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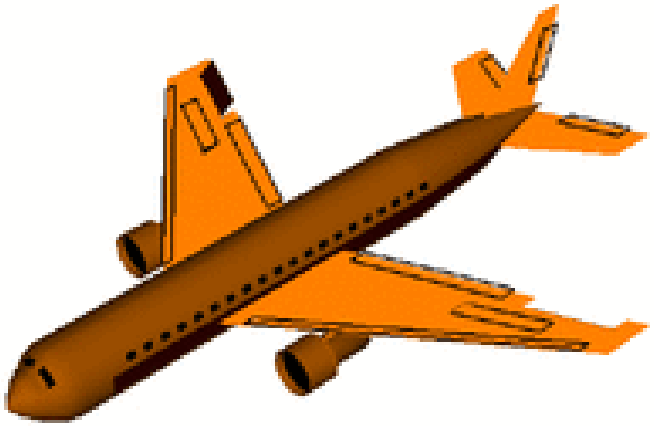
Corrosion



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FALL 2017-2018

Course Outline

1. Overview and introduction to corrosion.
2. Basic concepts: electrode potentials, corrosion cells, Pourbaix diagrams and other thermodynamic aspects.
3. Kinetics: corrosion rates, Polarization & Tafel's equation, mixed-potential theory & Evans diagrams, passivity.
4. Corrosion forms (types) applied to different practical materials and environments.
5. Corrosion Control: Cathodic and anodic protection, inhibition and coating.
6. Corrosion prevention by equipment design and materials selection.
7. Examples from the chemical process industry and local environment.

1.1 What is Corrosion

- Most commonly, a natural phenomenon in the form of an electrochemical reaction (on metals) that occurs over time.
- It happens at different rates with different metals and in different environments.
- Sometimes, corrosion is a chemical reaction.

- **Thus, two main categories exist:**
  a) Aqueous corrosion: reaction with water (usually containing dissolved ions); including atmospheric moisture
  b) High temperature corrosion: reaction with gases including oxygen.

Corrosion Reaction Examples

1. Aqueous corrosion (electrochemical, slow):

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

zinc corrosion (oxidation) $Zn \rightarrow Zn^{2+} + 2e^-$

Hydrogen Reduction $2H^+ + 2e^- \rightarrow H_2$

$2Al + 3H_2O \rightarrow Al_2O_3 + 6H^+$ *(Aluminium oxide is protective)*

2. Rusting of steel (electrochemical, slow):

$2Fe + 2H_2O + O_2 \rightarrow 2Fe(OH)_2\downarrow$

$2Fe(OH)_2 + H_2O + O_2 \rightarrow 2Fe(OH)_3\downarrow$

(corrosion product (rust) is solid but not protective)

3. High temperature oxidation/chemical reaction with gases:

$2Fe + 3O_2 \rightarrow Fe_2O_3$

$Fe + CO_2 \rightarrow FeO + CO$

$2Mg + O_2 \rightarrow 2MgO$ (Burning of Mg in air)

1.2 Definitions of Corrosion

1. Corrosion is the surface wastage that occurs when metals are exposed to reactive environments, resulting in gradual destruction.
2. Corrosion is an aspect of the decay of materials by chemical or biological agents.
3. Corrosion is the deterioration of materials as a result of reaction with its environment (Fontana).
4. Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with the environment (Uhlig).
5. Chemical or electrochemical reaction between a material (generally a metal) and the environment that leads to a degradation/deterioration in the material and its properties (ASM International)

- Corrosion is a natural and costly process of destruction like earthquakes, tornados, floods and volcanic eruptions.
- However, corrosion damage and loss can be minimized by prevention and control techniques.

1.3 Typical Corrosive Environments

Corrosion cannot be defined without a reference to environment. All environments are corrosive to some degree. The following is the list of typical corrosive environments:

(1) Air and humidity.
(2) Rain, fresh water, salty and marine waters.
(3) Natural, urban, marine and industrial atmospheres.
(4) Gases like Steam, chlorine, Ammonia, Hydrogen sulfide, Sulfur dioxide and oxides of nitrogen.
(5) Fuel combustion (flue or stack) gases.
(6) Acids and bases (Alkalis).
(7) Soils.

It may, therefore, be observed that corrosion is a potent force which destroys economy, depletes resources and causes costly and untimely failures of plants, equipment and components.

1.4 Cost of Corrosion

- In the 1970s, several countries began to think about the economic consequences of corrosion, the findings of these major investigations indicated that the range of the estimated cost of corrosion as percentage of the Gross Domestic Product (GNP).

