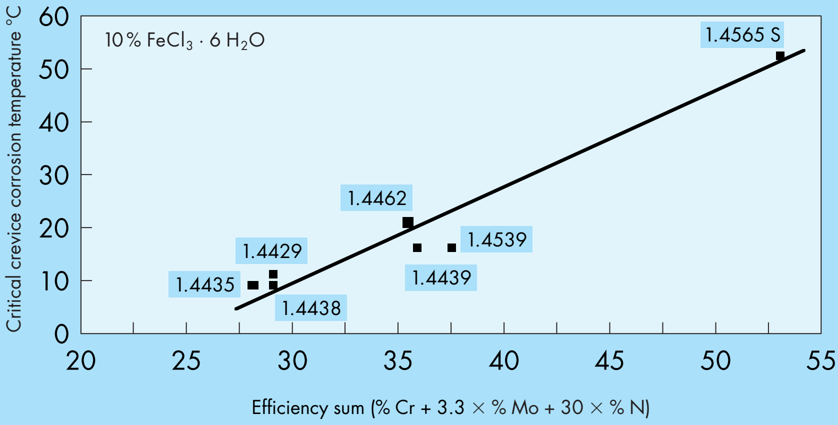


Crevice corrosion

Crevice corrosion occurs in crevices in which the exchange of liquid with the surroundings is restricted. Such crevices depend on the design or operating conditions and are found, for example, at flanges, pipe necks, under seals or incrustations.

The mechanism of this form of corrosion corresponds largely to that of pitting. However, the crevice geometry and the type of materials forming it are other influencing factors. Due to the fact that crevice corrosion occurs under far less demanding conditions than pitting, the formation of crevices in media involving chloride ions should be avoided as far as possible by means of appropriate design.

Critical crevice corrosion temperature as a factor of the efficiency sum



Given a homogeneous distribution of alloying elements, the relative resistance to pitting and crevice corrosion of a stainless steel can be judged approximately by using the efficiency sum „W“, where

$$W = \%\,Cr + 3.3 \times \%\,Mo + 30 \times \%\,N$$

or

$$W = \%\,Cr + 3.3 \times \%\,Mo.$$

The effect of nitrogen as an alloying element is, however, more complicated than expressed in this relationship. The strong effect suggested by the factor 30 is only likely to be fully achieved in high-alloy steels with increased molybdenum contents. Non-metallic impurities, above all sulphide precipitations, promote pitting and crevice corrosion when they reach the surface.

It can be advantageous to have a surface which is as smooth as possible. This makes it harder for deposits to gain a foothold and therefore does not provide the conditions for crevice corrosion.

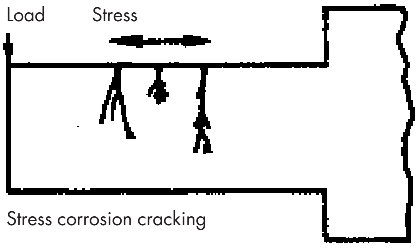
A high degree of resistance to pitting and crevice corrosion can only be expected given perfect surface finishes, i.e. a bright metal surface. For this very reason, tempering colours and scale from welding, foreign abraded particles, extraneous rust and any residues of grinding paste, etc. must be removed.

Extraneous rust

Extraneous rust refers to deposits of rust particles that did not develop at that particular spot but have been carried there from somewhere else. Extraneous rust tends to occur when „black“ and „white“ steels are stored and machined together. Abraded particles from tools can also cause extraneous rust. Deposits of extraneous rust can fulfil the conditions leading to crevice corrosion.

Stress corrosion cracking

Media containing components with specific effects – especially chloride ions – can lead to cracking corrosion in stainless steels exposed to tensile stress, even if the steel exhibits satisfactory corrosion resistance in the respective medium when not subjected to mechanical stress. This so-called stress corrosion cracking is not only initiated by tensile operating stresses. Indeed, more often than not the cause lies with internal stresses due to processes such as welding, grinding or cold working.

