



## Foreword

This brochure on the subject of corrosion covers the fundamental aspects of corrosion and protection against corrosion. It provides an introduction to the behavior of materials and protective coatings for fastening systems. The brochure is intended to provide users with basic information on the correct use of systems for protection against corrosion in the field of fastening technology.

The various fields of application of fasteners are described on the basis of examples and recommendations for correct material selection. These recommendations, however, do not apply generally to all applications in their respective surroundings. In view of this, it is each user's responsibility to check each application and, if necessary, to consult a corrosion specialist.

In view of this, it is important to realize that even after reading this brochure you will still not be an expert on corrosion. It is, however, essential that you are informed about possible and suitable solutions and it is extremely important that you are aware of the potential risks of using an unsuitable material.

Your local Hilti engineer will be pleased to support you and provide you with further information. He or she also will also be able to obtain support at any time from the specialists in our Corporate Research & Technology department, allowing you to take advantage of the in-depth know-how they have available.

Materials Research  
Corporate Research & Technology  
Hilti Corporation  
Principality of Liechtenstein

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# 1. Introduction

It takes roughly one fifth of the world's annual steel production to replace steel parts damaged by corrosion or lost forever through rusting. This amounts to a considerable economic loss. A great part of this loss could be avoided in view of the current level of knowledge on the subject of corrosion. In the long term, even if initial costs are higher, the more economical approach would be to select suitable methods of protection against corrosion, e.g. by using resistant materials or designing to resist corrosion.

Where fastening systems are concerned, great importance must also be attached to safety aspects in addition to cost-efficiency. Considering today's much greater awareness for safety, it is extremely important that products are brought into line with the "state of the art". Hilti is aware of its responsibility as a fastener manufacturer and regards this as a major challenge. By conducting practical research on corrosion topics and working with selected universities as well as college laboratories, Hilti strives to meet this great challenge. As a result, we are in a position to decisively improve the "state of the art" with applications in many highly corrosive surroundings and thus to increase the safety level of fasteners, e.g. those subjected to a road tunnel atmosphere.

To safeguard the quality of our fasteners, numerous tests are carried out on an ongoing basis. Investigations of their long-term behavior in a wide variety of environmental conditions such as in rural, industrial and coastal atmospheres began in 1982, and is continuing today. These studies help our researchers to understand the corrosion processes to which fastenings are exposed. This is a prerequisite when developing suitable protection against corrosion. For users of Hilti products, this gives the assurance of the highest level of safety.

Although laboratory tests can provide valuable input about general corrosion behavior, they are not always able to provide adequate long-term data on the corrosion behavior of materials and systems for protection against corrosion. In view of this, systems protecting against corrosion and the corrosion behavior of materials for special uses are kept under observation during special field tests.

Conditions prevailing in a road tunnel, for example, were investigated jointly by Hilti and the Swiss Federal Institute of Technology Zurich in the Mont Blanc Tunnel and several Swiss road tunnels. While doing so, many materials and protective coatings were exposed to tunnel atmospheres. A special information brochure (Korrosionstechnische Überlegungen für Verbindungsteile in Strassentunnelatmosphären, Hilti 2010) about these investigations is available. As a consequence from these investigations, the grade of steel recommended by Hilti, i.e. HCR (1.4529), is specified for use in road tunnel atmospheres and indoor swimming pools in most industrial countries of the world for safety reasons (HCR = highly corrosion resistant). Any recommendations for such use apply only so long as the conditions listed in the special information brochure are strictly adhered to. Please remember that Hilti makes no recommendations concerning applicable circumstances. These assessments must be made either by the contractor or a consultant assigned by the contractor.

Further to these tests in road tunnel atmospheres, Hilti Corporate Research carries out corrosion tests in highly corrosive surroundings in several other areas. The goal of testing in this way is to learn more about the specific conditions in individual areas so that suitable and safe materials for fastenings can be made available.

## 2. What is corrosion?

Corrosion is understood to be the tendency of a metal to revert from its synthetically produced state to its natural state, i.e. from a high-energy pure form to the low-energy but thermodynamically stable form of a metal oxide (ore). As a rule, an ore is the chemical compound of a metal with oxygen, hydrogen and possibly other elements. Corrosion is thus a natural process. In everyday usage, the word corrosion has many meanings.

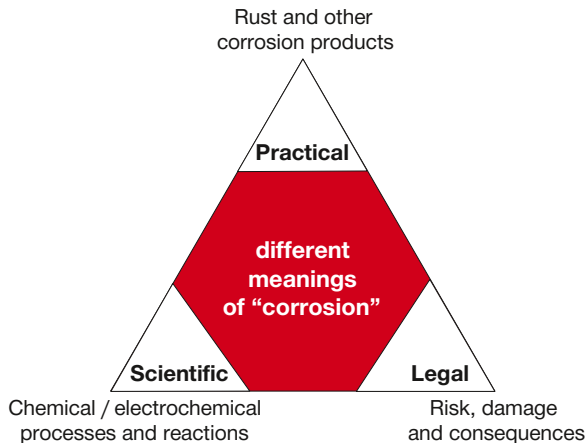


Fig. 1: Different meanings of corrosion.

With a view to achieving standardization when referring to and writing about this subject, the main terms have been defined, i.e. in ISO 8044. Accordingly, corrosion is a property of a system that is defined as follows.

Physicochemical interaction between a metal and its environment that results in changes in the properties of the metal, and which may lead to significant impairment of the function of the metal, the environment, or the technical system, of which these form a part [ISO 8044].

### Material

The definition of material corrosion does not, actually, exclude the destruction of wood, ceramics, textiles, etc., but in practice the term applies primarily to metals and plastics, i.e. corrosion is directly associated with metals. Corrosion of materials is influenced by different processes, i.e. alloying, heat treatment, cold forming, etc.

### Environment

The environment is characterized by temperature, humidity, pressure and composition/concentration of surrounding mediums (air, liquids and gases).

### Design

Corrosion resistance is greatly affected by factors such as design, i.e. loads, ventilation, crevices etc.. The design of a part can have a significant influence on how specific areas of it are affected by its surroundings and the prevailing environmental conditions.

### Reaction

Corrosion can be a chemical, electrochemical or a physicochemical reaction. Phase boundary reactions, reaction formulae and thermodynamics permit the processes taking place to be described. Generally, a distinction is made between types (the reaction between substances) and forms (the way the corrosion appears) of corrosion, which are explained in detail in this brochure.

### 3. When must corrosion be expected?

Corrosion must be expected when the properties of the metallic component or the entire structure (this includes the fastener, the base material and the fastened component) do not meet the requirements imposed by the surrounding conditions. To evaluate the risk of corrosion, it is essential that a profile of environmental conditions, specific materials or material combinations and design characteristics exists.

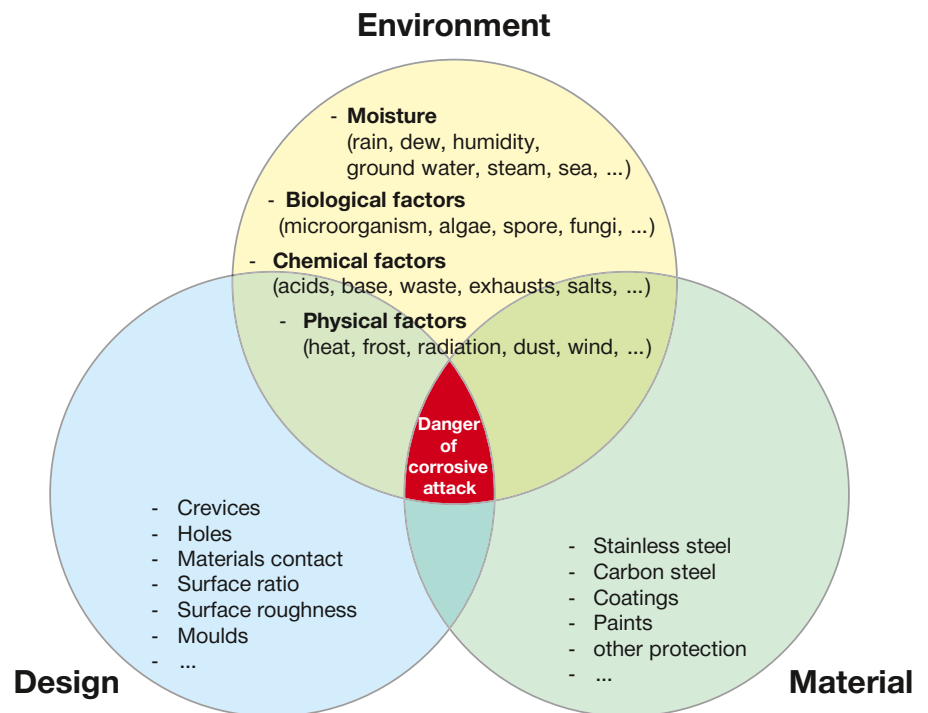
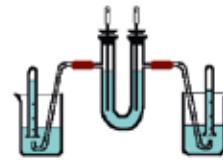


Fig. 2: Corrosion will occur only if more than one critical factor is present.

## 4. Types of corrosion

### 4.1 Chemical reaction

A typical chemical corrosion reaction is high-temperature corrosion. The metal reacts with hot gases and forms an oxide layer.



### 4.2 Metallophysical reaction

One example is the embrittlement caused by hydrogen diffusing into a material which can lead to failure of a building component.

Embrittlement can be the result of a careless manufacturing process, e.g. surface coating such as electrochemical zinc plating, and it can also be initiated by corrosion processes (metal dissolution). In the latter case, reference is made to corrosion-induced hydrogen embrittlement.

