Composites

Composite Materials

- Modern applications require materials with unusual combinations of properties

- These properties might even be contradictory

- Nature gives good examples: Wood (strong and flexible cellulose fibers embedded in stiff lignin) or bone (strong and soft collagen combined with hard and brittle apatite)

What kind of geometrical arrangements are generally possible?

Main divisions of Composite Materials

Composites

Particle-reinforced	Fiber-reinforced	Structural
Large particles or Dispersion strengthened	Continuous (aligned) or Discontinuous (short)	Laminates or Sandwich panels

What geometrical information do we need?

In order to describe the dispersed phase in the matrix the following terms are needed

- Concentration
- Size
- Shape
- Distribution
- Orientation

Particle reinforced composites

Large particle composite

Main goal here is an improvement of mechanical properties
Rule of mixture for elastic modulus

Upper bound

$$E_c(u) = E_m V_m + E_p V_p$$

Lower bound

$$E_c(l) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

- Polymers with fillers
- Concrete

Dispersion strengthened composites
Think tempered martensite

Fiber reinforced composites

Fiber reinforced composite materials are the technologically most important form of composite materials

Typical examples are

- Glass fiber reinforced polymers
- Carbon fiber reinforced polymers

The performance of such fiber reinforced composites – if everything else (fiber length, orientation etc.) is taken care of – critically depend on the interfacial bonding between fiber and matrix

This leads to a number of strategies to improve this bonding

- Plasma activation
- Chemical functionalization

Layered composites

- Laminar composites and sandwich panels are the standard macroscopic technologically exploited forms of “layered” composite systems

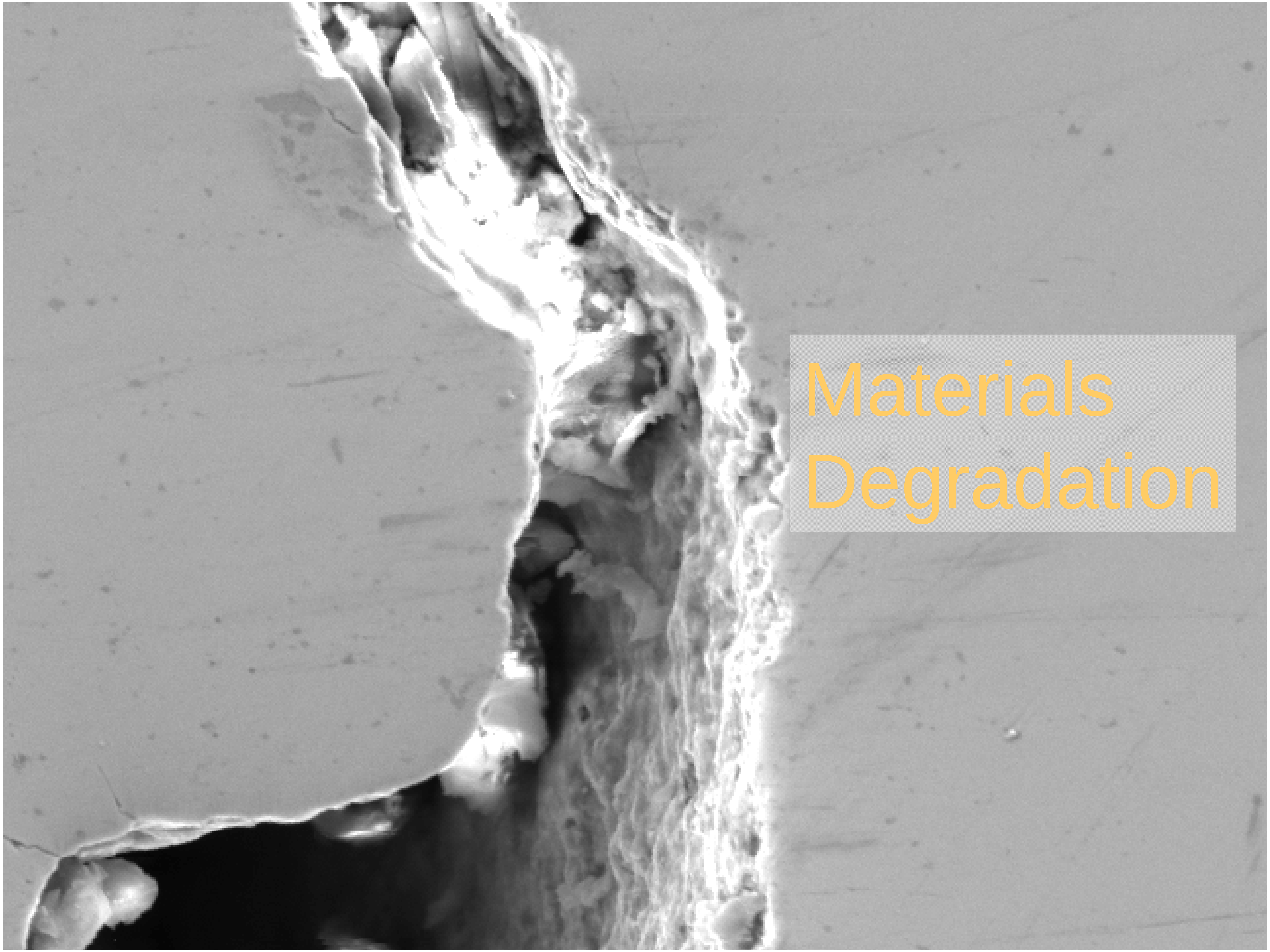
- Coating technology allows to create relative complex layered composite structures with relative ease