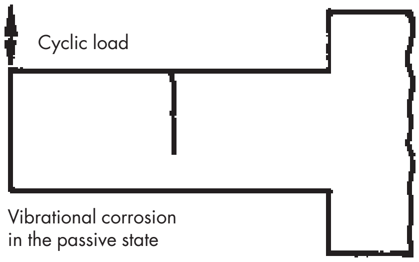


Stress corrosion cracking

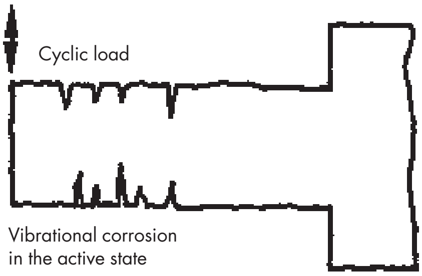
The danger of stress corrosion cracking in the presence of chlorides increases, as in the case of pitting and crevice corrosion, with the temperature and chloride ion concentration. From the point of view of the materials, however, other factors are important. For example, at temperatures above approx. 50 °C austenitic steels of the type 18/10-CrNi and 18/10/2-CrNiMo are particularly susceptible to stress corrosion cracking induced by chloride ions. However, by increasing the molybdenum and especially the nickel contents, resistance to this form of corrosion can be significantly improved. Ferritic and ferritic-austenitic stainless steels also exhibit relatively high corrosion resistance in this respect.

Vibrational corrosion

The resistance to vibrational corrosion of all NIROSTA® steels is reduced to a greater or lesser extent by simultaneous chemical attack.



Vibrational corrosion
in the passive state



Vibrational corrosion
in the active state

The reduction in resistance to vibrational corrosion also depends on the corrosive medium and the multiaxiality of the cyclic loading.

Contact corrosion

The possibility of contact corrosion exists when two metals with different electrochemical potentials are in conductive connection with one another in a corrosive medium. The metal with the lower electrochemical potential can be polarised, at least with respect to higher potentials, and thus be subject to preferential attack.

However, even with greater differences in electrochemical potential between the metals concerned, contact corrosion will not necessarily occur. This depends on the electrochemical behaviour of the two metals.

The conductivity of the medium and the behaviour of the two metal surfaces also play a significant role. If the less noble metal exhibits a much larger surface area than the other and the corrosive medium has a high electrical conductivity, there is less danger of corrosion damage. In any case, it is advisable to avoid the combination of a base metal of low surface area with a noble metal of large surface area.

In general, stainless steels have high values of electrochemical potential and are thus hardly in any danger of excessive attack by contact corrosion. Contact corrosion is much more frequent in cases where other metals with low electrochemical potentials are joined to stainless steels.

Execution and surface finish of sheet and strip[1]
DIN EN 10 088-2

Symbol[2]	Execution	Surface condition	Notes	Symbol to DIN 17440 Sept. 1996
Hot-rolled				
1U	Hot-rolled, not heat treated, not descaled	Covered with mill scale	Suitable for products which are further processed, e.g. strip for rerolling	
1C	Hot-rolled, heat treated, not descaled	Covered with mill scale	Suitable for parts which are subsequently descaled or machined, or for certain heat-resistant applications	I c
1E	Hot-rolled, heat treated, mechanically descaled	Free of scale	The type of mechanical descaling, e.g. rough grinding or blast-cleaning, depends on steel grade and product form and, unless agreed otherwise, is left to the discretion of the manufacturer.	II a
1D	Hot-rolled, heat treated, pickled	Free of scale	Normal standard for most steel grades to guarantee good corrosion resistance; also usual finish for further processing. Not as smooth as 2D or 2B.	II a
Cold-rolled				
2H	Strain-hardened	Bright	Cold worked to achieve higher strength levels	III a
2C	Cold-rolled, heat treated, not descaled	Smooth, with scale from heat treatment	Suitable for parts which are subsequently descaled or machined, or for certain heat-resistant applications	III s
2D	Cold-rolled, heat treated, pickled	Smooth	Finish for good formability but not as smooth as 2B or 2R	III b
2B	Cold-rolled, heat treated, pickled, cold rerolled	Smoother than 2D	Most frequent finish for most steel grades to ensure good corrosion resistance, smoothness and flatness. Also usual finish for further processing. Rerolling can also be by tension levelling.	III c
2R	Cold-rolled, bright annealed[3]	Smooth, bright, reflecting	Smoother and brighter than 2B. Also usual finish for further processing.	III d
Special finishes				
1G or 2G	Ground[4]	See footnote 5	Grit size or surface roughness can be fixed. Exquiaxed texture, low-reflecting.	IV
2J	Brushed[4] or matt-polished[4]	Smoother than ground. See footnote 5.	Brush type or polishing belt or surface roughness can be fixed. Exquiaxed texture, low-reflecting.	
2M	Patterned	Design to be agreed; second surface smooth	Excellent textured finish mainly for architectural applications	

[1] Not all finishes are available for all steels.

