Unit 3
Corrosion

DEFINITION AND SIGNIFICANCE OF CORROSION

Definition
Corrosion is the gradual destruction of materials (usually metals) by chemical or electrochemical reaction with their environment.

Significance of Corrosion

1. *Economic Loss:*
    - Billions are spent annually on corrosion-related repairs and maintenance across industries.
    - Increases the cost of product lifecycle.
2. *Safety Concerns:*
    - Corrosion can lead to structural failures in bridges, pipelines, pressure vessels, etc.
    - Poses serious risks to human life and property.
3. *Environmental Impact:*
    - Leakage of harmful chemicals due to corrosion can pollute air, water, and soil.
4. *Functional Degradation:*
    - Reduces the mechanical strength, conductivity, and appearance of components.
    - Leads to poor performance in industrial systems and electronic devices.
5. *Resource Wastage:*
    - Leads to loss of natural resources by turning usable metals into waste products.

MECHANISM OF CHEMICAL (DRY) AND ELECTROCHEMICAL (WET) CORROSION

Chemical Corrosion (Dry Corrosion)

- Occurs due to direct chemical attack of dry gases (such as oxygen, halogens) on the metal surface in the absence of moisture.
- Usually happens at high temperatures.
- Forms oxide scales on the metal.
- Example: $2Mg+O_2 \rightarrow 2MgO$
- Types:
    - Oxidation corrosion
    - Liquid metal corrosion
    - Corrosion due to other gases (e.g., SO_2, Cl_2)

Electrochemical Corrosion (Wet Corrosion)

- Takes place in the presence of an electrolyte (moisture).
- Metal acts as anode and undergoes oxidation
- Electrons flow to cathodic areas where reduction occurs:
    - In acidic medium
    - In neutral/alkaline medium with oxygen
- Example: Rusting of iron in the presence of water and air.

Key Differences

Aspect	*Chemical Corrosion*	*Electrochemical Corrosion*
Medium	Dry gases	Electrolyte (Moist)
Process	Direct chemical reaction	Redox reaction with electron flow
Speed	Slow	Generally faster
Example	Oxidation of metal at high temp	Rusting of iron

GALVANIC CORROSION

Galvanic (Bimetallic) Corrosion (also called dissimilar metal corrosion) occurs when two different metals are electrically connected and immersed in an electrolyte. One metal becomes the anode and corrodes, while the other becomes the cathode and is protected.

Conditions Required:

- Presence of two dissimilar metals (e.g., zinc and copper)
- Electrical contact between the metals
- Presence of an electrolyte (e.g., water with salts)
- A potential difference between the metals

Working Mechanism:

When two dissimilar metals are connected:

- The metal higher in the electrochemical series acts as the anode and loses electrons (oxidation).
- The metal lower in the series acts as the cathode and gains electrons (reduction).
- Current flows through the external connection, and ions migrate in the electrolyte.

Example:

If zinc and copper are in contact:

- Zinc (anode) → Zn → $Zn^{2+} + 2e^-$ (corrodes)
- Copper (cathode) → no corrosion

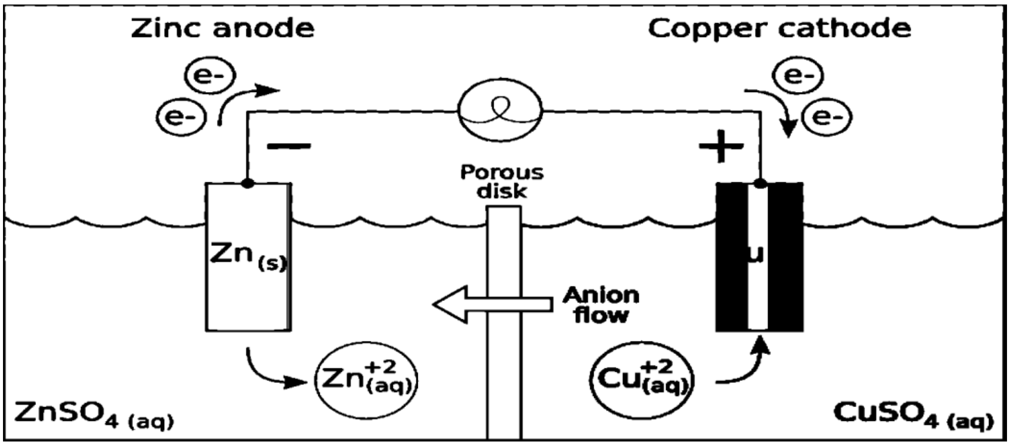
Electrochemical Series (Partial Example):

Metal	Position
Magnesium	Most active
Zinc	Anodic
Iron	
Copper	Cathodic
Gold	Least reactive

Metals higher up (more reactive) act as anodes.

