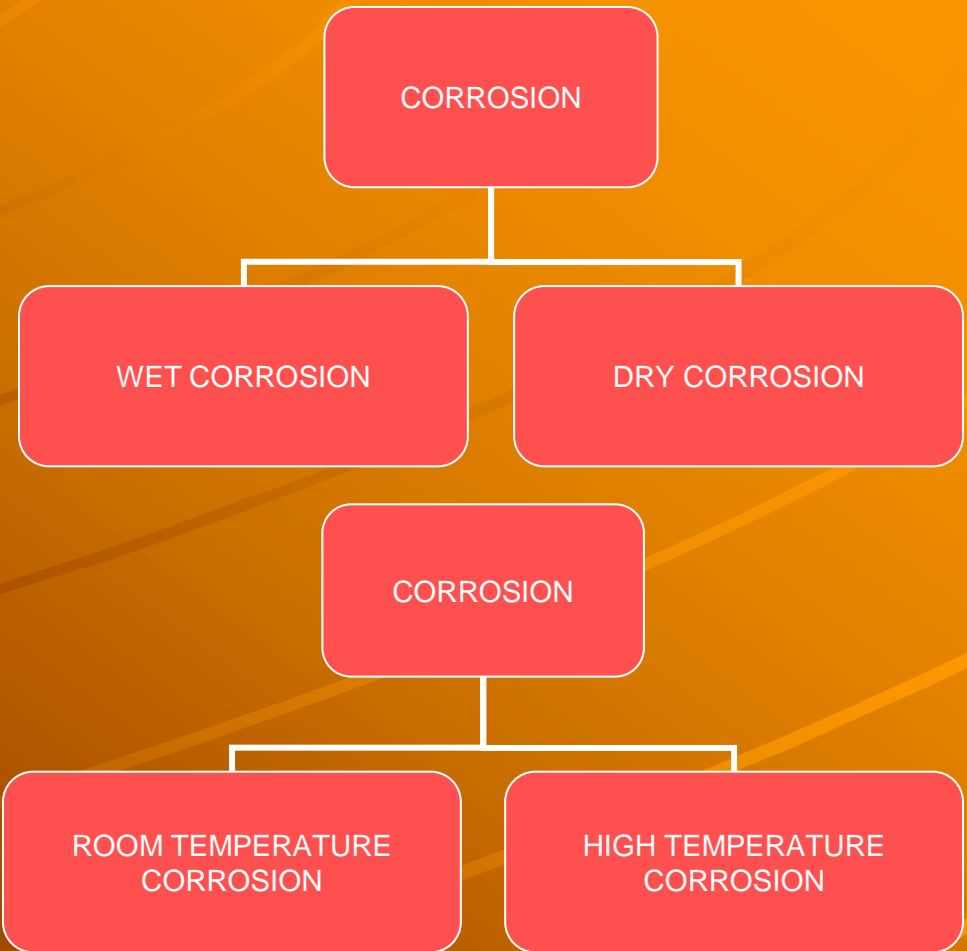


FORMS OF CORROSION

- ✦ Corrosion may be classified in different ways
- ✦ Wet / Aqueous corrosion & Dry Corrosion
- ✦ Room Temperature/ High Temperature Corrosion



WET & DRY CORROSION

- ◆ Wet / aqueous corrosion is the major form of corrosion which occurs at or near room temperature and in the presence of water
- ◆ Dry / gaseous corrosion is significant mainly at high temperatures

WET / AQUEOUS CORROSION

Based on the appearance of the corroded metal, wet corrosion may be classified as

- ◆ **Uniform or General**
- ◆ **Galvanic or Two-metal**
- ◆ **Crevice**
- ◆ **Pitting**
- ◆ **Dealloying**
- ◆ **Intergranular**
- ◆ **Velocity-assisted**
- ◆ **Environment-assisted cracking**