[2] First digit: 1 = hot-rolled, 2 = cold-rolled

[3] May be rerolled.

[4] One surface only unless expressly agreed when ordering.

[5] The surface properties may vary within each finish and it may be necessary for the manufacturer and fabricator to reach an agreement on the precise requirements (e.g. grit size or surface roughness).

Surface treatment

Mechanical surface treatment

Mechanical surface treatment can be necessary for various reasons. Firstly, to remove discolouring caused by welding or heat treatment, while, secondly, a mechanical treatment can be desirable from a purely aesthetic point of view to achieve a particular surface effect.

On grinding austenitic stainless steels it must be remembered that their thermal conductivity is less than that of the non-alloyed or ferritic stainless steels. To avoid local overheating and consequent discolouring or warping on grinding, the applied pressure must not be too great.

Abrasives used for non-alloyed steel parts may under no circumstances be used for stainless steels since abraded particles are pressed into the surface and later cause extraneous rust to form.

Furthermore, suitable abrasives must be free of iron and sulphur in order to avoid corrosion and extraneous rust.

The final grinding – done largely for aesthetic reasons – is usually carried out with grain sizes 120, 180, 240 and 320 (intermediate sizes on request). Since the ground finish is not only determined by the grain size, but also by the process (dry or wet grinding), the machines and the abrasive base, we recommend you to request samples.

Chemical surface treatment

It is often absolutely essential to pickle stainless steels in order to remove the layers of scale resulting from heat treatment or to eliminate the discolouring caused by welding.

Chemical treatment of the surfaces is carried out either in pickling baths or by using pickling pastes. Pickling pastes are usually used to remove partial discolouring after welding. Complete items, containers, etc. that have been heat treated are almost exclusively pickled to remove the layers of scale.

By passivating, once can accelerate the formation of the passive layer that usually already forms in the presence of water or atmospheric oxygen, making stainless steels resistant to corrosion. Passivating can thus be recommended, although it is often not necessary since the pickling baths and pastes already contain the oxidising acids required.

It is, however, advisable to confirm this with the manufacturers of pickling acids and pastes.

On pickling and passivating, it is essential that the safety precautions for working with acids and the regulations regarding water preservation and environmental protection are observed.

Electropolishing

Electropolishing or chemical polishing is particularly suitable for parts that cannot be polished mechanically (e.g. complex parts, thin-walled constructions or parts that can easily be bent).

On electropolishing, the parts are suspended in a special bath where the parts to be polished are used as the anode, so that the surface is removed as metal.

One of the typical pickling solutions has the following composition:	
Nitric acid (50 %):	10 to 30 % vol.
Hydrofluoric acid:	2.5 to 3.0 % vol.
Aqua:	Remainder
Bath temperature:	20 to 40 °C
Pickling time:	Varies according to thickness and composition of scale

Surface protection

Surface protection

Further processing (e.g. flanging, bending, stamping, deep drawing, etc.) often demands protection for the surfaces of strips and sheets. The surface protection is provided in the form of an adhesive foil. Since special equipment is required, it is advisable to order the sheets from us already protected by the desired foil, if necessary. Foils provide protection against surface damage during chipless machining, during and after assembly and also on deep drawing, since some foils then act as lubrication. The adhesive foils can be removed for localised work and can then be stuck back on again. Since all foils have a limited life, we recommend processing protected material as soon as possible. Materials should be stored in closed packs and store rooms to protect the foil from UV-radiation or protected by a UV-resistant foil.

Even when the foils can be peeled off with no visible residue, last traces of adhesive can nevertheless remain. Thorough cleansing after removing the foil is therefore essential.

