# *Types of Metallic Corrosion and Anticorrosive Methods*

*Alexandre Bastos*
*University of Aveiro*
*Portugal*
*(acbastos@ua.pt)*

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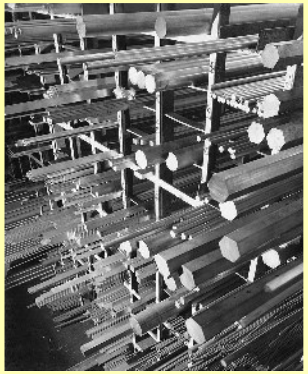
# RECAPITULATION

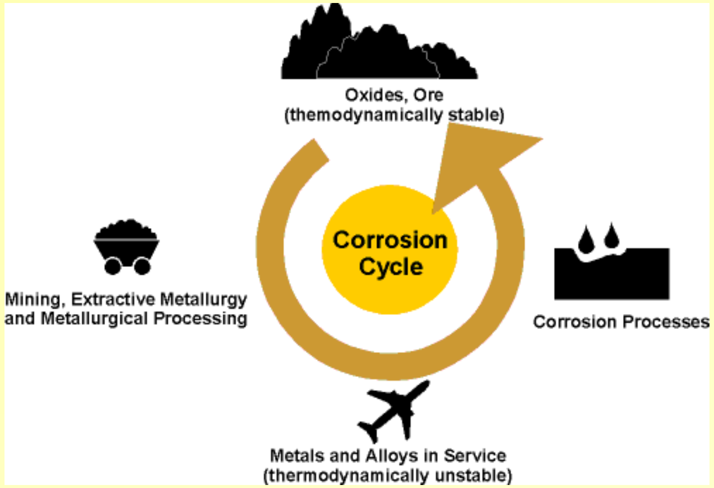
**What is corrosion?**

**Corrosion of metals x Degradation of materials**

**Economic impact of corrosion**

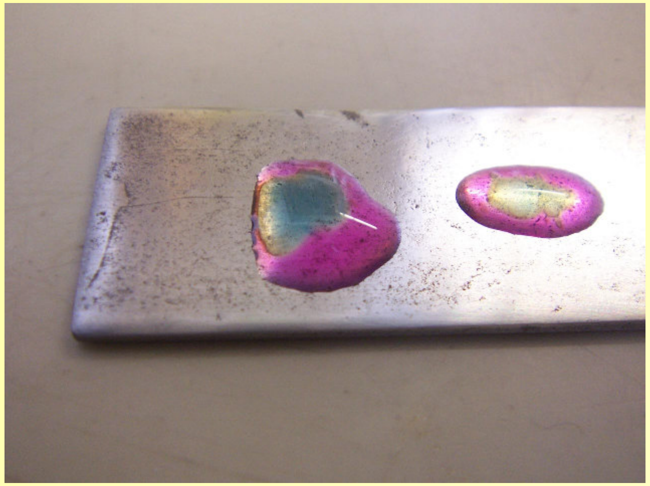
**Metallurgy vs corrosion**






**Thermodynamics and Kinetics**

# RECAPITULATION



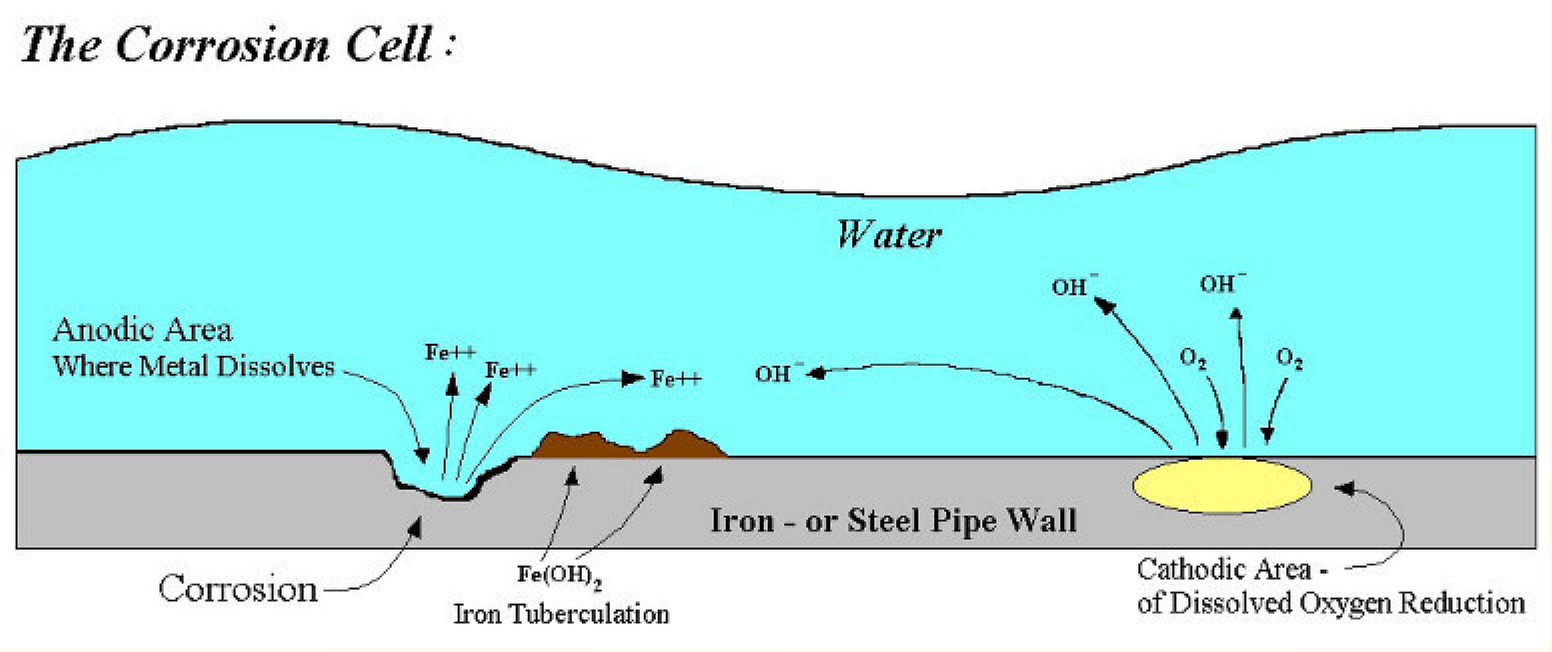
**“Wet” corrosion**

**All metals can corrode**

**Processes are similar**

**Electrochemical mechanism of corrosion**

**2 half-reactions separated in space occurring simultaneously**



# UNIFORM OR GENERALISED CORROSION

**Attack takes place over the entire area or at a large fraction of it.**

**The attacked area is divided in minute anodic and cathodic regions, that switch place with time.**

**Accounts for the greatest tonnage of metal consumed.**

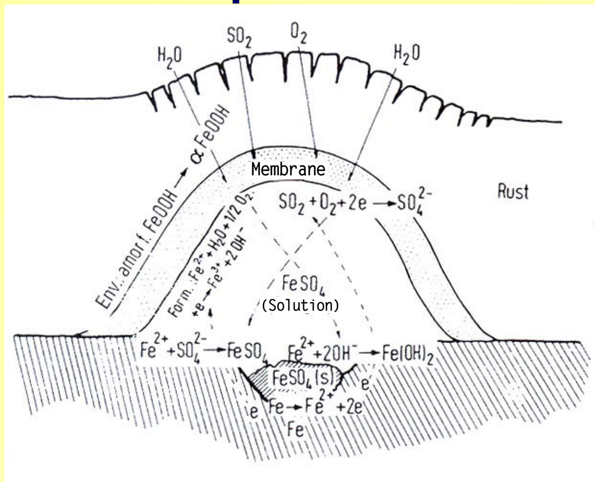
**Easy to detect, rarely leads to disastrous failures.**

**Usually, appearance is the main problem.**

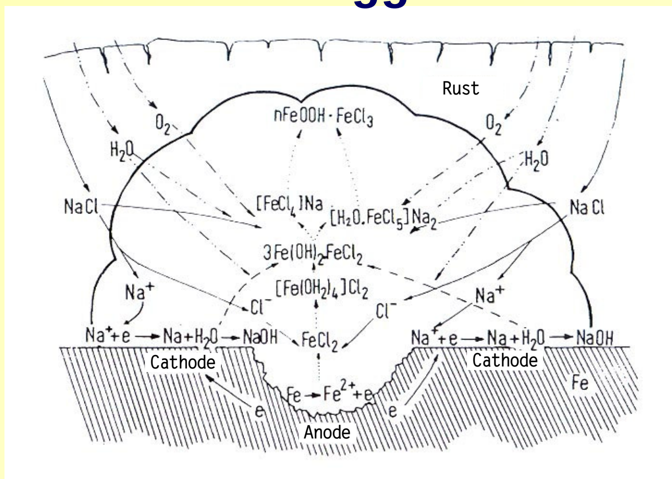
**Typical examples:**
**- atmospheric corrosion,**
**- steel corrosion in acid solution.**

Types of Corrosion and Anticorrosive Methods

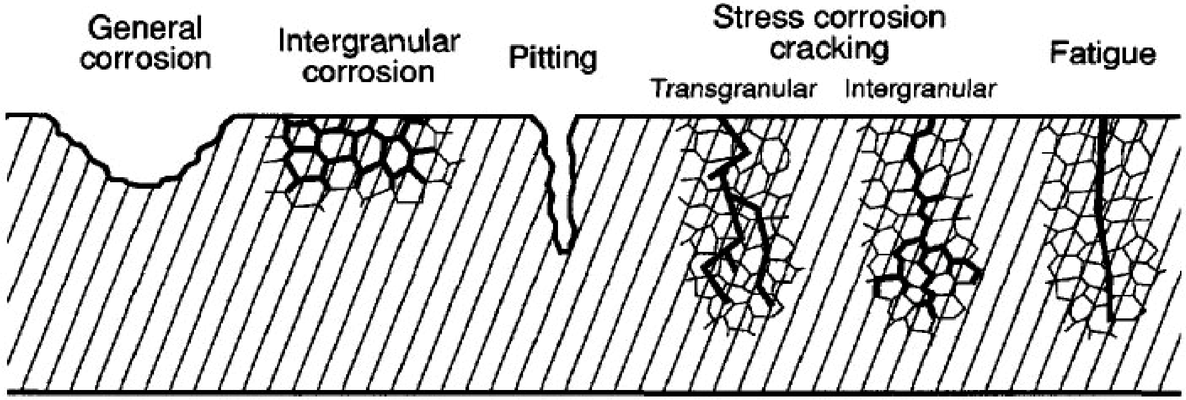
## Sulphate nest




## Chloride Agglomerate



# GENERALISED *VS* LOCALISED CORROSION

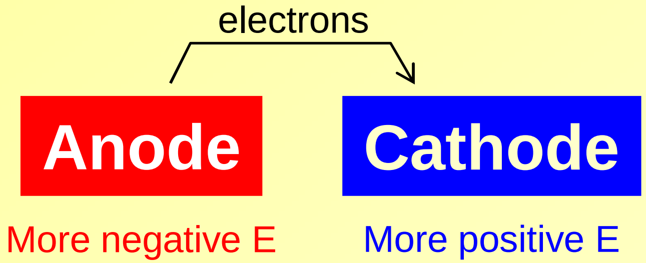


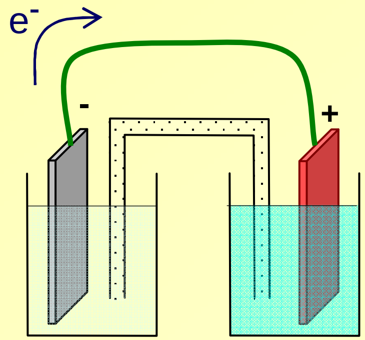

Schematic views of five intrinsic modes of corrosion penetration: general (including wear, erosion, and fretting), intergranular, pitting, stress corrosion cracking, and fatigue cracking.

