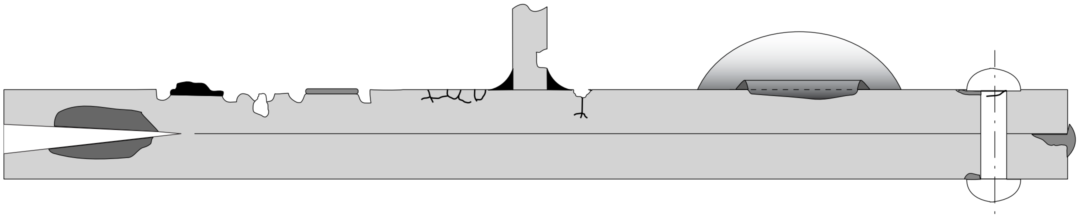
5.6 Corrosion.



Corrosion as damge through reaction of materials respectively machine elements must be considered **by the designer during dimensioning and shaping**. However the problem is the multitude of failure effective influences, the correlating technical terms and failure mechanisms (Lit. 5.6-5). The designer is urgent advised at not sufficient **experience**, to consult in his case **an expert and the specialist literature**. Thereby is an **exact as possible knowledge of the probable corrosion system** necessary (Ill. 5.6-1). This is true for the actual used material (condition) and the relevant operation influences like corrosion medium, load in hight and time related and the operation temperature.

There are a multitude corrosion types distinguished (Lit. 5.6-4):

- **Related to media: Atmospheric** corrosion through the environment. As corrosive medium there is especially the sea atmosphere to mention. Further are counted among:
  Water line corrosion respectively corrosion at the contact linie/three-phase border of liquid/air/metal (Ill. 5.6.1.2-7).
  Hydrogen induced corrosion in hydrogen atmosphere at elevated temperature. Damages often occur in different modes: **Decarburation** (unalloyed or low alloyed steels), inner **cracks** (oxygen containing copper alloys) and **bubbles** (Al alloys). At unalloyed and low alloyed steels we speak about **attack by compressed hydrogen** and '**hydrogen disease**'.
- **Design caused: Gap corrosion** appears in the region of gaps (Ill. 5.6.1.1-2.1).
- **Material peculiarity: Selective corrosion** is limited largely at certain **material structure components**. To this belongs **spongiosis** (graphite corrosion in grey cast iron), **dezincification** (brass alloys), **dealumination** (Al-Cu alloys), **ferrite** and **austenite corrosion** (austenitic steels with a share of ferrite), grain boundary attack (intercrystalline corrosion) and segregation corrosion.
- **Failure characteristics**: Type of the attack (Ill. 5.6-2 and Ill. 5.6.1.1-1) like laminar, **cavity**, **pitting**, **intercrystalline** a**nd blister formation** (e.g., **hydrogen disease).**
- **Temperature**: Primarily **high temperature corrosion** is concerned (chapter 5.6.1.4).
  To this count failure triggering oxidation/scaling and sulfidation.
  At low-temperature corrosion can be counted condensate corrosion and dew point corrosion (acid condansate corrosion). Thereby develops an aggressive condensate, which acts as electrolyte.
- **Load depending**: Basically tensile stresses are concerned.
  - Static load: **Stress corrosion cracking** (SCC, chapter 5.6.3.1).
  - Dynamic load: **Corrosion fatigue** (chapter 5.6.3.2):
- **Time depending**: To this counts primarily the so called **idle/stand still corrosion.**

- **Type of development**: To this belongs **hand perspiration**/sweat **corrosion** at components from low alloyed steels like antifriction bearings.
  Microbiological induced corrosion in waters with specific **bacteria and fungi**.
- **Additional failure mechanisms**:
  Erosion supported, so called erosion corrosion (Ill. 5.1-3, chapter 5.6.2).
  Cavitation corrosion (Ill. 5.5.1.3-4).
  Drop impact (Ill. 5.5.1.2-1 and Ill. 5.5.1.2-5).
  Fretting as **friction corrosion**/ (Ill. 5.9.3-2).

