ANCHOR DESIGN – CORROSION CONSIDERATIONS.

Faye Peate BEng (Hons)

AGENDA

1. Why we need to consider corrosion
2. Forms of corrosion
3. Corrosion of stainless steel
4. Corrosion protection
5. Selecting the right materials
6. Corrosion categories
7. Summary
8. Hilti Engineering Support

WHY WE NEED TO CONSIDER CORROSION?

It is essential to know about corrosion and its effects in order to avoid mistakes.

Wrong corrosion protection can lead to safety and liability risks and complaints.

WHY WE NEED TO CONSIDER CORROSION?

DIN EN ISO 8044

″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.″

WHY WE NEED TO CONSIDER CORROSION?

Metal winning

requires energy

Fe_2O_3 ⟷ $2\ Fe + 3/2\ O_2$

Low-energy state (stable)

Corrosion reaction

High-energy state (unstable)

Metal oxides are usually thermodynamically more stable than the pure metal

Exception

WHY WE NEED TO CONSIDER CORROSION?

The (electrochemical) corrosion reaction always consists of two partial reactions:

Anodic reaction- metal dissolution

- $Fe \rightarrow Fe^{2+} + 2\ e^-$

Cathodic reaction (mostly oxygen reduction)

- $O_2 + 2\ H_2O + 4\ e^- \rightarrow 4\ OH^-$

Requirements are:

- An electrolyte (moisture film is sufficient)
- Air

The inhibition of own partial reaction slows down the complete corrosion process.

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TYPES OF CORROSION

Uniform attack corrosion

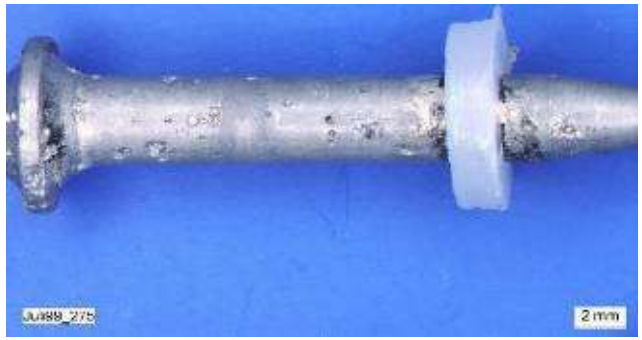
- Uniform attack over surface
- Calculable material loss (when environment is defined)
- Classification by appearance, not metal

TYPES OF CORROSION

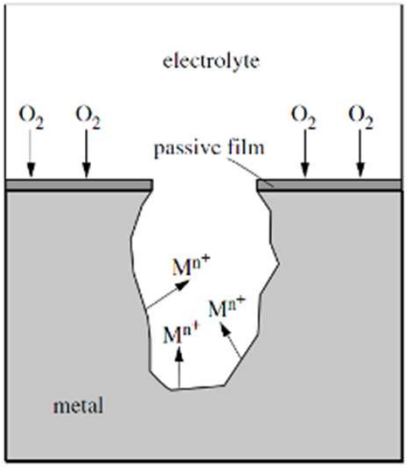
Localised attack corrosion

Pitting corrosion

- Pits with higher depth than diameter
- Phenomenon on passive metals (stainless steel, aluminium)
- Chloride induced break-down of passive film

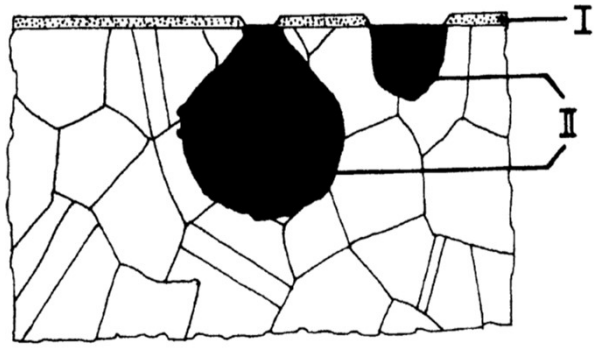


A4 nuts after 3 months coastal environment



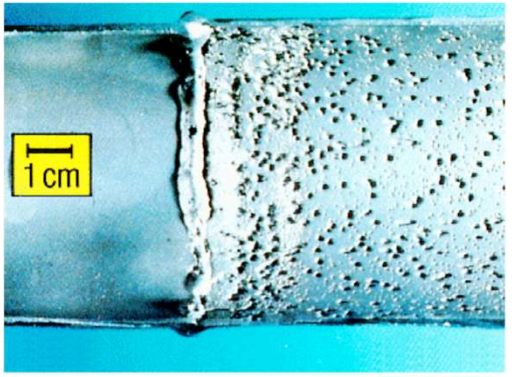
TYPES OF CORROSION

Pitting corrosion



I … Passive layer
II .. Local break-down of passive layer, active corrosion (pitting)

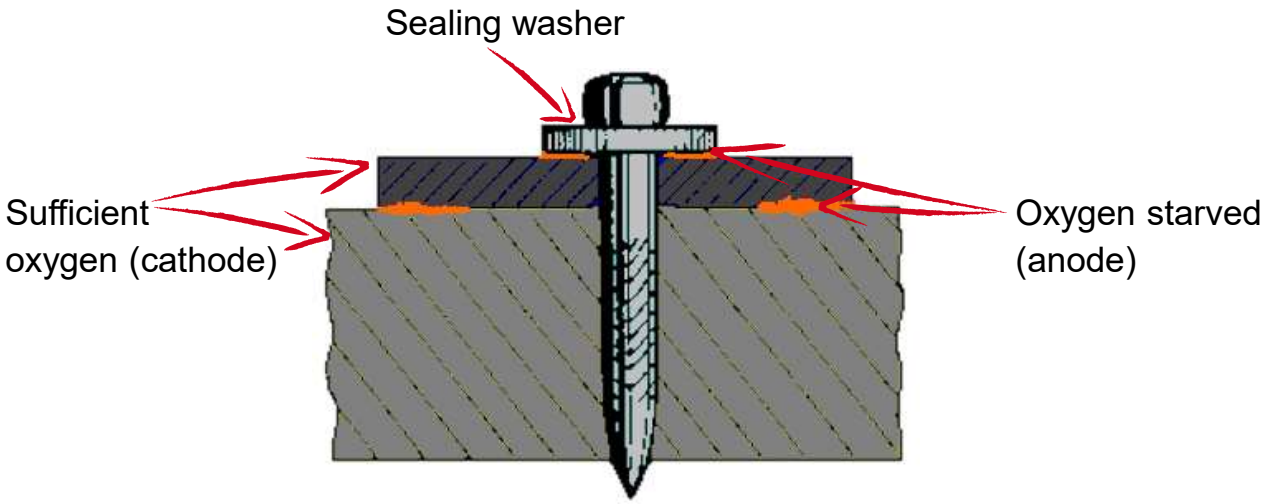
Stainless-steel sheet in an indoor swimming pool



Pitting indicates an incorrect combination of two different materials.