Here structures range from

MBE superlattices to “standard” multi-layers

- However, these layered systems should not be confused with functional layered systems

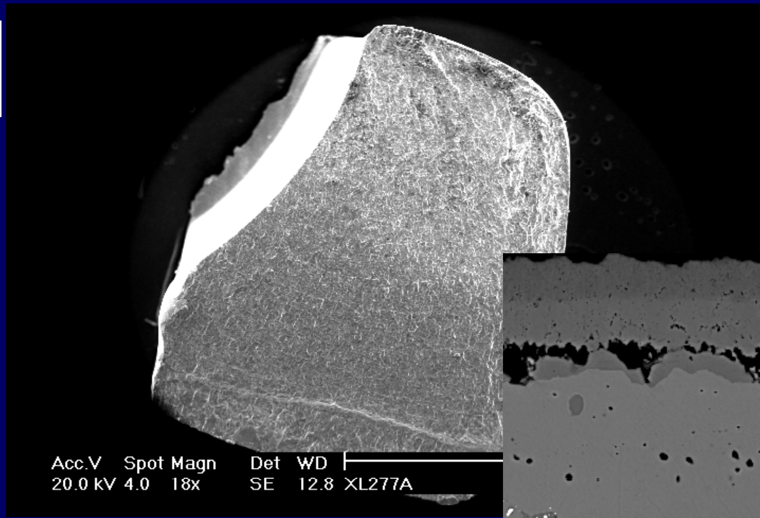
- Example: Quest for ultimate technological hardness


