TECHNICAL NOTE

AEFAC
Australian Engineered
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AEFAC – TN15

DURABILITY OF FASTENERS

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Revision Sheet

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0		Initial release	September 2024

1. Scope

This Technical Note provides general requirements for the durability assessment of fasteners during a given service life in concrete and masonry base materials. In the absence of relevant information available in the product assessment report (e.g. ETA), the provisions of this Technical Note may be used.

The following factors potentially affecting the durability of fasteners are discussed in this Technical Note or referenced in other Standards:

- Corrosion (atmospheric, galvanic, stress corrosion, etc.)
- Creep under sustained loads (static loads)
- Changes of the action effects (dynamic loads)
- Changes of the environmental conditions (e.g. elevated temperatures)
- Changes in the base material (e.g. concrete cracks, crack cycling, water saturation, etc.)
- Disaster events (e.g. fire, earthquakes)

Other site- and application-specific factors not discussed in this Standard may also affect fastener durability, which shall be considered on an individual basis.

2. Corrosion of fasteners

2.1. General

This section covers fasteners qualified in line with the specifications of Appendix A of AS 5216, presuming that the fastener has been assessed in its final supplied form and the materials used for production, including protective coatings are listed in the relevant assessment document (e.g. ETA). Any modification, treatment or additionally applied coating to the original fastener is not permitted without reassessing the final product in accordance with the provisions of Appendix A, as these changes might adversely affect the performance of the fastener.

Fasteners shall be installed according to the instructions listed in the qualification document or the manufacturer's installation instructions, including the setting tools required to avoid damage to the fastener or its protective coating during installation. Fasteners with any irregular visible defect or damage of the corrosion protection layer sustained before, during or after the installation shall not be used, unless some acceptable damages formed part of the durability assessment, e.g., those caused by normal installation and covered by the remote effect of zinc. Fasteners with irregular defects or damages shall not be used and disposed of safely to avoid reusability. Any exposure to short- or long-term elevated temperatures, other than the ones falling within the allowable temperature ranges specified by the manufacturer, are not permitted in order to avoid reduction of the fastener's performance or working life.

For the assessment of fastener durability, the designer shall consider both the macro- and micro-environments, which the fastening is located in. The microenvironment is defined as the immediate surroundings of the fastener, or parts of the fastener, which may directly affect its performance or functioning over the assigned design life. From the durability point of view, the microenvironment around a fastener might present significantly different conditions compared to the ones typical for the given geographical area. Therefore, a holistic approach shall always be applied, and special care shall be taken in understanding the potential corrosive effects typical to the immediate surroundings of the fastener.

There are four microenvironmental zones which shall be considered separately during the assessment of the durability of the fastener, as shown in Figure 1:

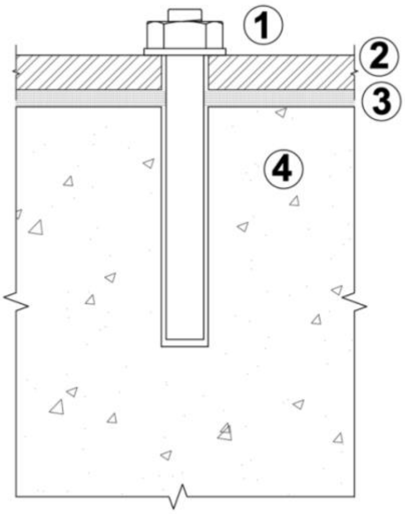

Figure 1: Relevant microenvironmental zones of corrosion

1. Environment around the exposed parts of the fastener
2. Fixture (with or without clearance hole)
3. Intermediate layer between the fixture and base material
4. Base material (potentially including gap and contaminants)

The exposed parts of the fastener shall be assessed against environmental corrosion in accordance with Section 4.1. The assessment shall consider atmospheric conditions and any other site-specific circumstances which may affect the durability of the fastener.

The annular clearance hole within the fixture shall be considered as a potential corrosive microenvironment, regardless of if the gap is filled with mortar, as the anchor rod might become exposed to moisture through water ingress, for example due to unfilled clearance hole or potential imperfections in the filling mortar. The time of wetness may be significantly increased inside the clearance hole due to hindered drying. In highly corrosive environments, the accumulation of aggressive contaminants inside the clearance hole is to be expected and adequate measures shall be taken to avoid an increased rate of corrosion, such as protecting the gap with an adequate sealing.

In case of metallic fixtures, bi-metallic corrosion between the fixture and the fastener shall be prevented by adequate galvanic separation of dissimilar metals or by the selection of suitable materials as described in Section 4.2.5.