UNIFORM CORROSION

- ◆ Corrosion over the entire exposed surface at a uniform rate. e.g., Atmospheric corrosion.
- ◆ Maximum metal loss by this form.
- ◆ Not dangerous. Rate can be measured in the laboratory



GALVANIC CORROSION

- ✦ **When two dissimilar metals are joined together and exposed, the more active of the two metals corrode faster and the nobler metal is protected. This excess corrosion is due to the galvanic current generated at the junction**
- ✦ a) Steel plates with copper rivets in seawater 15 months.
- ✦ b)) Copper plates with steel rivets, same environmental conditions



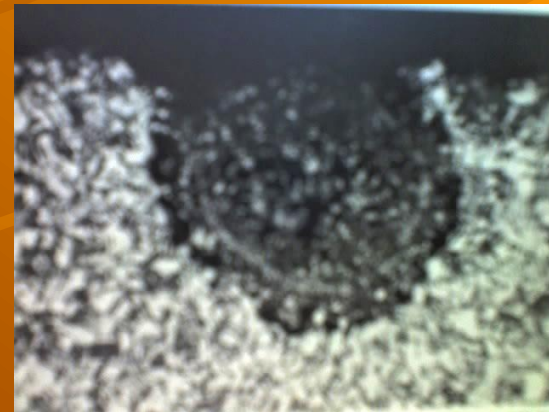
CREVICE CORROSION

- ✦ Intensive localized corrosion within crevices & shielded areas on metal surfaces
- ✦ Small volumes of stagnant corrosive caused by holes, gaskets, surface deposits, lap joints



DEALLOYING

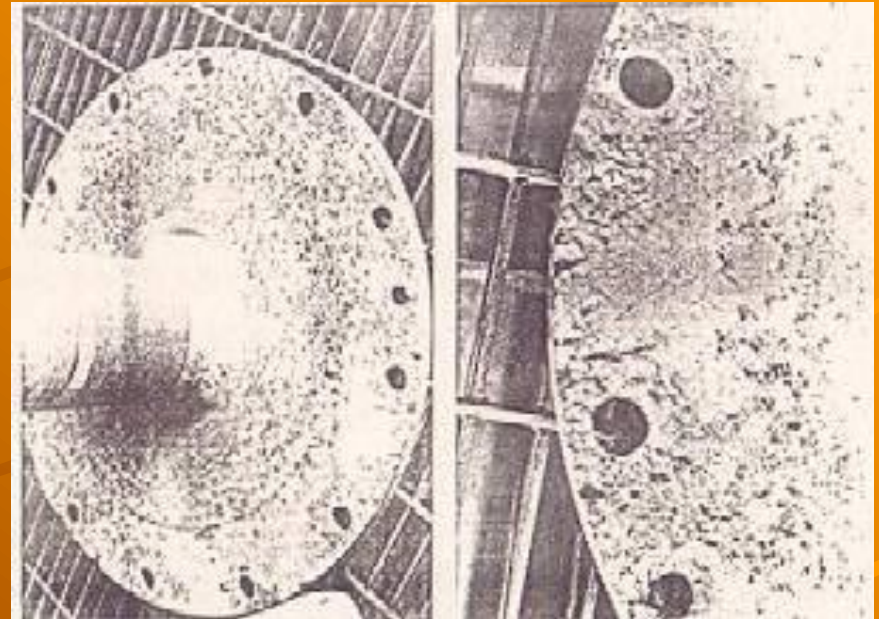
- ◆ Alloys exposed to corrosives experience selective leaching out of the more active constituent. e.g. Dezincification of brass.