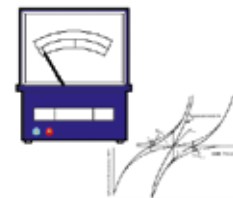
In general: the higher the strength of a component, the greater will be its tendency to suffer hydrogen embrittlement.



### 4.3 Electrochemical reaction (most frequent type of corrosion)

When moisture is present, mass transport through ions and a charge exchange through electrons take place at the metal-electrolyte phase boundary. An ion-conductive medium, e.g. water, is always required.

The result of this electrochemical reaction of carbon steel is known as common rust.



## 5. Forms of corrosion

### 5.1 Uniform corrosion/shallow pitting corrosion

According to ISO 8044, uniform corrosion is a form of corrosion where the surface is dissolved nearly uniformly. This also includes shallow pitting corrosion where local areas suffer greater attack than the rest of the surface. The extent of this form of corrosion can usually be well estimated through former experience. The rate of corrosion is usually given in mm/year or g/m<sup>2</sup>h. Using these average values, it is possible to calculate the life expectancy of a component, and thus to alter its life expectancy by, for example, increasing its thickness. Uniform corrosion takes place on materials such as carbon steel, low-alloyed steels or zinc under atmospheric conditions.

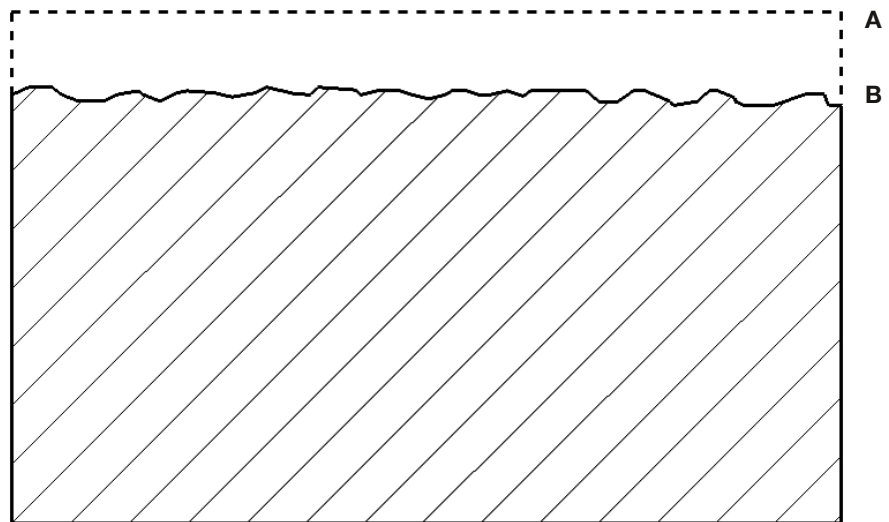
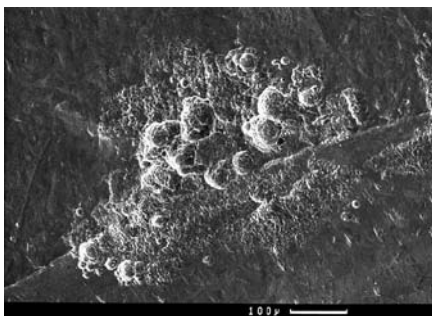


Fig. 3: Schematic representation of uniform corrosion

A... Starting level

B... Reduction of component thickness due to uniform removal by corrosion

In practice, in most cases, corrosion is a mixture of uniform and non-uniform corrosion, which leads to a rough surface.



Non-uniform general corrosion – wide/shallow pits on structural steel exposed to sea water

Shallow pitting corrosion is caused by the presence of local corrosion cells. A corrosion cell is a galvanic cell with locally differing corrosion potentials that cause metal dissolution. The different rates of dissolution may often be caused by material inhomogeneity, local variances in concentration and varying surrounding conditions.

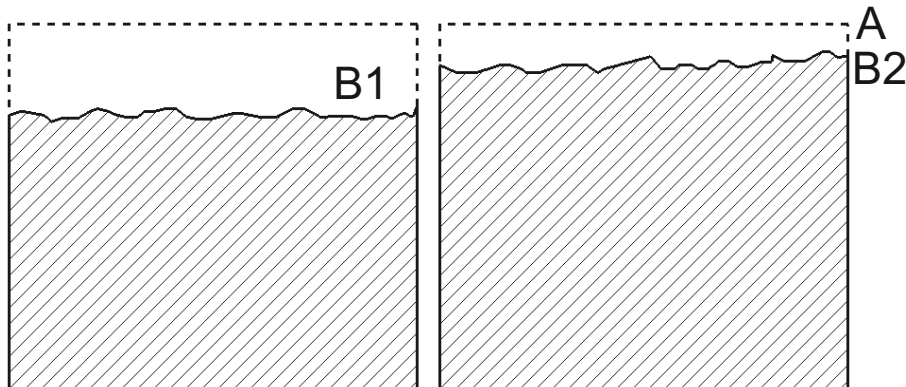
Many metals are not resistant in acidic or even neutral mediums. In the case of pure iron and low-alloyed steels, rates of corrosion are highly dependent on the pH value for values below 5. In the pH range between 5 and approx. 10, the rate of corrosion is almost independent of the pH value. Above the pH value of 12, iron has a passive behavior. This behavior allows the use of low-alloyed steels as conventional reinforcement in alkaline concrete without risk of corrosion.



## 5.2 Bimetallic corrosion

An electrically conductive link between two dissimilar metals in an aggressive medium (electrolyte) leads to bimetallic corrosion.

### Example 1:

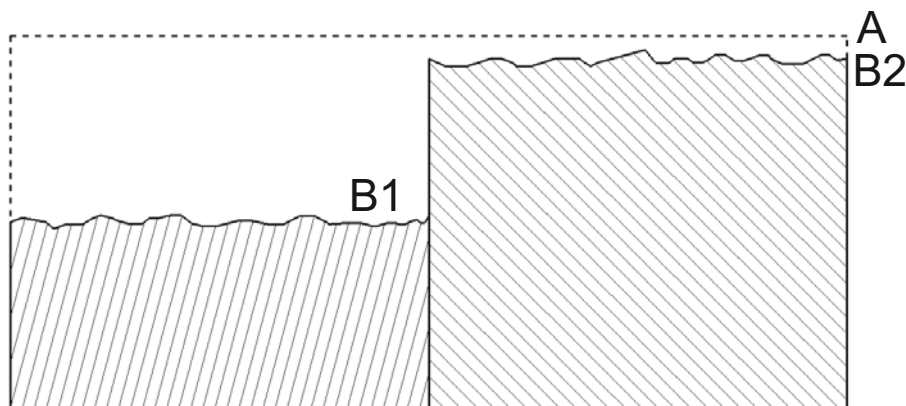


Materials of different resistance exposed to the same media but not in contact with each other

A... Starting level

B<sub>1</sub> B<sub>2</sub>... Reduction of thickness depending on the material's resistance to corrosion

### Example 2:



Materials of different resistance to the same aggressive medium and in contact with each other

A... Starting level

B<sub>1</sub> B<sub>2</sub>... Greater dissolution of the less resistant alloy 1, while the more resistant alloy 2 is protected electrochemically and the corrosive attack thus reduced.

The driving force behind contact corrosion is the potential difference of a pair of metals. The less noble material (alloy 1 in fig. 4) suffers greater corrosion and acts electrochemically like an anode, while the more noble material (alloy 2) acts like a cathode and suffers less corrosion. Whereas, in example 1, the two metals are linked only by the surrounding medium, in example 2 they are in direct electrical contact, which clearly increases the rate of corrosion of the less noble metal. The nobler metal is protected electrochemically in this way.

Fig. 4 : Schematic representation of contact corrosion



This is a typical case of contact corrosion. Here, zinc plated carbon steel and Cr/Ni steel were used together. The noble metal, the Cr/Ni steel, has the largest surface area which first causes heavy corrosion of the washer.

### Three factors affect the rate of attack during bimetallic corrosion

1. The difference in free corrosion potentials of the metals in contact
2. The surface condition of the metals in contact
3. The conductivity of the electrolyte

A positive example of active utilization of the bimetallic corrosion phenomenon described here is the way zinc protects carbon steels and low-alloyed steels. Zinc is the less noble metal which actively protects steel by suffering corrosion itself. To avoid bimetallic corrosion, the ratio of the surface areas of linked components must be taken into account. A fastener is always the smaller part of a system; it must be made of an equivalent or a more noble material than the components to be fastened. To avoid bimetallic corrosion around a fastener, measures such as galvanic separation, sealing the point of contact, etc., are necessary. (See active protection against corrosion.)

## 5.3 Pitting corrosion

Passive metals and alloys, such as aluminium alloys, titanium, chromium steels and chromium-nickel steels owe their resistance to corrosion to passivation (oxide) layers on their surface with a thickness of only a few nanometers. A local attack of corrosion can be initiated on stainless steels, for example, by only very small quantities of halogenides (anions: chloride, bromide and iodide). These anions are generally chlorides from sea water, road salt, etc.. The initiating process starts with a local break-down of the passivation layer due to halogenides. These local break-downs can be the starting point for different dangerous corrosion phenomena. In the following, the most significant of these corrosion phenomena, and how they affect stainless steel, are discussed with regard to their relevance for fasteners.

Pitting corrosion takes place when a critical electrode potential is exceeded (critical pitting potential). Each material has a different potential which is influenced by the surrounding medium and the surface quality of the metal.