TYPES OF CORROSION

Crevice corrosion – Direct Fastened Nail

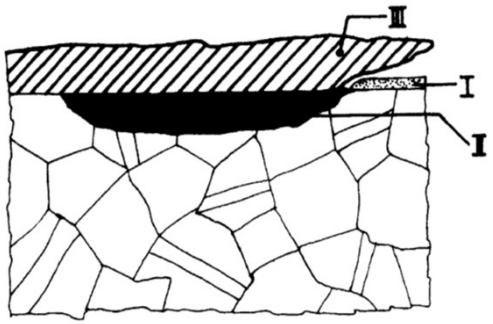


Crevice - caused by difference in concentration(oxygen, chloride, etc..) in the electrolyte

- Impurities in the surface

TYPES OF CORROSION

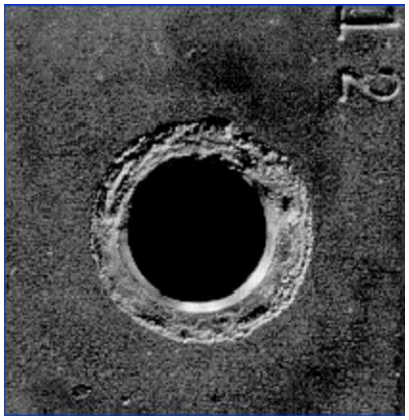
Crevice corrosion



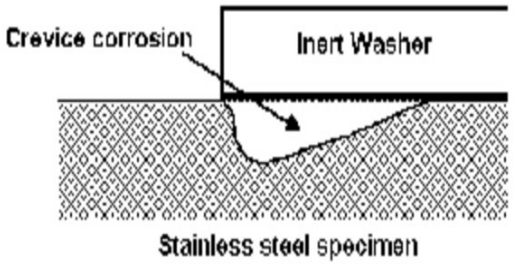
I... passive film which cannot reform due to decreasing crevice width

II... active dissolution of material, starting from point 1

III...crevice due to design, PE coating (layer), washer, surface contamination



Crevice corrosion of Type 316 stainless steel in acid condensate under a PTFE spacer



Typical schematic morphology with attack greatest at the mouth of the crevice.*

*Source: RM Kain, Metals Handbook' Corrosion, Vol 13, 9th ed., ASM, Metals Park, OH, p.109, 1987

TYPES OF CORROSION

Contact corrosion - Examples

Galvanised nail
in an A2 sheet

HKD-R with a
hot-dip galvanised bolt

Galvanised HKD
with an A2 bolt

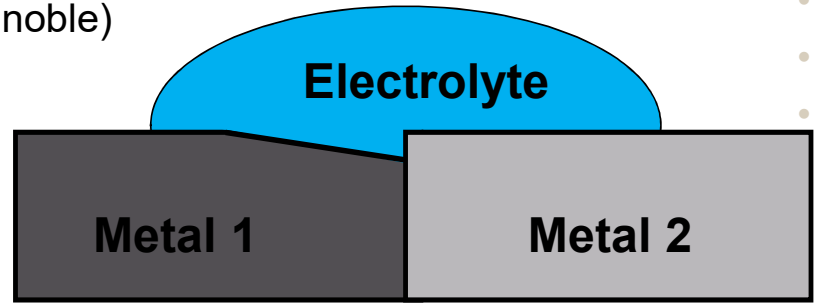
TYPES OF CORROSION

Contact (bimetallic) corrosion

Galvanic corrosion, when two different metals are in contact.

Requirements

- Metals with different corrosion Potential (noble – not noble)
- conducting contact
- electrolyte



Main factors

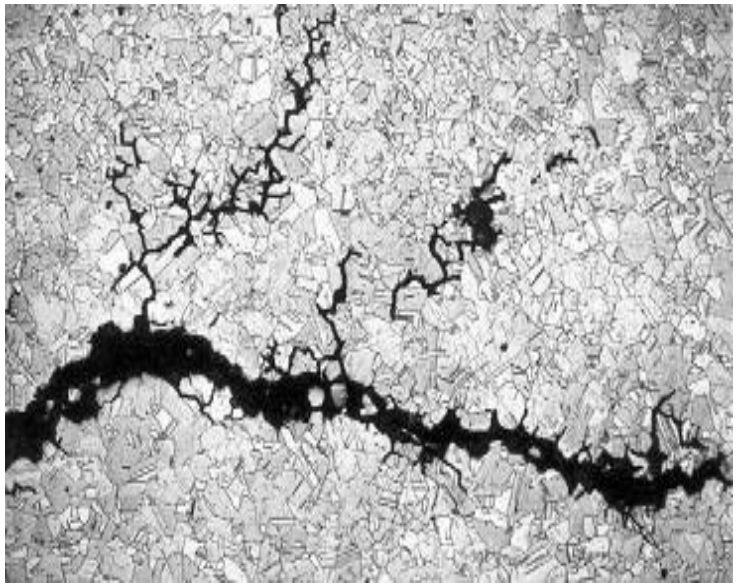
- Conductivity of electrolyte
- Environment (humidity)
- General kinetics of reaction
- Area proportion

TYPES OF CORROSION

Stress corrosion cracking

3 factors have to be fulfilled:

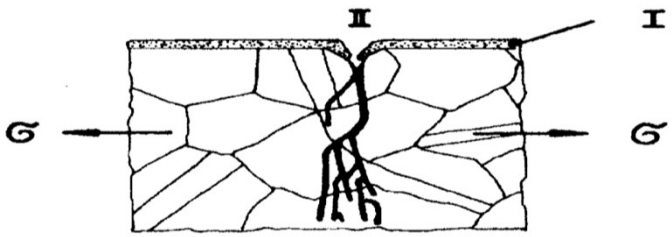
- Sensitive material (e.g. austenitic stainless steel)
- Corrosive environment (chlorides)
- Mechanical loads, also residual stresses can be sufficient