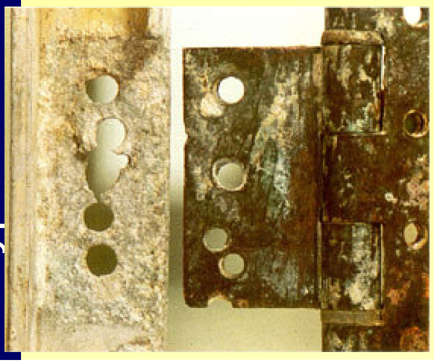
| Uniform Corrosion | Localised corrosion |
|---|---|
| All over the surface | Metal oxidation occurs in localised points usually with high current densities |
| Easy to detect, measure, predict and control | Difficult to detect, measure, predict and control |
| Loss of appearance is the main problem<br>Rarely leads to disastrous failures | Failure is often unpredictable leading to disastrous failures |
| Large loss of material | Small loss of material |
| | **Much more dangerous!** |

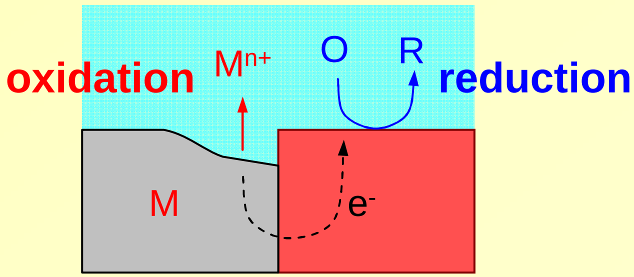
# GALVANIC CORROSION

**A metal is electrically connected to a different metal (or other conductive material) in a corrosive environment.**

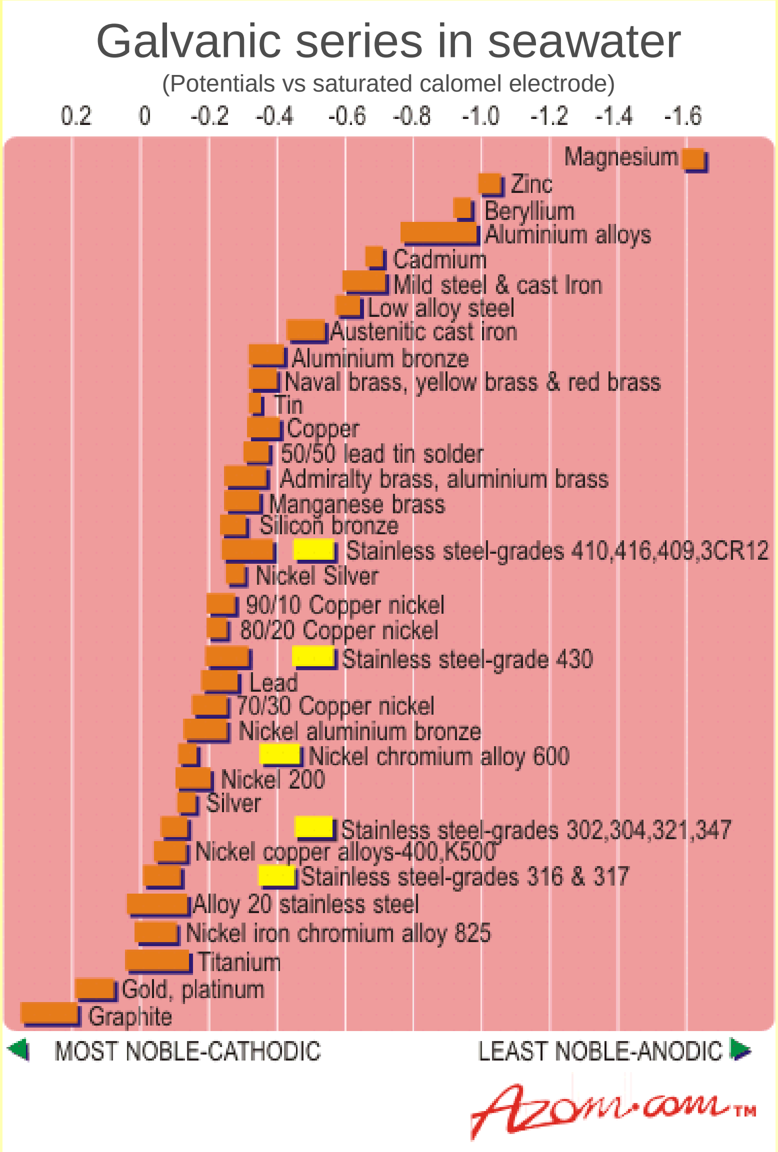


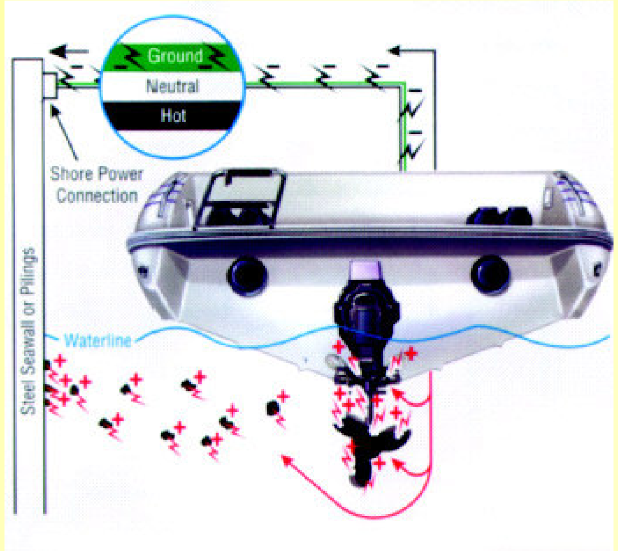





# GALVANIC CORROSION

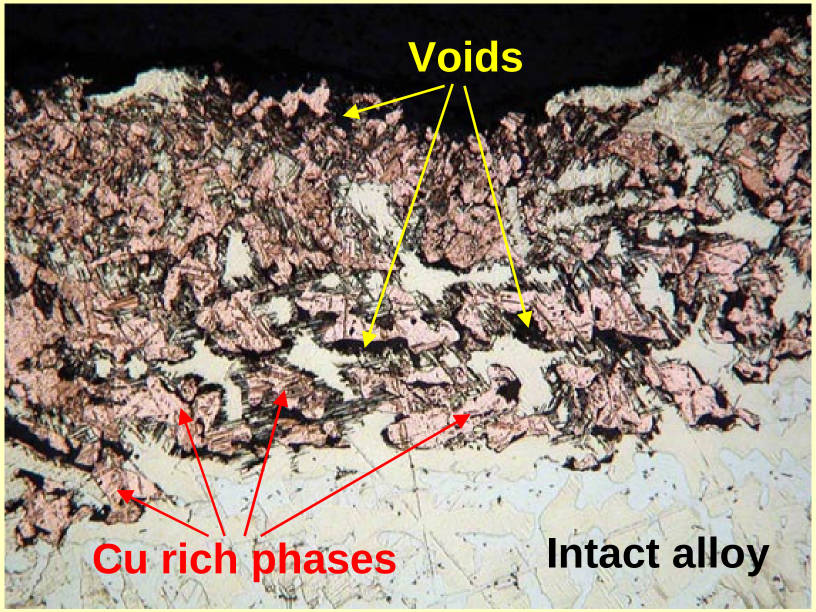



# SELECTIVE CORROSION
## (dealloying, selective leaching)

**Removal of a metal from an alloy by galvanic interaction with a more "noble" metal in the same alloy.**

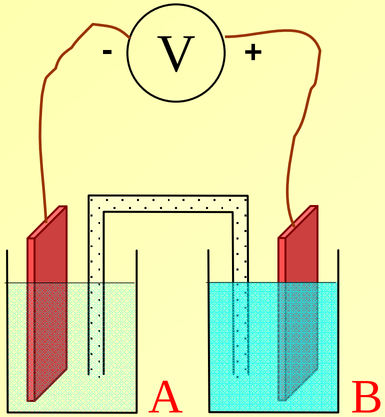
**Dezincification** (ex: Cu-Zn alloys with Zn > 15%)
**Decobaltification**
**Denickelification**
**Dealuminization (Dealuminification)**
**Graphitic corrosion** (ex: gray cast iron)
**Decarburization**

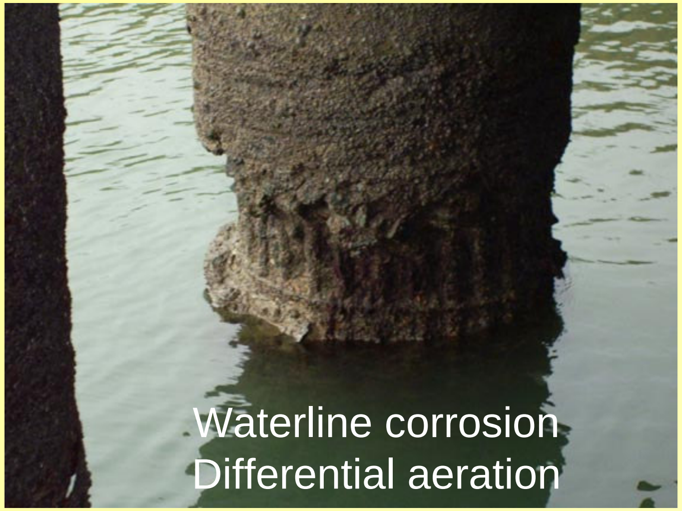


# CONCENTRATION CELLS

- Salt concentration cells
- Differential aeration cells
- Differential temperature cells

$$\Delta E = \left(E^{o}_{A} - E^{o}_{B}\right) + \frac{RT}{nF}\, ln\, \frac{a_A}{a_B}$$



Waterline corrosion
Differential aeration

**Differential temperature cells**

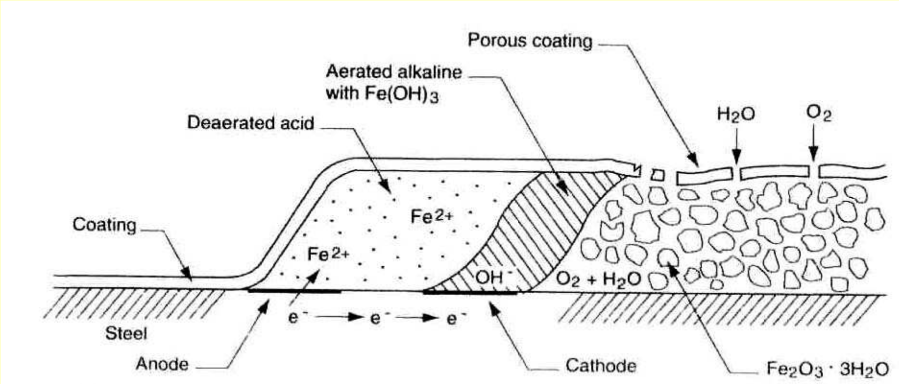
*Heat exchangers, boilers, immersion heaters, etc*

Cu: hot electrode is cathode; cold is anode.

Copper dissolves in the cold electrode and deposits on the hot electrode. Pb is similar but Ag is reversed.

Fe in NaCl: hot is anodic to cold electrode, but after several hours the polarity may reverse, depenging on aeration, stirring rate and wether the two electrodes are short-circuited.

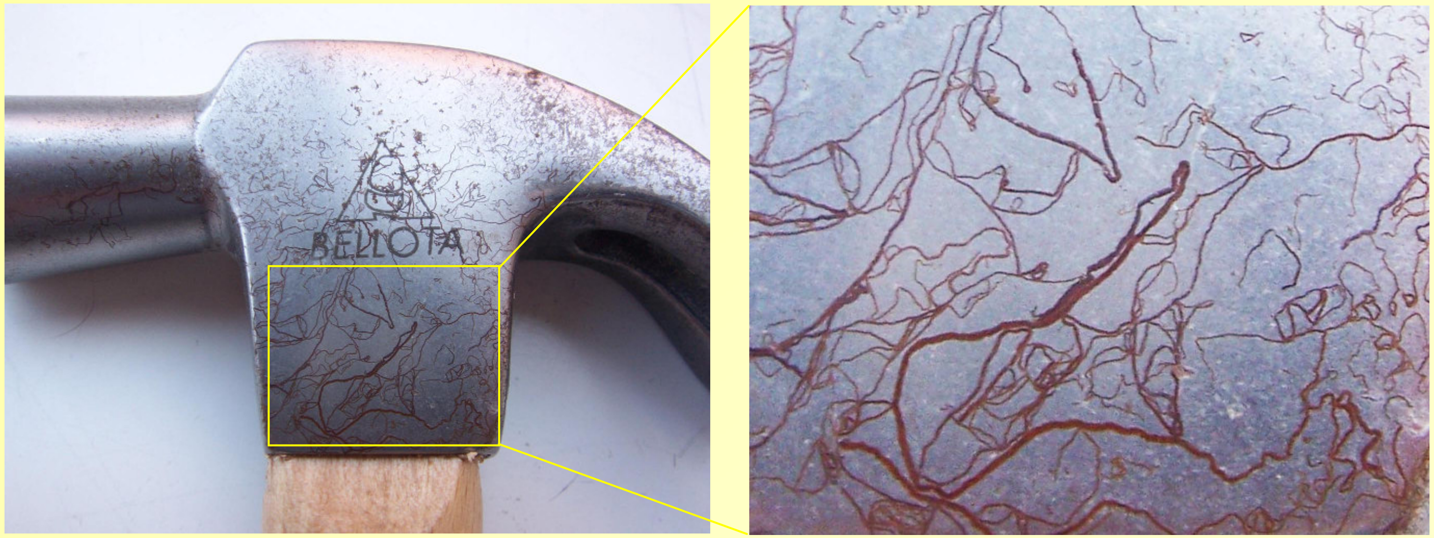
# CONCENTRATION CELLS
## FILIFORM CORROSION




**A special form of $O_2$ concentration cell which occurs on metals covered by an organic coating.**

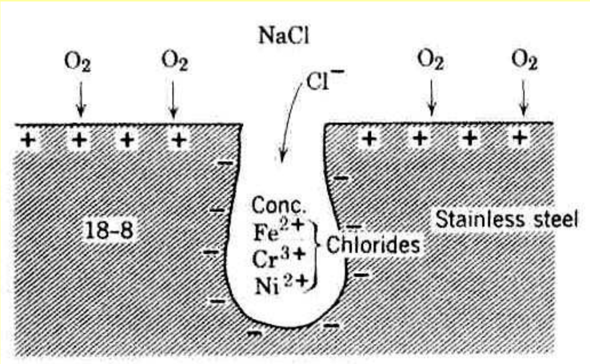
**Recognized by its characteristic worm like trace beneath the paint film.**