Materials
Degradation

Materials Degradation

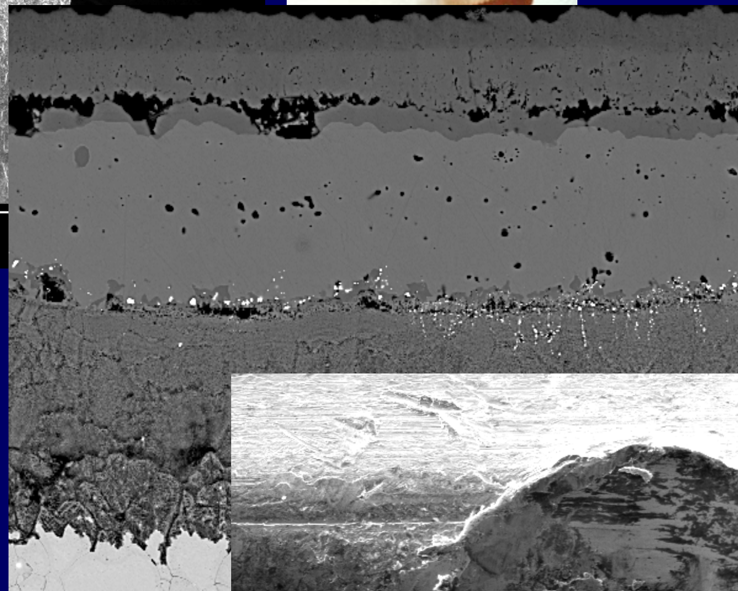
mechanical

fatigue
fracture



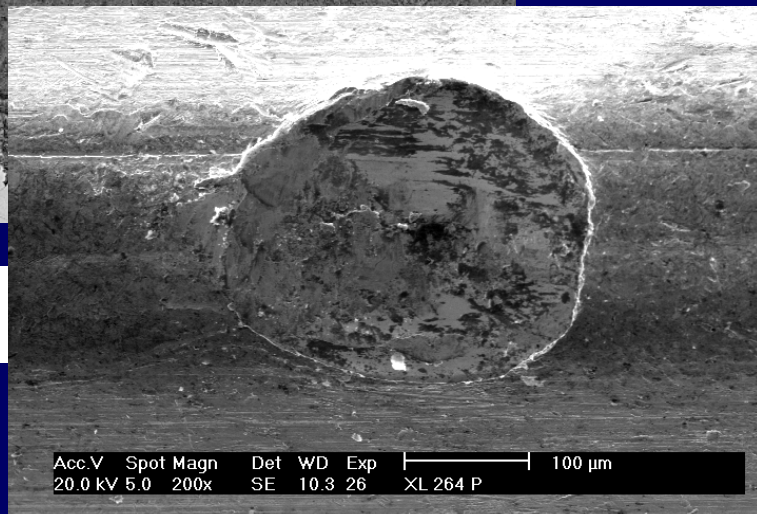
chemically

aqueous corrosion
high-temperature corrosion



tribological

abrasion
wear



Electrochemical Corrosion

approx. 5% of a nations income is spent on corrosion
rust, HT corrosion..

oxidation reactions – metal gives up electrons

$M \longrightarrow M^{n+} + ne^-$

anodic reaction

reduction reactions – species accepts electrons

$M^{n+} + ne^- \longrightarrow M$

$2H^+ + 2e^- \longrightarrow H_2$

cathodic reaction

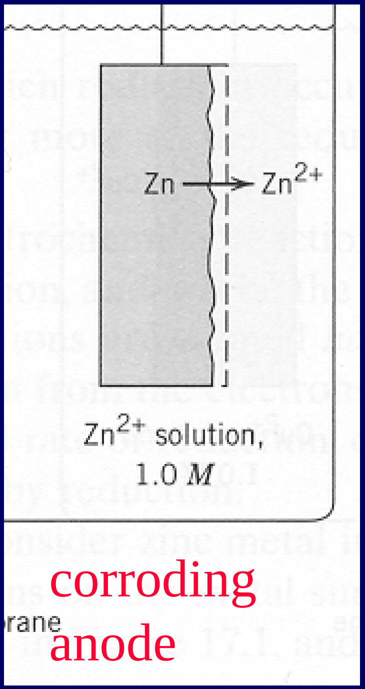
electrochemical reaction: two half reactions

e.g. $Zn \Rightarrow Zn^{2+} + 2e^-$ / $2H^+ + 2e^- \Rightarrow H_2$(gas)