The appearance of pitting corrosion on stainless steels depends greatly on many factors:

- Type, temperature, concentration and pH-value of the oxidizing agent
- Chemical composition of the steel (chromium, molybdenum and nitrogen)
- Microstructure of the metal
- Surface conditions present on the metal

The resistance of stainless steels to pitting corrosion can be roughly estimated by the PRE (pitting corrosion equivalent). The PRE is based on the chemical composition of steel, taking into account the amount of chromium, molybdenum and nitrogen. Different equations for the calculation are given in literature, the most common ones being:

- $PRE = \%Cr + 3.3 \times \%Mo$   
(for stainless steels with molybdenum content of < 3%)
- $PRE = \%Cr + 3.3 \times \%Mo + 30 \times \%N$   
(for stainless steels with molybdenum content of > 3%)

Pitting corrosion can be very dangerous. Whereas uniform corrosion can be seen clearly on the surface, pitting corrosion is often indicated only by small pinholes on the surface. The amount of material removed below the pinholes is generally unknown, i.e. hidden cavities may form. Rough surfaces, areas with local impurities on the surface or local plastic deformation can initiate pitting corrosion. Shallow corrosion and pitting corrosion are differentiated by the ratio of the diameter and depth of the corrosion attack. When the depth of corrosion is greater than its diameter, the term pitting corrosion is applied.

The process of pitting corrosion is defined by several steps as shown in fig. 5.

First step: Breakdown of the passivation layer due to halogenides.

Second step: The second step decides whether or not actual pitting will take place.

a) In the presence of sufficient oxygen and humidity, the surface can repassivate.

A passive film forms again over the pit produced by the break-through, i.e. repassivation or healing. No further corrosion attack takes place.

b) The other case shows the situation in which the surrounding conditions do not permit repassivation. The material is overtaxed. Stable growth of the pit takes place. This is now referred to as pitting corrosion which, depending on the circumstances, can propagate into a component. Rates of corrosion of more than 10 mm per year are not unusual.



Pitting of a fastener made out of DIN 1.4301 (AISI 304) material (competitor's product).

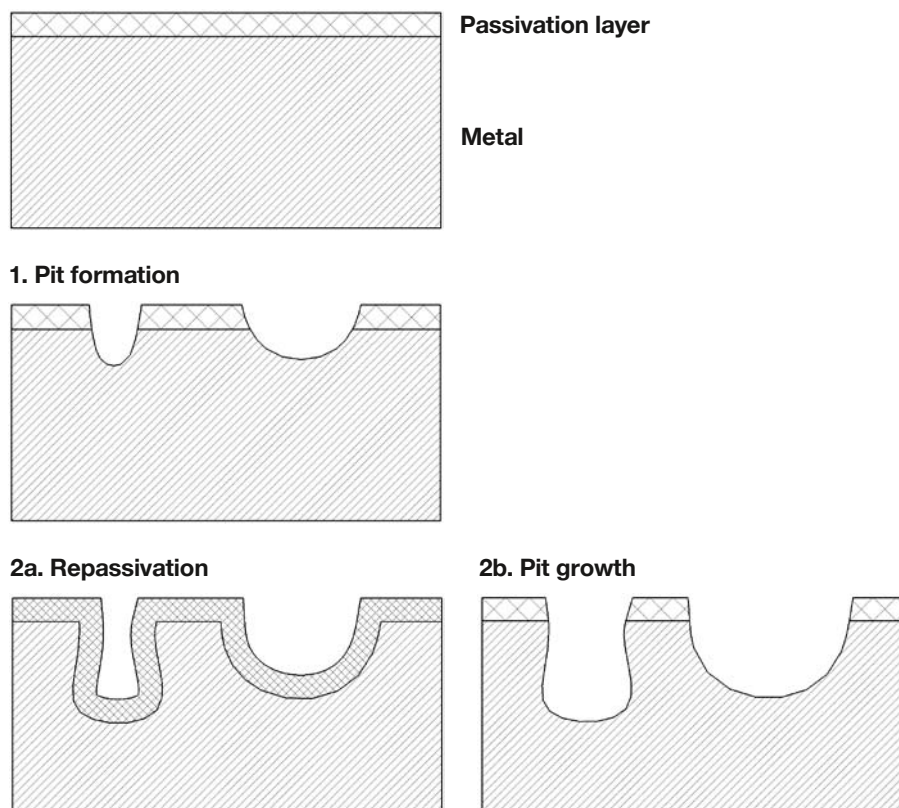


Fig. 5: Schematic representation of pitting corrosion

## 5.4 Crevice corrosion

Crevices can occur under coatings, deposits or due to the design of the parts. Crevice corrosion is relevant for stainless steels or other passive materials like aluminium. This type of corrosion is initiated by a decrease in the oxygen content. Due to low oxygen concentration, no formation of passive layers can be achieved. A local differential aeration cell is formed, where the dissolution of metal is in the crevice and the reduction of oxygen takes place outside the crevice. In addition, the chemical composition of the electrolyte can change and the speed of corrosion increases. It must be noted that the critical crevice width is about 2mm. The narrower the crevice, the more critical will be the situation. The minimum critical crevice width is in the order of several hundredths to tenths of a millimeter. In view of this, deposits of dust, for example, can often be more critical than the gap between the anchor and its bore-hole. As a practical example, the different positions of possible crevice corrosion on an anchor fastening are shown in fig. 6.

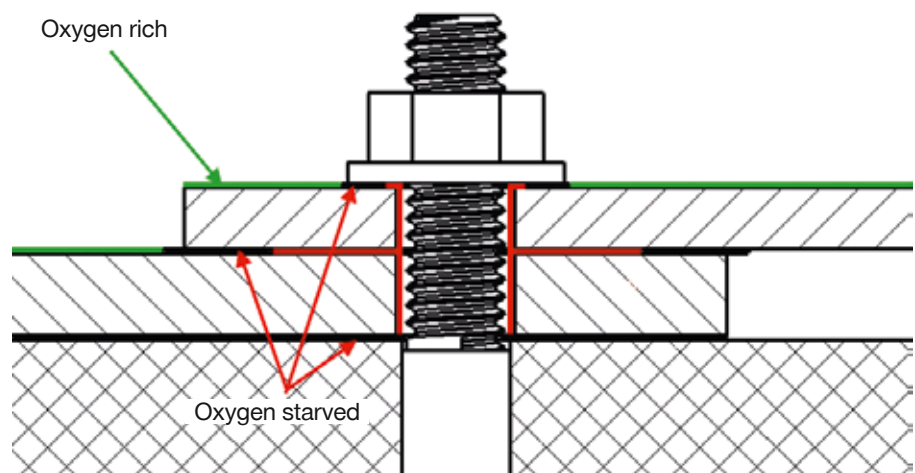


Fig. 6: Critical points for crevice corrosion at a fastener.

## 5.5 Stress corrosion cracking (SCC)

This corrosion phenomenon occurs only in the presence of certain mediums and when a component is subjected to a static tensile load. Internal stresses in a material can be sufficient to initiate an attack of stress corrosion cracking leading to sudden failure. This means, that the surrounding and environmental conditions always have to be taken into account when selecting materials in order to prevent failure. It is well known, that Cr-Ni and Cr-Ni-Mo steels can suffer stress corrosion cracking in an environment containing chlorides (chlorinated atmospheres in indoor swimming pools, road tunnels, etc.).

Stress corrosion cracking occurs only when different conditions are present at the same time:

- Sensitive material
- Specific media
- Critical tensile stresses

Fig. 7 below shows the interaction of material, environment and tensile stress which leads to stress corrosion cracking.

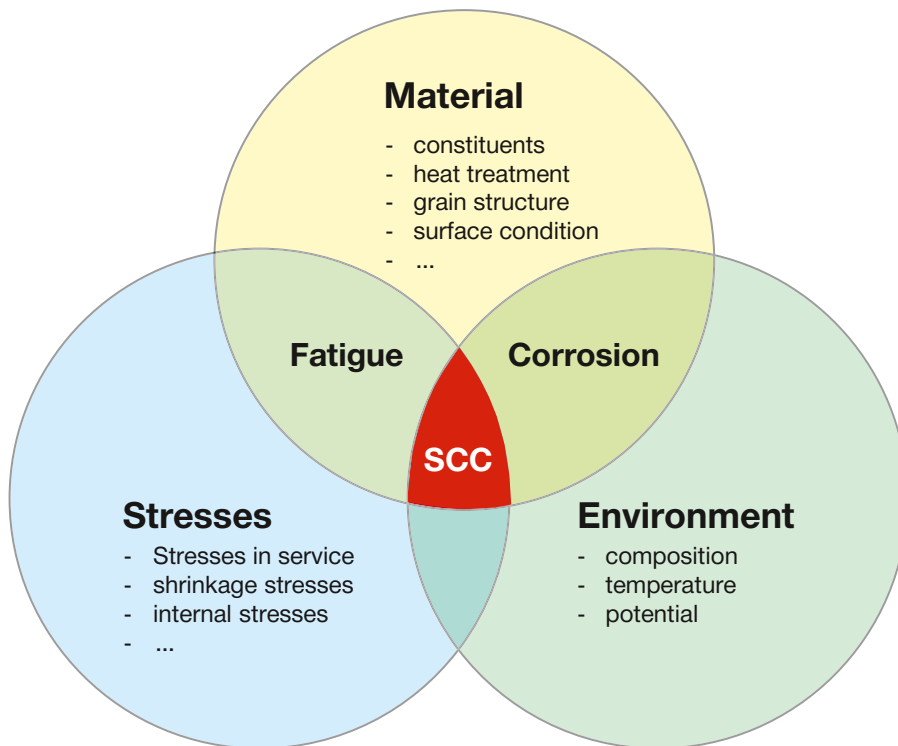


Fig. 7: Interactions resulting in stress corrosion cracking

Usually, most of the surface remains unaffected, but fine cracks penetrate into the material. These cracks can have an intergranular or a transgranular morphology. SCC fractures have a brittle appearance. Unfortunately, SCC is a catastrophic form of corrosion, as the detection of fine cracks is normally very difficult and the damage therefore cannot be easily predicted.