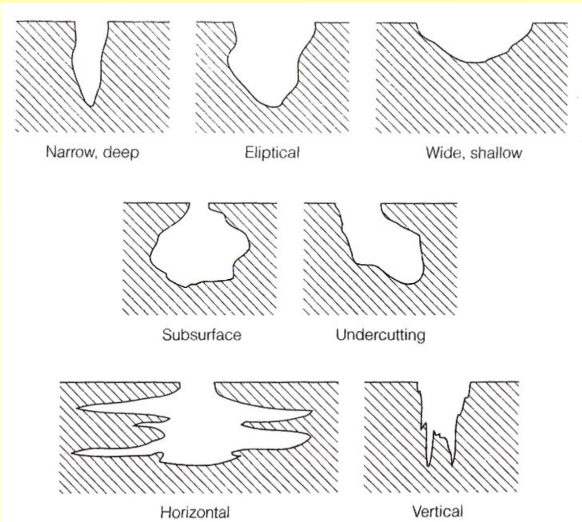
**Common in steel and Al alloys.**



# PITTING

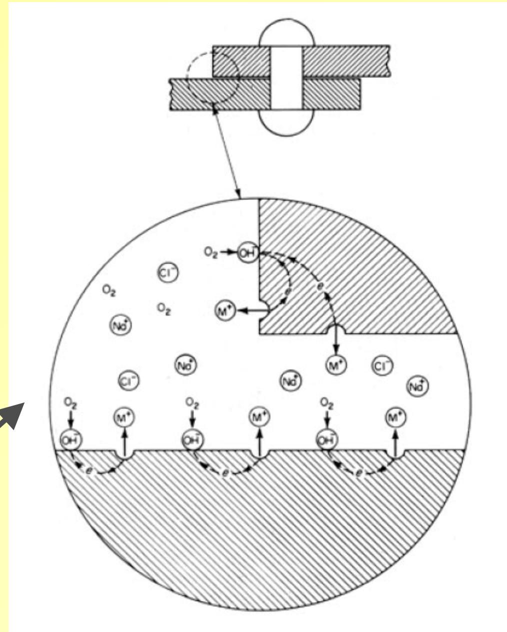
**Typical of passive metals (stainless steels, Al and Ni alloys) in the presence of chlorides.**
**Starts with depassivation in localized points which become anodic while the remaining area acts as cathode.**
**High current densities lead to rapid localised loss of material.**



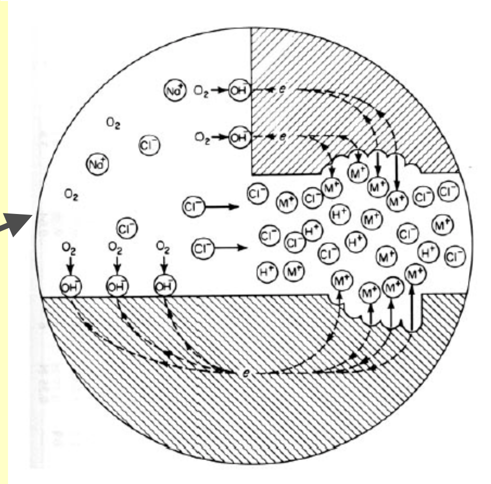

# CREVICE CORROSION

**Occurs at crevices in passive metals**



**Starts like a differential aeration cell**

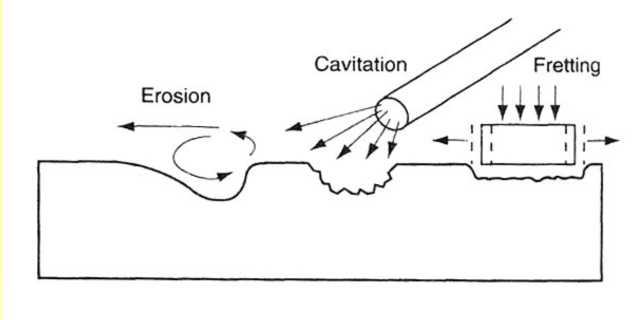
**Continues following pitting mechanism**



Types of Corrosion and Anticorrosive Methods

# CORROSION +
# MECHANICAL ATTACK AT THE SURFACE

(Removal of protective film)



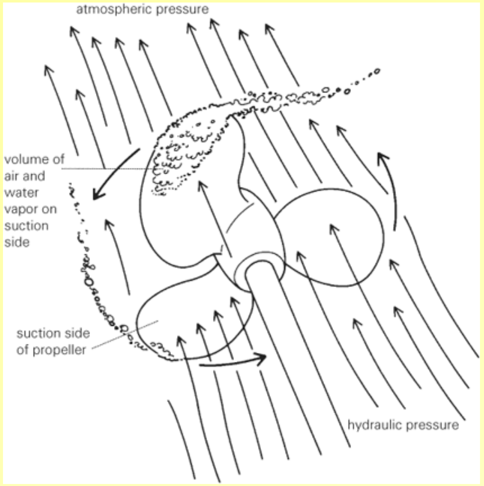

## FRETTING

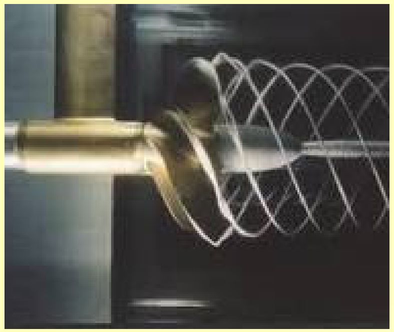
Surface against surface, often from vibration.

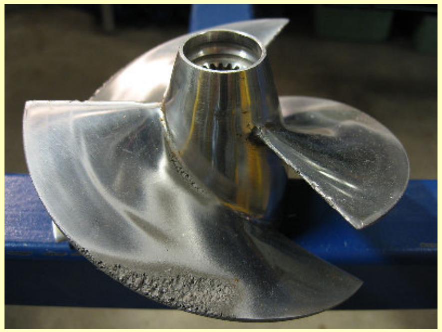
## EROSION

The flow of solution with suspended slurries removes the surface film.

## CAVITATION



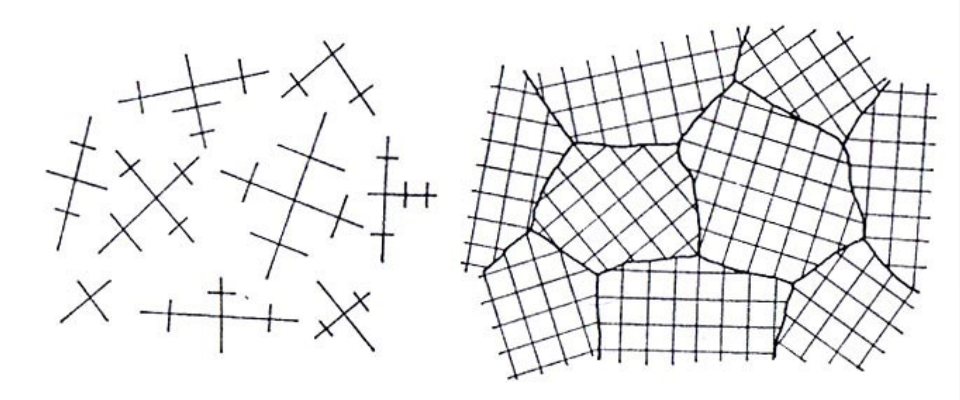


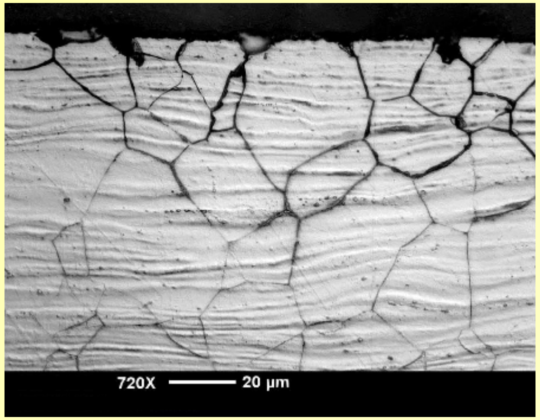
The fluid high velocity flow originates pressure reductions that lead to vapour bubbles which implode on the surface disrupting the protective film.

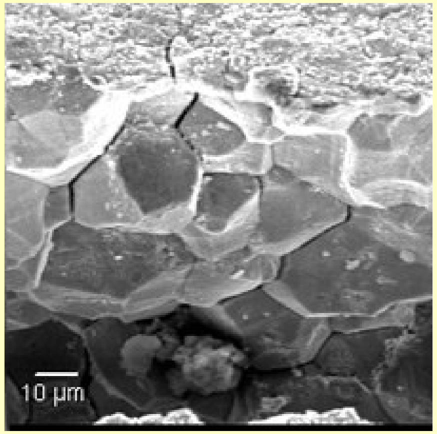
# INTERGRANULAR CORROSION

**Selective attack of a metal at or adjacent to grain boundaries.**

- Grain boundaries have higher energy (are more disorder) than the interior.
- Impurities tend to concentrate in the grain boundaries.
- Local depletion of an alloying element (e.g. by heat treatment, sensitization).



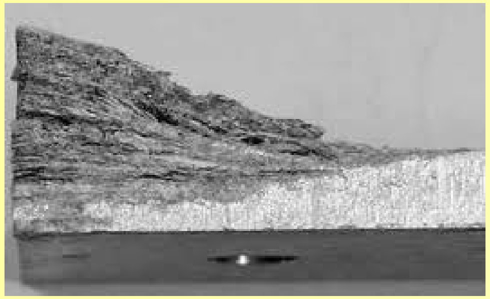


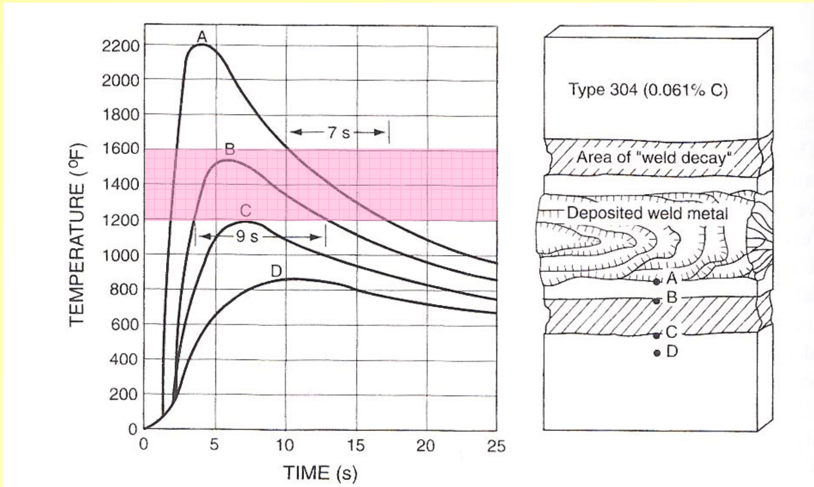



# INTERGRANULAR CORROSION

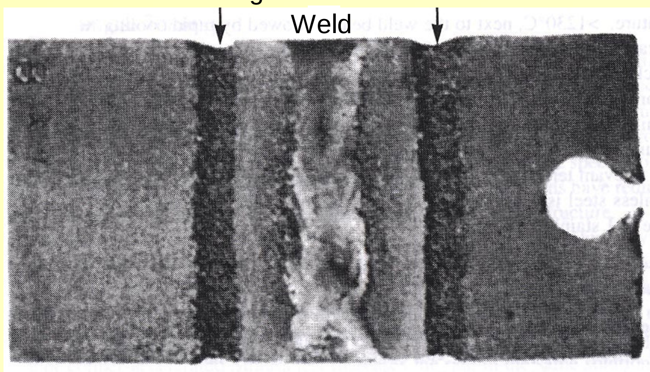
**EXFOLIATION CORROSION** is characterized by the lifting up of the surface grains by the expanding force of corrosion products produced at the grain boundaries just below.

**WELD DECAY** in 304 stainless steel. The heat generated during welding produces chromium carbides $(Fe,Cr)_{23}C_6$. This reduces the content in Cr and in these regions the alloy is not passive.






Intergranular corrosion
Weld



# CORROSION + EXTERNAL FORCES

## Static tensile stress

**STRESS CORROSION CRACKING (SCC)**

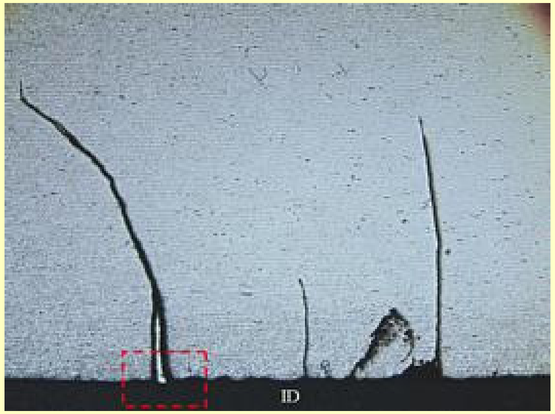
## Cyclic stress

**CORROSION FATIGUE**

**Both SCC and fatigue nucleate at pits**

**SCC cracks are higly branched**

**Fatigue cracks have little branches**



# HYDROGEN DAMAGE

Hydrogen is produced in many electrochemical processes: corrosion, electroplating, cathodic protection, metal pickling (cleaning), phosphating. It is also present in the petroleum industry, in storage tanks and refining processes.

