Corrosion
MM 454 IITB
by
Prof. Vijyashankar Dandapani
Prof. Smrutiranjan Parida

https://somphene.github.io/notes/

Notes
by
Som S. Phene

Spring 2020

When Corrosion Engineers don't work, the world rusts.

This is an **incomplete draft**. Please send corrections, comments, pictures of bad drawings, etc. to somphene1@gmail.com.

Last updated February 1, 2020.

Contents

1 Lecture Jan 13

§1.1 References

- Mars Guy Fontana's Corrosion engineering [Fo05].
- Edward McCafferty's Introduction to corrosion science [Mc10]
- R Winston Revie and Herbert H. Uhling's Corrosion and corrosion control: an introduction to corrosionscience and engineering [Re08]
- Specific scientific reports will be cited throughout the chapters and can be found in the Bibliography (at the end of these notes).

§1.2 Course objectives

- Provide a basic understansding of corrosion phenomena.
- Provide tools to measure, analyze and predict the corrosion of materials.
- Provide corrosion prevention and remediation strategies.

§1.3 Introduction to Corrosion

> **Question 1.3.1.** What is Corrosion?

Corrosion is degradation of materials. Basic notions of electrolyte, cathodes and anodes can be used to explain corrosion in Stainless Steel, pitting corrosion and other forms of corrosion. Any big tangible structures like ships or buildings or bridges, you will find steel/copper. Even in small devices like mobiles, laptops there are copper wires for conducting networks. Car frames and aeroplanes made of Aluminium. What metals undergo corrosion. Examples of corrosion detection are: rust in automobiles, titanium in implants (corrodes over a long period of time).

§1.4 Why study corrosion

- Fire on an aircraft Airbus A330 engine (Manchester, 2013) because of fracture of blades via fatigue. A good overview of applications of alloys in automative and aerospace industries is provided in [Zh+18].
- Bhopal Gas Tragedy also caused due to corrosion. Runaway chemical reaction-starts initiation but doesn't stop, for instance in mobile phones sparks. High temperature and pressure. High levels of chloroform. Carbon steel went corrosion in acidic media at high temperature.
- India loses upto $100 billion annually (according to Hind Zinc CEO Sunil Duggal) thats about 4-5 % of the GDP.

- Conservation of materials: Limited supply of materials in specific geographical locations. Wastage of energy and human effort. Service extension mitigates additional manufacturing.

- Development of corrosion resistant alloy oxides.

- A good account of how important and complex corrosion can be is given in Comsol Blogs Corrosion Resistance.

§1.5 Corrosion- Is it complex?

Various environments have various features unique to each of them. For instance- salts are available in Marine environment, Chloride anions from salts is significant. Sulphur dioxide in industrial applications. Sulphate anion in the soil. Materials prone to corrosion are steel, stainless steel, aluminium alloys, copper, nickel, titanium alloys. Complex systems of materials. Different case studies map to different root causes.

§1.6 Corrosion- An interdisciplinary field

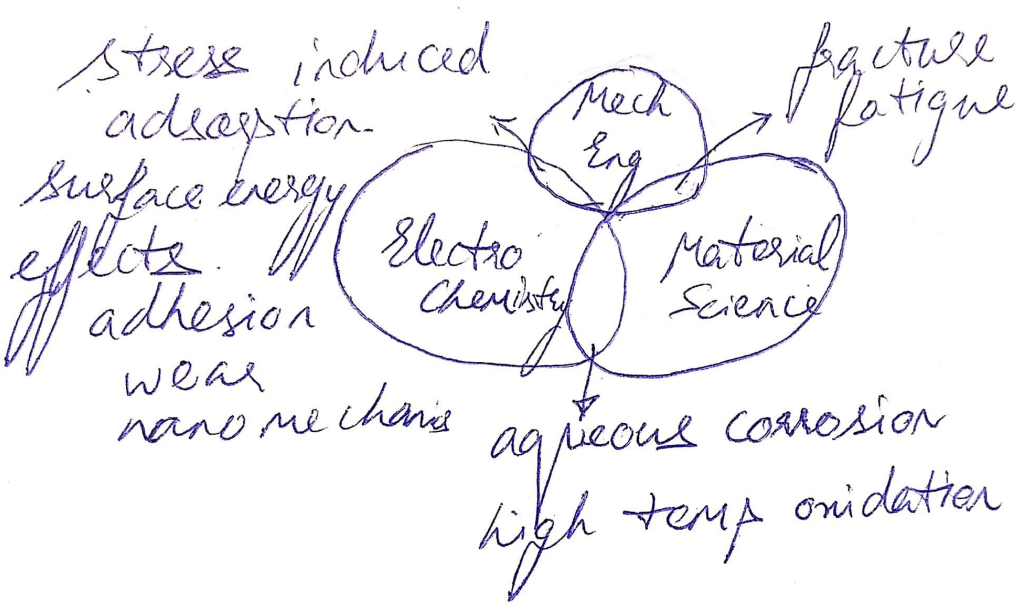

Figure 1.1: Venn Diagram of interacting fields

Electrochemistry, Mechanics/Engineering, Materials Science as in fig. 1.1. Involves interaction of Stress induced adsorption surface energy defects- adhesion, wear, nanomechanics, tribology. Aqueous corrosion- high temperature oxidation.