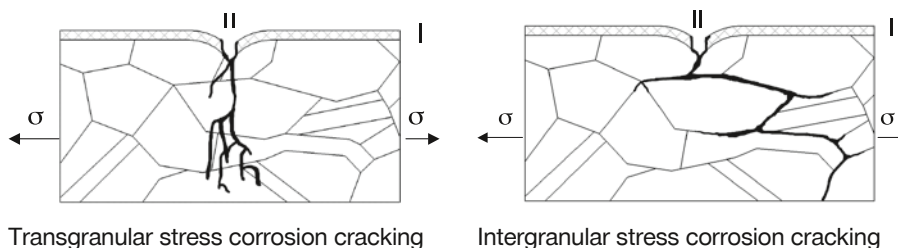


Fig. 8: Schematic representation of possible cracking phenomena. Crack propagation can be transcrystalline, i.e. through the middle of a grain, or intercrystalline, i.e. along grain boundaries.

I... Passivation layer

II... Local breakdown of passivation layer and stress corrosion cracking, propagating more or less at right angles to tensile stress.

The crack sides repassivate. The material at crack surface peaks is attacked.

$\sigma$ ... Tensile stress

In addition, a distinction is made between electrolytic stress corrosion cracking (anodic metal dissolution as described above) and metallophysical cracking (cathodic absorption-induced brittle failure) – hydrogen embrittlement (hydrogen dissolved in the metallic lattice).

With high-alloy stainless steels, stress corrosion cracking is synonymous with anodic SCC, whereas embrittlement due to hydrogen is the case with high-strength steels.



This shows SCC of a retaining strap made of the material 1.4301 (A2, 304) after approx. 4 years of use in an indoor swimming pool (CH).





This galvanized nail was used in a corrosive industrial environment. The cause of failure was secondary (corrosion-induced) hydrogen embrittlement.

## 5.6 Hydrogen embrittlement

Hydrogen embrittlement is one of the most dangerous corrosion phenomena. No products of corrosion can be seen at the surface of the material. Inside, however, cracks can be formed due to hydrogen diffusion.

Sudden failure can occur without previous visible indication.

Hydrogen embrittlement is only relevant for high-strength steel with a strength of approximately 1000 MPa or higher.

As with SCC, three different conditions must be present at the same time:

- Hydrogen
- (Internal) stresses
- High-strength steel

A distinction is made between primary hydrogen embrittlement and secondary hydrogen embrittlement (hydrogen-induced stress corrosion cracking).

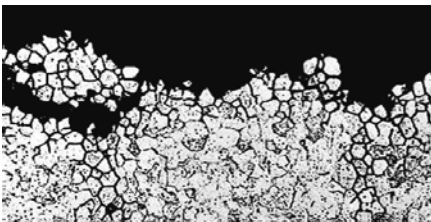
Primary hydrogen embrittlement can result from production processes:

- Electroplating
- Pickling
- etc.

Risk of primary hydrogen embrittlement can be reduced by tempering at about 200° C for several hours. After this treatment, the amount of dissolved hydrogen is significantly reduced.

Secondary (corrosion-induced) hydrogen embrittlement occurs with high-strength components that have already suffered an attack of corrosion. During this corrosion process, hydrogen is formed and diffuses into the material. This leads to a decrease in the ductility of the metal.

Please note: The higher the strength of the material, the greater will be the risk of hydrogen-induced stress corrosion cracking.



## 5.7 Intercrystalline (intergranular) corrosion

Intercrystalline corrosion is a special form of local corrosion, where the corrosion attack takes place next to the grain boundaries.

Example:

If the austenitic, chromium-nickel-molybdenum steel (1.4401) is kept in the temperature range from 500 °C to 800 °C for a considerable time, e.g. by welding processes etc., chromium carbides can separate at grain boundaries, resulting in chromium depletion near these boundaries.

Remedy: The carbon content must be reduced to below 0.03 percentage by weight and / or the metal “stabilized” by adding titanium or niobium. An example of “stabilized” materials of the A4 (316) grade are the titanium-stabilized material 1.4571 (316Ti) and the low carbon steel 1.4404 (316 L < 0.003 % C).

(Please note: Fasteners should never be welded.)



Micrograph of a metal and scanning electron microscope image of a selective attack (welded zone of a 1.4401 (A4, 316) material).

## 5.8 Corrosion fatigue cracking

Transcrystalline cracks can result from alternating mechanical stress with simultaneous corrosive action. This cracking is independent under critical limiting conditions, i.e. any material-medium combination can be affected and there is no minimum loading limit. Hardly deformed, mainly transcrystalline cracks appear, which can lead to sudden failure of a component. Corrosion fatigue cracking is often also called corrosion fatigue.

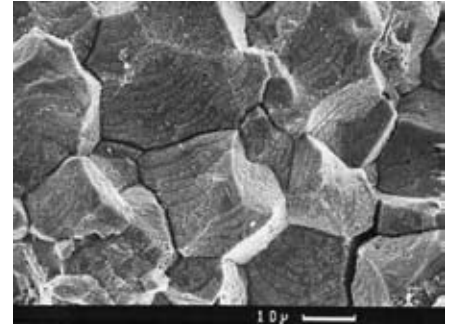


Image of a fracture after corrosion fatigue cracking of an anchor made of A2 (304) steel as per DIN 1.4301 (Source: Nürnberger)

## 5.9 Strain-induced corrosion

This is a form of stress corrosion cracking resulting from critical strain. It is a consequence of damage to protective layers and repeated critical extension or contraction of a component.

## 5.10 Microbial corrosion (bacterial corrosion)

Microbial corrosion is a type of corrosion in which microorganisms play a role, for example, by producing aggressive electrolytic solutions.

## 5.11 General points

In most cases, different forms of corrosion are present at the same time. During the corrosion process, the conditions and therefore the speed of corrosion changes. Despite continually increasing knowledge in the field of corrosion and extensive reference literature, it is often extremely difficult, even for specialists, to understand or explain certain corrosion processes. Consequently, widely differing experts' opinions and models exist for certain corrosion processes.

Even when knowledge of corrosion processes is available, a clear explanation of individual corrosion processes is sometimes very difficult to provide. Especially with hydrogen embrittlement, the scientific background is still not fully understood today.

## 6. Corrosion protection

The aim of corrosion protection is to increase the components service life expectancy. A distinction is made between active and passive protection. Active corrosion protection is the measures, like advance planning and design, that take corrosion into account, e.g. galvanic separation, resistant materials, protective measures in the medium and protection by impressed current systems. Passive protection is regarded as all measures which affect the component directly and by which medium access is stopped or hindered. This can be, for example, metallic or non-metallic protective coatings.

**Which types of corrosion protection are used by Hilti and how are Hilti fasteners and fastening systems protected against corrosion?**

Corrosion protection / materials	Used by Hilti
Polymers	Polyamide, polypropylene, polyethylene, POM
Organic coatings	Epoxy, acrylate and similar
Organic coatings with metallic contents and multiple-layer coatings	Duplex coatings (Zn + Topcoat); Zn flake coatings
Zinc-coated steel	Electrochemically zinc plated, sherardized, hot-dipped galvanized, Sendzimir zinc plated, etc.
Corrosion-resistant steels	Stainless steels, special alloys
Additional measures	Galvanic separation, etc.

Table 1:  
Corrosion protection systems  
used by Hilti

### 6.1 Polymers

Polyamide is characterized by good chemical resistance, and it is used by Hilti for light-duty plastic anchors.

Plastic fasteners suitable for the respective application are used to install insulating materials and as other connecting parts. Attention is paid to good chemical resistance and, where necessary, to long-term resistance to UV light.

RE 500, HEA, HVU, etc. are used for chemical fastenings, i.e. adhesive anchors and injection systems. Synthetic resin, hardener and fillers are formulated for each other so accurately that there is only very slight shrinkage, tendency to creep and water absorption. Resistance to alkaline, saline solutions and acids is very good.

### 6.2 Organic coatings

Organic coatings provide passive protection against corrosion, i.e. they stop or delay the access of corrosive mediums to a component surface. For optimal corrosion protection, the organic coatings have to be free of pores and mechanical damage (i.e. scratches) and complete adhesion must be ensured. In practice, all of these requirements are difficult to meet with fasteners for the following reasons:

Surfaces of fasteners are very often functional and their tribological properties are crucial for the function under relatively high mechanical loading and exposure to corrosion, e.g. threaded parts. This is the reason why only organic coatings of restricted thickness can be used. With thin coatings it is difficult to achieve a surface without pores. In most cases, the coating can be damaged during application.



## 6.3 Zinc flake coatings

Zinc flake coatings were invented with a view to protecting high strength steel products against corrosion. Whereas typical corrosion protection by using galvanizing or hot dipping processes for creating zinc layers can influence the characteristics of the underlying steel, these risks will normally not occur when zinc flake coatings are used because of the different temperatures used for zinc resp. zinc flake coatings. The structure of a zinc flake coating is often characterized by an inorganic matrix and embedded zinc flakes. Often, a top coat is also used. Cathodic protection is provided by the conductivity between the single flakes as well as between the flakes and the steel substrate.

## 6.4 Zinc-coated steel

The free corrosion potential of zinc is more negative than the free corrosion potential of steel. Zinc coatings on steel provide sacrificial cathodic protection against corrosion for the underlying steel surface even if the surface is damaged up to the ground material. In case of coating damage and under corrosive conditions, zinc donates its electrons to the steel. Due to this reaction, the steel will be protected. However, the zinc removal rate in regions close to the scratch will increase.