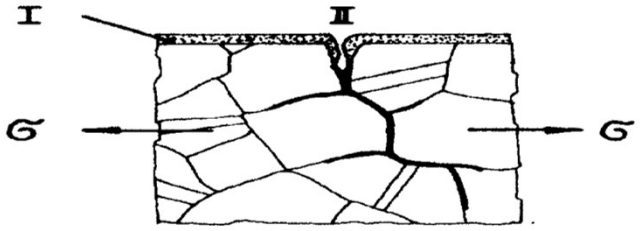
Accelerated crack propagation caused by corrosion and stress

TYPES OF CORROSION

Stress corrosion cracking

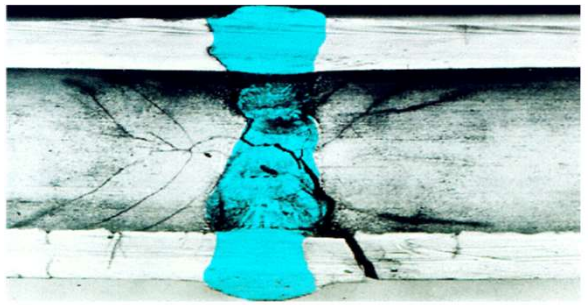


Transcrystalline stress corrosion cracking



Intercrystalline stress corrosion cracking

I...	Passive layer
II... layer	Local break-down of passive and start of stress corrosion cracking; cracking follows



TYPES OF CORROSION

Stress corrosion cracking

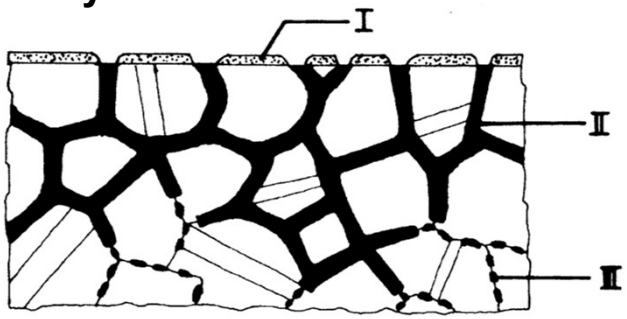
Uster, CH, Swimming Pool

Steenwijk, NL, Swimming Pool

Ohio, USA, Silver Bridge

TYPES OF CORROSION

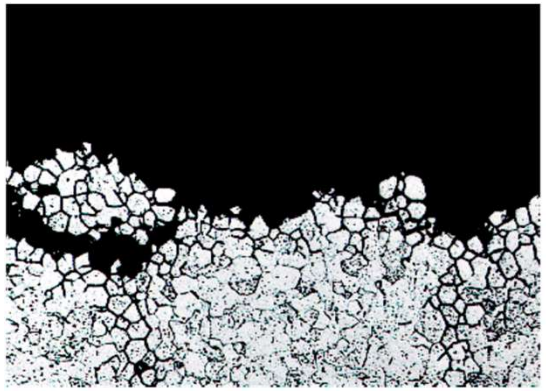
Intercrystalline corrosion



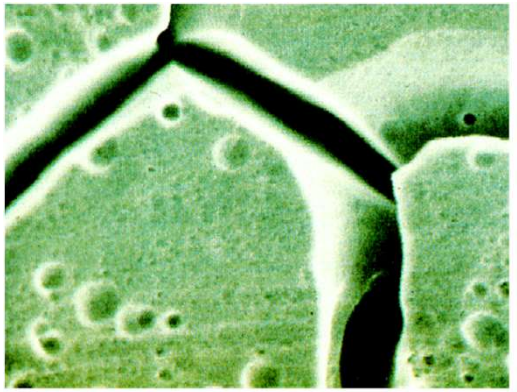
I.. Passive film on zone of crystal not chromium depleted

II.. Selective corrosion near grain boundary of chromium-depleted zone of crystal

III.. Grain boundary with separated-out chromium carbides



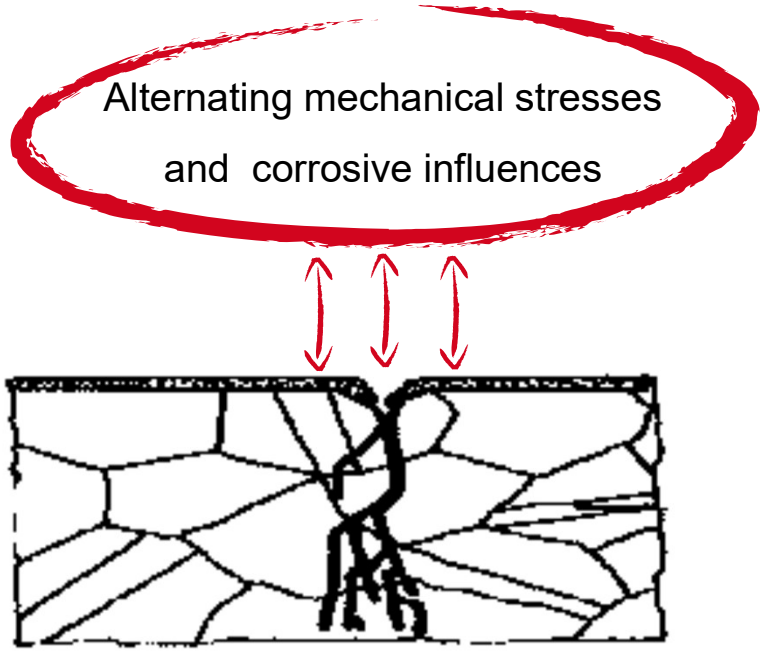
Metallographic cross-section of destroyed stainless steel

