

Corrosion occurs in various forms and has therefore to be dealt with case by case. Its origin and prevention are closely interconnected, and ignorance on the subject has often led to considerable damage. This article clarifies the origins of corrosion and recommends ways to prevent it.

# Preventing stainless steel corrosion

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Devices and installations have a technical and an economical lifetime, and technical lifetime is largely affected by corrosion. For this reason in every country every year hundreds of millions dollars are spent on renovating appliances and installations because the corrosion of the existing equipment has affected the technical function of the whole too much.

From a marketing and technical point of view the replacement of systems has certain advantages, but the aspiration will always be to keep the technical lifetime as long as possible. It is also important not to redesign, because in this case the technical lifetime will exceed the economical one. In itself this is not really needed because the device has to be replaced anyway in order to achieve greater efficiency. This article aims to help material specifiers make the best possible choice of material and process control.

## Forms of corrosion

Corrosion is often defined as the undesired deterioration of a metal as a consequence of chemical or electrochemical reactions on the metal surface through substances present in its surroundings.

Corrosion is a chemical reaction that starts spontaneously under certain thermodynamic conditions. The speed with which such a reaction takes place is also determines the choice of metal. Corrosion occurs in a variety of forms, each of which arises in a different way:

- general attack
- galvanic corrosion

- crevice corrosion
- intergranular corrosion
- high-temperature corrosion
- biological corrosion
- pitting
- stress corrosion cracking
- erosion/corrosion

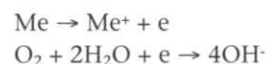
General attack is the least dangerous type of corrosion because the deterioration image expands over the whole surface of a metallic object.

The entity of the deterioration can easily be determined by, for example, expressing the loss of weight per time unity or surface unity (for example N/m<sup>2</sup>/hour) or a thickness decreases per time unity like mm/year. In practice, this last measure is the most used indicator. In this way it can be decided how much corrosion addition has to be given to a certain part in order to obtain the desired lifetime.

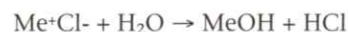
Galvanic corrosion is also called contact corrosion and is the result of an electric leading compound of two different metals which have come into contact with an aggressive environment. The least noble metal will be corroded much quicker than if it had been in contact only with this environment. The dissolving metal is the anode of the galvanic element. Even in one metal you can have a form of this corrosion, for example through a difference of potential which appears through differences of composition of the metal crystals or environment. This is called local element corrosion.

Crevice corrosion only appears in narrow cracks due to a difference in potential caused by the relatively

low oxygen content in the crack. This form of corrosion is greatly feared because it takes place in such a hidden way. It can even occur in cracks which are no bigger than 0.03 mm (for example non-narrowly adjacent packs on metal flanges). It is clear that in this case the dissolving electrode is the metal crack (the anode). The following reactions will take place in a crevice:



In a crevice the oxygen is consumed after a certain time. The metal ions will react with the chlorine ions, and that will lead to the following reaction:



The result of this reaction is the forming of hydrochloric acid, which is too aggressive for stainless steels and causes severe crevice corrosion. Grain border corrosion, also called intercrystalline corrosion, is the result of a difference between the borders of the metal crystals and the crystal itself. There is no point in using corrosion additives here. This type of corrosion is measured in penetration per time unity. The corrosion speed in general is high. The big danger of this form of corrosion is that through deterioration of the borders the mutual connection of the crystals is dissolved.

There are some reasons why the borders become sensitive to corrosion. One cause is precipitation of alloy elements which at certain saturation and a slow chilling can sep-





Stress corrosion cracking due to 'corrosion under insulation' from the outside to the inside of a hot water pipe. This is a AISI 304 pipe and the solution in this case is to change to duplex stainless steel. Duplex stainless steel is far less sensitive to chloride cracking than 304 and 316. Picture: J. Heselmans, Corrodium bv.