- ◆ Loss of structural stability and mechanical strength

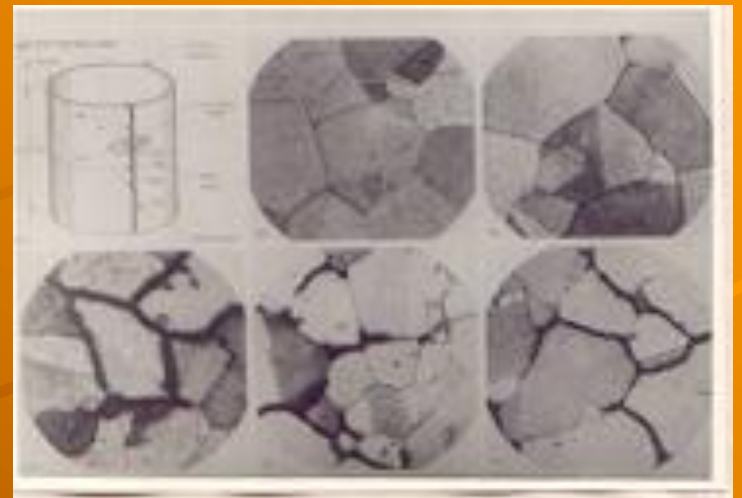
PITTING

- ◆ **A form of extremely localized attack causing holes in the metal**
- ◆ **Most destructive form**
- ◆ **Autocatalytic nature**
- ◆ **Difficult to detect and measure**



INTERGRANULAR CORROSION

- ✦ The grain boundaries in metals are more active than the grains because of segregation of impurities and depletion of protective elements. So preferential attack along grain boundaries occurs. e.g. weld decay in stainless steels



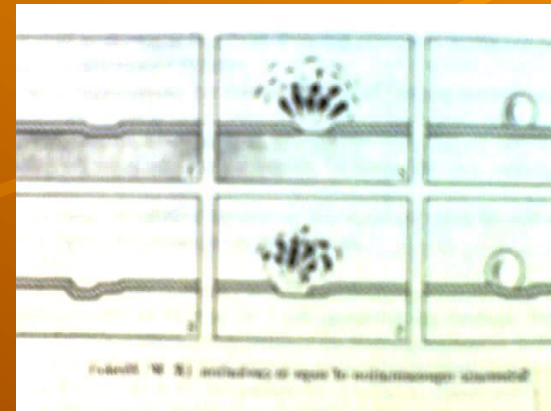
VELOCITY ASSISTED CORROSION

- ◆ Fast moving corrosives cause
 - ◆ a) Erosion-Corrosion,
 - ◆ b) Impingement attack, and
 - ◆ c) Cavitation damage in metals



CAVITATION DAMAGE

- ◆ Cavitation is a special case of Erosion-corrosion.
- ◆ In high velocity systems, local pressure reductions create water vapour bubbles which get attached to the metal surface and burst at increased pressure, causing metal damage

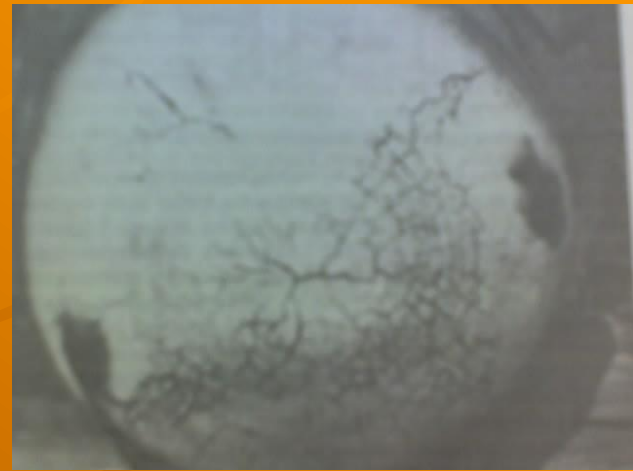


ENVIRONMENT ASSISTED CRACKING

- ◆ When a metal is subjected to a tensile stress and a corrosive medium, it may experience Environment Assisted Cracking. Four types:
 - ◆ Stress Corrosion Cracking
 - ◆ Hydrogen Embrittlement
 - ◆ Liquid Metal Embrittlement
 - ◆ Corrosion Fatigue