galvanic couple: $Fe^{2+} + Zn \Rightarrow Fe + Zn^{2+}$: potential: 0.323V

but: $Cu^{2+} + Fe \Rightarrow Cu + Fe^{2+}$: potential: 0.780V

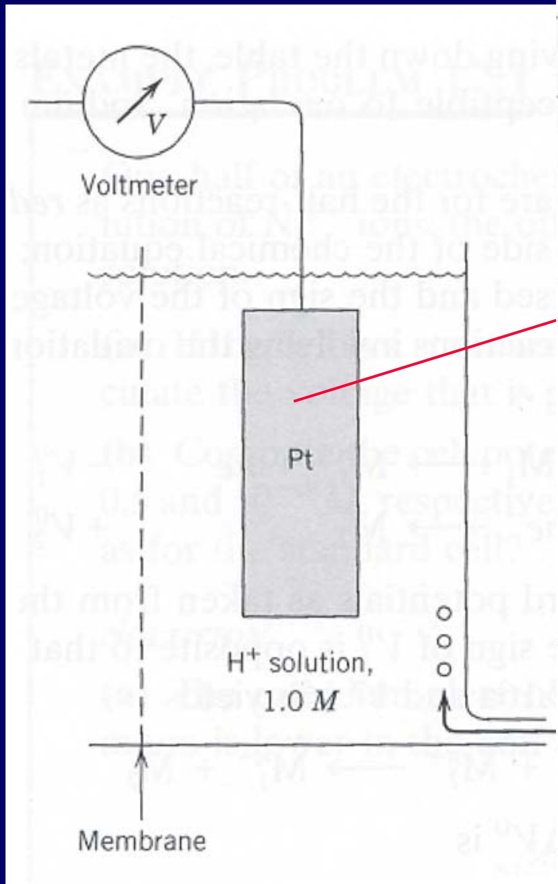
cathode



corroding
anode

Standard Hydrogen Reference Half-Cell

susceptibility to corrosion



electromotive force series

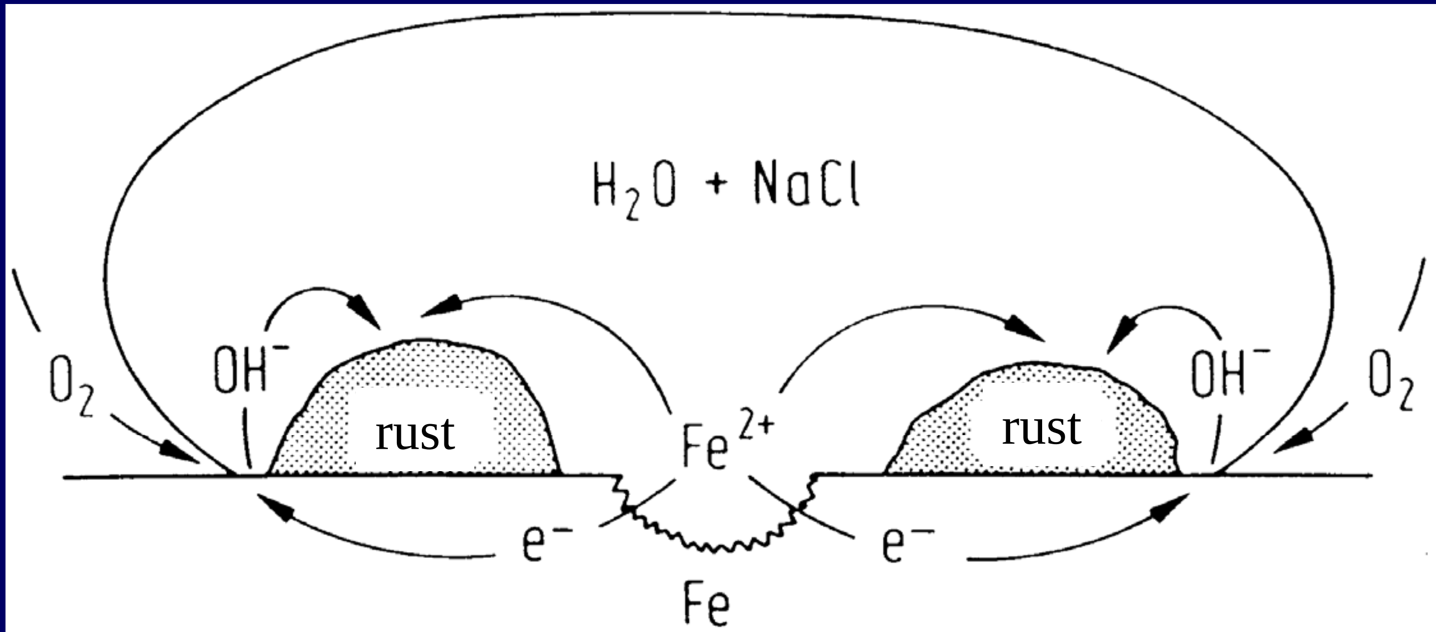
Increasingly inert
(cathodic)

Electrode Reaction	*Standard Electrode Potential, V^0(V)*
$Au^{3+} + 3e^- \longrightarrow Au$	+1.420
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.229
$Pt^{2+} + 2e^- \longrightarrow Pt$	~+1.2
$Ag^+ + e^- \longrightarrow Ag$	+0.800
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.771
$O_2 + 2H_2O + 4e^- \longrightarrow 4(OH^-)$	+0.401
$Cu^{2+} + 2e^- \longrightarrow Cu$	+0.340
$\boxed{2H^+ + 2e^- \longrightarrow H_2}$	$\boxed{0.000}$
$Pb^{2+} + 2e^- \longrightarrow Pb$	−0.126
$Sn^{2+} + 2e^- \longrightarrow Sn$	−0.136
$Ni^{2+} + 2e^- \longrightarrow Ni$	−0.250
$Co^{2+} + 2e^- \longrightarrow Co$	−0.277
$Cd^{2+} + 2e^- \longrightarrow Cd$	−0.403
$Fe^{2+} + 2e^- \longrightarrow Fe$	−0.440
$Cr^{3+} + 3e^- \longrightarrow Cr$	−0.744
$Zn^{2+} + 2e^- \longrightarrow Zn$	−0.763
$Al^{3+} + 3e^- \longrightarrow Al$	−1.662
$Mg^{2+} + 2e^- \longrightarrow Mg$	−2.363
$Na^+ + e^- \longrightarrow Na$	−2.714
$K^+ + e^- \longrightarrow K$	−2.924

ncreasingly active
(anodic)