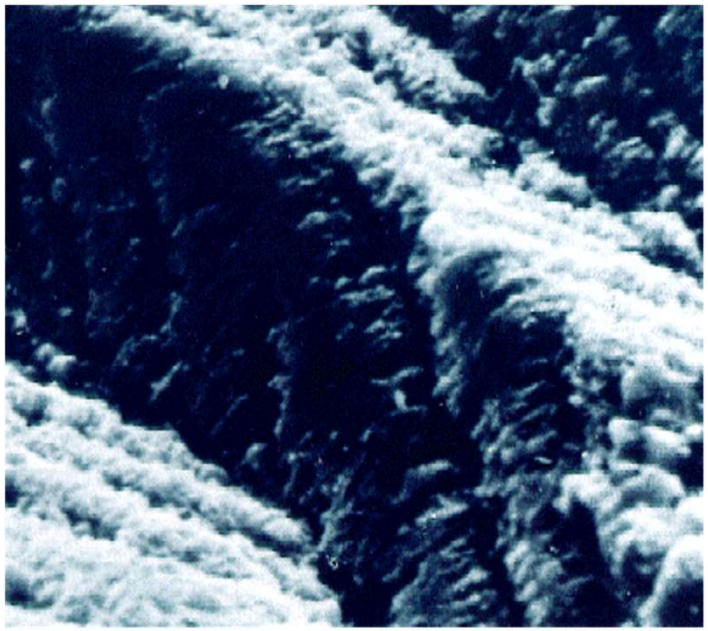


Scanning Electron Microscope photograph

TYPES OF CORROSION

Corrosion fatigue cracking





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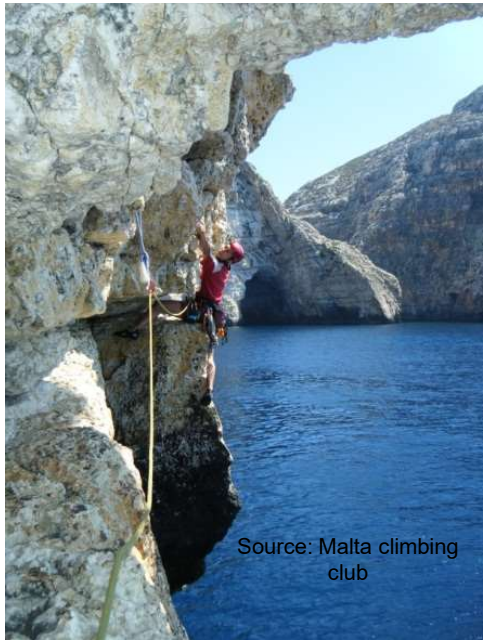
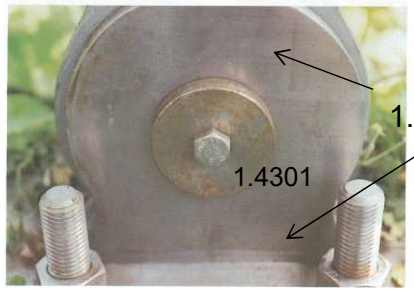
CORROSION OF STAINLESS STEEL



Stainless steel in a coastal environment

De-icing salt on parts near roads or in road tunnels

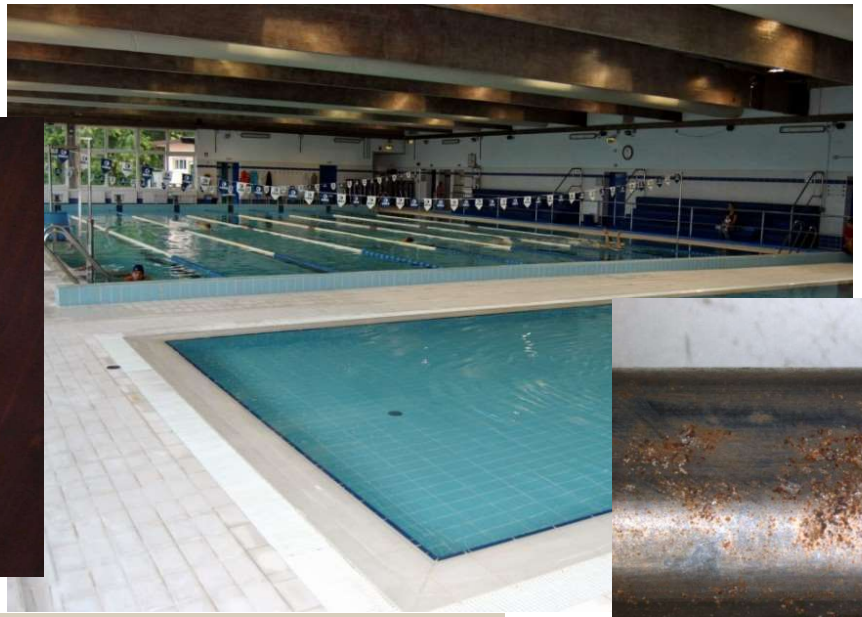


Source: Nürnberger, Korrosion im Bauwesen, Band 2

Source: Andreas Burkert, BAM

CORROSION OF STAINLESS STEEL

MQ channels in indoor swimming pool

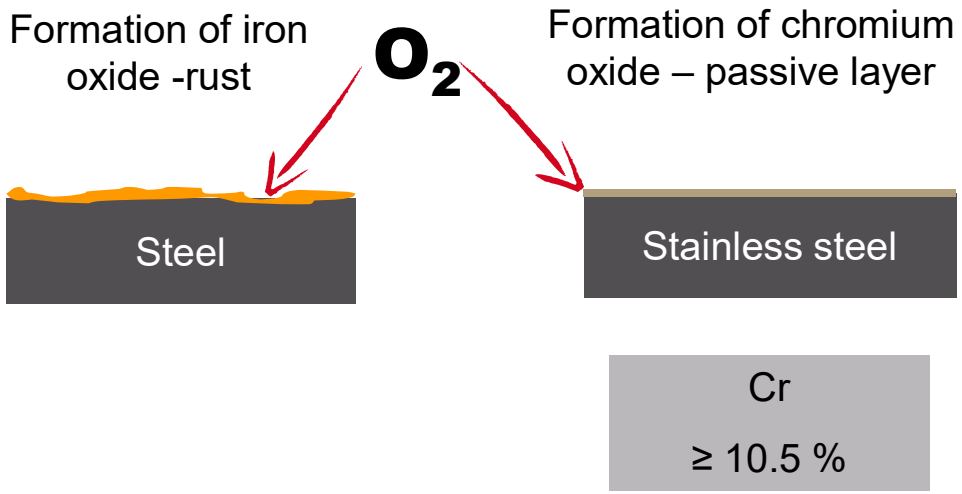


Indoor swimming pool, Italy

Humidity upto 100% every day

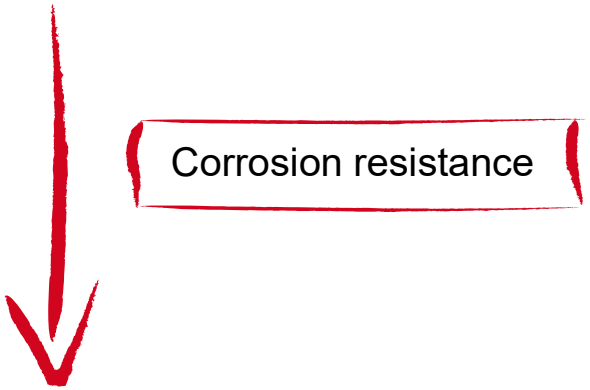
CORROSION OF STAINLESS STEEL

Cr in the steel enables the formation of a stable thin layer of chromium oxide



CORROSION OF STAINLESS STEEL

- A2 (V2A) 1.4301, 304
- A4 (V4A) 1.4401, 1.4404, 316, 316 L
- 1.4571
- 1.4529



Stable due to formation of oxide layer (passive layer ~ 10 nm thick)