In the intermediate layer, contact with other construction materials, such as grouts, sealants, timber, or insulation may cause a corrosive reaction to the fastener, which therefore shall be accounted for in the durability assessment.

The conditions in the base material around the embedded part of the fastener shall be assessed separately. Unless the gap is fully sealed, the ingress of moisture is to be expected in all environments other than dry, internal conditions. The presence of prolonged moisture or water inside the anchor hole may produce an alkaline environment. Similarly, to the clearance hole in the fixture, the presence of prolonged wetness potentially including corrosive contaminants (e.g. chlorides) shall be accounted for.

Fastening applications with exposed surfaces, potentially involving physical wear or damage to the coating or material of the fastener (e.g. abrasion, traffic, material handling) shall be specified with regular inspections and maintenance. For these applications, a preference shall be made for selecting fasteners made of corrosion resistant materials, such as stainless steel. The selection of corrosion resistant material alone does not negate the need for regular inspections and maintenance but serves as additional preventative measure against the untimely degradation of the fastener.

For post-installed bonded anchors, the cured adhesive mortar may reduce the corrosion rate of the fastener over the embedded depth inside the anchor hole, however the presence of the adhesive mortar shall not be taken as a guarantee to increase the durability of the fastener, unless the mortar has been assessed accordingly. Instead, a corrosion resistant material or surface coating shall be selected to achieve the required working life.

Note: *post-installed reinforcing bars may be used without surface protection coating if it can be verified that the bars are protected against corrosion, e.g. by the alkalinity and sufficient properties of the concrete cover present during the effective working life of the structure. Depending on the environmental conditions and the expected design life, some applications might require hot dip galvanized or stainless steel reinforcing bars.*

Unless otherwise noted, the basic assumed working life of fasteners covered in this section is 50 years. However, the information provided in This Technical Note may also be used to assess the durability of fasteners with a life expectancy other than 50 years.

The design life verifications in this document are typically limited to the time at the loss of protective coating or the appearance of surface rust on the fasteners. It should be noted however, that initial degradations associated with the onset of corrosion may not imminently render the fastener redundant, as depending on the rate of corrosion and amount of lost material, the fastener may remain fully or partly functional at a reduced strength over a prolonged lifespan.

Less severe cases of initial corrosion include the discolouration of coated or bare metallic surfaces, or the onset of surface rust in small, isolated or scattered patches. These changes typically only affect the surface of metal fasteners without compromising the underlying steel material, i.e. not involving the loss of effective steel cross section. A Qualified Expert, experienced in the field of corrosion shall assess the feasibility of the potential reinstatement of corrosion protection, or alternatively, nominate a the residual lifetime of the fasteners considering the potential reductions in strength and functionality.

In case a more severe level of corrosion is detected during the inspection, such as etching, pitting, flaking or scaling of the metal surface, the level of cross sectional reduction and residual capacity shall be carefully assessed by the Corrosion Expert and a remediation plan put in place accordingly.

3. Types of corrosion resistant fasteners

The following types of corrosion-resistant fasteners are covered in This Technical Note:

3.1. Carbon steel fasteners with protective surface coating

The corrosion resistance of surface coated fasteners depends on the material and technology used for the coating, as well as the coating thickness. The most common types of protective surface coatings are phosphating, mechanical galvanizing, electroplating (also known as zinc-plating or electro-galvanizing) and hot dip galvanizing. Some specialty fasteners or applications might demand alternative protective coatings in order to meet durability requirements, for example where a reduced coating thickness is preferred. These alternative finishes are referred to as innovative coatings and are covered in Section 4.1.2.2.