1M solution of H^+ ions saturated with H_2 gas at 25°C/1atm
(mole/1000cm³)

Iron Corrosion - Rust Formation



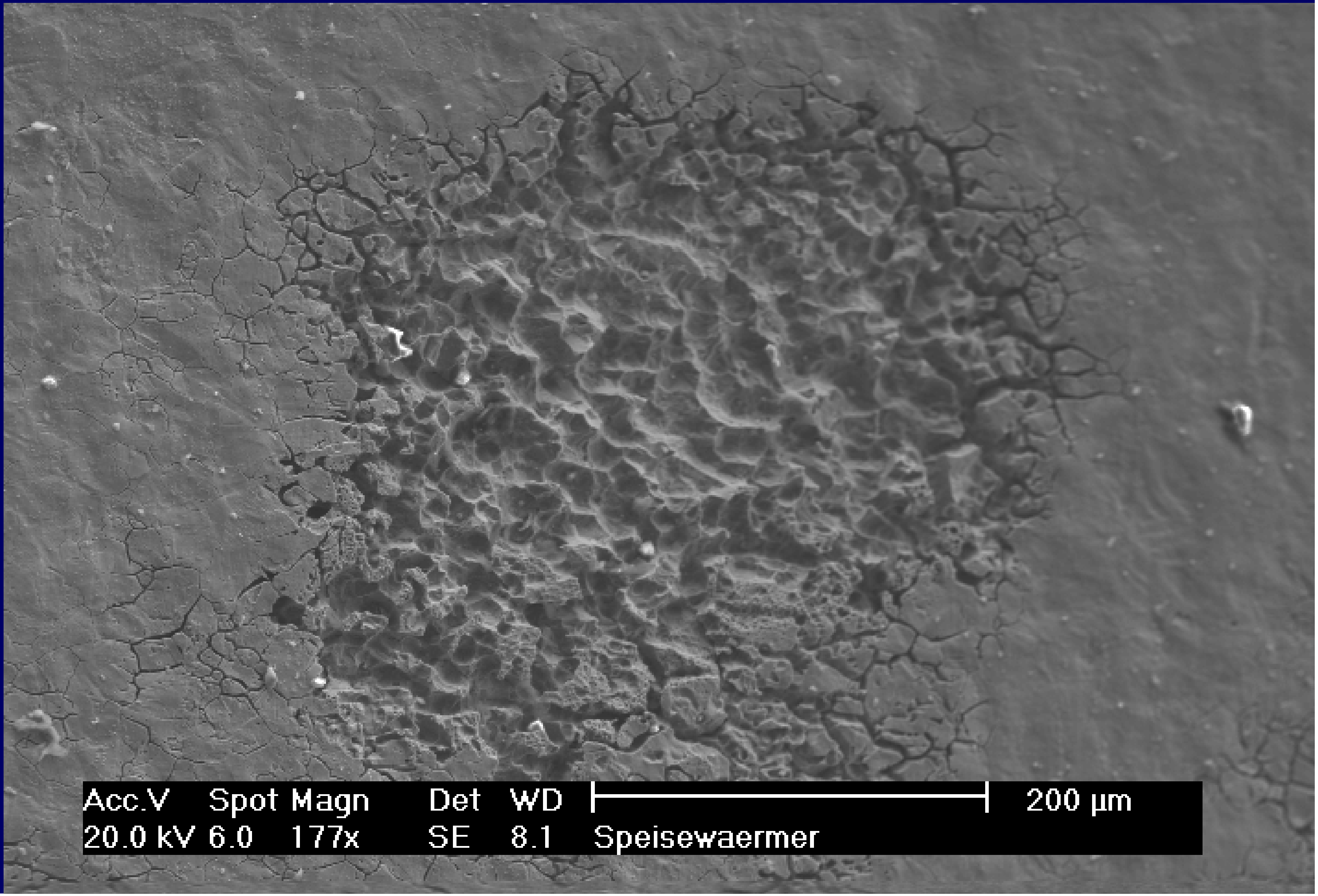
cathodic($+e^-$) anodic ($-e^-$)