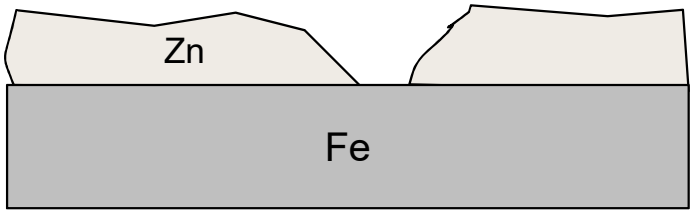
In case of break-down of passive layer, pitting corrosion may occur, can be prevented by elements which enhance repassivation (e.g. Mo).

CORROSION OF ZINC COATED STEEL

Zinc coated steel

Galvanized (~5µm)

Corrosion rates in outdoor environments are usually too high for this type of coating



Zinc provides ‘cathodic protection’

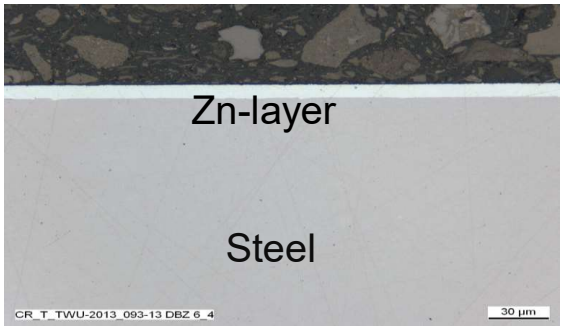
Zinc corrodes preferably and therefore protects the underlying steel even in case of small damages to the layer

HDG: hot dip galvanized (~50µm)

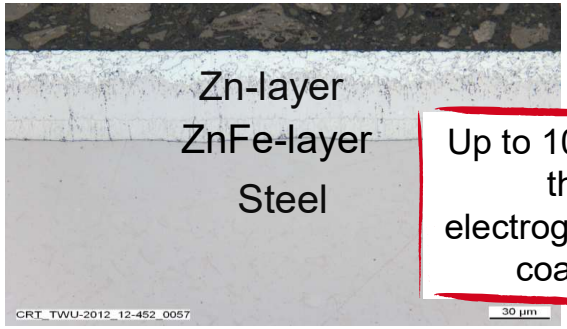
Corrosion resistance is around 10x higher than regular galvanized products

CORROSION OF ZINC COATED STEEL

Electrogalvanized zinc



Hot dip galvanized zinc



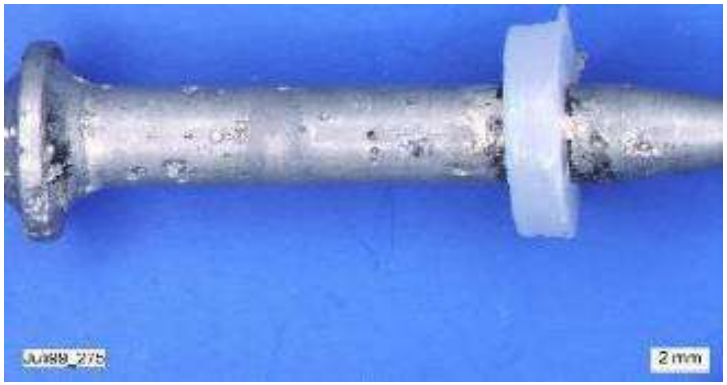
Up to 10 x bigger than electrogalvanised coatings

CORROSION OF ZINC COATED STEEL

Ramming profiles – Solar park in Toul, FR

Red corrosion points after a few months, cross section reveals superficial contamination - No corrosion of the hot dip galvanized layer

CORROSION OF STAINLESS - ZINC COATED STEEL



- Pitting corrosion
- Unpredictable decrease in life time
- A stainless steel grade suitable for the application has to be chosen

- Uniform corrosion
- Coating is consumed in nearly linear manner
- Life time in a certain application defined by coating thickness

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CORROSION PROTECTION

Q. What is corrosion protection?

A. A measure taken to avoid damage by corrosion

Q. Which means?

A. Longer life expectancy of a building component

CORROSION PROTECTION

Active protection against corrosion

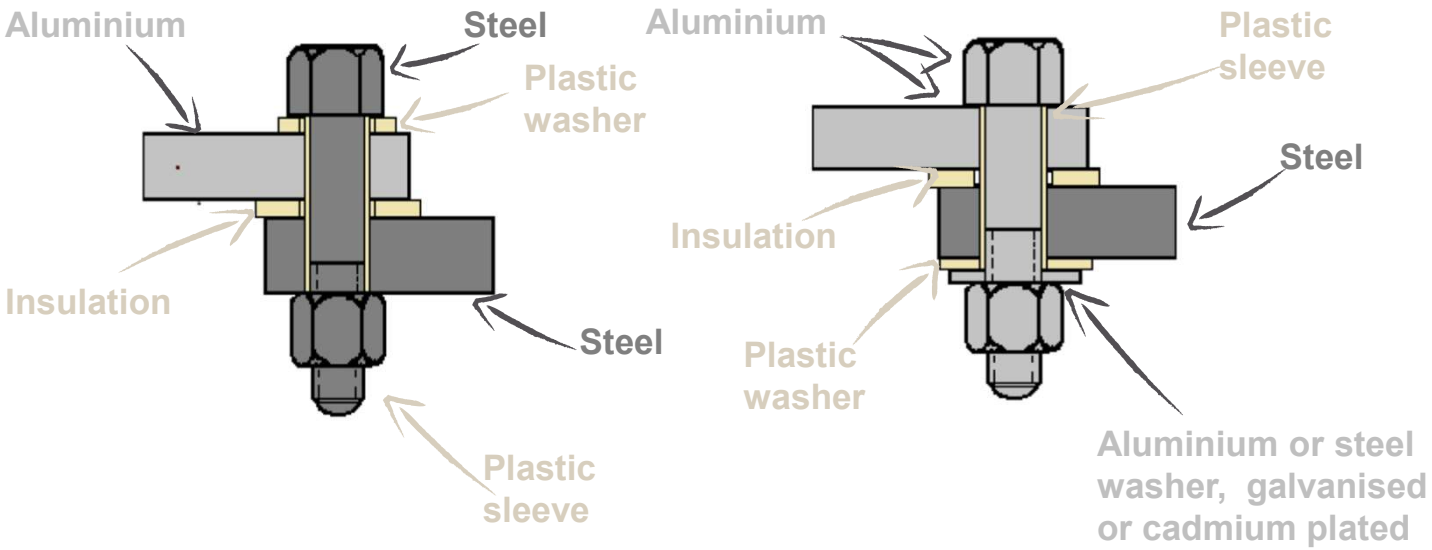
- Planning measures and design
- Protective measures in corrosive medium
- Impressed current