- The annual cost of corrosion worldwide in **2010** is estimated at US $ 2.2 trillion* which is about 3% of the world's GDP of US $ 73.33 trillion**

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*Corrosion cost the US economy: ~ $1 trillion in 2014.

**Ref. NACE-International, USA.

1.4 Cost of Corrosion

I. Direct Loss:

Direct replacement of corroded equipment and structures.

II. **Indirect loss** (Consequences):

1. Plant shutdown.
2. Loss of product.
3. Loss of efficiency
4. Contamination.
5. Over-design.

1.5 Consequences of Corrosion

Some important consequences of corrosion are summarized below:

1. *Plant shutdowns:*

   Shutdown of nuclear plants, process plants, power plants and refineries may cause severe problems to industry and consumers.

2. *Loss of products*:

   Leaking containers, storage tanks, water and oil transportation lines and fuel tanks cause significant loss of product and may generate severe accidents and hazards.

   It is well known that at least 25% of water is lost by leakage.

1.5 Consequences of Corrosion

3. Loss of efficiency.

Insulation of heat exchanger tubings and pipelines by corrosion products reduces heat transfer and piping capacity.

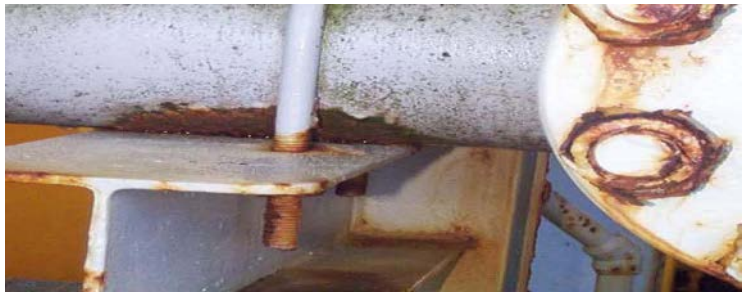
4. Contamination.

Corrosion products may contaminate chemicals, pharmaceuticals, dyes, etc…

5. Over-design.

More cost to be spent on corrosion prevention/ minimization at the design stage.

1.6 Functional Aspects of Corrosion



Corrosion may severely affect the following functions of metals, plant and equipment:

(1) **Mechanical strength**:

- Corrosion should not be allowed to affect the capability of material to withstand specified loads, and
- Material strength should not be undermined by corrosion.

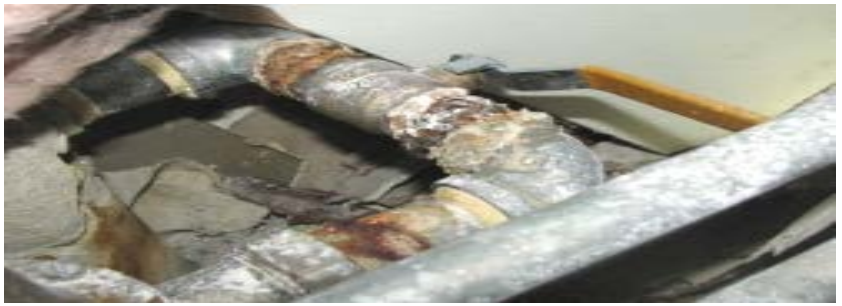
(2) **Dimensional integrity**:

Maintaining dimensions is critical to engineering designs and they should not be affected by corrosion.

(3) **Physical properties**:

For efficient operation, the physical properties of plants, equipment and materials, such as thermal conductivity and electrical properties, should not be allowed to be adversely affected by corrosion.

1.6 Functional Aspects of Corrosion (Cont'd)



(4) **Contamination**:

- Corrosion, if allowed to build up, can contaminate processing equipment, food products, drugs and pharmaceutical products and endanger health and environmental safety.

(5) **Damage to equipment**:

- Equipment adjacent to one which has suffered corrosion failure, may be damaged.
- Realizing that corrosion effectively blocks or impairs the functions of metals, plants and equipment, appropriate measures must be adopted to minimize loss or efficiency of function.

1.7 Health, Safety, Environment and Product Life

These aspects can involve the following:

(1) Safety: Sudden failure can cause

- explosions and fire,
- release of toxic products and collapse of equipment.
- Corrosion adversely affects structural integrity of components and makes them susceptible to failure and accident.
- Deaths are caused by accidents in civil structures because of the weakening of corroded components.