Generally, the rate of zinc corrosion is more or less linear with respect to time, depending on the atmosphere. Consequently, the duration of protection against corrosion is directly proportional to the plating thickness.

Atmosphere	Mean zinc plating surface removal per year
Rural	1 – 2 microns
Urban	3 – 5 microns
Industrial	6 – 10 microns
Coastal / marine	5 – 9 microns
Corrosion-resistant steels	Stainless steels, special alloys
Additional measures	Galvanic separation, etc.

Table 2  
Rates of zinc removal in various surroundings as per Corrosion Handbook, Kreysa, Schütze, 9/2009.

Consequently, a doubling of the zinc thickness will lead to a doubling of duration of protection. The desired duration of protection thus governs selection of the zinc-plating process and thickness.

### Corrosion behavior of zinc and zinc alloys

Zinc generally corrodes uniformly under atmospheric conditions. The products of zinc corrosion; formed by water, oxygen and  $\text{CO}_2$ ; are white to grey and this is referred to as white rust. On zinc-iron alloy coatings, e.g. hot-dipped galvanized or sherardized coatings, the products of corrosion are red-brown. Red rust is the name given to the products of corrosion of the underlying carbon steel. It appears at defects and / or after the zinc plating has weathered away. The products of zinc corrosion, which are primarily basic zinc carbonates, form a protective layer that slows down the corrosion rate. If exposed to the atmosphere, this protective layer is slowly removed by the atmosphere. During atmospheric corrosion, zinc corrodes approximately ten times slower than carbon steel. In an atmosphere loaded with sulphur dioxide (industrial climate), the protective layer (zinc carbonate) cannot form. As a result of the reaction with sulphur dioxide and oxygen-soluble zinc, a sulphate is formed and can be easily washed away by rain. The rate of zinc corrosion in an industrial atmosphere is therefore higher than in a rural or urban atmosphere. In atmospheres with a high relative humidity and hindered ventilation, the protective layer of zinc cannot be formed.

Use of zinc where it is immersed in water or in damp insulating materials is thus not permitted.

The application of zinc coatings is therefore highly dependent on the surroundings (pH-value, humidity, ...) which influence the rates of corrosion.

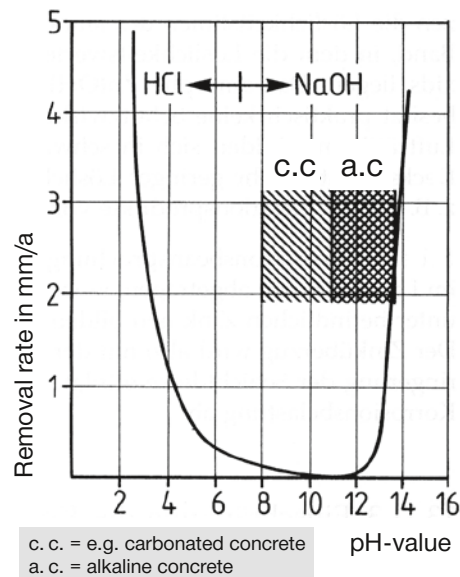


Diagram 1: Ranges of resistance of zinc coatings in relation to pH value

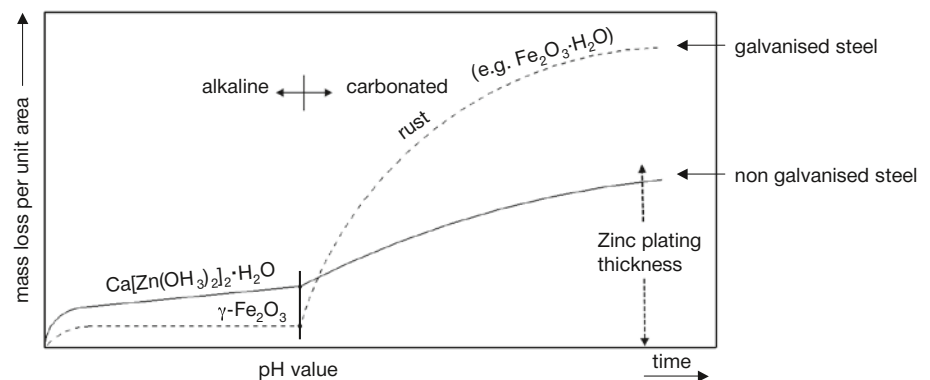


Diagram 2: Ranges of resistance and corrosion behavior of galvanized and non-galvanized steel in alkaline and carbonated concrete [source: Nürnberger]

The behavior of, for example, zinc-plated fasteners in concrete, can be calculated by using the foregoing diagrams 1 and 2. In general, the alkalinity of concrete protects a zinc plated fastener as long as the concrete is not carbonated (pH approx. >11). Although the rate of corrosion or rate of zinc removal in fresh concrete is higher than that of the underlying steel, zinc-plated fasteners can still be used without second thoughts. As a rule, the part of a zinc-plated fastener covered by the concrete is protected against corrosion for a very long time. If possible, zinc-plated fasteners should not be placed in very fresh concrete (less than 28 days old) because this can dissolve the zinc and thus reduce the life expectancy, especially in the transition zone to the atmosphere. However, even if the zinc coating is dissolved in this zone, protection against corrosion of the base material (bare carbon steel) is still very effective in alkaline concrete. This is why, for example, reinforcing bars are very well protected against corrosion as long as the surrounding concrete is sufficiently alkaline. If, however, the concrete loses alkalinity due to carbonation processes, etc., or is already carbonated, the rate of corrosion or rate of removal of both the zinc coating and the carbon steel will be much higher than in the alkaline zone (see diagrams 1 and 2: carbonated zones).

### Zinc-coating processes used by Hilti

There are many different zinc plating processes. Which one is used depends on the application as well as on the shape and size of the product.

Process	Products
Electrochemical zinc plating	DX nails and threaded studs, anchors, M installation system
Sendzimir zinc plating	Anchor parts, MQ installation system
Sherardizing	Anchors
Hot-dip galvanizing	Anchors, MQ installation system
Others	Miscellaneous
Additional measures	Galvanic separation, etc.

Table 3: Zinc-coating processes used by Hilti

## 6.5 Electrochemical zinc plating (galvanizing)

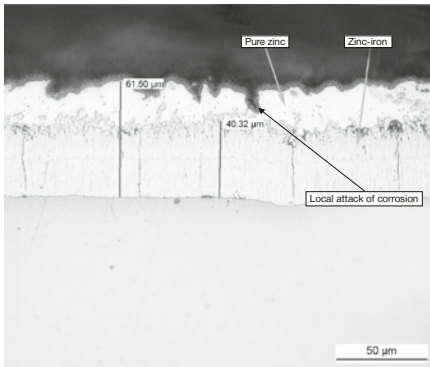
During electrochemical zinc plating, pure zinc or zinc alloy is deposited on steel from a zinc salt solution by applying an electrical voltage. The adhesion of the layers is good. The achievable layer thicknesses are limited to approximately 25 microns. Typically, electrochemically zinc-plated fasteners have a zinc thickness of at least 5 to 13 microns and, with few exceptions, they have a blue passivation. This gives them adequate protection against corrosion for use in dry indoor rooms. If they are exposed to moisture though, the corrosion rate increases due to condensation from the surrounding air.

## 6.6 Sendzimir zinc plating

During the Sendzimir process, sheet metal is drawn continuously through a bath of molten zinc after the surface has been cleaned. The thickness of the coating, which is generally about 20 microns on both sides, is controlled by removing zinc with a jet of air or steam. Sendzimir-plated sheet metal can be used for connector parts such as hangers or anchor sleeves and of course for installation channels.

## 6.7 Sherardizing

Sherardizing is a method of galvanizing also called vapor galvanizing. It is a diffusion process. During this process, zinc powder diffuses into the surface of metal parts. In this drum process, temperatures between 320° and 420°C are usual. Even on complicated threaded parts, this process produces wear and temperature-resistant, uniform zinc coatings. These zinc coatings consist of layers of Zn/Fe alloys which offer very good protection against corrosion that can be compared with hot-dip galvanizing. The achievable coating thicknesses range up to 45 microns.



Micrograph of a hot-dip galvanized steel with local points of corrosion in the zinc layer (white rust)

## 6.8 Hot-dip galvanizing

During the hot-dip galvanizing process, steel parts are dipped into a bath of molten zinc and are removed after a defined time. The thickness of the layer depends on the material thickness, the duration of dipping and other conditions. The typical thicknesses achieved are between 35 and 70 microns.

Coating composition after conventional, hot-dip galvanizing:

1. Layers of Zn/Fe alloys
2. Formation of a thin, overlying layer of pure zinc which gives the coated part a bright appearance (zinc spangle). The formation of a pure zinc layer depends on the reactivity of the underlying steel.

A coating thickness between 45 and 60 microns can be achieved on threaded parts and anchors. Hot-dip galvanized parts with a well-developed layer of pure zinc first suffer white rusting, i.e. the product of corrosion of the pure zinc layer. Afterwards, when the pure zinc layer has dissolved or broken down, brown rust appears, i.e. the product of corrosion of the Fe/Zn alloy layer. Brown rusting appears immediately on hot-dipped galvanized if the pure zinc layer is not present.

## 6.9 Corrosion-resistant steels

Corrosion-resistant materials form a protective passivation layer on their surface. This reaction depends on the material and the specific surrounding medium. Under atmospheric conditions, materials such as aluminium and stainless steels are known as corrosion-resistant.

### Stainless steels

In comparison to carbon steel, stainless steels have a chromium content of more than 12 wt%. A chromium oxide layer is formed as the result of a very short and intensive corrosion reaction. This invisible layer is very thin, less than 10 nm, with good adhesion properties and is normally without defects, resulting in very good corrosion protection.