Passive protection against corrosion

- Metallic coating
- Organic coating

CORROSION PROTECTION

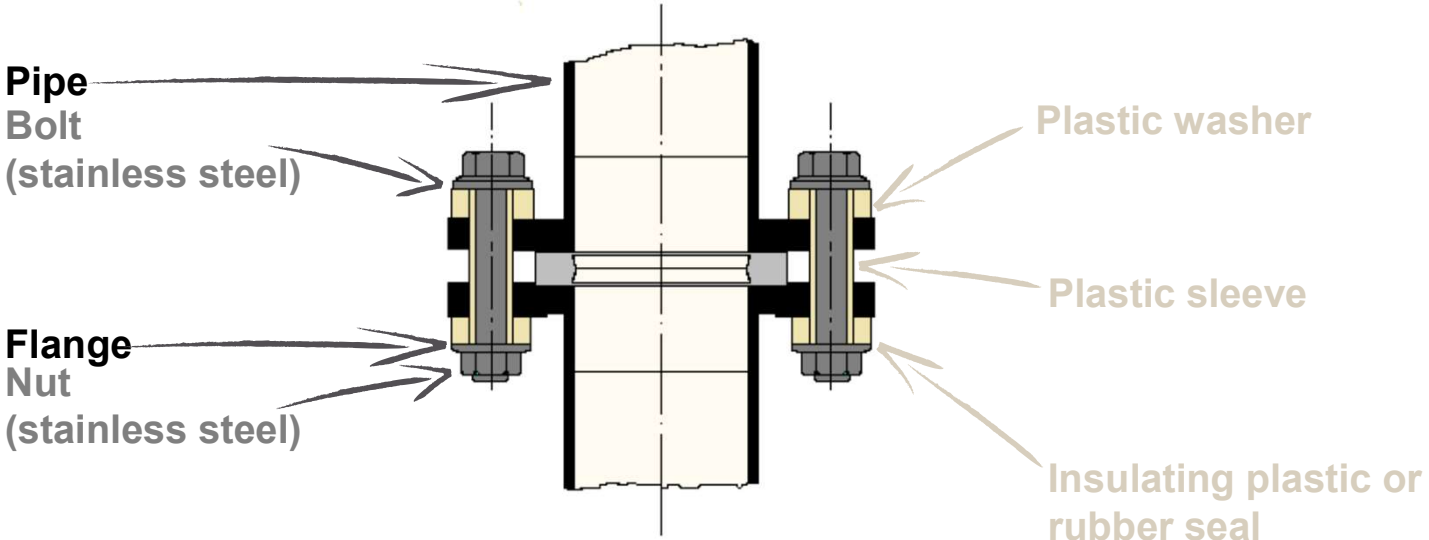
Active protection against corrosion



Galvanic separation of material combinations
Avoidance of contact corrosion Source: Nuernberger

CORROSION PROTECTION

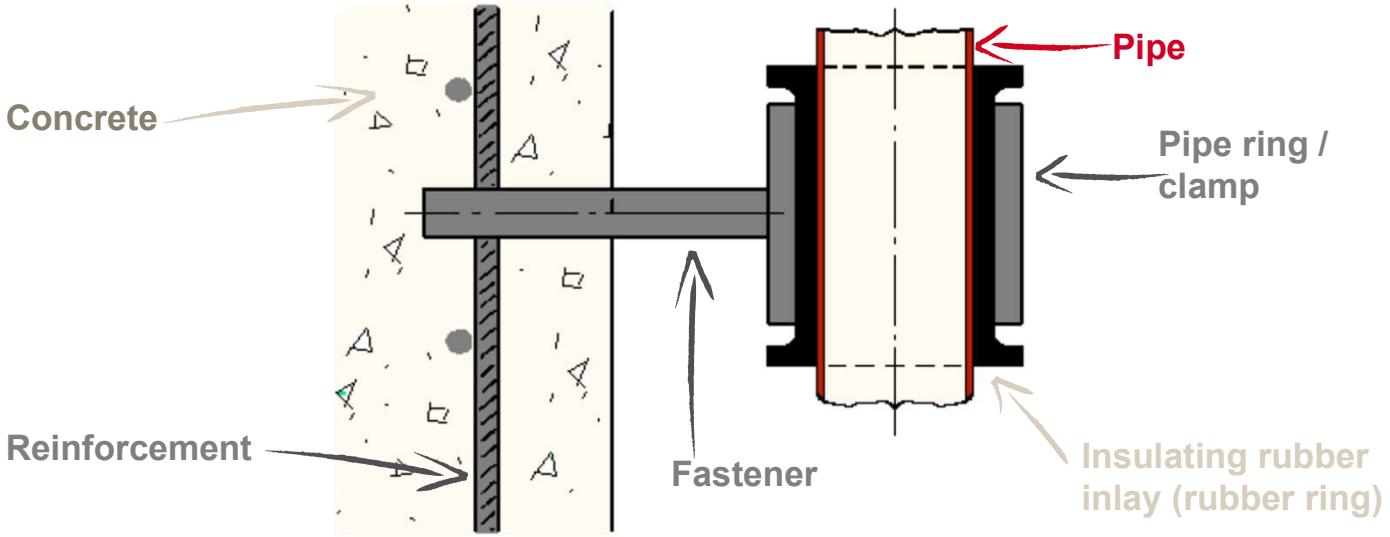
Active protection against corrosion



Galvanic separation of material combinations
Avoidance of contact corrosion Source: SGK