Inside of same pipe of picture A. After scratching rust scaling, pitting appeared to cause the leakage, which wetted the insulation material on the outside. The solution here is to change to duplex stainless steel as well because the PREN (pitting number) of duplex stainless steel is considerable better than the PREN of 304. For stress corrosion cracking resistance AISI 316 was no option. Picture: J. Heselmans, Corrodium bv.



Crevice corrosion in duplex stainless steel seawater cooler. The corrosion can be stopped by use of pulsing sacrificial anodes. Picture: Jan Heselmans, Corrodium bv.



Pitting in a sand bed filter, caused by an aggressive biofilm [Microbiologically Induced Corrosion]. The brown ring (rust deposit) shows the rust hood that has been on top of the pit, in which very sour water caused the pitting corrosion. Picture: Jan Heselmans, Corrodium bv.

arate themselves on the grain border. An example is the formation in stainless steel of chrome carbides which nestle on the grain border because of the undesired "friendliness" to germs of similar zones. Chrome carbides form a very un-noble area due to a lack of chrome and this area dissolves relatively quickly because of the difference in electric potential from the matrix, with all the related consequences. In this way chrome is subtracted from the matrix and there may not be enough chrome remaining to keep the stainless steel (locally) passive. Corrosion in borders also occurs when adjacent crystals cause dislocations because of their reciprocal positions, which is an easy inducement for the metal ions to quit that spot. Crystals can form, whereby impurities are expelled before the

coagulation front (segregation); these will eventually nestle on the grain borders. Similar impurities almost always react anodically in a chemical environment and for this reason the border always corrodes. High-temperature corrosion is also called oxidation because it describes the reaction of materials with oxygen at elevated temperatures. Oxide peels form on the material; these possess a different expansion than the mother material, so that when there is mechanical tension (for example because of large temperature differences) this peel will break off from the ground layer. By alloying this kind of metal in the right way with certain elements, oxidation resistance can be enormously increased. Examples are provided by the elements aluminium and silicon.

Biological corrosion occurs when micro-organisms die and are converted by oxygen into carbon and hydrogen. For this reason it is very important that bacteria and similar do not become lodged in the dead corners of systems, where this kind of corrosion is highly likely to appear. In this connection regular cleaning of constructions prone to biological corrosion is a must. Sometimes the metal itself fights against biological corrosion: ions arise which inhibit the growth of similar organisms, as for example in the case of copper ions. Pitting corrosion is distinguished by its local character. The symptoms are deterioration in well form (pitting), which usually forms quite quickly and deeply. The main cause is local damage of the passive oxide layer, resulting in severe damage



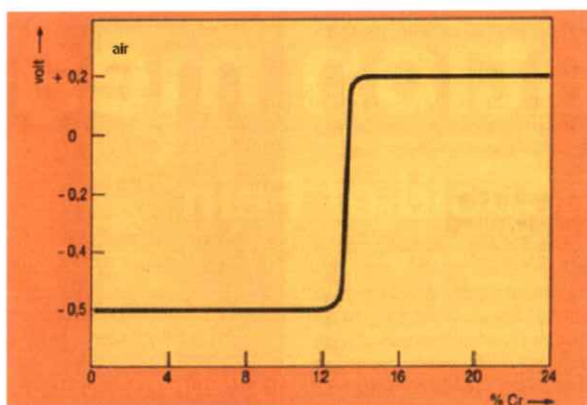


Figure 1. After alloying of minimal 12% chrome the steel becomes corrosion proof. An active metal becomes passive.

from an aggressive environment. Flaws in the oxide layer or undesired embedding of different parts in the surface can also cause pitting corrosion (think of steel polish particles, which penetrate a stainless steel surface). Another important cause is the penetration of specific components from an environment such as chlorine and halogen ions. Therefore, in addition to the pH value and the conduction ability of the electrolyte, it is also important to know the percentage of chlorine ions. Additional causes are wander streams and stream differences, which usually originate when turbulence gives rise to differences in the oxygen content.