Ill. 5.6-1: *Three main factors, i.e. corrosive media, materials, and mechanical loads, determine the behavior of a corrosion system. The depiction with the overlapping circles is based on Ill. 5.4.1-5. The three main influences are themselves affected by many different conditions (top diagram). This shows the complexity of corrosion processes.*

The bottom three diagrams show the conditions for three typical ***crack-initiating corrosion types*** *(black areas). As shown, the occurrence of* ***stress corrosion cracking*** *(SCC, chapter 5.6.3.1.1) requires the combination of all three main influences. If one of these influences is missing, such as sufficient tensile stress levels or stress concentration, then SCC can not occur. With* ***corrosion fatigue*** *(CF, chapter 5.6.4.2), a specific medium and sufficient (dynamic) loads are necessary, but a special material state of the affected material (such as 13% Cr steels in the typical state during operation) is not a prerequisite.*

In order for ***intergranular corrosion/attack*** *(IGC/IGA, Ill. 5.6.1.1-1 and Ill. 5.6.1.1-4) to occur, a sensitive material and a specific medium are necessary, but there is no specific minimum load level necessary for this type of corrosive attack.*

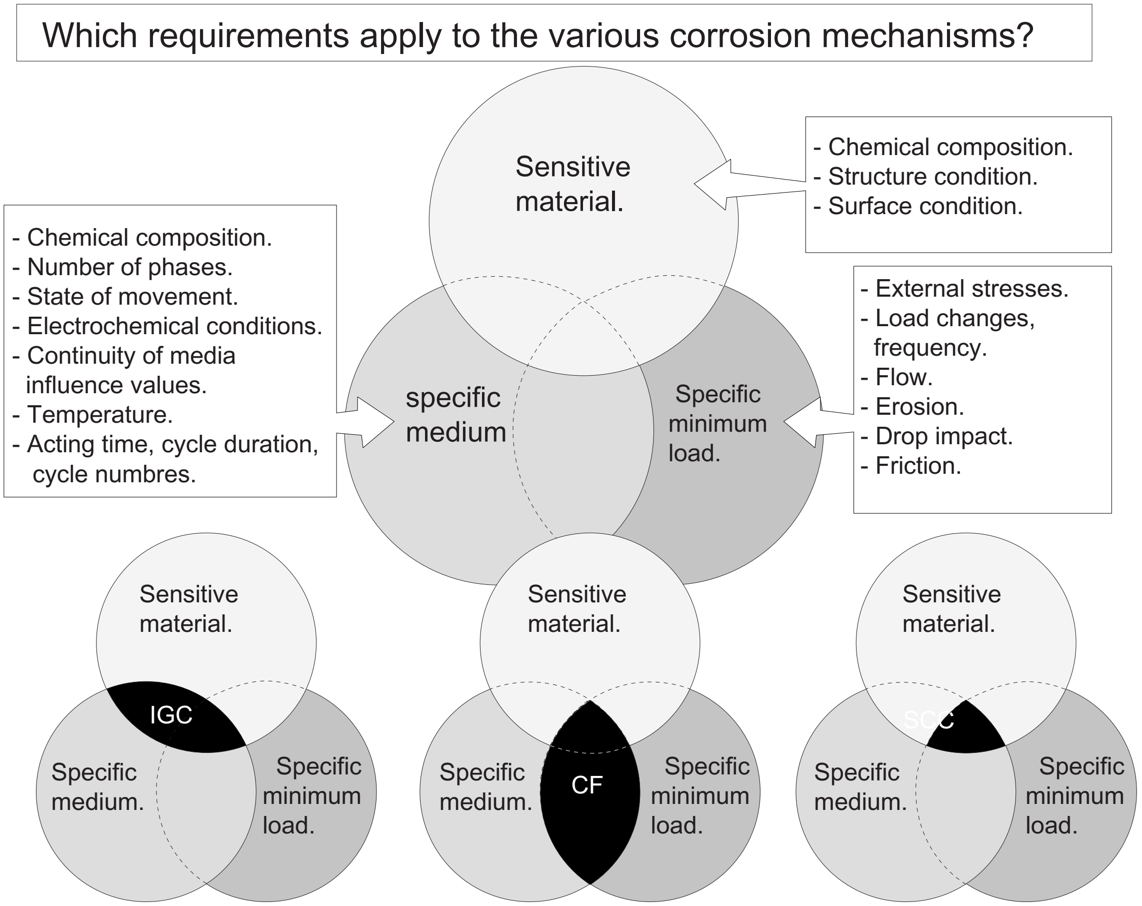
Ill. 5.6-2 *(Lit. 5.6-1): Corrosion can occur in different* ***form of appearances****. This is shown here with schematic metallographic cross sections (sketches below).*

In the chart above the corrosion behaviour of typical metallic materials of the modern mechanical engineering is summarized.