CORROSION PROTECTION

Active protection against corrosion



Galvanic separation of material combinations
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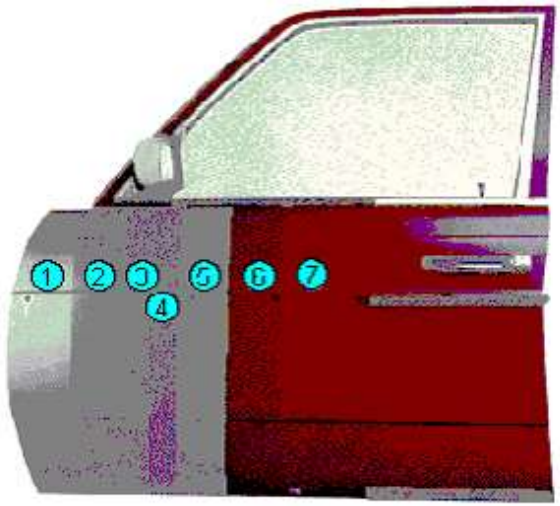
CORROSION PROTECTION

Passive protection against corrosion

Organic Coatings

- Painting / lacquering
  - Spraying process
- Powder coating
  - Electrostatic
  - Fluidised-bed (whirl) sintering
  - Centrifugal process
  - Flame spraying
- Electrodip painting
  - Electrical deposition of special paint / lacquer systems

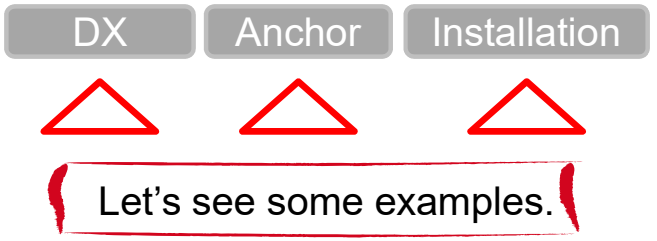


Paint layer build-up on a car door

1. Sheet metal surface
2. Phosphating
3. Electrodip priming
4. Undercoat against stone damage
5. Ground coat
6. Enamel undercoat
7. Enamel topcoat

CORROSION PROTECTION

- Galvanized Zn: Zinc coating electroplated with a thickness from 5 to 13 µm.
- HDG: Hot dip galvanized zinc coating with a coating thickness around 50 µm.
- Stainless steel (grade A2/304/1.4301): stainless steel with 18 % Cr and 10 % Ni.
- Stainless steel (grade A4/316/1.4401): similar to A2/304, but contains around 2 % Mo, which increases the corrosion resistance.
- Stainless steel (HCR, 1.4529): increased contents of Ni, Cr and Mo (up to 7 %), very high corrosion resistance in aggressive environments.



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X-EM8 Threaded stud for steel

X-CRW6 Stainless stud for concrete

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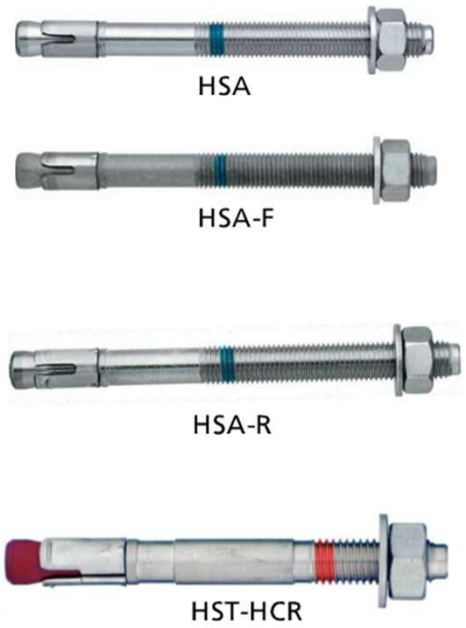

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SELECTION OF A SUITABLE MATERIAL

- What environmental conditions exist?
  - Wet / Dry
  - Temperature
  - Pollutants
- Which materials are being combined?
  - Material of the fastener
  - Material of the part being fastened
- Safety aspects of the fastening

SELECTION OF A SUITABLE MATERIAL

Application ⟷ Limits to use

Stainless-steel façade

Collapse of swimming pool ceiling in Uster, Switzerland (1985) - Due to wrong design and material

SELECTION OF A SUITABLE MATERIAL

Environmental conditions

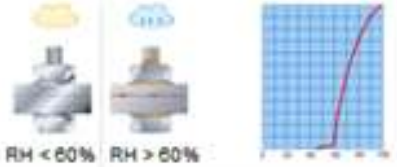
Selection of a suitable material based on corrosiveness

- Weak corrosive conditions
  - Dry inside rooms without air exposure
  - Normal atmosphere, not directly weathered
- Medium corrosiveness
  - Damp rooms
  - Outside applications in normal atmosphere
- Highly corrosive conditions
  - Coastal area
  - Industrial atmosphere
  - Road tunnel
  - Special applications, e.g. water treatment plants, etc.