(1) $\boxed{Fe} + \boxed{1/2\ O_2 + H_2O} \Rightarrow \boxed{Fe^{2+}} + \boxed{2OH^-} \Rightarrow Fe(OH)_2$

(2) $2Fe(OH)_2 + 1/2O_2 + H_2O \Rightarrow$ **$2Fe(OH)_3$**

RUST

Forms of Corrosion



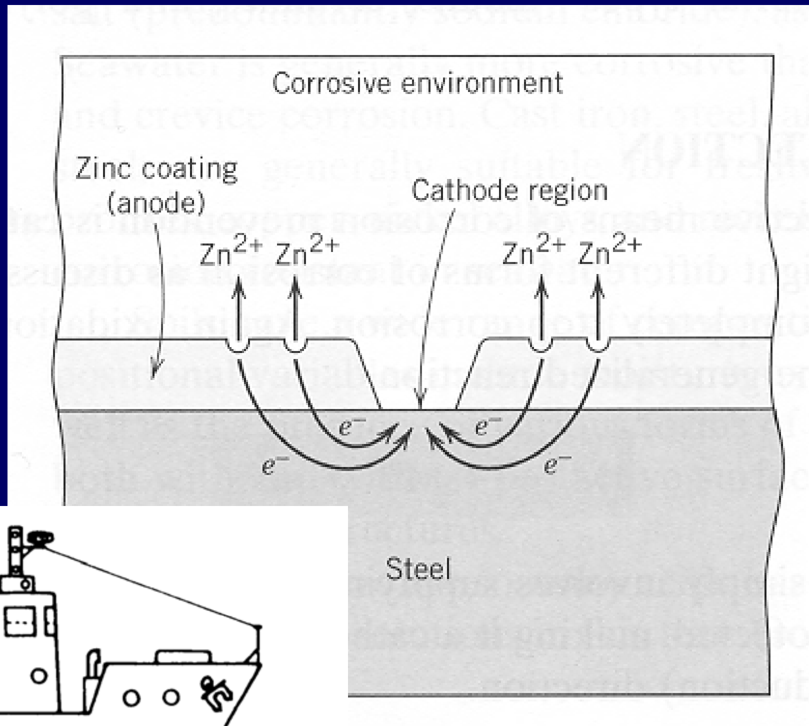
Corrosion Protection

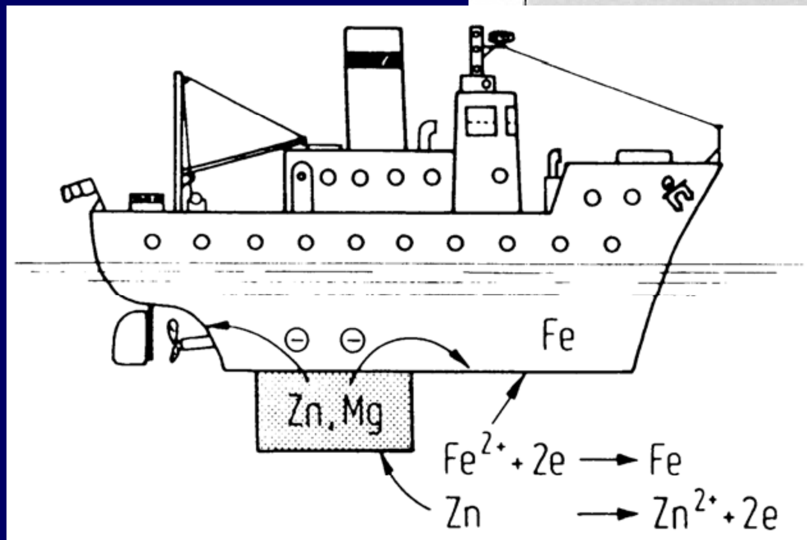
galvanic protection – Zn coating

cathodic protection (sacrificial anode)

coatings/inhibitors (paint, enamel..)