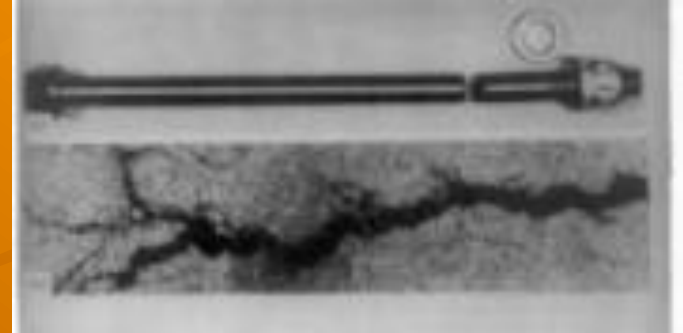
STRESS CORROSION CRACKING

- ◆ Static tensile stress and specific environments produce cracking
- ◆ Examples:
 - ◆ 1) Stainless steels in hot chloride
 - ◆ 2) Ti alloys in nitrogen tetroxide
 - ◆ 3) Brass in ammonia



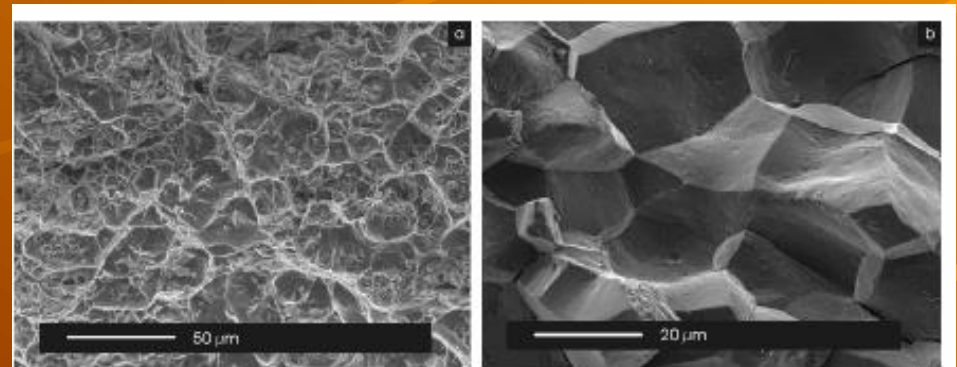
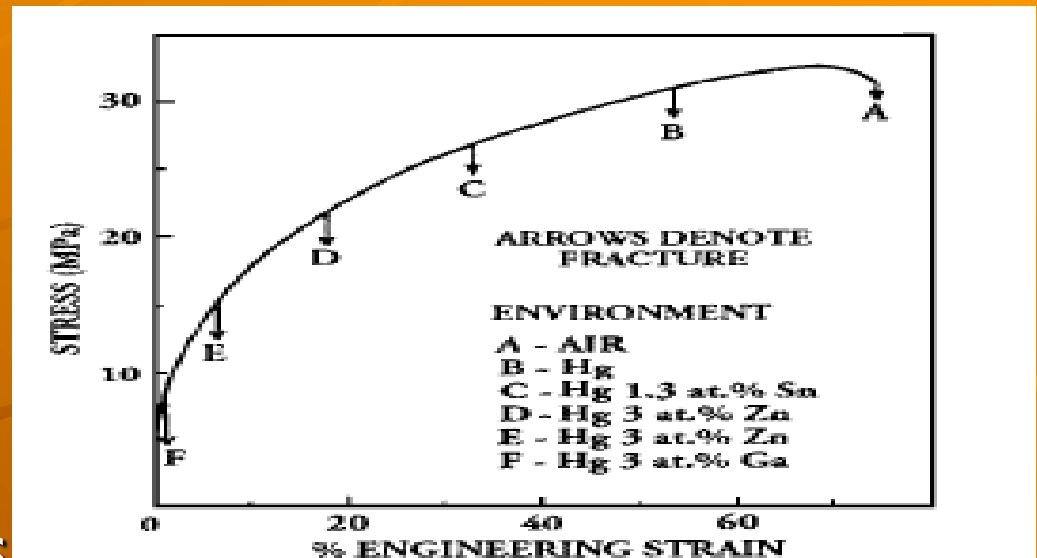
HYDROGEN EMBRITTLEMENT