SELECTION OF A SUITABLE MATERIAL

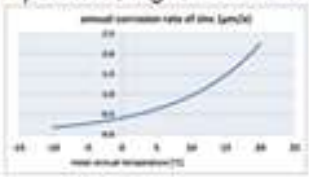
Humidity

humidity is needed for the corrosion reaction



Temperature

higher temperature, higher corrosion attack



Salt

Near the sea coast & used for deicing in winter

Chloride concentration in atmosphere

Road salt

Industrial pollution

mainly sulphur dioxide accelerates corrosion

SELECTION OF A SUITABLE MATERIAL

Environmental conditions

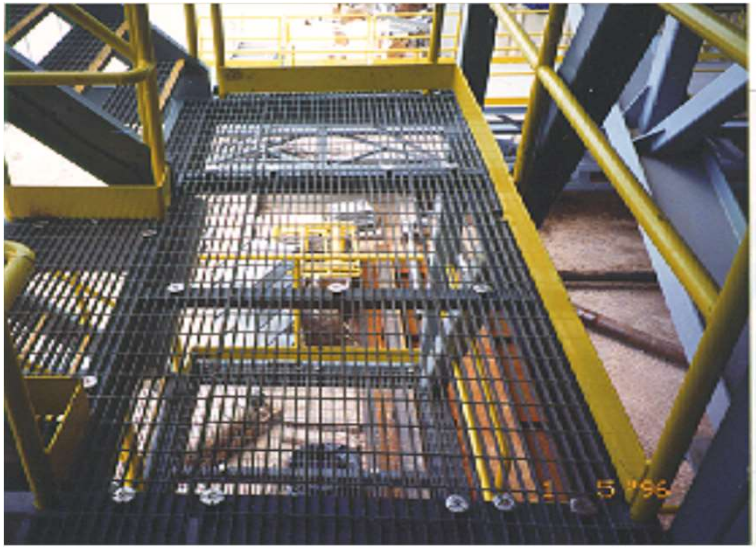
Grating fastened with X-CR

Pipefitting and electrical installations

X-CR in a water treatment plant

SELECTION OF A SUITABLE MATERIAL

Environmental conditions



Fastening of walkways on aluminium or steel structures using X- CR studs. For example, in the chemical industry, on off-shore platforms and in power plant construction

SELECTION OF A SUITABLE MATERIAL

Corrosion loss of zinc and unalloyed steel

Atmosphere	Zinc µm/year	Unalloyed steel µm/year
Rural	1.0 - 2.0 µm	6.0 - 50 µm
Town	1.0 – 6.0 µm	30 - 170 µm
Industrial	3.8 - 19 µm	30 - 160 µm
Coastal	2.4 - 15 µm	20 - 130 µm

SELECTION OF A SUITABLE MATERIAL

Fastener / Part fastened	Galvanised	Hot-dip galvanised	Aluminium Alloy	Mild Steel	Stainless Steel	Brass
Zinc	○	○	○	○	○	○
Hot-dip galvanised	○	○	○	○	○	○
Aluminiumalloy	●	■	○	○	○	○
Cadmium plating	●	■	○	○	○	○
Mild steel	●	●	●	○	○	○
Cast steel	●	●	●	●	○	○
Chromium steel	●	●	●	●	○	■
CrNi(Mo) - steel	●	●	●	●	○	●
Tin	●	●	●	●	○	■
Copper	●	●	●	●	●	●
Brass	●	●	●	●	●	○

■ **Low Corrosion of the fastener**
● **Heavy Corrosion of the fastener**
○ **Low or no Corrosion of the fastener**

NOTE: This relates to the fastener and NOT the combination!!!

SELECTION OF A SUITABLE MATERIAL

Zinc in the atmosphere

Hot-dip galvanised sheet metal (~ 30 microns) in coastal atmosphere - cut edges no longer covered

Hot-dip galvanised sheet metal (~ 30 microns) in coastal atmosphere and fastened with galvanised bolts (~ 7 microns)

SELECTION OF A SUITABLE MATERIAL

Environmental conditions (according to EC2)



Environmental conditions

Galvanised 5-20µ	• Hot dipped Galvanised • Sherardised	A2 Steel	A4 Steel	HCR
• Inside rooms without humidity • Outside only for temporary applications	• Damp inside rooms • Slightly corrosive outside atmosphere • Occasional exposure to condensation	• Inside rooms with heavy condensation • Outside without chlorides	• Inside rooms with heavy condensation • Outside with moderate chlorides	• Highly corrosive surroundings like road tunnels, indoor swimming pools

Low — Corrosion resistance — High

AGENDA

1. Why we need to consider corrosion
2. Forms of corrosion
3. Corrosion of stainless steel
4. Corrosion protection
5. Selecting the right materials
6. Corrosion categories
7. Summary
8. Hilti Engineering Support

CORROSION CATEGORIES

Very low

CORROSION CLASS C1 – ACC TO ISO 9223

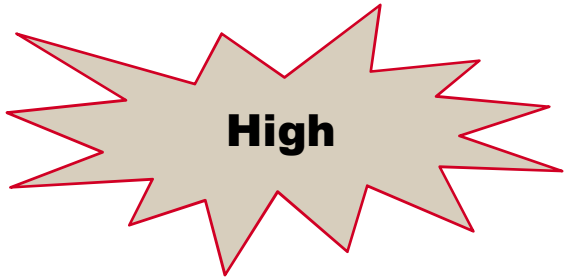
- Mainly dry indoor
- Corrosion protection

  zinc galv., phosphatation

Annual corrosion rate for the duration of 10 years (ISO 9224:2012)

Corrosivity category (ISO 9223)	Units	Carbon steel	Zinc	Copper
C1	Corrosion rate [µm/a]	<0.4	<0,07	<0,05

CORROSION CATEGORIES



CORROSION CLASS C4

- Indoor: industrial processing plant, swimming pools
- Outdoor: industrial areas, coastal areas
- Corrosion protection: HDG, stainless steel

Annual corrosion rate for the duration of 10 years (ISO 9224:2012)

Corrosivity category (ISO 9223)	Units	Carbon steel	Zinc	Copper
C4	Corrosion rate [µm/a]	17 - 27	1.4 – 2.7	0.6 – 1.3

CORROSION CATEGORIES

CORROSION CLASS C5

- Outdoor: hot, humid coastal areas or areas with high pollution
- Corrosion protection: stainless

Annual corrosion rate for the duration of 10 years (ISO 9224:2012)

Corrosivity category (ISO 9223)	Units	Carbon steel	Zinc	Copper
C5	Corrosion rate [µm/a]	27 - 67	2.7 – 5.5	1.3 – 2.6

CORROSION CATEGORIES

CORROSION CLASS CX

- New category introduced in ISO 9223:2012
- CX for Zn: 8 – 25 µm/a corrosion loss
- Hilti test field (project OFT) Yucatan, Mexico
- ~ 20 µm/a Zn loss (in the first year)

Annual corrosion rate for the duration of 10 years (ISO 9224:2012)

Corrosivity category (ISO 9223)	Units	Carbon steel	Zinc	Copper
CX	Corrosion rate [µm/a]	67 - 233	5.5 - 16	2.6 – 4.6

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SUMMARY

- Corrosion is a natural process
- Corrosion must be understood as a system property
- Corrosion cannot be stopped, we can only reduce it by providing the right protection
- Corrosion influences the economy
- Higher investment`s (e.g. higher grade of fastening material) are economical

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THANK YOU

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