Plane corrosion *is observed, if there is no tension stress or it does not yet act in an initial stage. The development of a layer of corrosion products can be observed especially at lowalloyed/ unalloyed steels like construction steels and carbon steels. The emaciation indeed changes the geometry and leads to a weakening through decrease of the cross section, however the notch effect is at additional dynamic load rather not main cause of a failing.*

Pitting *distinguishes itself by local attack of the surface in form of pits (corrosion pittings). Concerned are especially so called corrosion resistant, high alloyed steels like martensitic 13%-Cr-steels (heat treatment steels) or austenitic Cr-Ni-steels. Endangered is so called not stabilized (without Ti or Nb, Ill. 5.6.1.1-1 and Ill. 5.6.1.1-4) CrNi18/8 steel. At these in an extreme case pittings as fine holes of few tenth of a millimeter (****pinholing corrosion****) can even penetrate thicker metal sheets and cause leakage*

Influences from Outside: Corrosion Without Mechanical Load: Introduction.



Ill. 5.6-1

Intergranular corrosion (IGC). Corrosion fatigue (CF). Stress corrosion Cracking (SCC.)

(heat exchanger, boiler). Cause is a local corrosion cell formation, mostly because of material specific inhomogenity. It must be expected, that the notch effect of the pittings lowers the dynamic fatigue strength up to the failure cause. ***Intergranular attack (IGA)*** *runs along the grain boundarie. Cause is an especially* ***sensitivity of the grain boundaries*** *through enrichments of corrosion promoting or depletion of corrosion inhibiting alloy components. IGA can occur load specific for material and medium at all corrosion types. It is especially observed in the region of unsuitable structure zones* ***along of weld seams*** *(heat affected zones) at unloaded high alloyed austenitic steels of the type CrNi18/8 without Ti and Nb addition.*

Transgranular *running separations through the grains/crystals. This damage picture can be found at SCC and CF, especially if the mechanical* ***load level is high****. Does the stress drop to the inside* ***ramifications at the crack tip*** *are typically.*

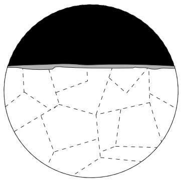
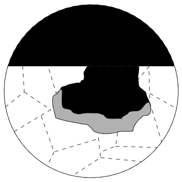
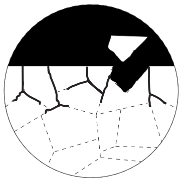
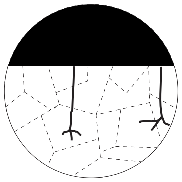
Influences from Outside: Corrosion Without Mechanical Load: Introduction.

Corrosion behaviour of selected materials of the mechanical engineering.

Material.	Type / example.	Semi finished.		Blades		Disks.	Casings.	Behaviour in watery corrosion.	Preferred corrosion types in different corrosion media.
		forged, wrought.	Casting.	Rotor	Vane.				
Low alloyed steels.	Heat treated steels	*	*			*	*	--	Plane, cavity, pitting.
Cr Steels.	10-13% Cr	*	*	*	*	*	*	-	Pitting, SCC, CF
Cr/Ni Steels	18/9, A-286	*	*		*		*	+	Pitting, IGA
Fe content with high Cr and Ni share.	IN 718	*	*			*	*	+++	IGA (in etching baths).
Ni alloys.	Nimonic Waspalloy	*		*	*	*	*	+++	IGA (in etchning baths) Pitting corrosion (Ag involved).
Ti alloys.	TiAl6V4	*	*	*	*	*	*	+++	SCC (with Cl from 300°C), sea salt from 500°C,
Al alloys	AlCuMg	*	*	*	*	*	*	0	SCC, pitting, plane.
Mg alloys	MgTh		*				*	---	Plane, pitting. Effect of sea salt.
Be alloys	BeCu	*			*			0	SCC, pitting, plane (corresponding Al alloys).
C fiber with oranic matrix (CFRP).				*			*	+++	As at contact corrosion as cathode ("nobel").

very good +++ ++ + 0 - -- --- bad

Appearances of the corrosion in a meatallographic cross section.