- ◆ High strength materials stressed in presence of hydrogen crack at reduced stress levels.
- ◆ Hydrogen may be dissolved in the metal or present as a gas outside.
- ◆ Only ppm levels of H needed



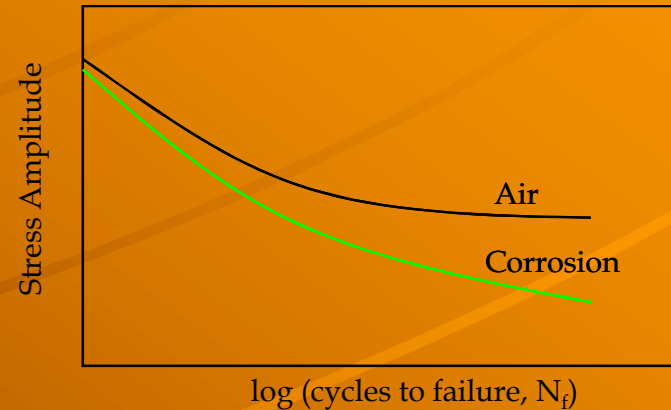
LIQUID METAL EMBRITTLEMENT

- ◆ Certain metals like Al and stainless steels undergo brittle failure when stressed in contact with liquid metals like Hg, Zn, Sn, Pb Cd etc.
- ◆ Molten metal atoms penetrate the grain boundaries and fracture the metal
- ◆ Fig. Shows brittle IG fracture in Al alloy by Pb



CORROSION FATIGUE S-N DIAGRAM

- ◆ Synergistic action of corrosion & cyclic stress. Both crack nucleation and propagation are accelerated by corrodent and the S-N diagram is shifted to the left



CORROSION FATIGUE, CRACK PROPAGATION

- ◆ Crack propagation rate is increased by the corrosive action



log (Crack Growth Rate, da/dN)



Log (Stress Intensity Factor Range, ΔK)

HIGH TEMPERATURE(DRY) CORROSION

- ◆ Exposure to high temperatures in air or other gaseous environments causes severe material damage. The major corrosion processes are:
 - ◆ Oxidation
 - ◆ Corrosion in Sulfur environments
 - ◆ Hydrogen attack

OXIDATION

- ✦ Oxidation, Scaling, Tarnishing refer to the reaction between air or oxygen in the absence of water.
- ✦ Pilling-Bedworth ratio ($R = Md / nmD$ where M is the molecular weight of the scale, D is the density of the scale, m is the atomic weight of the metal, d is the density of the metal, and n is the number of metal atoms in a molecular formula of the scale) indicates the oxidation resistance of a metal. For best resistance, R should be near unity.