Prevention Methods:

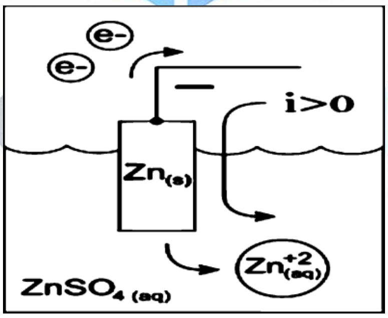
- Use similar metals in construction
- Isolate metals using non-conductive gaskets or coatings
- Apply cathodic protection (e.g., sacrificial anodes)
- Use inhibitors in the electrolyte
- Apply protective coatings



CONCENTRATION CORROSION AND PITTING CORROSION

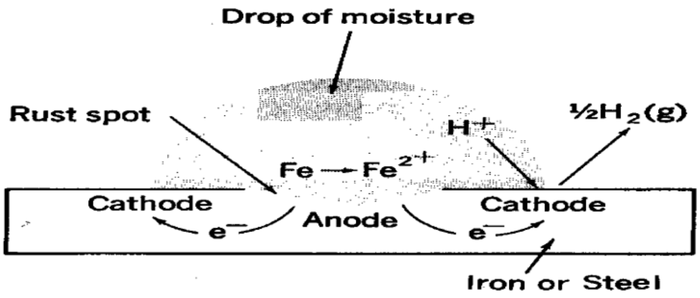
Concentration Cell Corrosion (Differential Aeration Corrosion)

- *Definition:* Corrosion caused by differences in the concentration of electrolytes or oxygen on different parts of the same metal surface.
- *Mechanism:*
  - The area with lower oxygen concentration becomes anodic and corrodes faster.
  - The area with higher oxygen acts as the cathode.
- Common in areas under deposits, gaskets, or water droplets.
- *Types:*
  - Oxygen concentration cells
  - Ion concentration cells
- *Example:* Iron surface covered partially with water or mud, where oxygen concentration differs.



Pitting Corrosion

- *Definition:* Pitting corrosion is a localized form of electrochemical corrosion that leads to the formation of small, deep holes or pits on the metal surface.
- *Mechanism:*
  - Initiated by the breakdown of a protective oxide film (e.g., on stainless steel).
  - The exposed area becomes anodic, while the surrounding surface acts as the cathode.
  - This leads to localized attack and deep penetration.
- *Conditions Favouring Pitting:*
  - Presence of chloride ions (e.g., NaCl in seawater)
  - Poor maintenance or surface damage
  - Stagnant water zones
- *Example:* Stainless steel immersed in chloride-rich environments such as marine water.



PROTECTION FROM CORROSION: PROTECTIVE COATINGS-GALVANISATION AND TINNING

Protective coatings are surface treatments applied to metals to prevent direct contact with corrosive environments, thereby reducing or eliminating corrosion.

Galvanisation

- *Definition:* Galvanisation is the process of coating iron or steel with a thin layer of zinc.
- *Mechanism:* Zinc acts as a sacrificial anode. Even if the coating is scratched, zinc corrodes preferentially, protecting the base metal.
- *Applications:* Used in iron pipes, roofing sheets, bolts, and wire fences.

Tinning

- *Definition:* Tinning is the process of coating iron or steel with a thin layer of tin.
- *Purpose:* Tin prevents corrosion because it is non-toxic and corrosion-resistant.
- *Applications:* Commonly used in food cans, containers, and utensils due to its safe and non-reactive nature.

Comparison:

Property	Galvanisation	Tinning
Metal Used	Zinc	Tin
Protection	Sacrificial (active)	Barrier (passive)
Common Uses	Pipes, fencing, roofing	Food containers, cans

CATHODIC PROTECTION

Cathodic protection is a technique used to prevent corrosion of a metal by converting it into a cathode of an electrochemical cell.
This is done by supplying electrons to the metal to reduce its tendency to lose electrons (oxidation).

Types of Cathodic Protection

1. Sacrificial Anode Method

- A more active metal (like Zn, Mg, or Al) is connected to the base metal (iron/steel).
- The anode corrodes instead of the protected metal.
- Applications: Underground pipelines, ship hulls, water heaters.
- Example: $Zn \rightarrow Zn^{2+} + 2e^-$ (sacrifices itself)

2. Impressed Current Method

- An external power source is used to supply current.
- An inert electrode (like graphite or platinum) is connected as the anode, and the structure is made cathodic.
- Applications: Large structures like bridges, tanks, offshore platforms.

Advantages of Cathodic Protection

- Prevents corrosion even if protective coatings are damaged.
- Cost-effective over long durations.
- Widely used in marine, oil & gas, and underground applications.

SACRIFICIAL ANODE MODIFICATION DESIGN

In sacrificial anode cathodic protection, a more reactive metal is electrically connected to the structure to be protected (e.g., iron pipe). The reactive metal acts as the anode and corrodes instead of the main metal, thereby protecting it.

Modification Design Aspects

To ensure efficient and long-term corrosion protection, several design modifications are made in the sacrificial anode system:

1. Selection of Anode Material
    - Must be more electrochemically active than the protected metal.
    - Common materials:
        - Zinc (Zn) – used in seawater
        - Magnesium (Mg) – used in soil
        - Aluminium (Al) – used in large structures
2. Positioning and Placement
    - Anodes must be electrically connected and close enough to provide current uniformly.
    - Distributed anodes are used for large or irregularly shaped structures.
    - Placement should ensure complete surface protection, avoiding shielding.
3. Surface Area Calculation
    - The total number and size of anodes are calculated based on:
        - Structure size
        - Environmental conditions
        - Design life
        - Current density required
4. Electrical Connection
    - Anodes must have low-resistance electrical connections to the structure.
    - Bonding wires and welding are used.
5. Monitoring and Maintenance
    - Periodic checks are needed to ensure anodes are active and consuming at a controlled rate.
    - Anodes are replaced when consumed.

Applications

- Buried pipelines
- Storage tanks
- Marine vessels
- Heat exchangers