(2) **Health**: Adverse effects on health may be caused by corroding structures, such as a plumbing system affecting the quality of water and escaping of products into environment from corroded structures.

1.7 Health, Safety, Environment and Product Life (Cont'd)

(3) Depletion of resources: Corrosion puts a heavy constraint on natural resources of a country because of their wastage by corrosion.

(4) **Appearance and cleanliness**:

- A product designed to function properly must have an aesthetic appeal & corrosion destroys the aesthetic appeal of the product.
- Surface finishing processes such as electroplating, mechanical polishing, etc. lead to the dual purpose of enhancement of aesthetic value and surface integrity of the product.

(5) **Product life**:

- Corrosion shortens the predicted design life, a time span after which replacement is anticipated.
- Cars have a design life of twelve years, but several brands survive much longer.

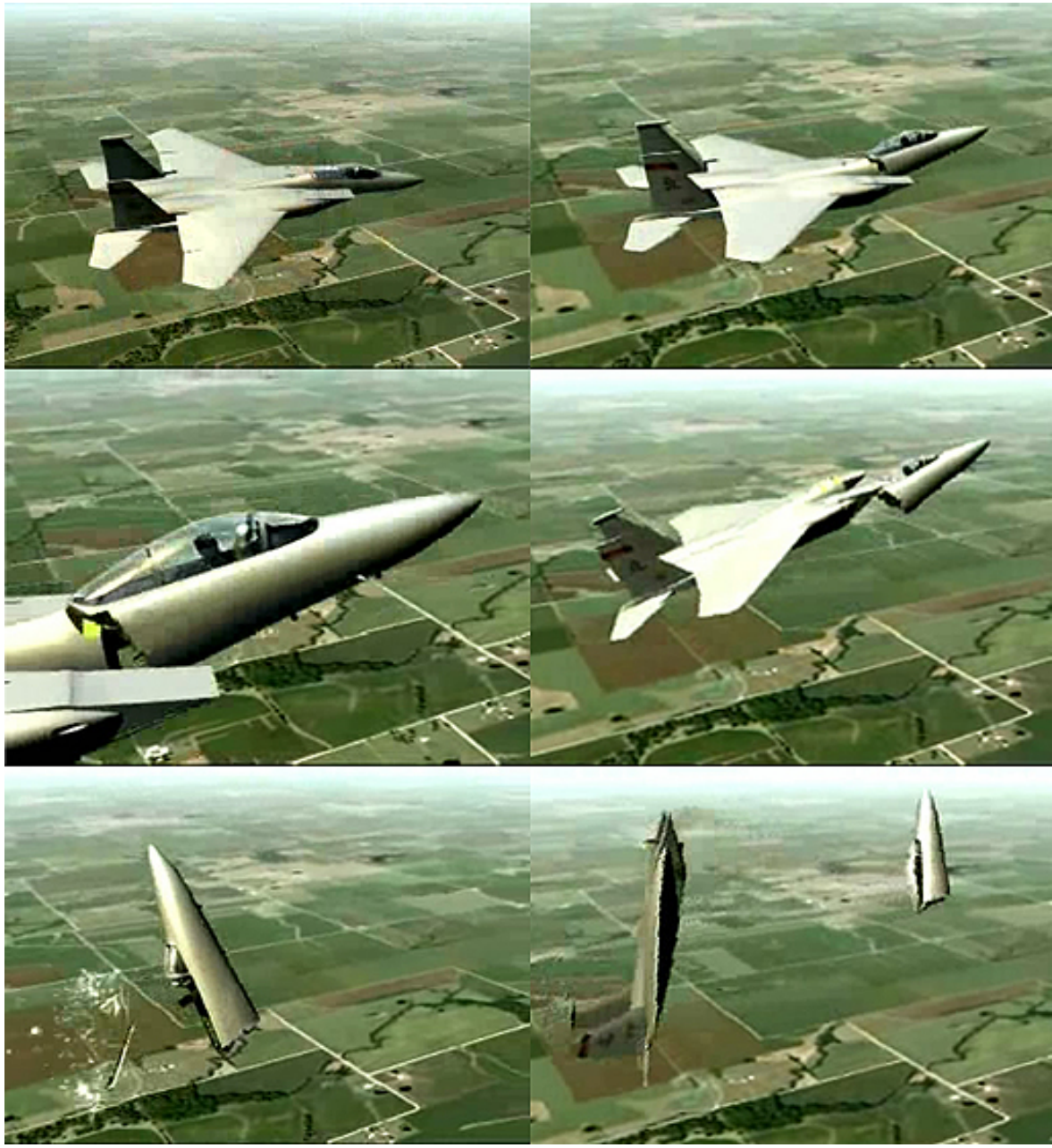
Commonly Affected Structures

- Steel Bridges
- Storage Tanks & Pipes- above Ground & Underground
- Mechanical Equipment
- Reinforcing Steel in Concrete
- Buried Piping
- Vehicles & Boats

Commonly Affected Structures

Other Affected Structures

- aircrafts and ships.