corrosion.protection-oriented design



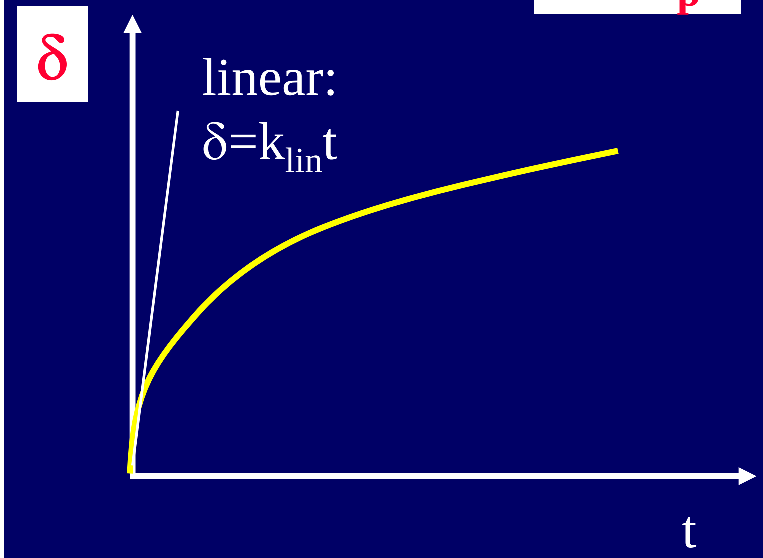


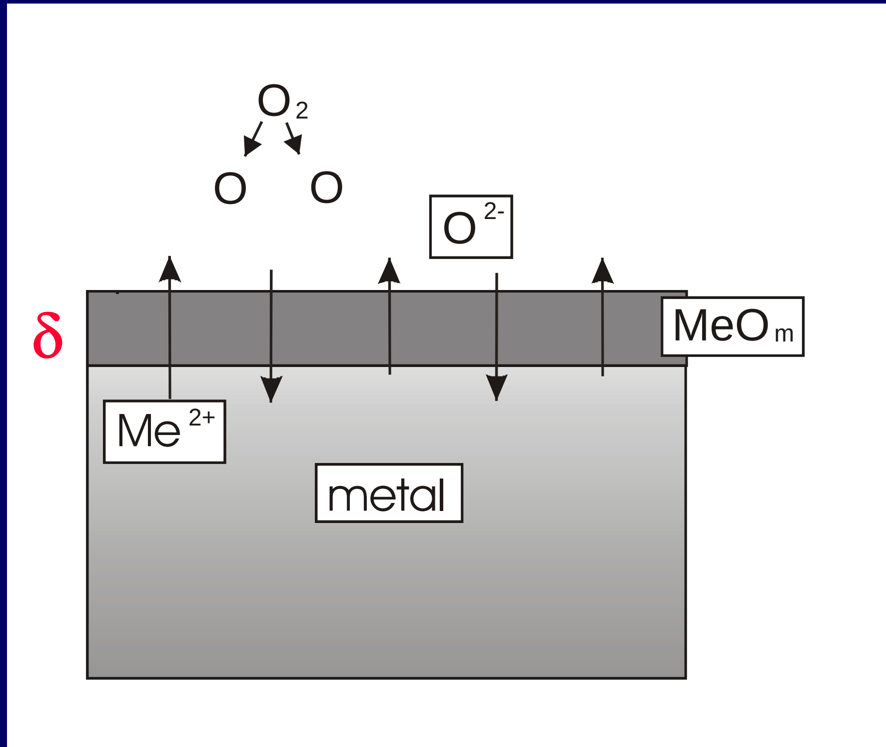
High Temperature Corrosion

$M+1/2O_2 \Rightarrow MO$

>500°C
rate is determined by diffusion through scale

non-porous and adherent scale:
parabolic rate law $\boldsymbol{\delta^2 = k_p t}$





(instead of δ often the weight gain W is measured)

Materials Selection

1 analysis of the application

-functional - structural
-loading conditions
-environment (T,atmosphere)

-safety requirements
-service life
-recycling
-cost
-design

-one ore more parts
-engineering design (FEM)

valves, e.g. exhaust valve

Materials Selection

2 materials preselection

-metal (steel, Aluminum..)
-polymer
-ceramic
-composite
-new material development

fulfillment of the loading criteria
cost/availability
manufacturing
joining
recycling

3 materials modification

-heat treatment
-coating (corrosion protection,
(wear resistance...)

Materials Selection

4 materials/component testing

-mechanical properties
-corrosion resistance
-prototype – testing under near service conditions

5 design modifications