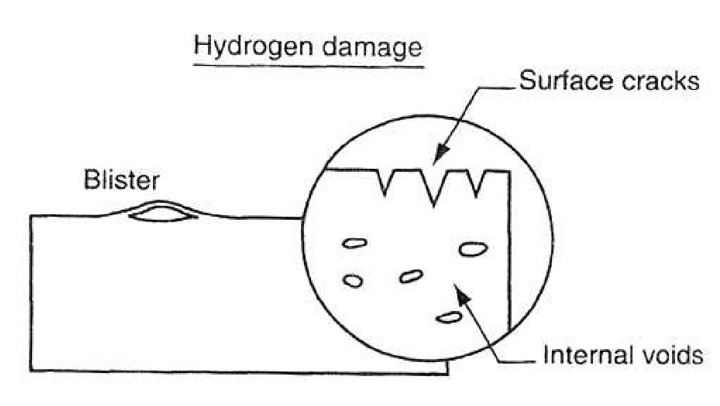
Atomic hydrogen diffuses readily through many metals. Molecular hydrogen does not.

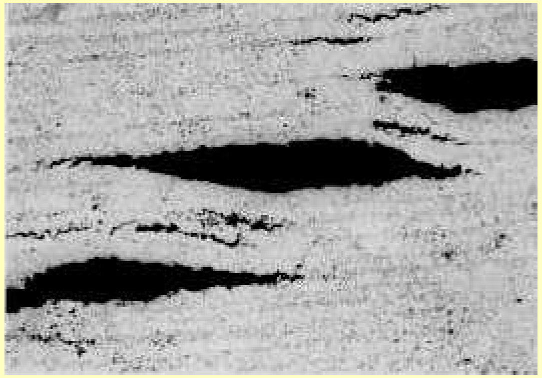
**Hydrogen blistering**

Atomic H occupies voids inside the metal where it combines to molecular $H_2$.The concentration and internal pressure increase with time, ultimately resulting in cracking.

**Hydrogen embrittlement**

Not so well understood. Once inside the metal, H forms brittle hydrides leading to cracking. This is proved for Ti, Zr, V, but still unclear for iron and steel.



**At high temperatures**

Hydrogen can remove carbon from steel (**decarburization**) or interact with other elements from the alloy (**hydrogen attack**), leading to reduction of tensile strength, increase in ductility and creep rate.

# SUMMARY

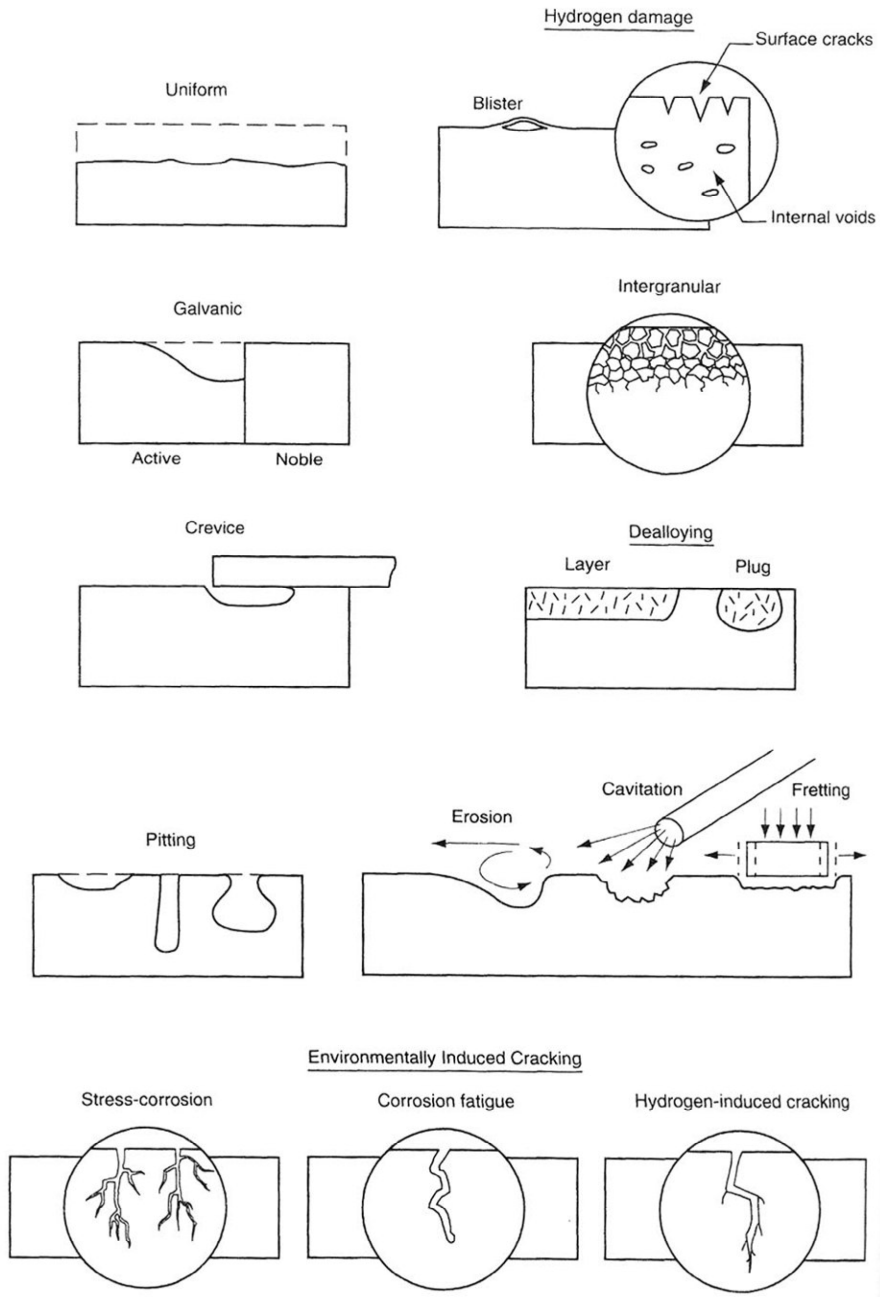



**FIGURE 1.4** Schematic summary of the various forms of corrosion.

D.A. Jones, Principles and Prevention of Corrosion 2$^{nd}$ Ed Prentice Hall, 1996

# MICROBIOLOGICAL CORROSION

**The presence of microbial colonies on a metal surface can promote corrosion in many ways and lead to several types of corrosion.**

**Aerobic colonies consume oxygen and originate differential aeration cells.**

**Sulfate-reducing bacteria** operate in anaerobic conditions. Reduce sulfate to sulfides which react with the metal.

**Acid-producing bacteria**
Produce acids that dissolve the passive film (oxide) and accelerate the cathodic reaction rate.

**Hydrogen-producing bacteria**
Can be a source of hydrogen damage.

**Iron bacteria**
Oxidize $Fe^{2+}$ to $Fe^{3+}$. The ferric iron attracts chloride ions and produces highly corrosive $FeCl_3$ deposits.

The sunken **Titanic** is covered by rusticles, 'rust flows' and 'rust flakes, which are a mixture of goethite and lepidocrocite, both polymorphs of the iron oxyhydroxide, respectively $\alpha$-FeO(OH) and $\gamma$-FeO(OH). Due to the very low $O_2$ content, corrosion is mainly due to sulfate-reducing bacteria that grow rapidly under anaerobic conditions.

**Biofouling or biological fouling is the undesirable accumulation of microorganisms, plants, algae, and animals on immersed structures, especially ships' hulls. These lead to differential aeration cells.**

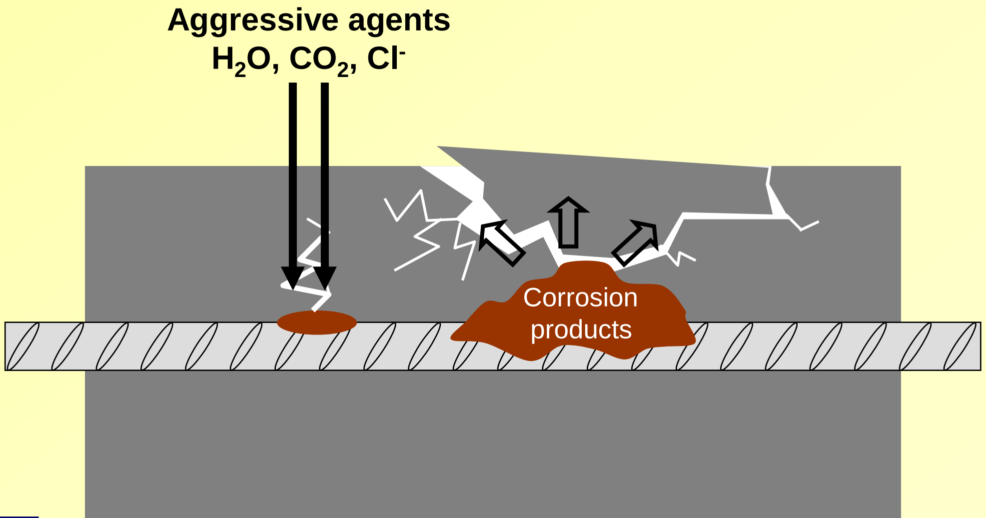
# CORROSION IN CONCRETE

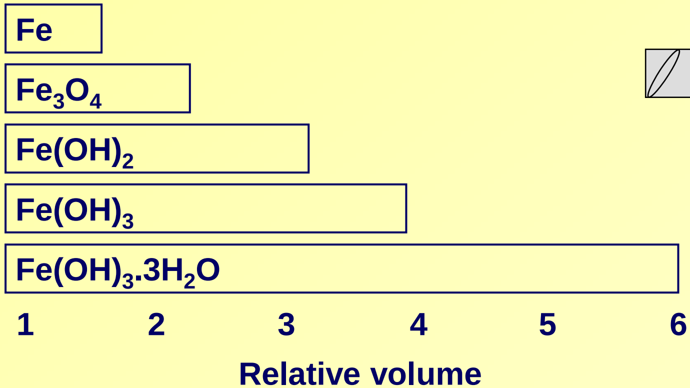
Originally steel in concrete is in passive state
(pH inside concrete pores is around 13, $Ca(OH)_2$).

With time, $H_2O$ and $CO_2$ ingress leads to carbonatation of concrete and lowering of pH.

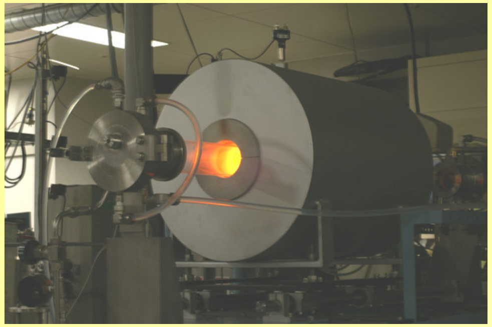
At a certain point corrosion starts. This is accelerated in the presence of chlorides (e.g. marine environment).

Accumulation of corrosion products generates internal stresses that lead to cracking and delamination of concrete.



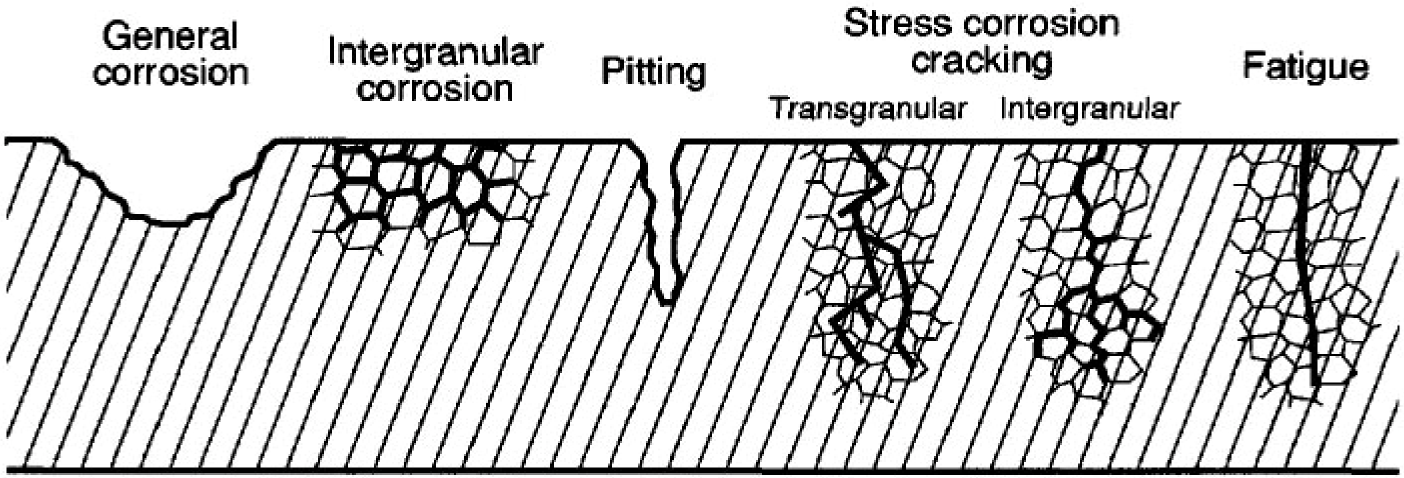



# HIGH TEMPERATURE CORROSION

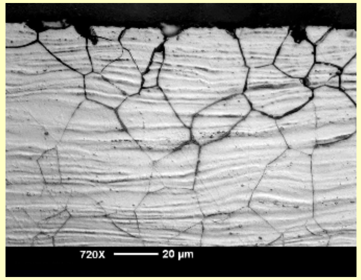


# RECAPITULATION

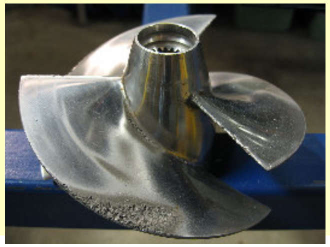
## Forms of corrosion




Schematic views of five intrinsic modes of corrosion penetration: general (including wear, erosion, and fretting), intergranular, pitting, stress corrosion cracking, and fatigue cracking.