Electroplated fasteners typically exhibit a zinc thickness of 3-15 microns and hot-dip galvanized fasteners involve a coating thickness between 40 to 65 microns. In order to specify the minimum and maximum thickness of zinc coating as a result of electroplating, mechanical or hot-dip galvanizing, the characteristics unique to the type of selected fastener shall be considered. Various fasteners may have different application limits depending on their manufacturing process, geometrical constraints or functional requirements. This technical note is specific to post-installed and cast-in fasteners in concrete and masonry base material, therefore, the provisions from this document shall not be taken as a general guide applicable to other types of fasteners, such as structural steel bolts or screw fixings used in metal or timber. For concrete fasteners, specific boundary conditions are taken into account for the specification of the lower and upper limits of the protective coating thickness. For example, friction-controlled mechanical anchors may have functional constraints in terms of the maximum applicable zinc thickness due to its potential negative impact on anchor performance, such as changes in the tightening torque and clamping force or creep behaviour. Similarly, power-actuated fasteners (PAF) may have restrictions on the applicable zinc thickness due to the unique load transfer mechanism between the fastener and concrete. In case of threaded anchor parts, the coating thickness shall be specified considering both the tolerance and clearance requirements of the assembly. The use of matching and qualified system components for such assemblies is critical in ensuring fastener safety, especially where the alteration of the connecting parts is required following hot-dip galvanizing, e.g. re-tapping of nuts. Due to the above reasons, the achievable maximum coating thickness may be less for fasteners of small diameters (e.g. M12 and under) compared to medium- and large-size fasteners. An upper limit for the coating thickness may also be specified to avoid potential galling between connecting steel parts. Therefore, the lower and upper limits of the protective coating shall be ascertained by the manufacturer and the performance of the fastener, including functional fitness to be verified during the prequalification tests in accordance with *Appendix A* of *AS 5216* [1]. Depending on the type and thickness of the applied protective coating, the durability of the selected fasteners is to be assessed based on sections 4.1.2.1 and 4.1.2.2 of this document.

3.2. Fasteners made of stainless steel

Fasteners manufactured of stainless steel contain at least 10.5% chromium and potentially other alloying elements, such as molybdenum, nickel, nitrogen, etc. Stainless steel fasteners resist corrosion via the formation of a passive film layer on their surface and they are classified based on the grade of the alloyed material they are made of. Although stainless steel fasteners are considered highly resistant against general atmospheric conditions, potential aggressive contaminants, such as chlorides or sulphur dioxide may degrade certain types of stainless steel.

Section 4.1.2 provides guidance on the selection of stainless steel grades for specific environmental conditions.

4. Potential forms of corrosion

The following forms of corrosion may affect the durability of fastenings and therefore must be accounted for when verifying the working life of the connection:

- Environmental corrosion
- Pitting corrosion
- Galvanic corrosion (bimetallic or contact corrosion)
- Stress corrosion
- Crevice corrosion
- Hydrogen corrosion
- Intercrystalline corrosion

4.1. Environmental corrosion

Fasteners permanently or periodically exposed to moisture or **environmental conditions** shall be made of corrosion resistant material or have adequate surface coating to protect the fastener from degradation during its expected working life. Potential environmental effects include atmospheric conditions (e.g. humidity, condensation, weather) and other site- or application-specific conditions related to human activities or the natural surroundings of the fastenings.

For the assessment of fasteners installed in a specific environment, the corrosivity categories and respective corrosion rates may be determined in accordance with the specifications of AS 4312. The typical corrosive environments found in Australia and the respective corrosivity categories are summarised in Table 1:

Table 1: Summary of corrosivity in Australia as described in AS 4312

Category			Generic examples	Specific examples
C1	Very low	Dry indoors	Inside heated or air-conditioned buildings with clean atmosphere	Commercial buildings
C2	Low	Arid/urban inland	Most inland cities and rural areas of Australia at least 50km from the coast From 1km to 10km from quiet, sheltered seas From 5km to 15km from semi-sheltered seas	Canberra, Ballarat, Toowoomba, Alice Springs Suburbs of Melbourne, Geelong, Hobart Sheltered suburbs of Adelaide, Brisbane, Perth
C3	Medium	Coastal or light industrial	Coastal areas with low salinity, from 1km to 15km from breaking surf, depending on wind, vegetation and topography From 50m to 1km inland around sheltered bays From 1km to 50km from unsheltered breaking surf with significant salt spray	Metro areas of Wollongong, Sydney, Newcastle, Perth, Adelaide, Brisbane and Gold Coast Port Philip Bay & urban or industrial areas with low pollution Coastal areas with breaking surf and significant salt spray
C4	High	Sea shore (calm)	From the shoreline to 50m inland around sheltered bays From 50m to 500m from semi-sheltered or turbulent coasts In and near large industrial plants with steam production	Beachfront sites in Melbourne & Hobart Beachside suburbs of Adelaide, Brisbane, Perth Swimming pools, smelters, chemical processing plants
C5	Very high	Sea shore (surf)	Up to 50m inland in semi-sheltered coasts From 50 to 500m from rough seas & surf beaches	Beachfront sites in Adelaide, Brisbane & Perth Beachside suburbs of Sydney, Wollongong, Newcastle & Gold Coast
CX	Extreme	Severe surf or heavy industrial	Up to 50m inland from shoreline exposed to rough seas and surf From 50m to 200m from the most severe shorelines with rough sea conditions Offshore structures, extreme industrial facilities	Beachfront sites in Sydney, Wollongong, Newcastle, Gold Coast, Cairns, Townsville & Mackay, Some beachside suburbs of Cairns, Townsville, Mackay, Newcastle & Gold Coast