1.8 Five Good Reasons to Study Corrosion

(1) Materials are precious resources of a country.

Our material resources of Fe, Al , Cu, Cr, Mn, Ti, etc… are dwindling fast. Some day there will be an acute shortage of these materials.

To preserve these valuable resources, we need to understand how these resources are destroyed by corrosion AND how they must be preserved by applying corrosion protection technology.

(2) Engineering knowledge is incomplete without an understanding of corrosion.

Aeroplanes, ships and automobiles as well as industrial equipment cannot be designed without any recourse to the corrosion behavior of materials used in these structures.

1.8 Five Good Reasons to Study Corrosion

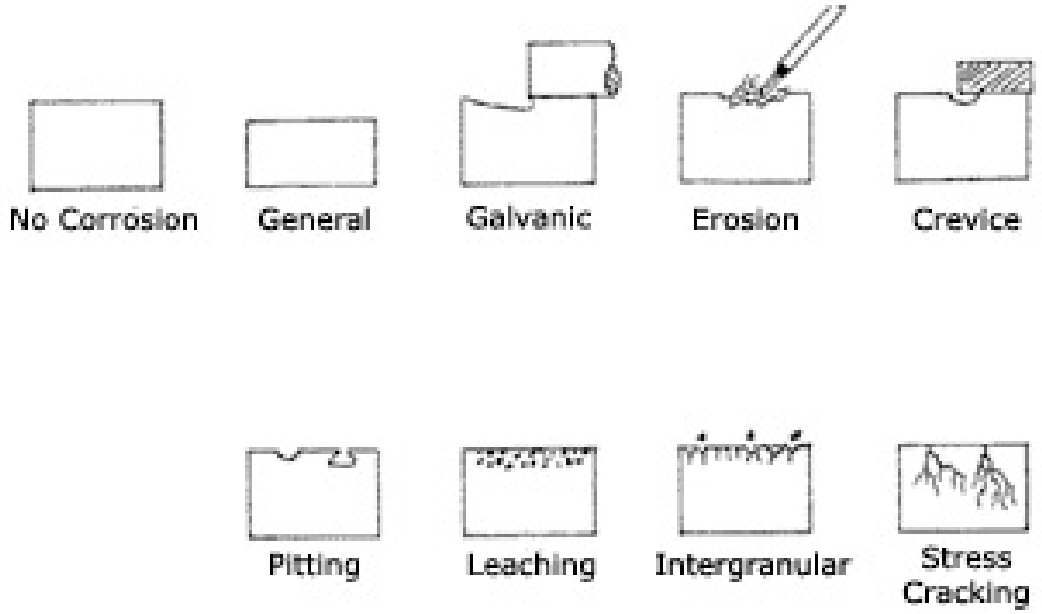
(3) Several engineering disasters (e.g. crashing of aircrafts or ships, explosion of oil pipelines & storage tanks, collapse of bridges, failure of drilling platforms and tanker trucks) have been witnessed in recent years. Corrosion has been a very important factor in these disasters.

(4) Designing of artificial implants for the human body requires a complete understanding of the corrosion science and engineering. Surgical implants must be very corrosion-resistant because of corrosive nature of human blood.

(5) Corrosion is a threat to the environment. For instance, water can become contaminated by corrosion products and unsuitable for consumption. Corrosion prevention is imperative to stop contamination of air, water and soil.

Forms of Corrosion

1. General corrosion (or Uniform attack)
2. Galvanic corrosion
3. Crevice corrosion
4. Pitting corrosion



5. Inter-granular attack (IGA)
6. Selective leaching (or De-alloying)
7. Stress corrosion cracking (SCC)
8. Erosion (or Velocity-accelerated corrosion)
9. Fretting (Friction) Corrosion
10. Dry (high temperature) corrosion

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Journals

- Corrosion
- Materials and Corrosion
- Corrosion Science
- Corrosion Science and Technology
- Journal of the Electrochemical Society.
- Electrochimica Acta