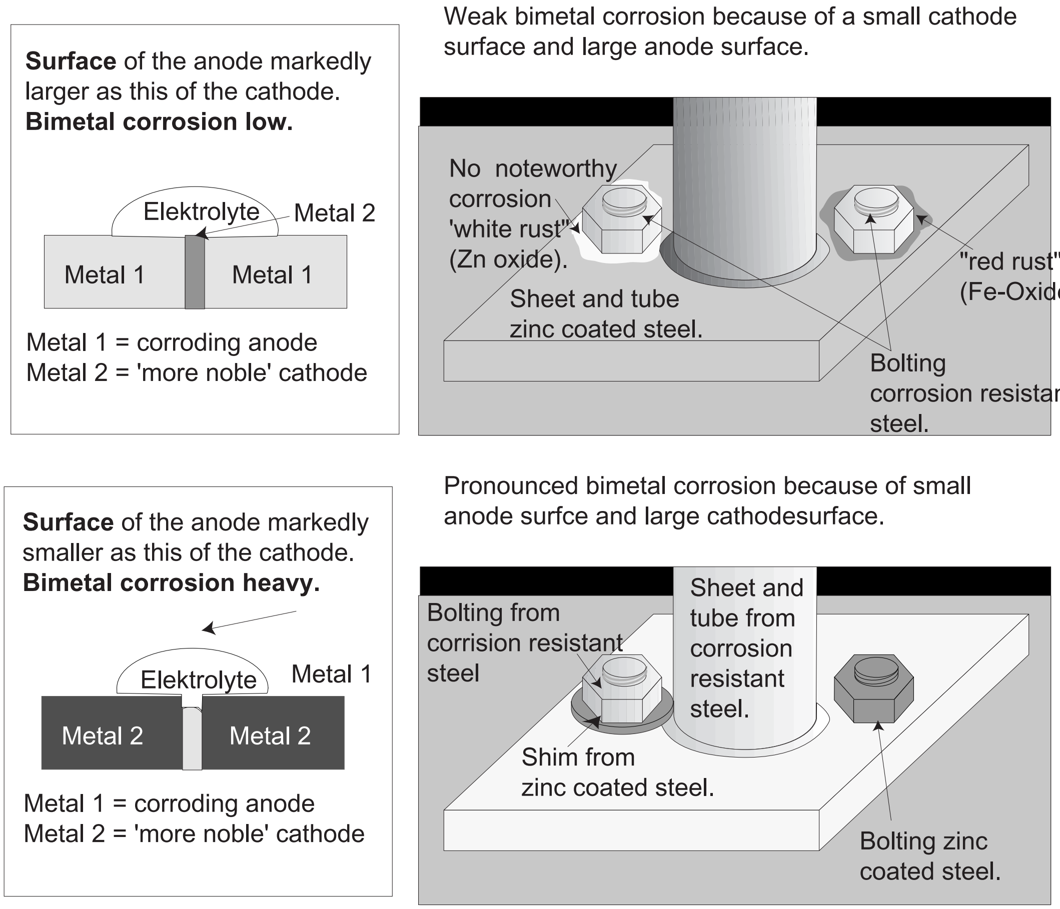
Corrosion attack.	Plane.	Pitting.	Intergranular.	Transgranular
Metallographic cross section.				
Load influence/ corrosion type.	- without	- without pitting	- Without IGA, grain desintegration. - Static SCC - Dynamic, corrosion fatigue CF.	- without - static SCC - Dynamic corrosion fatigue CF.
Pictures/ illustrations.	Ill. 5.6.1-2	Ill. 5.6.1-2 Ill. 5.6.1-3 Ill. 5.6.1.2-2 Ill. 5.6.1.2-3 Ill. 5.6.4.2-2	Ill. 5.6.1-7 Ill. 5.6.1-8 Ill. 5.6.1-9 Ill. 5.6.4.1.1-7 Ill. 5.6.4.1.2-2 Ill. 5.6.4.1.2-3	Ill. 5.6.4.1.1-7 Ill. 5.6.4.1.1-8 Ill. 5.6.4.2-2

Ill. 5.6-2

Ill. description see page before.

Bimetal corrosion.

Typical appearances of the "bimetal corrosion".