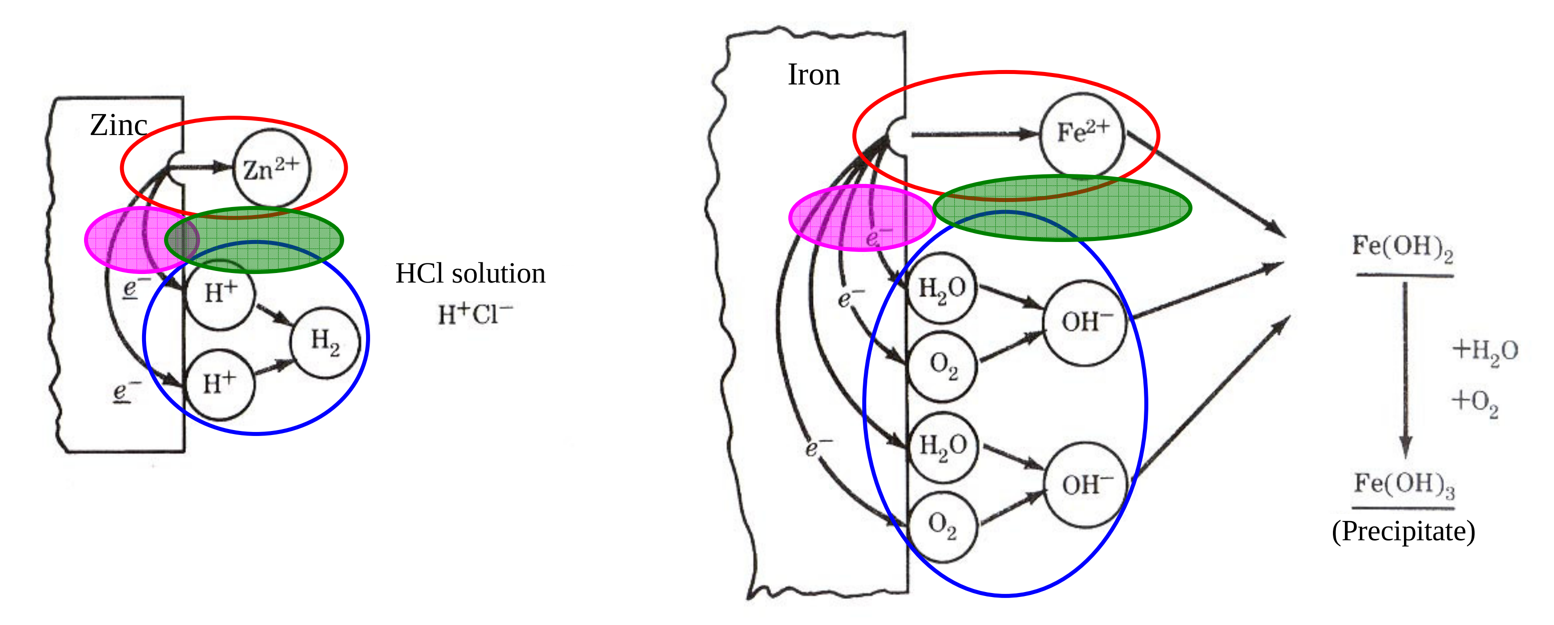




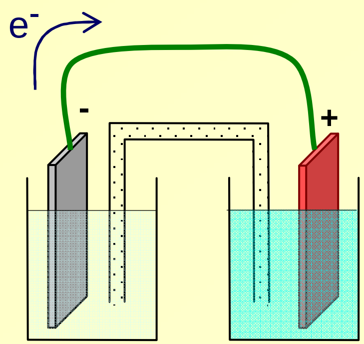


# ANTICORROSIVE PROTECTION

## RECALL THE CORROSION MECHANISM




**Anodic reaction**
**Cathodic reaction** **(amount of oxidizer)**
**Electronic path** **(internal resistance)**
**Ionic path** **(external resistance; solution conductivity)**



# ANTICORROSIVE PROTECTION

- Selection of materials
- Design of structures
- Location / placement of structures
- Modification of environment
  - controling humidity
  - removing $O_2$
- Corrosion Inhibitors
- Cathodic protection
- Anodic protection
- Coatings
  - metallic
  - inorganic (CCC, phosphate, anodized)
  - organic (paints and varnishes)

# SELECTION OF MATERIALS



**Corrosion Data**

| Chemicals | Aluminum | Brass | Carbon Steel | Ductile Iron/Cast Iron | 316 Stainless Steel | 17-4PH | Alloy 20 | Monel | Hastelloy C | Buna-N (Nitrile) | Delrin | EPDM/EPR | Viton | Flexible Graphite | Teflon-Reinforced/ or NRG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acetaldehyde | B | C | C | C | A | | A | A | A | D | A | B | C | | A |
| Acetamide | B | B | B | B | B | | | | | A | A | | | | A |
| Acetate Solvents | A | B | A | B | A | | | A | A | D | D | | D | | A |
| Acetic Acid, aerated | B | D | D | D | A | | | A | A | C | D | | C | A | A |
| Acetic Acid, Air Free | B | B | D | D | A | A | A | A | A | C | D | | D | A | A |
| Acetic Acid, crude | C | C | C | C | A | A | A | B | A | D | D | | D | A | A |
| Acetic Acid, glacial | | | | | | A | | | A | D | | B | C | A | A |
| Acetic Acid, pure | C | C | D | D | A | A | A | D | A | D | D | | D | A | A |
| Acetic Acid, 10% | C | C | C | C | A | A | A | B | A | D | B | B | D | A | A |
| Acetic Acid, 80% | C | C | C | C | A | A | A | B | A | D | D | C | D | A | A |
| Acetic Acid Vapors | B | D | | | D | D | B | C | A | D | | | | A | A |
| Acetic Anhydride | B | D | D | D | B | B | B | B | A | D | C | C | D | A | A |
| Acetone | A | A | A | A | A | A | A | A | A | D | A | A | D | A | A |
| Other Ketones | A | A | A | A | A | A | A | A | A | D | A | D | D | | A |
| Acetyl Chloride | D | A | | D | C | | | B | A | D | D | D | D | | A |
| Acetylene | A | B | A | A | A | A | A | A | A | B | A | A | A | | A |
| Acid Fumes | B | D | D | D | B | | B | | | C | D | | | | A |
| Acrylonite | B | A | A | C | A | | B | A | A | D | D | D | C | | A |
| Air | A | A | A | A | A | | A | A | A | A | A | A | A | | A |
| Alcohol, Amyl | B | B | B | C | A | | B | B | B | C | A | A | B | A | A |
| Alcohol, Butyl | B | B | B | C | A | | A | A | A | B | A | C | A | A | A |
| Alcohol, Diacetone | A | A | A | A | A | | A | B | A | D | A | B | D | A | A |
| Alcohol, Ethyl | B | B | B | B | B | | A | B | A | A | A | A | A | A | A |
| Alcohol, Fatty | B | B | B | B | A | | A | | A | B | A | A | | A | A |
| Alcohol, Isopropyl | B | B | B | B | B | | A | B | B | C | A | A | A | A | A |
| Alcohol, Methyl | B | B | B | B | A | | A | A | A | B | A | A | C | A | A |
| Alcohol, Propyl | A | A | B | B | A | | A | A | A | B | A | A | A | A | A |
| Alumina | A | A | | | | | | | A | A | A | A | | | A |
| Aluminum Acetate | C | D | | D | A | B | B | C | B | D | D | A | D | | A |
| Aluminum Chloride dry | B | B | C | D | C | | D | B | B | B | A | A | A | A | A |
| Aluminum Chloride Solution | C | | | | D | C | B | B | A | B | D | | A | A | A |
| Aluminum Fluoride | C | | D | D | C | | | B | A | A | C | A | A | | A |
| Aluminum Hydroxide | A | A | D | D | A | B | B | B | B | A | C | A | A | | A |
| Aluminum Nitrate | D | D | | D | C | | B | C | B | B | D | B | D | | A |
| Aluminum Oxalate | B | | | | | | A | B | A | | | | | | A |
| Alum (Aluminum Potassium Sulfate) | D | D | | D | B | C | B | C | A | B | D | | B | A | A |
| Alum (Aluminum Sulfate) | C | C | D | D | B | A | B | C | A | A | D | A | A | A | A |
| Amines | B | B | B | C | A | A | A | B | B | D | C | C | D | | A |
| Ammonia, Alum | C | | | | A | | A | | A | B | C | | | A | A |
| Ammonia, Anhydrous Liquid | A | D | A | B | A | A | A | B | A | B | D | B | D | A | A |
| Ammonia, Aqueous | B | D | A | A | A | | A | B | B | B | D | | A | A | A |
| Ammonia, Gas, hot | A | D | | B | A | | A | B | B | C | D | A | D | A | A |
| Ammonia Liquor | | | | | A | | A | | B | | | | | A | A |
| Ammonia Solutions | C | D | B | B | A | | A | B | B | B | D | B | D | A | A |
| Ammonium Acetate | B | D | | B | B | | A | B | B | B | D | A | D | | A |
| Ammonium Bicarbonate | B | B | C | B | B | | B | B | | B | A | A | A | | A |
| Ammonium Bromide 5% | D | | | | B | | B | B | | | A | | | | A |
| Ammonium Carbonate | B | B | B | B | B | | B | B | | C | D | A | B | | A |
| Ammonium Chloride | D | D | D | D | C | C | B | B | B | B | C | A | A | | A |
| Ammonium Hydroxide 28% | C | D | C | C | B | A | A | D | B | B | D | B | A | A | A |

**Ratings:** A - Excellent B - Good C - Poor D - Do not use **Blank** - No information

C-2

Tables with the susceptibility of each alloy to different environments and applications.

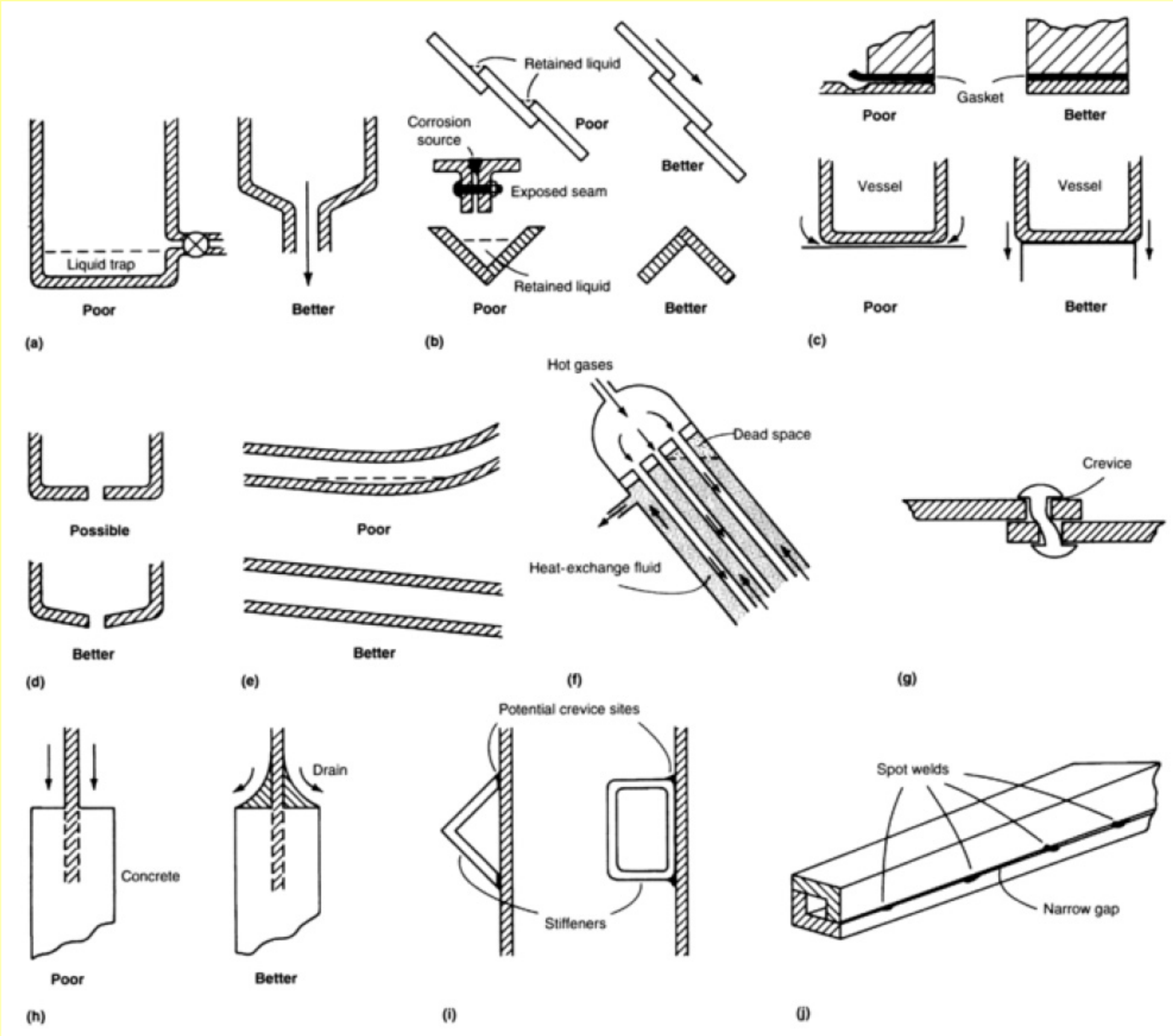
Most of the corrosion cases can be prevented by choosing a proper alloy.