Beside the corrosive properties present in typical macro- or microenvironments, such as the ones listed in Table 1, there are several other factors which may also influence the corrosion rate of fasteners. These additional factors shall also be considered when assessing the durability of fastenings:

a) Potential exposure to aggressive contaminants (e.g. chlorides, SO2, etc.)
b) Lack of, or inability for clean water washing such as rain to flush contaminants
c) Build-up of debris such as dirt, dust and animal waste (faeces, nests, feathers) without washing or periodic cleaning
d) Time of wetness and potential aggravating or alleviating factors, e.g. sheltered location with hindered drying vs. exposure to sun, etc.
e) Prolonged moisture or water inside the clearance hole of the fixture or inside the base material (e.g. poor drainage, lack of drain holes, capillary actions)
f) Time to first exposure (due to typically increased first-year corrosion rates)
g) Orientation of fastenings (vertical vs. horizontal), as it may affect the total time of wetness
h) Height above sea level
i) Distance from marine environment
j) Micro-organisms, bacteria (anaerobic corrosion)
k) Tannins from timber (can cause corrosion issues).

For further guidance on the effect of the above parameters refer to the relevant sections of the AS 4312.

4.1.1. Fasteners in dry internal conditions

Dry, indoor environments without condensation or the presence of moisture generally do not require special corrosion protection measures other than the basic coating applied to the fastener to prevent corrosion during transportation and storage, like phosphating or electroplating. Uncoated elements, such as fasteners with black steel finish, shall not be specified for safety-critical applications.

In case a quantitative assessment of the fasteners in dry, internal conditions is necessary, the corrosion rates of the C1 environmental category may be considered in accordance with the AS 4312.

Environments prone to condensation or high relative humidity (e.g. greater than 80%), or areas involving moisture-producing activities shall not be considered as dry internal environments.

4.1.2. Fasteners exposed to moisture or external atmospheric conditions

4.1.2.1 Hot dip galvanized fasteners

Hot dip galvanized fasteners may be selected for areas exposed to moisture or external atmospheric conditions in line with the corrosivity categories specified in AS 4312, if it can be verified that the effective coating thickness available on the fastener after installation is sufficient to protect the fastener over its intended working life.

The corrosion rate of zinc during the first year of exposure is generally higher than the long-term reduction rate, which tends to slow down and stabilise over time. Due to the large number of variables however, the atmospheric corrosion rate of zinc is conservatively assumed to be linear with time for design and assessment purposes. Consequently, fasteners with a longer design life, as well as fasteners exposed to more severe environmental conditions require greater zinc coating thickness.

The verification of the effective zinc thickness for a specific working life shall be carried out based on the provisions of the AS 2312.2. The corrosion rates of zinc during the first year of exposure had been empirically established for the six main environmental categories, which are listed in Table 2. For the assessment of fastener durability, the first-year corrosion rate of zinc may be taken as the average expected annual reduction rate over the entire design life of the fastener. If the corrosivity category of a certain application cannot be determined with high certainty, always the more severe category with the higher reduction rate shall be selected from Table 2.:

Table 2: Corrosion rates of zinc finishes based on the AS 2312.2 and ISO 9223

Category	Description	Typical environments	Corrosion rate of zinc for the first year (µm/year)
C1	Very low	Dry indoors Air-conditioned buildings with clean atmosphere	≤0.1
C2	Low	Arid/Urban inland Temporarily wet indoors with little condensation (no significant pollution)	>0.1 to ≤0.7
C3	Medium	Coastal areas (small salinity) Moderate industrial pollution High humidity indoors with moderate pollution	>0.7 to ≤2.1

C4	High	Industrial areas and calm seashores (moderate salinity) Permanently wet indoor areas (moderate pollution)	>2.1 to ≤4.2
C5	Very high	Surf sea shores Industrial areas with damp conditions and aggressive pollutants Permanently wet indoors with aggressive contaminants	>4.2 to ≤8.4
CX	Extreme	Ocean/Off-shore (intense saline atmosphere) Extreme indoor/outdoor pollution	>8.4 to ≤25

Based on the corrosion rates specified in Table 2, hot dip galvanized fasteners should not be selected for environments classified as C4, C5 and CX categories for a 50-year design life. For categories C4 and C5 hot dip galvanizing might provide sufficient protection with a reduced working life, typically less than 50 years. Alternatively, fasteners with innovative coatings or fasteners made of stainless steel may be selected to achieve the required level of durability.