After incurring damage, the oxide layer is reformed (repassivation) if oxygen and humidity are present. Under special circumstances, the passivation layer can be locally destroyed and repassivation is not possible. This leads to local corrosion, e.g. pitting corrosion.

In the past, this has led to certain concerns, especially after an accident at an indoor swimming pool at Uster in Switzerland. Subsequently, the trend for some time was completely away from use of stainless steels, reverting to “traditional” materials such as hot-dip galvanized steel. Nowadays, however, considering the material’s properties, the mechanisms of corrosion and the application limits, it is clear that stainless steels are the only meaningful solution for many applications from a technical as well as cost-efficiency point of view. In the meantime, stainless steels have been fully accepted in many areas of everyday life, not least due to price developments. The main fields of application for stainless steel fasteners and connectors are in road construction, bridge building, facade installation, the fabrication of industrial equipment and waste-water technology. A general answer cannot be given to the question of where the limits to the use of various materials lie. Apart from the surrounding conditions, the strength and state of processing as well as design features have an influence on the corrosion behavior of stainless steels. Many different aspects have to be considered when critical applications are involved and these sometimes make long-term

field tests and other measures necessary. For many years, Hilti has conducted long-term field tests in a variety of highly corrosive environments.

The following mediums can lead to corrosion of stainless steels:

- Very acidic medium (mineral acids, etc.)
- Oxidizing or reducing mediums (chlorine gas, hypochlorite, NO<sub>x</sub>, HCl, etc.)
- Substances containing halogenides, e.g. road salt, sea water, etc.
- Combinations of mediums containing chlorides and acids
- Poor ventilation, inadequate access of oxygen to crevices and beneath deposits, etc.

### Designations of stainless steels

A range of designations (standards) for stainless steels exist in industrial countries. The most important ones have been given here for the sake of a better understanding. The American Iron and Steel Institute (AISI) has a designation system that is used world wide. It consists of a number to which one of several letters are sometimes added.

200 – designates an austenitic steel containing chromium, nickel and manganese

300 – designates an austenitic steel containing chromium, nickel

400 – designates ferritic and martensitic chromium steels

### The additional letters (some shown below) indicate the following:

- L = low carbon  
 N = nitrogen  
 Se = selenium / easy machining  
 Ti = titanium  
 F = easy machining  
 Nb = niobium

Similarly, the German system of numbering materials in accordance with DIN is used in several countries. Each number has five digits, such as 1. 4404.

The digit “1” stands for steel, the next two digits “44” stand for chemical-resistant steels containing Mo, but no Nb or Ti. The last two digits “04” designate the exact alloy. In addition to the designation “44”, the following designations for stainless steel exist:

- “40” = without Mo, Nb, Ti, Ni < 2.5 %  
 “41” = with Mo, without Nb and Ti, Ni < 2.5 %  
 “43” = without Mo, Nb and Ti, Ni ≥ 2.5 %  
 “44” = with Mo, without Nb and Ti, Ni ≥ 2.5 %  
 “45” = with additional elements

In Germany and other European countries, an abbreviated form of designation according to the chemical analyses of materials is also in use (see DIN EN 10088.)

For example: X 2 Cr Ni Mo 17 12 2

- X = High-alloy steel  
 2 = Carbon content in 1 / 100%, in this case: C= 0.02%  
 Cr = Chromium, in this case: 17%  
 Ni = Nickel, in this case: 12 %  
 Mo = Molybdenum, 2%

This steel corresponds to the AISI type 316 L and the DIN material no. 1.4404.

Designation V2A (A2) or V4A (A4):

In some countries (D, CH and A) the designation V2A (A2) or V4A (A4) has become accepted, especially in the construction industry. This designation can be traced back to the early days of stainless steel production. It is the brand designation used by a steel manufacturer. V2A steels are understood to be the group of austenitic CrNi steels without molybdenum, whereas austenitic steels of the V4A grade contain at least 2% molybdenum. Accordingly, this designation provides an initial indication of corrosion resistance.

The usual designations for fasteners made of austenitic stainless steels are explained in ISO 3506.

A4-70 as an example:

A = Austenitic stainless steel (also possible, F = ferritic, C = martensitic)

4 = Chromium-nickel-molybdenum steel

70 = Tensile strength of 700 N/mm<sup>2</sup> (strain hardened)

According to German construction supervisory authority approval Z-30.3-6 dated April 20, 2009, corrosion-resistant steels are grouped in various corrosion resistance categories (WK = Widerstandsklasse, i.e. German for "resistance category").

Material no.	Short designation	AISI	WK (DIBT Z.30.3-6)
1.4301	X5CrNi18-10	304	II
1.4401	X5CrNiMo17-12-2	316	III
1.4404	X2CrNiMo17-12-2	316L	III
1.4571	X6CrNiMoTi17-12-2	316Ti	III
1.4362	X2CrNiN23-4	---	III
1.4462	X2CrNiMoN22-5-3	---	IV
1.4565	X2CrNiMnMoNbN25-18-5-4	---	IV
1.4529	X1NiCrMoCuN25-20-7	---	IV

Table 4: Stainless steels used by Hilti for most fasteners and connectors

#### Hilti HCR products (highly corrosion-resistant)

HCR products are made of 1.4529 material, which is recommended by Hilti for anchor fastenings in atmospheres containing chlorides (road tunnels, indoor swimming pools and in sea water) where high safety requirements must be met.

As a result of long-term field tests carried out by Hilti, the use of stainless steels other than HCR is not recommended for safety-relevant fastenings in the fields described above. More information about field tests in road tunnels is available in another Hilti brochure. Please ask your Hilti representative.

#### Hilti X-CR direct fastening products (corrosion-resistant)

X-CR material is a stainless steel of the WK4 category, and has a very high strength. It is used for direct fastening applications (i.e. threaded studs and nails driven by powder-actuated and gas-actuated tools). This material was developed jointly by Hilti and a steel manufacturer. X-CR has a higher chromium and molybdenum content than 1.4401, and therefore higher corrosion resistance according to PRE.

## 6.10 Materials for special applications

In addition to those already mentioned there are, of course, numerous other materials available on the market. Only the most common materials and those mainly used for Hilti products are discussed in this brochure. A very high number of materials and material combinations have been investigated in the past in laboratory tests and field tests. This has been done in order to take unusual environmental conditions into account or to meet the requirements of special applications. However, in some cases, these materials are difficult to handle during production or the basic material costs are higher. This usually results in higher product costs.

With regard to corrosion resistance as defined, for example, by the pitting resistance equivalent PRE (described earlier in this brochure) for stainless steels, it must be pointed out that materials with high potential for Hilti products also exist. Duplex materials such as 1.4162, 1.4362 or 1.4462 with a combined austenitic and ferritic microstructure, higher chromium content and lower nickel content compared to 1.4301 and 1.4401/1.4404 stainless steels, are a few examples. At the moment, however, only some of these materials are approved for applications in the construction industry. Hilti is, nevertheless, in a position to produce products made from these materials and other materials if necessary. In certain surroundings, where stainless steels corrode, materials of even higher resistance, such as titanium and some nickel-based alloys, can be used. Please ask your Hilti representative for further information if you need special materials for a particular application.

## 6.11 Designs against corrosion

To avoid corrosion problems, some guidelines must be taken into account. A summary is given in EN ISO 12944-3:1998. Some important factors are:

- Crevices
- Accessibility
- Threaded fastening
- Edges
- Avoidance of contact corrosion
- (Precautionary measures to avoid deposition)

Further information is provided in the section "Forms of corrosion".

## 6.12 Avoidance of contact corrosion

Contact corrosion is described in section 5.2. It can be avoided through the right choice of material combinations. This, however, is not always possible, so that other measures have to be taken into account. One example is galvanic separation of the different materials, as shown in fig. 9.

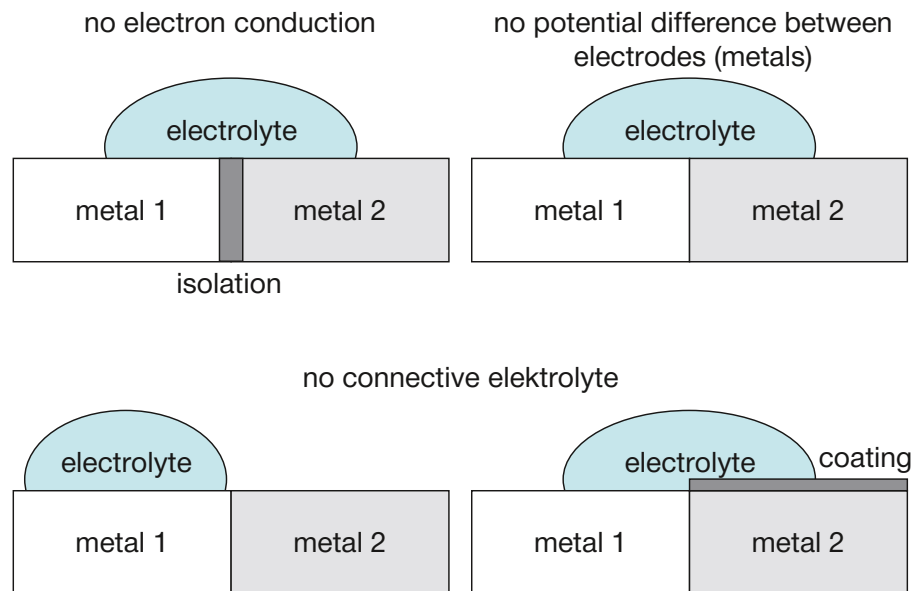
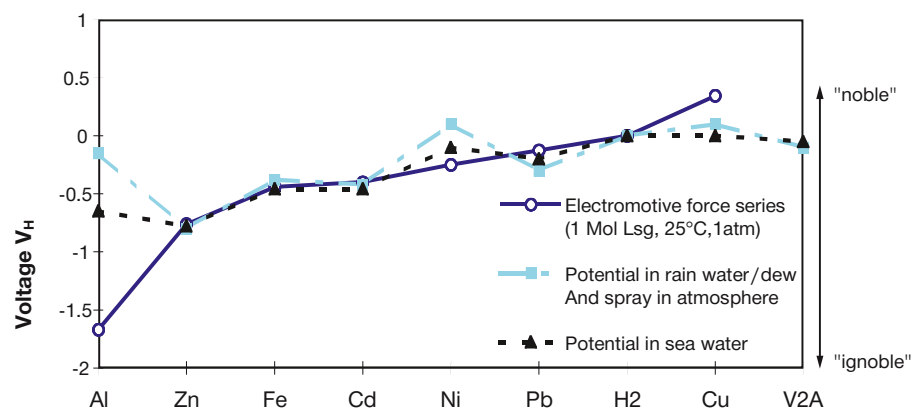


Fig. 9: Conditions for bimetallic coupling without risk of corrosion.