### Combined corrosion

Besides from the corrosion types described above, corrosion phenomena can appear in combination. Examples of this type include:

- stress corrosion cracking
- fatigue corrosion
- erosion/corrosion

A combination of mechanical stress and a corroding environment causes corrosion to occur more quickly in the places where the stress is highest. Cracks form relatively quickly, whereas the surrounding material is completely sound.

Sometimes the cracks run along the grain border (intercrystalline) and sometimes even through the grains (transcrystalline); this arises depending on the kind of metal and the environment.

Corrosion focuses so intensely on a stress area because the stress causes small cracks to originate on the surface layer, resulting in a difference

in potential between the often oxidised layer and the blank metal in the cracks. There is thus a relatively small active fracture surface on the one hand and a big passive smooth one on the other. Besides this and through the notch effect in the small cracks, stress in the metal is locally very high, causing the crack formation to propagate quickly and eventually leading to fracture. Hydrogen brittleness is an example of this form of corrosion.

Fatigue corrosion is a combination of metal fatigue as a consequence of a long-persisting variable stress and the presence of a corroding environment that induces accelerated corrosion in places that function as anodes. Erosion/corrosion, also called cavitation corrosion, also leads to accelerated corrosion, which often concerns a general deterioration. It usually occurs when the passive metal layer is scratched by an abrasive substance and therefore the metal will not have a chance to passivate itself again, causing accelerated corrosion.

### Inhibitors

Corrosion can be contained or prevented altogether by adding an inhibitor to the corrosive medium. This is an extremely simple method to fight corrosion; however, it is important to determine the right "braking material". Organic amines, for example, decrease the aggressiveness of muriatic (also known as hydrochloric) acid with regard to steel. The braking mechanism can be explained by adsorption (cover layer formation) on the anode or cathode. These "braking substances" are called anodic and cathodic inhibitors.

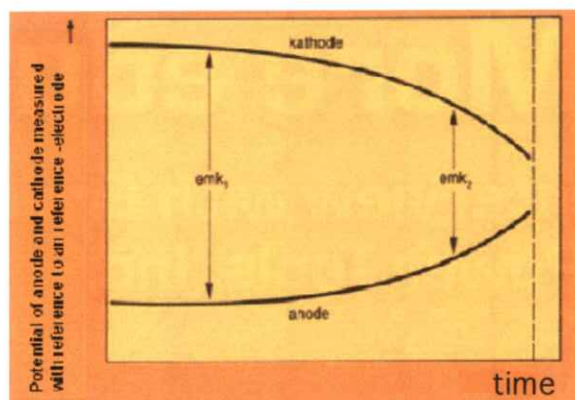


Figure 2. Polarisation curve  $emk_1-emk_2$

### Conclusion

There are many other methods to fight corrosion, such as chlorinating, phosphating, scoping, sherardising, aluminizing, anodic protection, control of the oxygen content and similar. However, in general it can be said that, in the metal world as elsewhere, "prevention is better than cure". This begins at the planning stage, when constructors should concentrate on making their constructions impervious to corrosion. Often it turns out that due to ignorance and neglect all kinds of unnecessary cracks and dead corners are taken up in a system which later lead to corrosion. Also, the combination of the various metal bonds is sometimes chosen rashly. Furthermore, it is important to use knowledge, logic, empiricism and consultation to arrive at correct decisions.

### About the author



Ko Buijs is a recognized metallurgical / corrosion specialist on stainless steels as well as special metals. He works for Van Leeuwen

Stainless. In addition, Mr Buijs is a lecturer for various organisations such as steel associations, technical high schools and innovation centres. He has published over 100 papers in a number of technical magazines. In close co-operation with Barsukoff Software Mr Buijs has developed the computer programme Corrosion Wizard 2.0. Info [www.corrosionwizard.com](http://www.corrosionwizard.com)