Cleaning and servicing

After completing assembly of parts or plant, the protective foils should be removed immediately. Heat and light cause accelerated ageing of the foils so that it becomes impossible to pull them off cleanly or even to pull them off at all. In addition, aggressive media can develop, causing corrosive attack.

Remains of the adhesive and dirt from machining and assembly must be removed by thorough cleaning. The frequency of later cleaning processes depends on the degree of contamination, type of contamination and the demands made on the surface finish. Only cleaning materials should be used that have been developed exclusively by the industry for cleaning stainless steels. The manufacturer's instructions must be observed exactly.

In case of doubt, we recommend requesting information from the manufacturer.

Processing

Cutting

Since stainless steels, particularly austenitic types, possess a higher shearing strength than non-alloyed mass-produced steel, higher forces are necessary to cut them.

The cutting gap should be approximately 5 % of the thickness. It is correctly set when the cut part of the edge is approx. 40 %. Blunt cutters cause rough edges and make higher forces necessary.

Shears with blankholders should have their seats covered with rubber, felt, plastic, etc. to avoid damaging the surfaces.

Stamping

Stamping or punching, like cutting, also requires greater forces due to the high shearing strength. The force required can, however, be reduced by bevelling the edge of the cutting tool.

If it is intended to make use of the part punched out, the lower die is bevelled, while the punch is left flat.

If, however, the punched out part is waste, the punch is bevelled so that the product remains flat.

The shearing gap must be smaller than for non-alloyed steels to ensure that the material is not unnecessarily work hardened and the tools overstressed. The cutting gap should not be more than 10 % of the thickness. For thicknesses ≤ 1.0 mm, the gap can be smaller than with greater thicknesses. Recommended is a gap of 0.025 to 0.035 mm per side.

To avoid built-up edges on cutting, high viscosity lubricants should be used.

When punching holes, the smallest hole diameter should at least correspond to twice the thickness and the distance between holes be at least half the hole diameter (i.e. approx. = sheet thickness).

The tools must be sharp and free of welding pick-up.

Spinning

Due to their toughness, austenitic stainless steels can be spun and flow turned extremely well. Their strong tendency to work hardening, however, makes greater forces necessary. Their spring-back resilience is also greater than with non-alloyed steels.

Ferritic stainless steels are less suitable for spinning and flow turning. The degree of cold working before a possible intermediate annealing process is generally lower than that with non-alloyed steels. After spinning, it is of advantage to leave a flange of at least 25 mm to avoid later cracking of the finished products (stress corrosion cracking).

A particularly good and intensive lubrication should be provided for spinning. The lubricants must be completely removed before intermediate or final annealing.

Flanging

Basically, stainless steels can be flanged just as well as non-alloyed steels. It must be realised, however, that higher forces are necessary and that the spring-back resilience is greater.

With chrome-nickel steels in the soft-annealed state, the direction of rolling is of no consequence, i.e. they can be flanged in the direction of rolling or transversely.

Ferritic steels, on the other hand, must always be flanged at right angles to the direction of rolling due to the fact that the rolling structure is considerably more noticeable with these materials. Bending radii should be at least twice the sheet thickness. In cases where the construction does not allow these conditions to be fulfilled, please ask for information since a specific production may be necessary for these special applications.

Stainless steels can be machined with prismatic flanging tools. The width of the prisms at the working surfaces should be approx. eight times bigger than the inside radius. Due to stretching near the outer radius on flanging, a certain roughness of the surface must be reckoned with.

The smaller the bending radii and the larger the bending angles, the rougher the surface will be. Some form of surface protection is often used to avoid surface damage on flanging. The thickness and toughness of the foil used depends mainly on the desired form and the sheet thickness.

Roll bending

Roll bending is carried out exactly as with non-alloyed steels. Again, the greater forces and spring-back resilience must be taken into account. Otherwise, roll bending of stainless steels is quite straightforward.

Roller shaping

Austenitic stainless steels can easily be roller shaped. However, the greater spring-back resilience and force requirement must be taken into consideration. With ferritic stainless steels, the required bending radii must receive special attention. Suitable lubricants are high-viscosity oils and greases or, for slight shaping, emulsions.