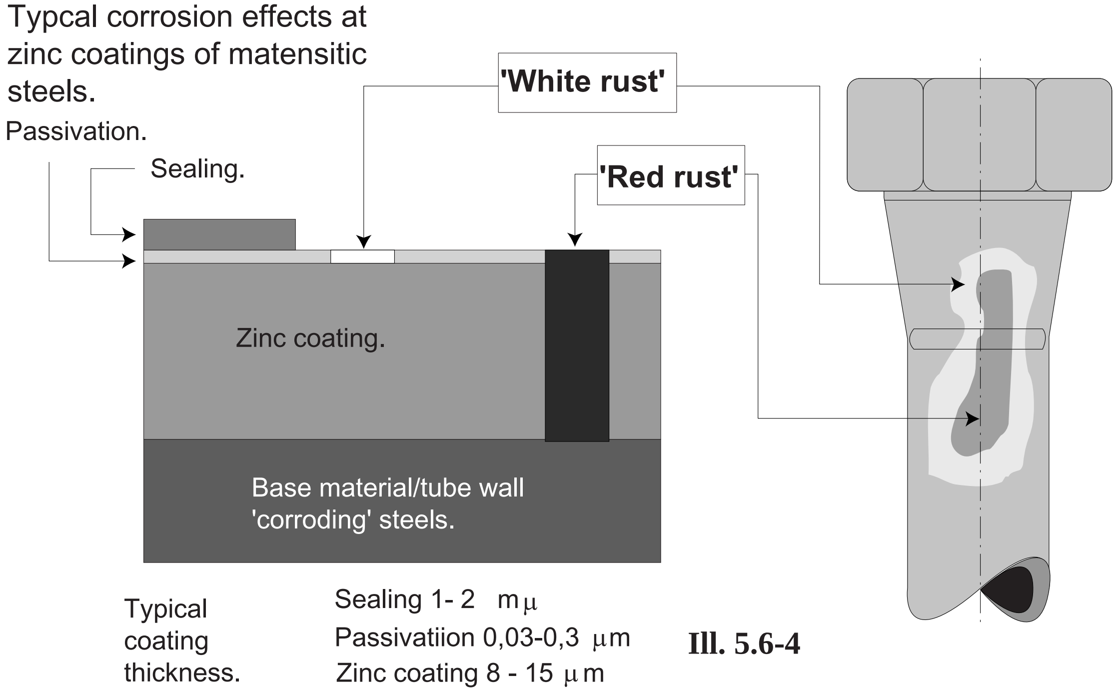
Ill. 5.6-3

Bild 5.6-3 *(Lit. 5.6-2): The so called* ***bimetal corrosion*** *is a frequently occuring problem in form of a* ***corrosion cell development*** *(Ill. 5.6-5 and Ill. 5.6.1.1-3). Typical is the combination of a* ***zinc coated steel*** *with an austenitic/'****corrosion resistant'****. The* ***intensity of the corrosion depends from the ratio between the electrolyte wetted area of the corroding anode to the 'more noble' cathode****. The smaller the anode the more severe is the attack (sketch below left). In contrast with a smaller corrosion resistent area the corrosion at the anode is lower (sketch above left).*

This arrangement can be found especially frequent at the infrastrukture of buildings and facilities/plants. Here are handrails and platforms concerned (sketches right).

Above the case of a small cathode area as a ***bolting from austenitic steel*** *is shown. The large anode area is formed by the* ***zinc coated tube*** *and the* ***support plate*** *. As electrolyte acts humidity from the surrounding (rain, condensate). Corrosion can be observed merely at a small zone around the contact of the nut. It can be desinguished the for the protection effect inevitable* ***initial condition „white rust“*** *(Zn oxides) from the* ***final condition „read rust“*** *where the zinc coating is dissolved down to the base material (Ill. 5.6-4). If the zinc coated area of the bolting*

Bimetal corrosion at zinc coated pipe lines of the machanical engineering (e.g., hydraulic tubes).



Ill. 5.6-4

*is small (nut, shim) it comes to the fast dissolution **of the zinc coating and formation of „red rust“** (sketch below right).*

***Ill. 5.6-4** (Lit. 5.6-3): In many facilities of the mechanic engineering (e.g., hydraulic, motors) and the home equipment (heating and tap water) zinc plated steel pipes are used. If for example only a **passivation** (e.g., chromate layer) is damaged (scratches during handling) the zinc acts protective. This shows as grey veil, the so called **white rust** correspondent Ill. 5.6-3. This is indeed optical unwanted, however technical unproblematic and shows the effectivity of the corrosion protection. However, if the zinc coating is penetrated, **read rust** from the attack of the base material can be observed. In this phase **the consumption of the cathodic protecting zinc coating accelerates** which additionally can be undercut.*