Similarly to the above, great care needs to be taken during the specification of surface-coated fasteners in the C3 corrosivity category. The verification shall establish an objective probability assessment of the expected annual corrosion rate specific to the site and application, taken into account the potential macro- and microenvironmental factors listed in Clause 4.1. In case the given protective coating cannot be verified against the specified design life with a satisfying level of certainty, an alternative coating with a higher degree of protection, or fasteners made of stainless steel material shall be selected for the application.

The durability assessment shall follow the same logic for the verification of fasteners within the C2 corrosivity class. It is generally expected, that most hot-dip galvanized fasteners achieve a 50-year design life in this category, unless special site-specific conditions exist which may accelerate the reduction of the protective coating.

4.1.2.2 Fasteners with innovative coatings

The continued development of fasteners resulted in the introduction of innovative anti-corrosion coatings, which may provide a similar level of protection to conventional zinc finishes, but with potentially less coating thickness. Usually, protective finishes other than common phosphating, zinc-plating, hot dip galvanizing or sherardizing may be considered as innovative coatings. This category includes but is not limited to fasteners with zinc-flake finishes or other hybrid coatings, such as zinc-magnesium or zinc-nickel covers with optional resin overlays.

There are currently no generally accepted evaluation methods for the durability of fasteners with innovative coatings, other than long-term, realistic exposure tests. The current established methods of laboratory testing, such as accelerated salt spray tests may be suitable for the quality control of repetitive production batches, however these tests are limited to certain pre-set conditions, which do not necessary account for the complexity of prolonged environmental conditions. Furthermore, when comparing the corrosion performance of common zinc finishes to hybrid coatings, the results largely depend on the selected test regime and therefore, quantifying the differences between various coatings remains a challenge up to this day.

Another challenge with accelerated salt spray testing is the ambiguity of results concerning the functional durability of the assessed fastener. These tests are not designed to accurately assess material aging or overall functional degradation with time. For example, certain fasteners apply specific functional coatings to achieve the desired level of friction between the fastener parts, which are crucial in sustaining the fastener’s performance over its design life. Accelerated laboratory tests might not provide an accurate picture about the long term performance of functional coatings.

In view of the aforementioned reasons, the verification of innovative coatings represents a complex task, which requires a holistic approach and shall be carried out on a case-by-case basis by a technical professional with adequate experience in this field.

In case the suitability of coated fasteners cannot be verified for moist internal or general external conditions, fixings made of stainless steel may be specified for the application. The assessment and selection of stainless fasteners are described in Section 4.1.2.3.1.

4.1.3. Fasteners in highly corrosive environments

The definition of highly corrosive environments includes, but is not limited to, areas where the fasteners may be in contact with water or soil over a prolonged period of time, exposed to sea water or sea mist (marine environments), positioned in potential splash or flood zones, or located in industrial areas, where the presence of corrosive contaminants are to be expected.

In the potential presence of dissolved or deposited contaminants, such as forms of chlorides and salts (NaCl, MgCl, CaCl, etc.) or other airborne pollutants, such as typically isolated microenvironments with increased concentrations of sulphur dioxide (SO2) or oxides of nitrogen (NOx), the significant growth of corrosion rates is to be expected and the durability of fasteners shall be assessed accordingly.

Furthermore, most waste products, like fertilisers, pesticides and industrial chemicals are to be considered corrosive to metal fasteners. In the presence of moisture combined with salts or other aggressive contaminants, corrosion rates may be manifold compared to applications without pollutants. Therefore, highly corrosive environments typically warrant the selection of stainless-steel fasteners, unless surface coated fasteners can be verified with high certainty for the given application.

4.1.3.1 stainless steel fasteners

AS4312 is one of the key standards in Australia for dealing with corrosion related to design and/or construction. It is mainly based on ISO9223. It provides information on the atmospheric corrosivity in Australia and the corresponding durability of the different types of metals, primarily steel and zinc. However, for stainless steel it references EN1993-1-4:2006+A1:2015 where the stainless-steel type selection is related to the corresponding corrosive environment it will be exposed.

EN 1993-4:2015 also provides guidance in quantifying corrosion resistance, identifying corrosive environments and material selection. This technical note summarizes the approach that is contained in EN1993-4:2015.