§1.7 Corrosion- Definition

Origin- comes from Latin corrodere- gnaw away or eat away.

Corrosion is characterized as:

- Natural phenomenon
- destructive attack on metal by its environment, mainly electrochemical factors.
- causes deterioration of properties of the metal.

Plastics, concrete, wood, ceramics, composite materials undergo deterioration by environment but don't corrode.
Rusting applies to plain carbon steel and iron. **Rust**: hydrated ferric oxide is red or dark brown color. Non ferrous metals- aluminium, copper, zinc corrode but don't rust.

§1.8 Thermodynamic viewpoint

Thermodynamic reaction by which a metal returns back to its natural form as an ore. Extraction/alloying is gaining energy (opposite to spontaneous reaction requires input of energy). Corrosion involves release of energy. This is in the opposite direction of extractive metallurgy.

For instance, Fe+C (+Cr, Ni, Si) corrosion cycle.

Fe alloys - Haematite (Fe_2O_3), Wustite (FeO) are common.

Cr_2O_3 layer stops corrosion. Thermodynamics drives corrosion.

§1.9 Electrochemical Reactions

Corrosion is predominantly an electrochemical process involving coupled electrochemical half cell reactions.

Half Cell reaction- Anodic

- Species undergoes oxidation.
- Loss of electrons from the species at the anodic site, ie. electrons are produced at the anodic site.

Example 1.9.1
The following reactions are common examples of anodic reactions:

- $Fe \longrightarrow Fe^{2+} + 2e^-$
- $Al \longrightarrow Al^{3+} + 3e^-$
- $2Cu\,(s) + H_2O\,(l) \longrightarrow Cu_2O\,(s) + 2H^+\,(aq) + 2e^-$

Half Cell reaction- Cathodic

- Species undergoes reduction.
- Gain of electrons for species at the cathodic site, ie. electrons are consumed at the cathode.

Example 1.9.2

The following reactions are common examples of anodic reactions:

- In acidic medium: $H^+ + 2e^- \longrightarrow H_2$
- In basic/neutral medium: $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-\,(aq)$

Charge + Mass transport.

Corrosion involves simultaneous transfer of mass and charge across a metal/solution interface.

Corrosion involves both half cell reactions to form a coupled electrochemical reaction.

Example 1.9.3 (Iron in Acidic Solution Environment)

The following half-cell reactions couple to give an electrochemical reaction for Iron corrosion in acidic environment.

At anodic sites:	Fe	$\longrightarrow$	$Fe^{2+} + 2e^-$
At cathodic sites:	$2H^+ + 2e^-$	$\longrightarrow$	H_2
Overall reaction:	$Fe + 2H^+$	$\longrightarrow$	$Fe^{2+} + H_2$

Thus, corrosion involves the following components:

- Anodic reaction
- Cathodic reaction
- Electrolyte
- Metallic contact to serve as path between anode and cathode for electron transport.

Question 1.9.4. How can two different electrochemical reactions happen on the same metal surface?

Energy of surface drives reaction. Difference in energies between two points on the metal surfaces exist thus favoring different reactions at different points. Insert diagram (later). *Heterogeneous nature of the surface* creates difference in energy.

Half reactions. Insert diagram (later).

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2\,(s)$$

In the presence of an acidic media, there is a different reaction leading to Hydrogen embrittlement.

§1.10 Faraday's Law

Corrosion involves simultaneous charge and mass transfer. Charge transfer and Mass transfer related by **Faraday's Law** which states that the mass W of metal (liberated or deposited/corroded) is given by:

$$W = \frac{ItM}{nF} \tag{1.1}$$

where F is called the **Faraday's Constant**.

$$F = \frac{96500\,C}{\text{Mole equivalent}}$$

I is the current, t is the time taken for the transfer, M is the Molar Mass of the metal and n is the # of elementary charge (e) particles per mole of the metal involved in the reaction given by the stoichiometry.

Example 1.10.1 (Iron half cell reaction)

Consider the Reaction:

$$Fe \longrightarrow Fe^{2+} + 2e^{-}$$

This involves 2 e^{-} per mole of Fe^{2+} produced. Thus, $n = 2$ is to be used in Faraday's Law.

Bibliography

[**Fo05**] Mars Guy Fontana. *Corrosion engineering*. Tata McGraw-Hill Education, 2005.

[**Mc10**] Edward McCafferty. *Introduction to corrosion science*. Springer Science & Business Media, 2010.

[**Re08**] R Winston Revie. *Corrosion and corrosion control: an introduction to corrosion science and engineering*. John Wiley & Sons, 2008.

[**Zh+18**] Kailun Zheng et al. "A review on forming techniques for manufacturing lightweight complex—shaped aluminium panel components". In: *International Journal of Lightweight Materials and Manufacture* 1.2 (2018), pp. 55–80. ISSN: 2588-8404. DOI: https://doi.org/10.1016/j.ijlmm.2018.03.006. URL: http://www.sciencedirect.com/science/article/pii/S258884041830012X.