***Ill. 5.6-5** (Lit. 5.6-2): Bimetal corrosion needs requirements („**A**“). Unfortunately these are in practice frequently fulfilled. However this gives hints how this corrosion type can be avoided respectively controlled („**B**“). Of especially importance is the **electrical resistance of the electrolyte** („**C**“). The higher it is, the less the bimetal corrosion. The **specific conductivity resistance** for different waters shows „**F**“.*

*The ‘**practical electromotive chain** („**D**“) shows the corrosion behaviour of metallic **construction materials** (mostly alloys) in **sea water**. This is as well true for the direct contact like during operation of a ship and offshore as also for condensate in sea atmosphere.*

***An impression of site specific corrosion load** of facilities for a time period of one yers shows „**E**“.*

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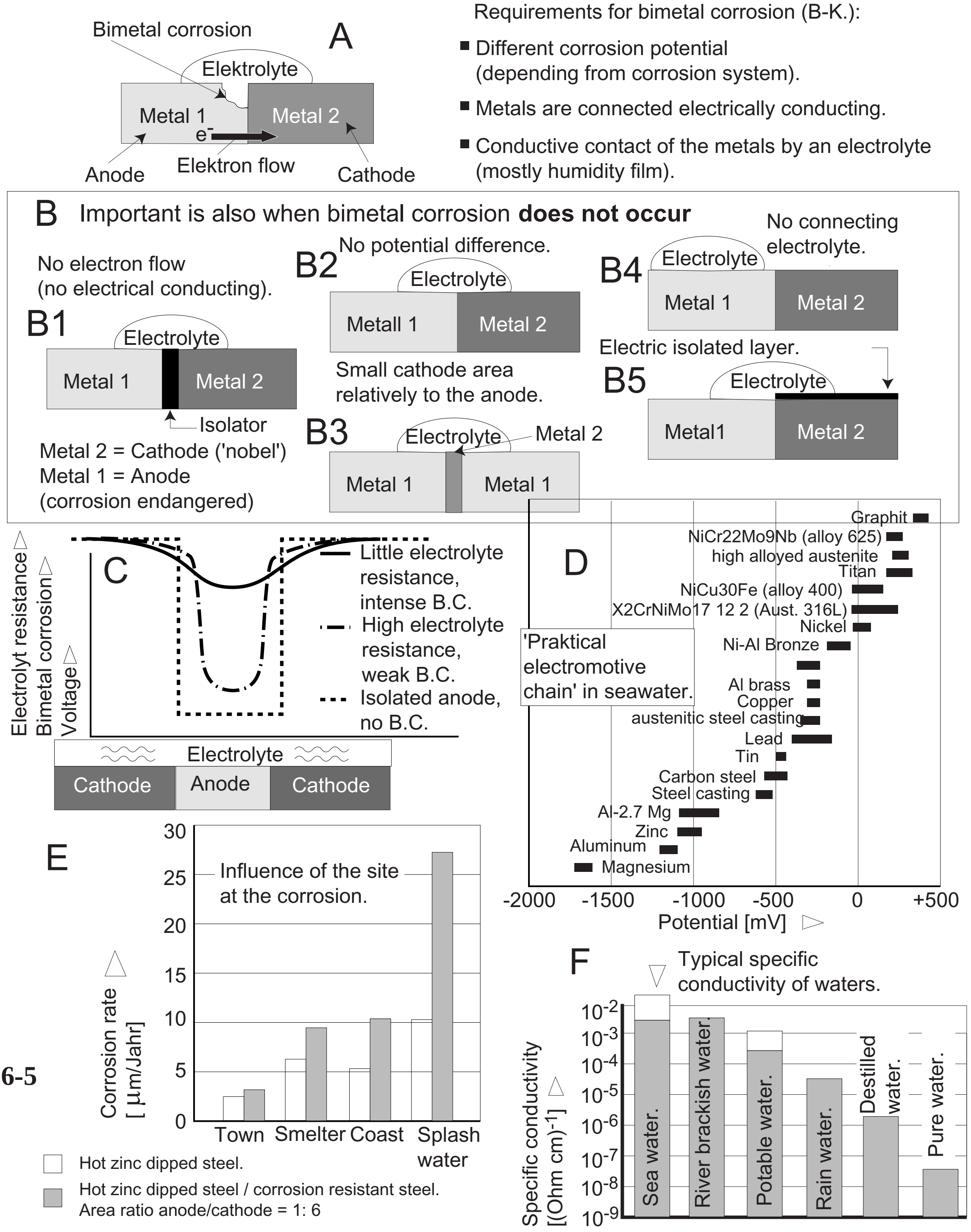
"Bimetal corrosion" is especially identified at mixed constructions from 'corrosion resistant' steel with other metals.