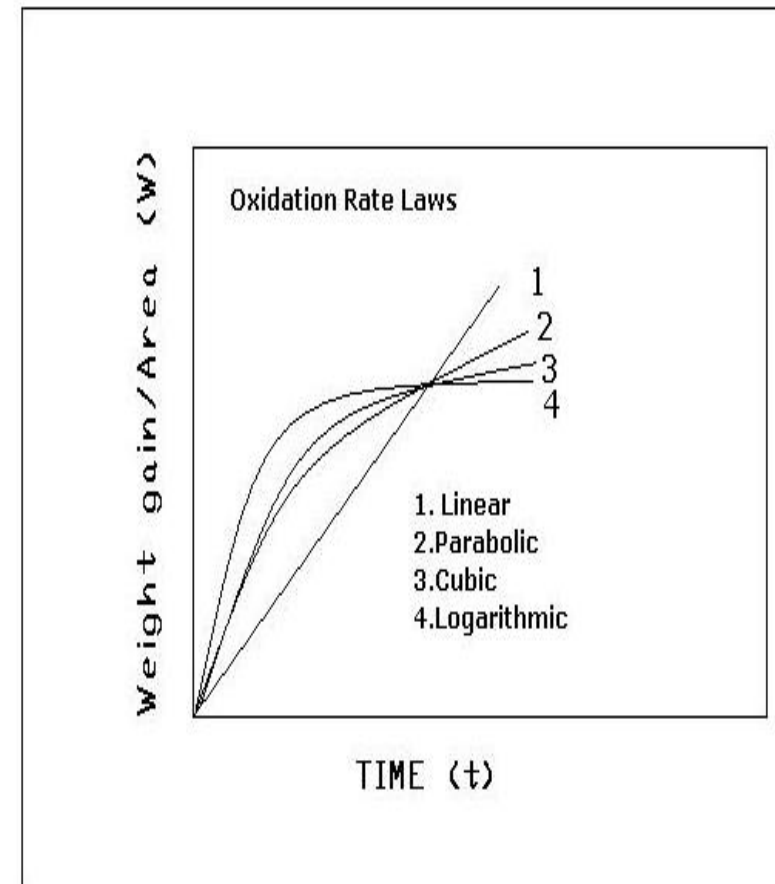
OXIDATION-ELECTROCHEMICAL REACTION

- ◆ Oxidation, like aqueous corrosion is an electrochemical process, consisting of two partial processes,
- ◆ $M \rightarrow M^{+2} + 2 e^{-}$ ----- Metal oxidation at metal-scale interface
- ◆ $\frac{1}{2} O_2 + 2 e^{-} \rightarrow O^{2-}$ ----- Oxygen reduction at scale-gas interface.
- ◆ -----
- ◆ $M + \frac{1}{2} O_2 \rightarrow MO$ -----Overall reaction
- ◆ The oxide scale acts as the electrolyte through which ions and electrons move to make the above reactions possible. The electronic and ionic conductivities of the scale thus determine the rate of oxidation of the metal.

KINETICS OF OXIDATION

Oxidation leads to scale formation and weight gain. The reaction follows several rate laws. If Y is the thickness of the oxide scale and t the time of exposure, then

1. Linear: $dy/dt = K_L$ or $Y = K_L t + \text{constant}$ where K_L is the linear rate constant. e.g. Na, K.
2. Parabolic: $dy/dt = K_p / Y$ or $Y^2 = 2K_p t + \text{constant}$. K_p is parabolic rate constant. e.g. Cu, Ni, Fe, Cr and Co at elevated temperatures.
3. Cubic: $Y^3 = K_c t + \text{constant}$. K_c is cubic rate constant. e.g. Zr and Hf exposed for short durations.
- ◆ Logarithmic: $Y = K_l \log(Ct + A)$. K_l is logarithmic rate constant, and C and A are constants. e.g. Initial oxidation rate of many metals at low temperatures



Oxidation-resistant alloys

- ◆ The oxide characteristics determine the oxidation resistance of an alloy
- ◆ Most oxides are non-stoichiometric compounds with structural defects. They may be n-type or p-type semiconductors whose conductivities could be altered by alloy additions.
- ◆ This principle is used in developing high temperature oxidation resistant alloys like Fe-Cr, Fe-Cr-Al, and Ni-base alloys.

CORROSION IN OTHER GASEOUS ENVIRONMENTS

- ✦ **Sulfur compounds:** High temperature degradation of metals when exposed to sulfur compounds like H_2S , SO_2 and vaporized sulfur is referred to as sulfidation. Rapid scaling and internal precipitation of stable sulfides lead to degradation in mechanical properties of high temperature alloys
- ✦ **Decarburization and hydrogen attack:** When steels are exposed to hydrogen at high temperatures, Decarburization occurs by the reaction, $C (Fe) + 4 H \rightarrow CH_4$
- ✦ **Hot Corrosion:** accelerated high temperature corrosion of materials under sulfur gaseous atmospheres and the presence of fused sulphate compounds on the metal surface.