Consider using non metallic materials: wood, ceramics, polymers, etc.

The best solution is a cost - benefit compromise.

# DESIGN OF STRUCTURES

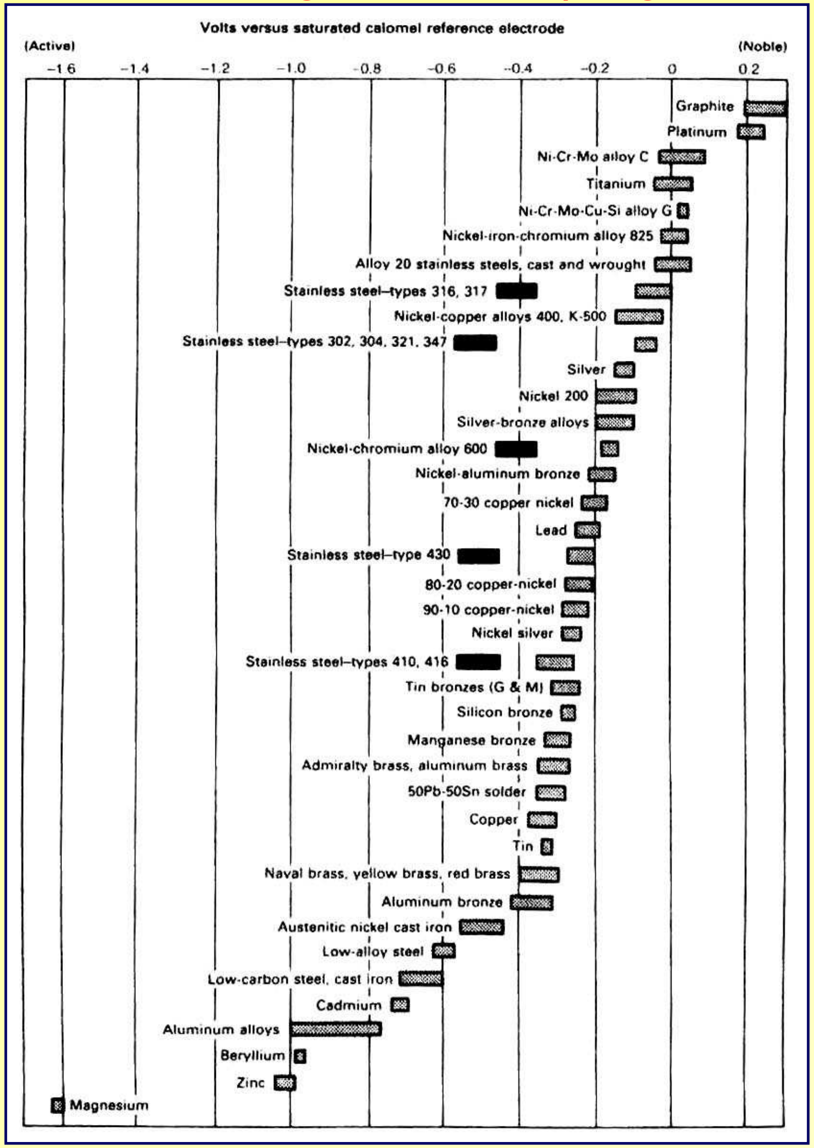
Avoid water accumulation.



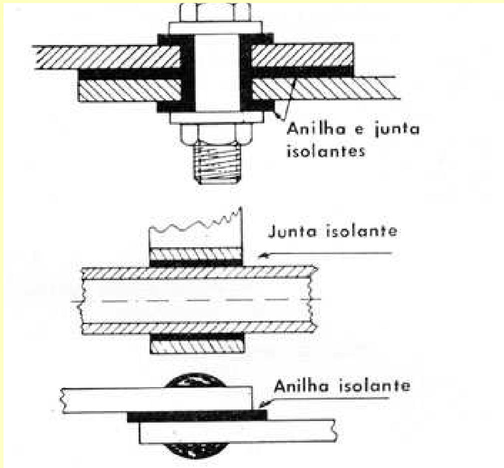

ASM Handbook, Vol. 13A, Corrosion, ASM International, 2003

# DESIGN OF STRUCTURES

Avoid galvanic coupling.




**Usually galvanic coupling becomes a problem for potential differences higher than 50 mV!**



# LOCATION OF STRUCTURES

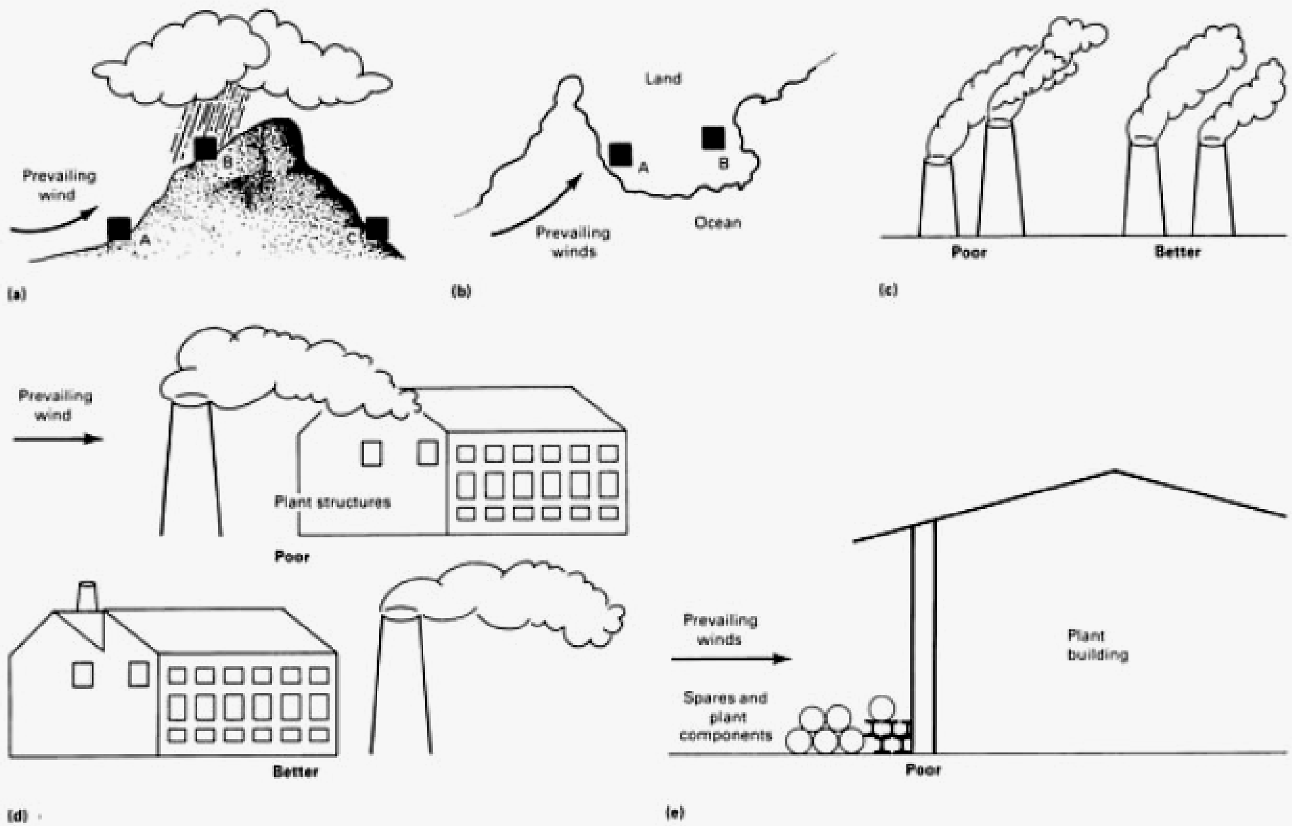
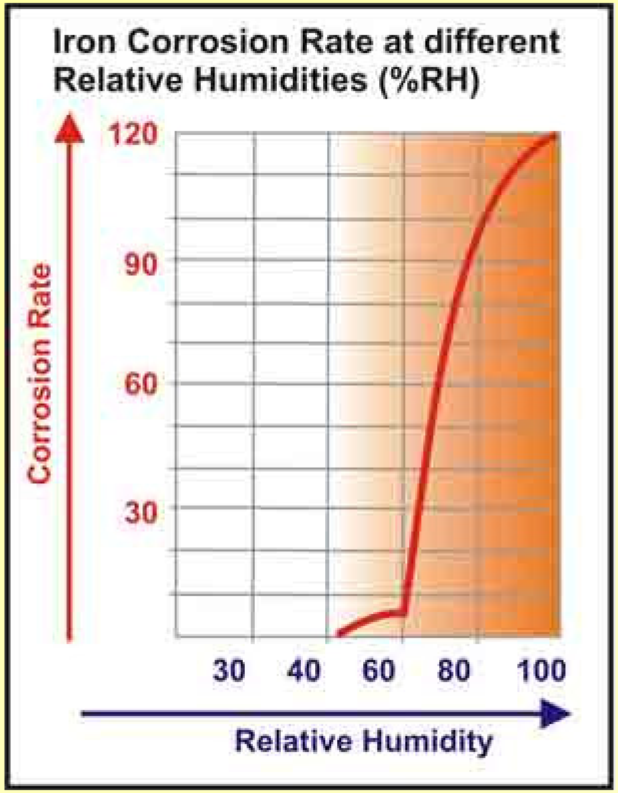



**Fig. 5** Site location as a design consideration. (a) Topographic features must be considered in choosing a site. Location C would be the preferred site. (b) In marine atmospheres, prevailing winds should be taken into account; location B is the preferred site. (c) Local industry can affect corrosion of chimney stacks and similar structures. "Lick-over" of gases, which relates to stack height, location, and prevailing winds, should be avoided. (d) Plant structures should be located upwind from stacks. (e) spares and components should be stored away from the prevailing wind.