EN1993-4:2015 address stainless steel durability by establishing the corrosiveness of a specific environment and the selection of a particular type of stainless steel based on its resistance to corrosion. The corrosiveness of a specific environment is represented by the Corrosion Resistance Factor (CRF), while the choice of material based on its corrosion resistance is represented by the Corrosion Resistance Class (CRC).

Corrosion resistance factor (CRF)

The environment can be quantitatively assessed using the CRF, which in turn is made up of three components F1, F2 and F3 as shown in Equation 1.

$$CRF = F1 + F2 + F3 \qquad \text{Eq. (1)}$$

F1 represents the risk to chloride exposure expressed as a function of the distance from the chloride source, which can be a sea water coastline or a road where de-icing salts were used. This technical note will only consider distance from the coastline since de-icing salts are usually not used in most places in Australia. The values of F1 are given in Table 3, where M represents the distance from the chloride source.

Table 3: Values of F1 based on the distance from the chloride source

F_1	Exposure risk	Environment Description
1	Internally controlled environment	
0	Low risk of exposure	M > 10 km
-3	Medium risk of exposure	1 km < M ≤ 10 km
-7	High risk of exposure	0.25 km < M ≤ 1 km
-10	Very high risk of exposure	Road tunnels where de-icing salt is used or where vehicles might carry de-icing salts into the tunnel
-10	Very high risk of exposure	M ≤ 0.25 km (North Sea coast of Germany, All Baltic coastal areas)
-15	Very high risk of exposure	M ≤ 0.25 km (Atlantic coastline of Portugal, Spain, France, Coastline of UK, France, Belgium, Netherlands, Southern Sweden, All other coastal areas of UK, Norway, Denmark and Ireland, Mediterranean Coast)

F2 represents the risk to sulphur dioxide exposure expressed as a function of sulphur dioxide deposition in μg/m^3. For European coastal environments the sulphur dioxide value is usually low. For inland environments the sulphur dioxide value is either low or medium. The high classification is unusual and is associated with particularly heavy industrial locations or specific environments such as road tunnels. Sulphur dioxide deposition may be evaluated according to the method in ISO9225. The values for F2 are given in Table 4, where M represents the distance from the chloride source.

Table 4: Values of F2 based on the deposition rate of sulphur dioxide

F_2	Exposure risk	Deposition Description
0	Low risk of exposure	< 10 μg/m^3 average deposition
-5	Medium risk of exposure	10 - 90 μg/m^3 average deposition
-10	High risk of exposure	90 - 250 μg/m^3 average deposition

F3 represents the influence of periodic washing or cleaning of the stainless steel surface which promotes better corrosion resistance longevity. The values of F3 are given in Table 5.

Table 5: Values of F3 based on the cleaning regime or exposure to washing by rain

F_3	Washing/Cleaning regime
0	Fully exposed to rain washing
-5	Specified cleaning regime
-10	No washing or specified cleaning

Corrosion Resistance Class (CRC)

The CRC is currently divided into five resistance classes and is expressed as a function of the CRF as enumerated in Table 6.

Table 6: CRC based on resistance to stainless steel corrosion and CRF value

CRC	Resistance to Corrosion	CRF
I	Low	CRF = 1
II	Moderate	0 ≥ CRF > -7
III	Medium	-7 ≥ CRF > -15
IV	Strong	-15 ≥ CRF ≥ -20
V	Very Strong	CRF < -20

EN 1993-4:2015 then gives a table that groups the type of stainless steels that best suit the corrosion resistance class as shown in Table 7.

Table 7: Suitable stainless grouped according to their corrosion resistance class

Corrosion Resistance Class CRC														
I			II			III			IV			V		
EN	US	UNS	EN	US	UNS	EN	US	UNS	EN	US	UNS	EN	US	UNS
1.4003	12Cr	S40977	1.4301	304	S30400	1.4401	316	S31600	1.4439	317LMN	S31726	1.4565	-	S34565
1.4016	430	S43000	1.4307	304L	S30403	1.4404	316L	S31603	1.4539	904L	N08904	1.4529	926	N08926
1.4512	409	S40900	1.4311	304LN	S30453	1.4435	316LMo	S31603	1.4462	2205	S32205	1.4547	254	S31254
			1.4541	321	S32100	1.4571	316Ti	S31635				1.4410	2507	S32750
			1.4318	301LN	S30153	1.4429	316LN	S31653				1.4501	Z100	S32760
			1.4306	304L	more alloy	1.4432	316L	more alloy				1.4507	alloy255	S32550
			1.4567	302HQ	S30430	1.4578	316Cu	None						
			1.4482	2001	S32001	1.4662	2403	S82441						
						1.4362	2304	S32304						
						1.4062	2202	S32202						
						1.4162	2101	S32101						