Requirements for bimetal corrosion (B-K.):

- Different corrosion potential (depending from corrosion system).
- Metals are connected electrically conducting.
- Conductive contact of the metals by an electrolyte (mostly humidity film).

Ill. 5.6-5

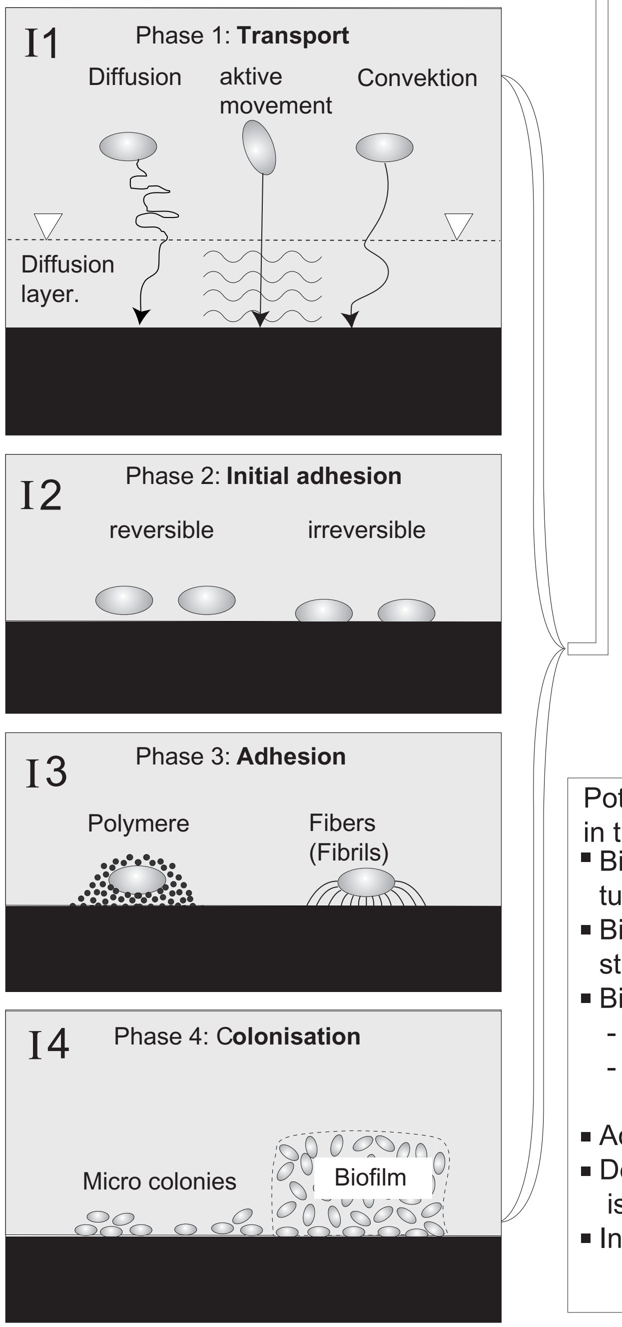
Influences from Outside: Corrosion Without Mechanical Load: Introduction.

Biofilms.

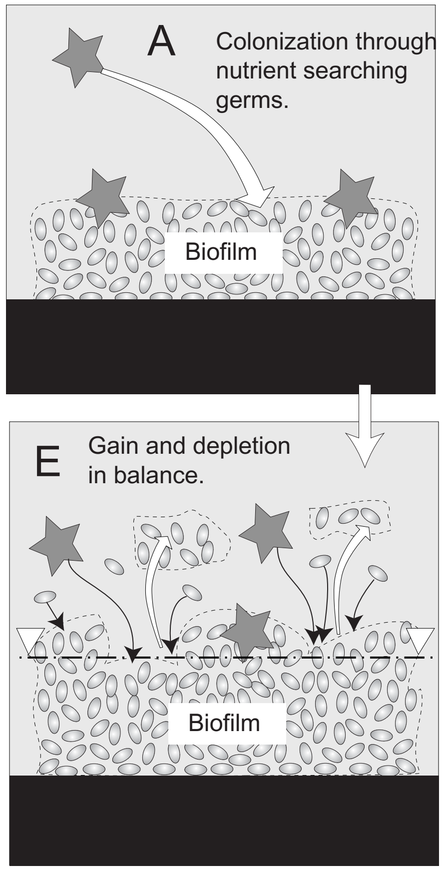
Biofilms, in the nature vital, in the technique often unwanted and trigger of failures.