ASM Handbook, Vol. 13A, Corrosion, ASM International, 2003

# MODIFICATION OF ENVIRONMENT

Controlling humidity



# MODIFICATION OF ENVIRONMENT

## Removing dissolved $O_2$

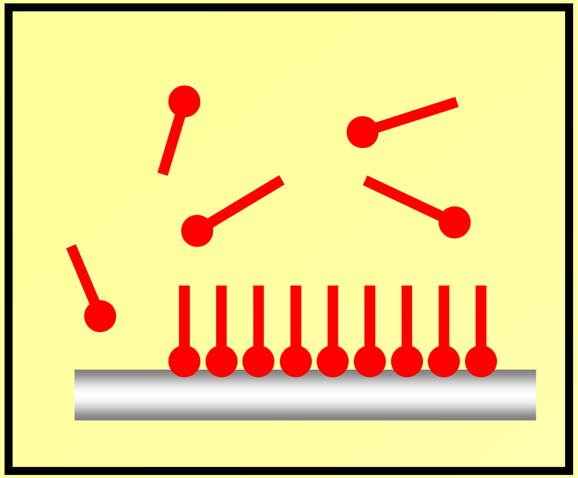
- Bubbling inert gasses

- Oxygen scavengers

Hidrazine: $N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$

Sodium sulfite: $Na_2SO_3 + \frac{1}{2}O_2 \rightarrow Na_2SO_4$

# CORROSION INHIBITORS



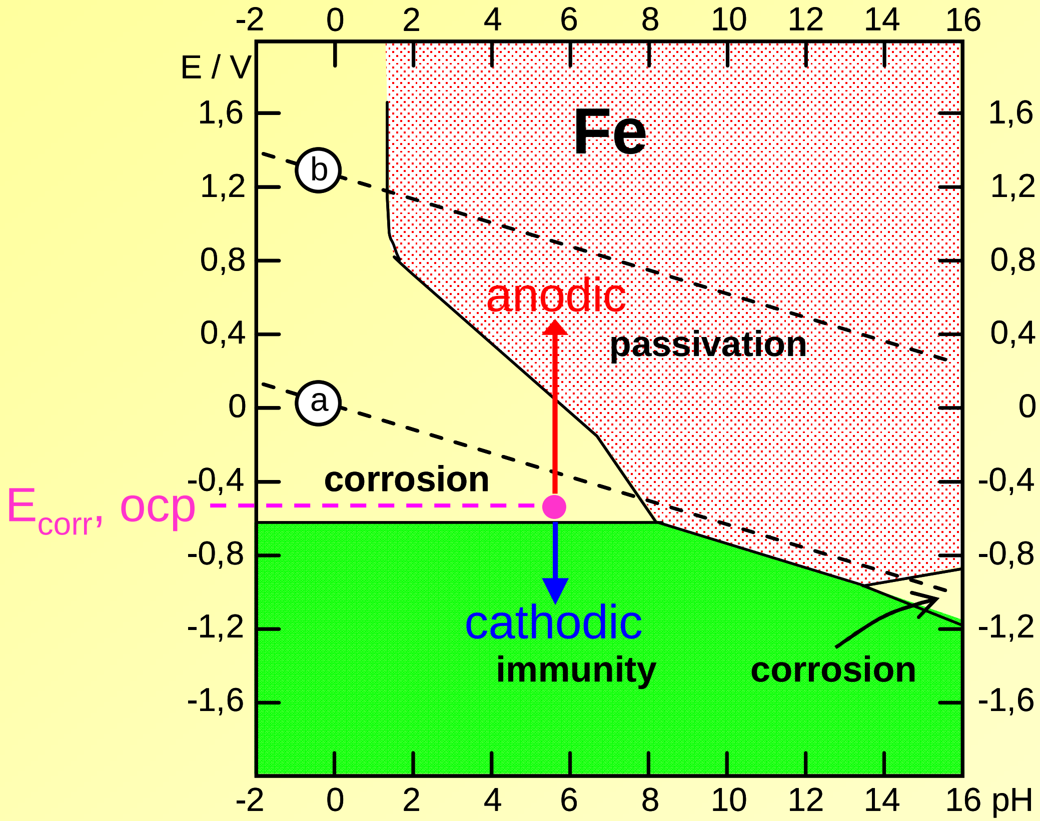
Passivating films
- adsorption
- adherent,non porous, insoluble precipitates

Inhibitors
- anodic
- cathodic
- mixed

TABLE 10.1 Some Corrosive Systems and the Inhibitors Used to Protect Them

| System | Inhibitor | Metals | Concentration |
|---|---|---|---|
| | Acids | | |
| HCl | Ethylaniline | Fe | 0.5% |
| | MBT* | .. | 1% |
| | Pyridine + phenylhydrazine | .. | 0.5% + 0.5% |
| | Rosin amine + ethylene oxide | .. | 0.2% |
| $H_2SO_4$ | Phenylacridine | .. | 0.5% |
| $H_3PO_4$ | NaI | .. | 200 ppm |
| Others | Thiourea | .. | 1% |
| | Sulfonated castor oil | .. | 0.5–1.0% |
| | $As_2O_3$ | .. | 0.5% |
| | $Na_3AsO_4$ | .. | 0.5% |
| | Water | | |
| Potable | $Ca(HCO_3)_2$ | Steel, cast iron | 10 ppm |
| | Polyphosphate | Fe, Zn, Cu, Al | 5–10 ppm |
| | $Ca(OH)_2$ | Fe, Zn, Cu | 10 ppm |
| | $Na_2SiO_3$ | .. | 10–20 ppm |
| Cooling | $Ca(HCO_3)_2$ | Steel, cast iron | 10 ppm |
| | $Na_2CrO_4$ | Fe, Zn, Cu | 0.1% |
| | $NaNO_2$ | Fe | 0.05% |
| | $NaH_2PO_4$ | .. | 1% |
| | Morpholine | .. | 0.2% |
| Boilers | $NaH_2PO_4$ | Fe, Zn, Cu | 10 ppm |
| | Polyphosphate | .. | 10 ppm |
| | Morpholine | Fe | Variable |
| | Hydrazine | .. | $O_2$ scavenger |
| | Ammonia | .. | Neutralizer |
| | Octadecylamine | .. | Variable |
| Engine coolants | $Na_2CrO_4$ | Fe, Pb, Cu, Zn | 0.1–1% |
| | $NaNO_2$ | Fe | 0.1–1% |
| | Borax | .. | 1% |
| Glycol/water | Borax + MBT* | All | 1% + 0.1% |
| Oil field brines | $Na_2SiO_3$ | Fe | 0.01% |
| | Quaternaries | .. | 10–25 ppm |
| | Imidazoline | .. | 10–25 ppm |
| Seawater | $Na_2SiO_3$ | Zn | 10 ppm |
| | $NaNO_2$ | Fe | 0.5% |
| | $Ca(HCO_3)_2$ | All | pH dependent |
| | $NaH_2PO_4 + NaNO_2$ | Fe | 10 ppm + 0.5% |

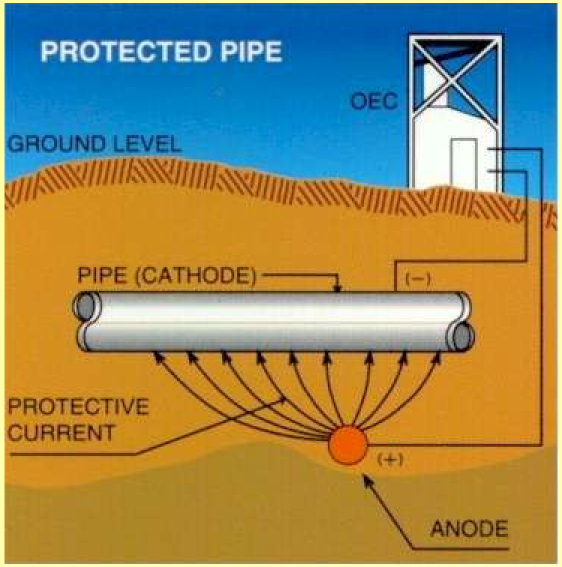
# ANODIC AND CATHODIC PROTECTION



# CATHODIC PROTECTION

**Widely used in pipelines, storage tanks, bridges, naval ships, off shore structures, etc.**

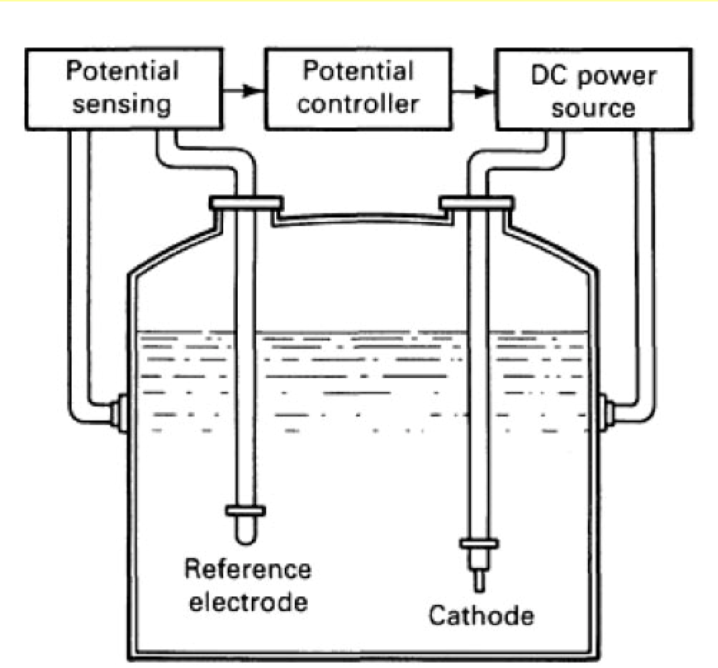
**2 ways: sacrificial anodes; imposed currents**



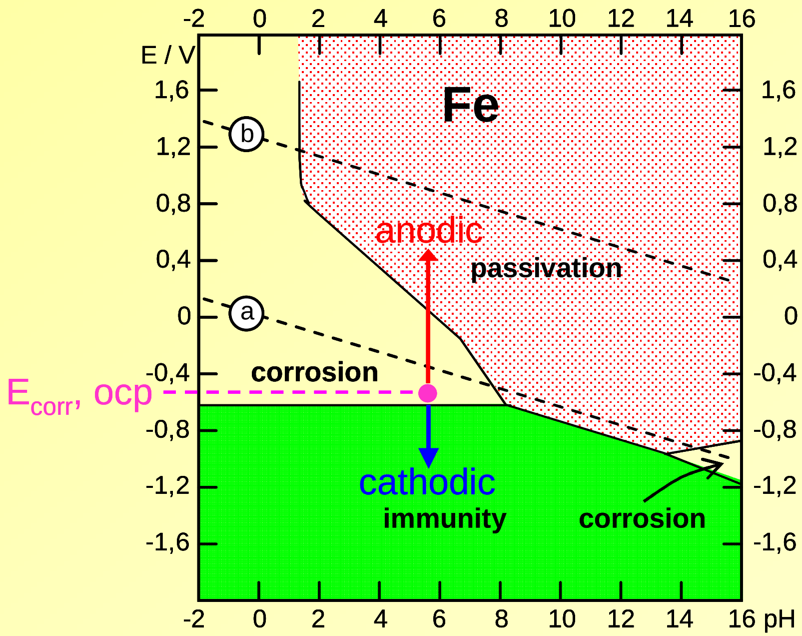


Types of Corrosion and Anticorrosive Methods

# ANODIC PROTECTION




ASM Handbook, Vol. 13A, Corrosion, ASM International, 2003




Anodic inhibitors

Oxidant environments

# STAINLESS STEELS

**100 Series - austenitic chromium-nickel-manganese alloys**

Type 101 - austenitic that is hardenable through cold working for furniture
Type 102 - austenitic general purpose stainless steel working for furniture

**200 Series - austenitic chromium-nickel-manganese alloys**

Type 201 - austenitic that is hardenable through cold working
Type 202 - austenitic general purpose stainless steel

**300 Series - austenitic chromium-nickel alloys**

Type 301 - highly ductile, for formed products. Good weldability. Better wear resistance and fatigue strength than 304.
Type 302 - same corrosion resistance as 304, with slightly higher strength due to additional carbon.
Type 303 - free machining version of 304 via addition of sulfur and phosphorus.
Type 304 - the most common grade; the classic 18/8 stainless steel.
Type 304L - same as the 304 grade but contains less carbon to increase weldability. Is slightly weaker than 304.
Type 304LN - same as 304L, but also nitrogen is added to obtain a much higher yield and tensile strength than 304L.
Type 308 - used as the filler metal when welding 304
Type 309 - better temperature resistance than 304, also sometimes used as filler metal when welding dissimilar steels.
Type 316 - the second most common grade (after 304). For food and surgical uses. Also known as marine grade stainless steel.
Type 321- similar to 304 but lower risk of weld decay due to addition of Ti. See also 347 with Nb for desensitization during welding.

**400 Series - ferritic and martensitic chromium alloys**

Type 405 - ferritic for welding applications
Type 408 - heat-resistant; poor corrosion resistance; 11% chromium, 8% nickel.
Type 409 - cheapest type; used for automobile exhausts; ferritic (iron/chromium only).
Type 410 - martensitic (high-strength iron/chromium). Wear-resistant, but less corrosion-resistant.
Type 416 - easy to machine due to additional sulfur
Type 420 - Cutlery Grade martensitic; similar to the Brearley's original rustless steel. Excellent polishability.
Type 430 - decorative, e.g., for automotive trim; ferritic. Good formability, but with reduced temperature and corrosion resistance.
Type 440 - a higher grade of cutlery steel also known as razor blade steel. Used on display-only and replica swords or knives.
Type 446 - For elevated temperature service

**500 Series - heat-resisting chromium alloys**

**600 Series - martensitic precipitation hardening alloys**

601 through 604: Martensitic low-alloy steels.
610 through 613: Martensitic secondary hardening steels.
614 through 619: Martensitic chromium steels.
630 through 635: Semiaustenitic and martensitic precipitation-hardening stainless steels.
650 through 653: Austenitic steels strengthened by hot/cold work.
660 through 665: Austenitic superalloys; all grades except alloy 661 are strengthened by second-phase precipitation.

**Type 2205** - the most widely used duplex (ferritic/austenitic) stainless steel grade. Excellent corrosion resistance and high strength.