Ferritic
Standard austenitic
Mo austenitic
HiMo austenitic
Super austenitic (PRE ≥ 40)
Lean duplex
Standard duplex (PRE mid/high 30s)
Super duplex (PRE ≥ 40)

4.2. Other forms of corrosion

4.2.1. Pitting Corrosion

Pitting corrosion mainly affects metals which are known to form a passive protective layer on their surface, such as stainless steel, aluminium or titanium. This form of corrosion starts by the localised breakdown of the passive layer, for example initiated by chloride ion attack on stainless steel.

Unlike uniform "red rust" corrosion, the challenge with pitting corrosion is that the reduction of the metal may develop in the form of narrow pinholes, hardly visible from the surface. These pinholes may also become the starting point for corrosion induced cracking under stress. Besides being hardly detectable, pitting corrosion is also difficult to control or predict, therefore the best protection measure is full prevention. This is possible by the selection of suitable materials for the given environment.

4.2.2. Crevice corrosion

Crevice corrosion takes place in cracks and crevices between metals and other metallic or non-metallic materials. A typical occurrence of this type of corrosion in fastening technology is on the surface of the fixture underneath washers or gaskets. The reason behind crevice corrosion is the lack of oxygen along with prolonged presence of moisture inside a narrow space. These conditions create an anodic environment, whereas the surrounding, exposed parts of the fixture become the cathode to initiate the chemical reaction. As a result, the dissolution of the confined metallic surfaces leads to crevice corrosion.

This type of corrosion can be prevented by the selection of adequately resistant materials, detailed design to eliminate narrow cracks or crevices, or by eliminating the presence of moisture to serve as an electrolyte for the anodic reaction.

4.2.3. Stress corrosion cracking

Stress corrosion cracking (SCC) may occur as a combined result of internal tensile stress and the simultaneous exposure of the fastener or fixture to a corrosive environment. Similarly to pitting corrosion, the potential local breakdown of the passive surface layer along with the externally induced or residual stresses in the material may cause the formation of micro cracks on the surface, exposing new active metal parts for further anodic reactions to take place. The gradual dissolution of metal then causes the crack to propagate deeper into the cross section resulting in a self-accelerating, progressive deterioration of the material.

Stress corrosion cracking therefore is a hazardous, rapid form of corrosion, which starts out in the form of microscopic cracks, making it difficult to detect and may lead to the unexpected, abrupt failure of otherwise ductile metal parts. Based on empirical information, certain alloy types are known to be more prone to stress corrosion cracking when exposed to corrosive environments which therefore shall be avoided, for example SS304 (A2) stainless steel in indoor swimming pool applications (high chloride concentrations.

4.2.4. Hydrogen-assisted cracking

Hydrogen-assisted cracking may occur as a result of three combined factors: high-strength, hardened fastener material; residual or applied stress in the metal and the source of hydrogen in the proximity of the fastener. Most cases of hydrogen-assisted cracking are not considered a direct form of corrosion; however the existing corrosion of the metal parts may produce atomic hydrogen which can diffuse into the metallic structure. This phenomenon falls into the category of secondary hydrogen-assisted cracking, where the hydrogen diffusion occurs during the service life of the fastener, independent from the manufacturing process. The presence of hydrogen in the lattice weakens the mechanical integrity of the metal and leads to crack growth and brittle fracture at stress levels below yield strength. Similarly to stress corrosion cracking, it can lead to the reduced ductility and sudden failure of metal parts without noticeable warning signs. Therefore, to avoid secondary hydrogen-assisted cracking, special care shall be taken of application conditions with potential exposure to atomic hydrogen, when specifying high-strength, hardened steel fasteners.