Phases of biofilm formation
acc. van Lossdrecht et al.

I Induction phase.



Accumulation phase



Potential damages/failures and problems in the technique:

- Biocorrosion: Elastomers like isolations, tube/pipe walls and paints.
- Biocorrosion also at 'corrosion resistant steels (Typ CrNi 18/8).
- Biofouling (deposits):
  - Flow resistance (tubes/pipes, ships).
  - Blocking of systems (filters, pipe lines , membranes).
- Accumulations of sulfur (fuel).
- Deteriorated heat transfer throug isolating effect and low flow velocity.
- Influencing of sensors.

Ill. 5.6-6

Influences from Outside: Corrosion Without Mechanical Load: Introduction.

Ill. 5.6-6 *(Lit. 5.6-6 and Lit. 5.6-8):* ***Biofilms*** *usually make itself noticeable as* ***slimy layer/ covering*** *from algae, fungi, bacteria and unicellular organisms. These layers can develop and adhere at all boundary surfaces (substratum).*

- ***Gas and liquid phase*** *(e.g., water level on air).*
- ***Liquid and solid phase*** *inside (tube/pipe and vessel walls) and outside (e.g., pipes in the ground, Ill. 5.6.1.2-8 and Ill. 5.6.1.2 -9), hulls, membranes of water processing and desalination facilities (e.g., reverse osmosis).*
- ***Liquid and liquid*** *like* ***fuel or oil*** *at the transition to water as droplets or water level (volume 2, Ill. 8.3-5).*

The ***development of biofilms*** *takes place in* ***3 main phases****.*

*„****I****“* ***Incubation phase*** *splits into 4 phase steps („****I1****“, „****I2****“, „****I3****“, „****I4****“), however must not always exist. These develop through attachment processes of organic particles which then are colonized by microorganisms.*

*„****A****“* ***Accumulation phase*** *describes the process at which microorganisms utilize organic substances of the layer as nutrition. Cell reproduction leads to further layer setup.*

*„***E***“* ***Existence phase*** *exists at a* ***balance*** *between removing and setup processes and with this a medium film thickness is reached.*

In the following a selection of ***deteriorations/ damages and problems*** *(frame below right) will be closer considered.*

*„****Bio corrosion****“* ***of polymers****: The water, bonded in the biofilm, together with acid metabolism products, develops organic (aceticitric acid and succinic acid), and anorganic (sulfuric acid, nitric acid) acids. These are in the position to damage plastics dangerously in form of pittings, cracks and aging (embrittlement through remove of plasticiser).*

*„****Bio corrosion****“* ***of metals*** *(microbial induced corrosion = MIC): Endagered are almost all metals but titanium and nickel-cadmium (very poisonous, prohibited!). The protecting passive layer of the metals will be deteriorated by oxygen absorbing (aerobic) layer components („iron oxidators“). These unprotected spots are attacked by components (anaerobic) which react with sulfur compounds (sulfates). Such a corrosion process determines by guess markedly above 1/ 5 of all corrosion failures. Deteriorated are unexpected also, austenitic CrNi steels (’corrosion resistant steels of the type CrNi 18/8).*
MIC is also caused by acid developing bacteria with a markedly locally drop of the pH-value. In contrast even corrosion sensitive metals like copper and stainless steels (see above) are not safe.

„Bio fouling“ *names physical disturbing biofilm depositions. To the unwanted effects belong:*

- ***Thermal insulation*** *decreases together with a impairment of the flow the efficiency of coolers and heat exchangers.*
- ***Blocking of flow cross sections*** *up to several centimeter width.*
- ***Blocking of filters*** *(ultrafiltration) and separating diaphragms (****reverse osmosis****).*
- *Rising of the* ***flow resistance*** *(e.g., at submerged surfaces like hulls.*
- *Influencing of* ***sensors*** *through* ***isolation****,* ***flow disturbance*** *and blockage.*

Sulfur enrichment in fuel *(volume 2, Ill. 8.3-5) can lead to sulfidation (Ill. 5.6.1.4.1-3) at metal surfaces, exposed to combustion gas. A further problem is the* ***jamming*** *(seizing, galling, chapter 5.9.2)* ***of silver plated sliding faces*** *in control units and at valves (Ill. 8.3-4).*