Diagram 3: Shows the free corrosion potential of various materials in different environments.



To avoid contact corrosion, the difference in free corrosion potential between the materials should be as low as possible, and/or the surface ratio of anode/cathode should be very high. Typical values of the free corrosion potentials in different electrolytes are shown in diagram 3. The designer should always bear in mind that the reinforcement in concrete can also be one of the metals forming a pair in contact. Rebars are often very noble.



Table 5 shows the suitability of metals when in contact with each other. It also shows which metal combinations are permitted in practice and which should be avoided.

Fastened part	Fastener					
	Galva-nized steel	Hot-dip galva-nized	Alu-minum alloy	Struc-tural steel	Stain-less steel	Brass
Galvanized steel	+	+	+	+	+	+
Hot-dip galvanized	+	+	+	+	+	+
Aluminum alloy	-	±	+	+	+	+
Structural steel	-	-	-	+	+	+
Cast steel	-	-	-	±	+	+
Chromium steel	-	-	-	-	+	±
CrNi(Mo) steel	-	-	-	-	+	-
Tin	-	-	-	-	+	±
Copper	-	-	-	-	+	±
Brass	-	-	-	-	+	±

+ slight or no corrosion of fastener

- heavy corrosion of fastener

± moderate corrosion of fastener

Table 5: Risk of bimetal corrosion under atmospheric conditions

## 7. Selection of a suitable fastener

If a fastening has to be perfectly satisfactory and reliable for its entire service life, all surrounding conditions, must be ascertained before a suitable fastener can be selected.

When selecting suitable materials and systems for corrosion protection, consideration must be given to the desired service life, technical safety aspects and last, but not least, the appearance of the parts (color, brightness, etc.). Therefore, it is necessary to take into account where the parts are installed, indoor or outdoor. For outdoor applications, a distinction is made between: rural, urban, industrial and marine atmospheres. Nevertheless, there are special applications like waste water treatment plants, industrial installations, road tunnels and swimming pools. In view of this, each application must be evaluated separately and the findings considered when selecting a material with the required corrosion behavior or a system that provides adequate corrosion protection. Products must be designed to avoid crevices and cavities where contaminants can build up. When material combinations are used, an evaluation of their electrochemical behavior has to be performed to avoid contact corrosion.

Another point of crucial importance when selecting a fastener or material for a practical application is its actual relevance to safety in each case. Legislation, regulations and building codes often apply and these must be observed by whoever carries out the fastening work.

It is important that the users in charge of the work are well informed about possible suitable solutions, but it is even more important that they are aware of the potential risk of using an unsuitable material. If any uncertainty exists, it is absolutely essential that you consult a corrosion specialist. Your local Hilti technical staff can provide you with contacts. The information in the following section may be of assistance as it provides some important points that aid selection. The table, however, cannot cover all individual aspects for each application.

## 8. How does Hilti solve the corrosion problem in practice?

The table 6 can be used to select the necessary corrosion protection system for the fastener and structure.

Impact	Exposure	Surroundings	Examples	Stainless steel WK				Carbon steel with zinc coating			Others
				I	II	III	IV	galv. Zinc <sup>5)</sup>	HDG <sup>6)</sup>	HDG plus <sup>7)</sup>	
Humidity, annual average value U	SF0	dry	U < 60 %								
	SF1	rarely wet	60 % < U < 80 %								
	SF2	often wet	80 % < U < 95 %								
	SF3	mostly wet	95 % < U							8)	
Chloride content of surroundings, distance M from sea, distance S from roads with high traffic volume and de-icing salt in use	SC0	low	countryside, town M > 10 km, S > 0.1 km								
	SC1	medium	industrial zone, 10 km > M > 1 km, 0.1 km > S > 0.01 km								
	SC2	high	M < 1 km S < 0.01 km			1)					
	SC3	very high	indoor swimming pools, road tunnels			2)				8)	
Redox-effective Substances(S O <sub>2</sub> , Cl <sub>2</sub> , H <sub>2</sub> O <sub>2</sub> )	SR0	low	countryside, town								
	SR1	medium	industrial zone			1)					
	SR2	high	indoor swimming pools, road tunnels			2)				8)	
pH-value at the surface	SH0	neutral	5 < pH < 9								
	SH1	alkaline (e.g. contact with concrete)	pH > 9					9)	9)	9)	9)
	SH2	slightly acidic (e.g. contact with wood)	3 < pH < 5					10)	10)	10)	10)
	SH3	acidic	pH < 3								
Exposure of the parts	SL0	indoor	heated and unheated rooms								
	SL1	outdoor, under roof	roofed structures		3) 4)						8)
	SL2	outdoor, exposed to weather	weathered structures		3) 4)						8)
	SL3	outdoor, concealed, may be affected by ambient air	ventilated facades			4)	11)	11)	8)	8)	8)

Colored cells in the table: Material can be used.

Impact: The factors to be considered where highest corrosion resistance is required.

A combination of different impacting factors does not necessarily lead to higher demands.

Generally speaking, specific design features of relevance to corrosion and surface quality must be taken into consideration.

Please note that national or international standards may contradict information provided in this table.

Only structural aspects are taken into consideration. If decorative aspects are an issue, please ask your Hilti representative for further information.

Material selection here takes only external corrosion reactions into account. The risk of hydrogen embrittlement (materials with strength >1000MPa) is not taken into consideration.

<sup>1)</sup> A reduction of the WK is possible if the parts are accessible and frequently cleaned by hand or by rain.

<sup>2)</sup> Frequent cleaning of accessible parts may allow reduction of the WK.

<sup>3)</sup> If pitting corrosion up to 500µm is possible and lifetime is less than 20 years, WK I is possible.

<sup>4)</sup> If good visual appearance is required, a very smooth surface finish is necessary. It is not possible to use higher alloyed steels. In this case, ask your Hilti representative for further information.

<sup>5)</sup> The thickness of galvanized zinc layers is between 3 and 30 µm (ISO 4042) or between 5 and 25 µm (DIN 50961). The expected lifetime of an approx. 12 µm zinc layer is more than 20 years if all exposure classes are O.

<sup>6)</sup> Hilti HDG provides a layer thickness of approx. 45µm. The expected lifetime of these products is more than 20 years if the materials selection table is used correctly.

<sup>7)</sup> Hilti HDG plus provides a layer thickness of approx. 60 µm. The expected lifetime of these products is more than 20 years if the materials selection table is used correctly.

<sup>8)</sup> This system can be used if an additional organic coating (ISO 12944) is applied. The expected lifetime depends on the coating system.

<sup>9)</sup> Contact with dry and carbonated concrete is not critical. Zinc is not corrosion resistant if in contact with (liquid) alkaline media. Zinc-coated steel parts can be used in alkaline concrete if the parts are completely embedded (in this case, no zinc layer is necessary).

<sup>10)</sup> Contact with dry wood is not critical. Zinc is not corrosion resistant if in contact with (liquid) acid media.

<sup>11)</sup> In Germany according to DIBt 2008: Galvanic coated screws for plastic frame anchoring can be used, if an additional bitumen-oil combined coating is applied which protects the screws against rain and humidity.

Table 6: Selection aid for fasteners in different environments

Only common corrosion protection systems are shown in the table above.

Hilti products are available with a number of other protection systems.

On the following pages you will find examples of how the above material selection table can be used.

**Example 1:**

Fastener and substructure for ventilated facade in Paris, France

Humidity: SF1 (weather data for Barcelona) → WK I or HDG

Chlorides: SC1 (distance from busy road > 10 m) → WK II or HDG

Redox substances: SR0 (no chemicals) → WK I, galvanizing or zinc flakes

pH-value: SH0 (dry concrete, not critical) → WK I, galvanizing or zinc flakes

Exposure: SL3 (outdoor, concealed) → WK III or HDG with organic coating (ISO 12944)

Selection: Fasteners made of stainless steel (AISI 316, A4 and A5); substructure

made of stainless steel (AISI 316 A4 and A5) or HDG + organic coating (ISO 12944).

Note: Use of a plastic anchor which encloses a galvanized screw is possible if the head of the screw is protected by suitable seals.

**Example 2:**

Fasteners for seats in a football stadium in Pretoria, South Africa.