# METALLIC COATINGS

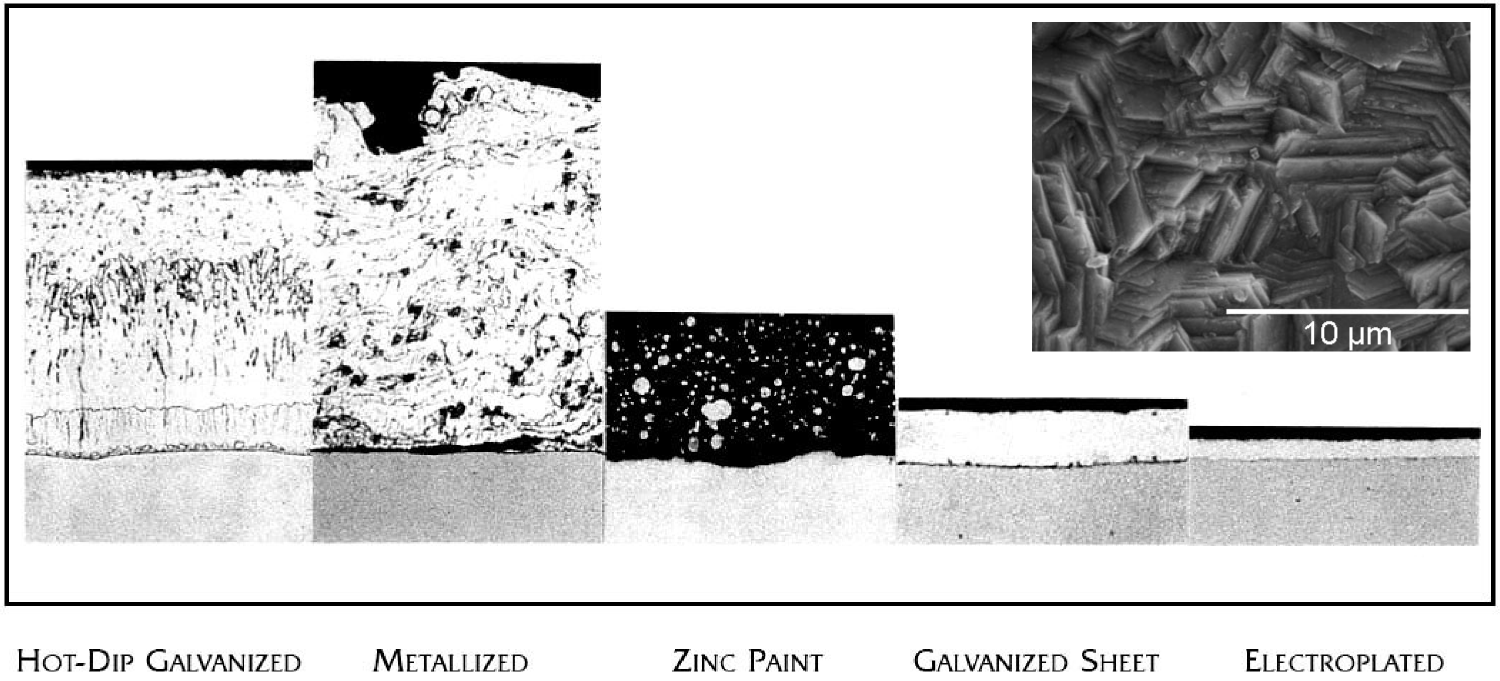
**Electrodeposition (electroplating)**
**Hot dipping (Molten metal bath)**
**Diffusion**
**Spraying**
**Chemical reduction, "e*lectroless*" deposition**
**Vacuum evaporation**
**Chemical vapour deposition (CVD)**
**Physical vapour deposition (PVD)**
**Ionic implantation**
**Plasma deposition**

Some of these processes lead to very thin films. Many times the objective is not anticorrosive protection, rather the modification of surface properties: hardness, wear resistance, colour, brightness, electrical or thermal conductivity, etc.
It is possible to co-deposit various metals or non metallic elements.

Types of Corrosion and Anticorrosive Methods

# METALLIC COATINGS

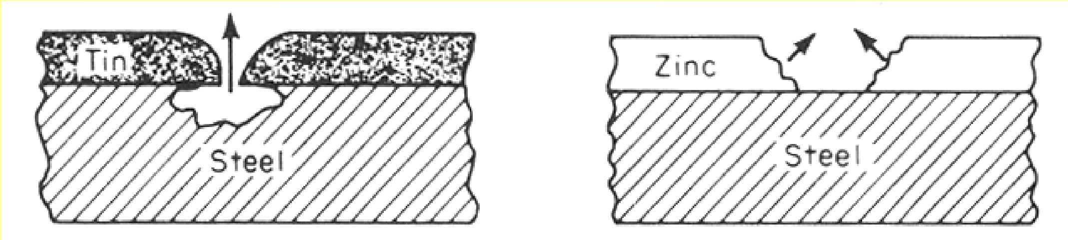
## Example for zinc




- **GALVALUME** (55% Zn, 43,5% Al, 1,5% Si)
- **GALFAN** (95% Zn, 5% Al)
- **GALVANNEALED** (HDG followed by thermal treatment)
- **Co-deposition:** Zn-Fe, Zn-Ni, Zn-Co, Sn-Zn.

# METALLIC COATINGS

Steel pipe protected with a metallic coating

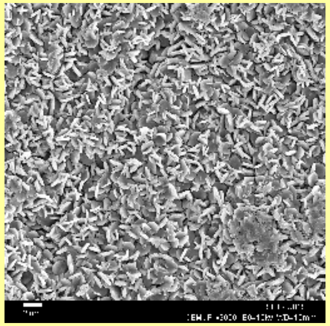


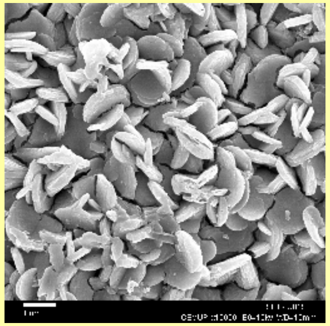

| Standard electrode potentials | | Galvanic potentials in 3% NaCl | |
|---|---|---|---|
| $Sn^{2+}/Sn$ | – 0,136 V | Cr | + 0,23 V |
| $Fe^{2+}/Fe$ | – 0,440 V | Sn | – 0,25 V |
| $Cr^{3+}/Cr$ | – 0,74 V | Fe | – 0,50 V |
| $Zn^{2+}/Zn$ | – 0,763 V | Zn | – 0,83 V |

**The electrochemical series suggests that chromium protects cathodically iron, which actually is not true. For corrosion problems the galvanic series are safer.**

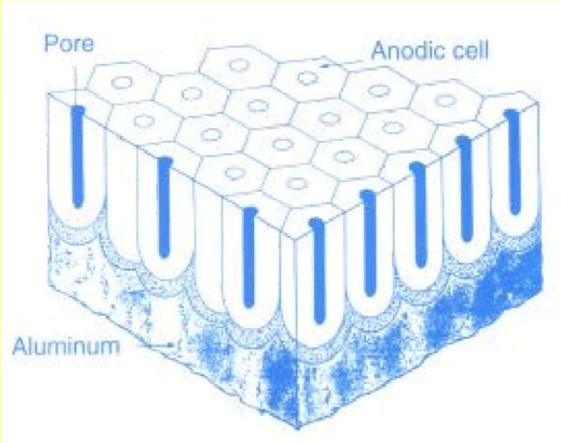
# INORGANIC COATINGS

## Phosphate coatings





## Anodizing




## Chromate Conversion Coatings

**Silanes**

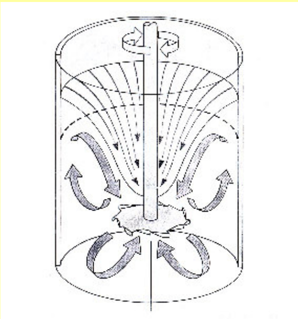
**Sol-gel**

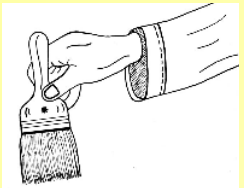
**Hybrids…**

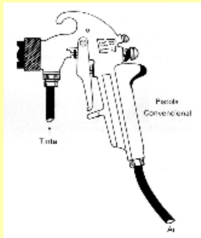
# ORGANIC COATINGS (PAINTS)

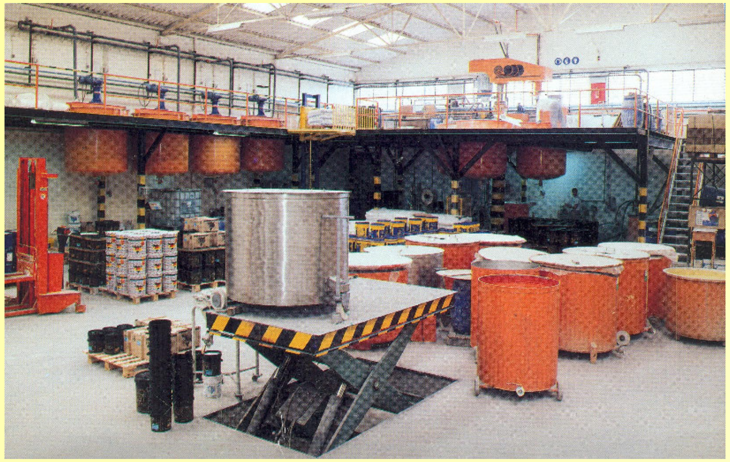
**Widely used, low-price, versatile.**

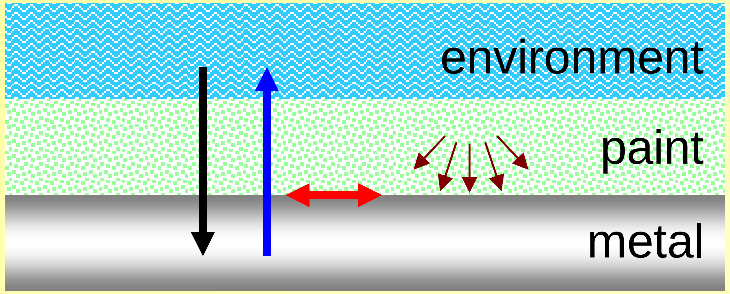
Binder (first natural oils, now synthetic resins)
Pigments (and fillers)
Solvents
Additives (defoamers, dispersants, thickeners…)









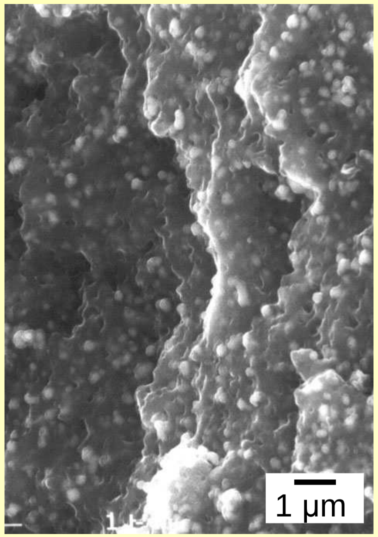


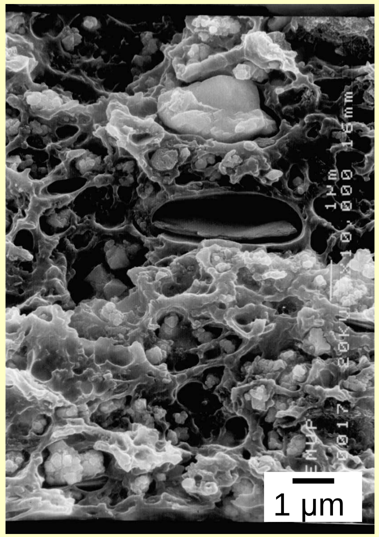

**Barrier effect**
**(water, gases, ions)**

**Barrier effect**
**(corrosion products)**

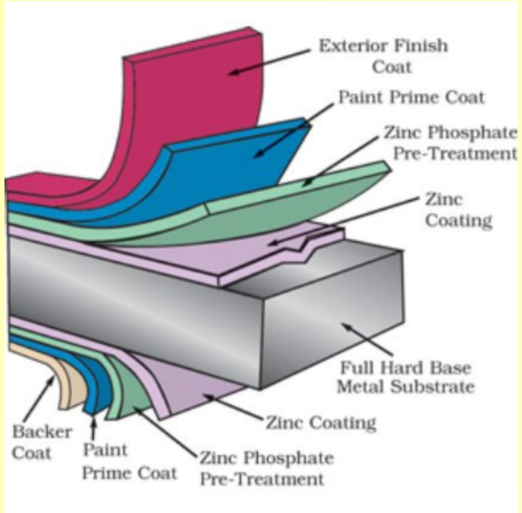
**Adhesion**
**(high R between anode and cathode)**

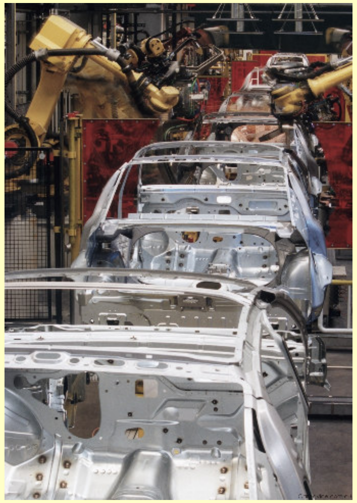
**Anticorrosive pigments**



# Anticorrosive protection of a car


ALL ALUMINIUM AUDI A2
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**Objectives:**

- Costs and impact of corrosion

- Metallurgy vs corrosion

- Thermodynamics and Kinetics

- Corrosion (activity), passivity, immunity

- Types and forms of corrosion

- Anticorrosive measures and methods

## For further reading…

### Websites

http://www.corrosion-doctors.org

http://www.efcweb.org

http://www.nace.org

http://corrosion.ksc.nasa.gov

### Books

D.A.Jones, Principles and Prevention of Corrosion 2nd Ed, Prentice Hall, 1996

M.G.Fontana, Corrosion Engineering 3rd Ed, McGraw-Hill, 1987

R.W.Revie, H.H.Uhlig, Corrosion and Corrosion Control 4th Ed, Wiley, 2008

H.Kaesche, Corrosion of Metals, Springer, 2003