4.2.5. Galvanic corrosion (bimetallic or contact corrosion)

Galvanic corrosion occurs as a result of electrochemical connection between two or more dissimilar metals in the presence of some type of electrolytic medium, such as condensation, precipitation or other sources of moisture. The dissimilarity of two metals is expressed by their electrochemical potentials. The higher the electrochemical potential, the more noble the metal. When two dissimilar metals are in contact in the presence of an electrolyte, galvanic corrosion of the less noble metal via anodic dissolution is to be expected, whereas the more noble material acts as a cathode and is therefore not negatively affected by galvanic corrosion. Figure 2 demonstrates the electrochemical potentials of common metals immersed in sea water compared to silver chloride:

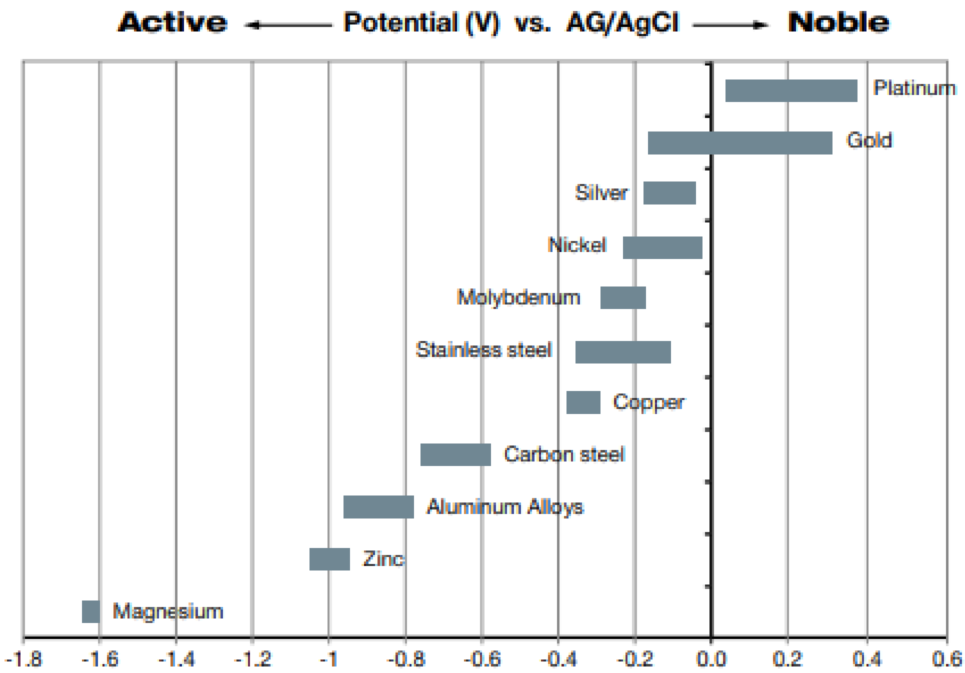

Figure 2 Corrosion potential of various metals in sea water

Where galvanic corrosion takes place, the rate of corrosion of the less noble metal is higher than it would be in a general environment without contact to another metal. Based on empirical experience in typical fastening applications, it is possible to predict which material combinations are likely to have a negative impact on durability as a result of galvanic corrosion. Table 1 demonstrates the level of risk from bimetallic corrosion between common dissimilar metals and surface coatings:

Table 8: The potential impact of galvanic corrosion between dissimilar metals

Fastened part (large area)	Fastener (Small area)			
	Electrogalvanized	**Duplex-coated carbon steel**	**Hot-dip galvanized**	**Stainless steel**
Electrogalvanized	●	●	●	●
Hot-dip galvanized	●	●	●	●
Aluminium	◆	◆	◆	●
Structural or cast steel	Δ	Δ	Δ	●
Stainless steel (CrNi or CrNiMo)	Δ	Δ	Δ	●
Tin	Δ	Δ	Δ	●
Coppor	Δ	Δ	Δ	●
Brass	Δ	Δ	Δ	●
●	No impact on lifetime			
◆	Moderate impact on lifetime, technically acceptable in many cases			
Δ	Strong impact on lifetime			

Galvanic corrosion may be avoided by the adequate selection of material combinations in the design phase. As a general rule, the difference in corrosion potential between the materials should be kept as low as possible, and the surface ratio of less noble metal to nobler metal should be very high. The fastener shall always be made of the same or a more noble metal than the part to be fastened, since it typically has the smaller surface area, and failure of the fastener is usually critical.

4.2.6. Intercrystalline corrosion (intergranular corrosion)

Intercrystalline corrosion may occur in certain types of metal alloys that contain chromium and are exposed to elevated temperatures for a considerable amount of time (e.g. heat treatment, welding, etc.). As a result of increased temperature (approx. 500-800°C), chromium carbides form along the grain boundaries inside the metal structure which will later become potential pathways for localised corrosion. The degradation of the material can lead to loss of ductility of the metal parts resulting in premature failure. Intercrystalline corrosion may be prevented by appropriate production controls, the right selection of materials and the elimination of activities involving high temperatures.

5. References

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