Humidity: SF1 (weather data for Pretoria) → WK I or HDG

Chlorides: SC0 (town) → WK I, galvanizing, zinc flakes

Redox substances: SR0 (no chemicals) → WK I, galvanizing or zinc flakes

pH-value: SH0 (dry concrete, not critical) → WK I, galvanizing or zinc flakes

Exposure: SL1 (outdoor, visible) → WK II or HDG

Selection: Fasteners made of stainless steel (such as Hilti HSA R) or HDG galvanized (such as Hilti HSA-F) could be used.

**Example 3:**

Fasteners for securing ventilators in a road tunnel near Sapporo, Japan.

Humidity: SF2 (specific tunnel atmosphere) → WK II or HDGplus

Chlorides: SC3 (road tunnel) → WK IV

Redox substances: SR2 (road tunnel) → WK IV

pH-value: SH3 (moist vapours) → WK III

Exposure: SL3 (outdoor, concealed) → WK III

Selection: Only fasteners made of stainless steel (material according to WK IV) can be used (such as Hilti HCR). Further information about this special case is given in the Hilti brochure on recommendations for fasteners in tunnel applications (see ref. 5).

**Example 4:**

Use of a reinforcing bar spacer for a concrete deck overlay in Las Vegas, USA.

Humidity: dry concrete, not a corrosive environment → table cannot be used

Chlorides: (no chlorides expected → table cannot be used)

Redox substances: concrete → table cannot be used

pH-value: SH1 (non carbonated concrete) → WK I, galvanizing or zinc flakes (footnote 9: Part is completely embedded in concrete)

Exposure: SL 0 (indoors) → WK I, galvanizing or zinc flakes

Selection: Due to the fact that the steel part is completely embedded in concrete, corrosion protection for the steel parts is not necessary (footnote 9).

The table at the beginning of chapter 8 shows that WK I or similar should be used for this environment. However, as no atmospheric environment is present, only the pH-value has to be taken into consideration.



**Example 5:**

Installation system for heating pipes in an apartment house in Moscow, Russia.

Humidity: SF0 (dry, indoor) → WK I, galvanizing or zinc flakes

Chlorides: SC0 (no chlorides expected) → WK I, galvanizing or zinc flakes

Redox substances: SR0 (no chemicals) → WK I, galvanizing or zinc flakes

pH-value: SH 0 (neutral) → WK I, galvanizing or zinc flakes (footnote 9: Part is completely embedded in concrete)

Exposure: SL 0 (indoor) → WK I, galvanizing or zinc-flakes

Selection: Galvanizing or zinc flakes are suitable for this slightly corrosive atmosphere. Use of stainless steels (WK I) is also possible.



## 9. Case study

A solution for a façade installation using powder-actuated fastening and an anchor system is shown in the figure 10. The following points have to be taken into consideration:

1. The surrounding conditions
2. Metals in contact
3. Possible changes in corrosivity over the lifetime of the façade
4. Special circumstances or possibilities such as condensation

**The example shows the fastening system used for a façade in an urban environment comprising insulation panels plus natural stone slabs fastened to concrete on brackets.**

The façade is installed on a heated commercial building (shopping center) in a city in central Europe. In recent years, traffic has increased and will increase further. Salt is used on the roads in winter for de-icing. The cladding – natural stone panels – starts at a height of 1.5 meters above the ground.

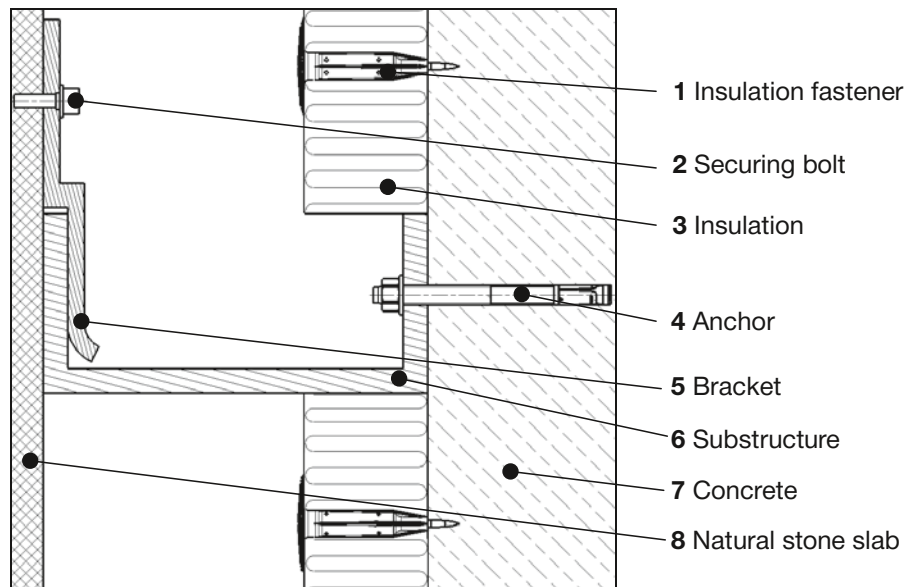


Fig. 10: Example of a facade installation.

### Recommendation and reasons

#### 1. Fastening the entire façade to the concrete (no. 4)

The surrounding conditions are slightly acidic, with small amounts of chlorides in the atmosphere. As the façade panels start slightly above ground level (1.5 m) and are well protected from the weather from a design point of view (insulation, etc.), no extreme exposure to pollutants is expected in this area. In addition, little dampness is anticipated, although the possibility of condensation cannot be excluded. In view of this, a material of the A4 (316) grade (DIN 1.4404 or 1.4401) should be used. Furthermore, a visual check is virtually impossible once the façade is in place. This is a further reason why a material of the A4 (316) grade is proposed (long life expectancy).

→ Anchors made of stainless steel material AISI 316 (A4)

## 2. Fastening the bracket to the natural stone slab (no. 2)

The conditions are the same as for fastening no. 4.

→ securing screw made of stainless steel material AISI 316 (A4).

## 3. Insulation installed using powder-actuated fasteners (no. 1)

X-CR material (AISI 316; A4) is predestined for this application. In this area there are crevices and condensation may form on the nail due to temperature differences.

Under these circumstances, damp phases can last for quite some time. The X-CR nail gives the assurance of long life expectancy under these conditions and thus provides a reliable fastening.

→XIE-R (XCR material)

## 4. Use of a metal substructure

In accordance with the circumstances described above, consideration may be given to some other possibilities for protection of the concealed substructure from corrosion. As the surface of the substructure will not be damaged during installation, a paint coating system (ISO 12944) can be used on the carbon steel. It would also be possible to use a resistant base material such as aluminium or stainless steel.

The suitable materials are listed in DIN 18516.

→ Stainless steel (AISI 316), aluminium (AlMn1, AlMnCu, AlMn1Mg0.5, AlMn1Mg1, AlMg1,AlMg1.5 and AlMg2.5)

## 10. Recommended reference literature

- 1) W. Stichel, "Korrosion und Korrosionsschutz in Schwimmhallen", BAM-Forschungsbericht 126
- 2) D. Binschedler und H.-D. Seghezzi, "Korrosionsprobleme in der Befestigungstechnik", Schweizer Ingenieur und Architekt 48
- 3) D. Binschedler, "Korrosionssichere Profilblechbefestigungen durch den Einsatz von Direktmontageelementen", Bauingenieur 63
- 4) Ulf Nürnberger, "Korrosion und Korrosionsschutz im Bauwesen", Bauverlag
- 5) Hilti: "Korrosionstechnische Überlegungen für Verbindungsteile in Strassentunnelatmosphären", 2009
- 6) Kunze, Egon: "Korrosion und Korrosionsschutz", Band 1-6, WILEY-VCH Verlag, Weinheim 2001.
- 7) Kreysa, Gerhard; Schütze, Michael: Corrosion Handbook - Corrosive Agents and their Interaction with Materials, Volume 1-13, 2nd Edition, Wiley-VCH-Verlag Weinheim 2009.
- 8) Rahmel, Alfred; Schwenk, Wilhelm: "Korrosion und Korrosionsschutz von Stählen", WILEY-VCH Verlag, Weinheim 1984..
- 9) Informationsstelle Edelstahl Rostfrei (ISER): "Erzeugnisse, Verbindungsmittel und Bauteile aus nichtrostenden Stählen, Allgemeine bauaufsichtliche Zulassung" Z.30.3 6; Sonderdruck 862, April 2009



## 11. Disclaimer

All results, considerations and recommendations given in this brochure are based on the tests, principles and formulas described in this brochure and on the safety requirements in accordance with the technical instructions issued by Hilti. They apply only to applications comparable to the test constellations described. This applies, in particular, to the case studies on the selection of materials. Extrapolation of the results to other environments is not permissible. The case studies as well as the considerations and recommendations given here and, in particular, limiting values for individual applications, must be regarded only as an approximate guide. Significant scatter of values may also occur within the bandwidth of environmental parameters applicable to a specific structure. Assessment of the applicable structure, particularly in terms of the prevailing environmental parameters, is the responsibility of the planning specialist or, respectively, the client. As the corrosion processes described here are long-term, in the event of a decision to use a material that is considered not to provide long-term stability, it is expressly recommended that specimens are taken from the structure periodically for subsequent specialist analysis. This report must be regarded as a unit and may be passed on to others or copied for further use only in its entirety. Hilti accepts no liability whatsoever for damage or injury resulting from use of only parts of this report. Hilti accepts no liability whatsoever for damage or injury stemming from estimation of the safety relevance of a fastening and the resulting selection of a material. Likewise, Hilti accepts no liability for damage or injury stemming from assessment of the environmental conditions applicable to a structure. Such assessments are exclusively the responsibility of the planning specialist or, respectively, the client. The considerations given here serve only to point out a few of the relevant aspects regarding fastening technology. It must be stated clearly that special attention must be given not only to the selection of a suitable material for a fastening, other relevant points such as legal and operational aspects must also be taken into account.





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