CE1205
CONSTRUCTION MATERIALS

WEEK 4
Chapter 3
FATIGUE, CREEP AND CORROSION
'METAL FAILURE'

PowerPoint® Slides
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Chapter Overview

- Chapter 3 exposed you with the different types of metal failures.
- You learned about what are the factors that cause the failures.
- You also learned how to control these failures.

Learning Objectives

- To expose the students to different types of metal failure such as fatigue, creep and corrosion, what are the factors that cause these failures and how to control them.

Learning Outcomes

- At the end of the lesson, students should be able to identify and explain the types of metal failures, the contributing factors and controlling method.

INTRODUCTION TO FATIGUE

- **Definition:** The effect on metal of repeated cycles of __________.

- The insidious feature of fatigue failure is that there is _______ obvious warning, a crack forms without appreciable deformation of structure making it difficult to detect the presence of growing cracks.

- Fracture usually start from small nicks or scratches or fillets which cause a localised concentration of stress.

- Failure can be influenced by a number of factors including size, shape and design of the component, condition of the surface or operating environment.

- Fatigue results in a bittle appearing fracture, with no gross deformation at the fracture.

- A fatigue failure can usually be recognized from the appearance of the fracture surface which shows a smooth region, due to the rubbing action as the crack propagated through the section, and a rough region, where the member has failed in a ductile manner when the cross section was no longer able to carry the load.

- Three basic factors are necessary to cause fatigue failure. These are:

1. maximum <u>tensile</u> stress of sufficiently high value,
2. large enough variation or <u>flucti </u>in the applied stress, and
3. sufficiently large number of <u>ryeles </u>of the applied stress.

- In addition, there are a host of other variables, such as:
  - stress concentration,
  - corosion
  - temperature
  - overload,
  - metallurgical structure,
  - residual stresses, and
  - combined stresses, which tend to alter the conditions for fatigue.

METALLURGY

- The science that deals with procedures used in extracting metals from their ores, purifying and alloying metals, and creating useful objects from metals.
- The study of metals and their properties in bulk and at the atomic level.

Residual Stresses

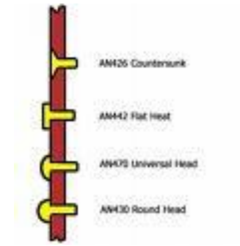
- **Definition**: Stresses that remain in material or body without application of an external load (applied force, displacement of thermal gradient).
- **Origin:** Usually originates during manufacturing and processing of materials due to *heterogeneous plastic deformations, thermal contractions and phase transformations

*Heterogeneous: Consisting of dissimilar elements or parts; not homogeneous.

Fatigue Design Guideline (minimize stress concentrations)

1. Consider <u>all types</u> stresses, including stress concentrations, rather than to nominal average stresses.
2. Visualize load <u>distribution</u> from one part or section to another and the distortions that occur during loading to locate points of high stress
3. Avoid adding or attaching <u>more</u> brackets, fittings, handles, steps, bosses, grooves, and openings at locations of high stress
4. Use <u>gradual changes</u> changes in section and symmetry of design to reduce secondary flexure

5. Consider location and <u>types</u> of joints (frequent cause of fatigue problems)



6. Use <u>double</u> shear joints when possible

7. Do not use <u>rivets</u> for carrying repeated tensile loads (bolts superior)

8. Avoid open and loosely filled <u>holes</u>

9. Consider <u>standard</u> methods,
specify strict requirements when needed

10. Choose proper surface <u>arushes</u> but not overly severe (rivet holes, welds, openings etc. may be larger drivers)

11. Provide suitable protection against corrosion

12. Avoid metal piahrg plating with widely different properties than underlying material

13. Consider pre-stressery when feasible

14. Consider maintenance, to include inspection and protection against corrosion, wear, abuse, overheating, and repeated overloading

15. Avoid use of structures at critical or fundamental frequency of individual parts or of the structure as a whole (induces many cycles of relatively high stress)

16. Consider temperature effects

INTRODUCTION TO CORROSION

- Corrosion is <u>chemically </u>induced damage to a material that results in deterioration of the material and its properties.

WHY METALS CORRODE?

Metals corrode because we use them in environments where they are chemically unstable .Only copper and the precious metals (gold, silver, platinum, etc.) are found in nature in their metallic state. All other metals, to include iron-the metal most commonly used-are processed from minerals or ores into metals which are inherently unstable in their environments.

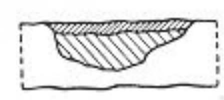
Design considerations
Factors that can influence corrosion:

- **Environment**
  - Chemical
  - Natural
  - Storage, transit
- **Stress**
  - Residual stress from fabrication
  - Static, variable and alternating operating stresses
- **Shape**
  - Joints and flanges
  - Crevices and deposits
  - Trapped and contained liquid
- **Compatibility**
  - Metals with metals
  - Metals with other materials
  - Quality control of materials
- **Movement**
  - Flowing fluids
  - Parts moving in fluids
  - Two- and three-phase flow
  - Entrained solids
  - Vibration and pulsing
- **Temperature**
  - Oxidation, scales and tarnishes
  - Heat-transfer effects
  - Molten deposits
  - Condensation and dewpoints
- **Control**
  - Surface cleaning and preparation
  - Coatings
  - Cathodic protection
  - Inhibitors
  - Inspection
  - Planned maintenance

- Several factors should be considered during a failure analysis to determine the affect corrosion played in a failure. Examples are listed below:
  - Type of corrosion
  - Corrosion rate
  - The extent of the corrosion
  - Interaction between corrosion and other failure mechanisms

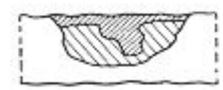
COMMON TYPES OF CORROSION

- **Uniform or General Corrosion**



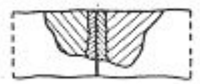
  - The metal loss is uniform from the surface.
  - The reaction starts at the surface and proceeds uniformly.
  - Often combined with high-velocity fluid erosion, with or without abrasives.

- **Pitting Corrosion**

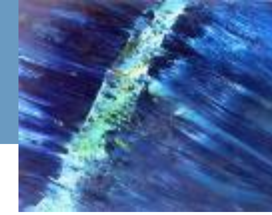


  - The metal loss is randomly located on the metal surface.
  - The basis metal is eaten away and perforated in places in the manner of holes, the rest of the surface being affected only slightly or not at all.
  - Often combined with stagnant fluid or in areas with low fluid velocity.

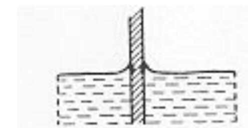
- **Galvanic Corrosion**



  - Increased corrosion in crevices or cracks or at contact surfaces between two metal articles.
  - Occurs when two metals with different electrode potential is connected in a corrosive electrolytic environment.
  - The anodic metal develops deep pits and groves in the surface.



- ## *Crevice Corrosion
  - Occurs at places with gaskets, bolts and lap joints where crevice exists.
  - Crevice corrosion creates pits similar to pitting corrosion.



- ## Concentration Cell Corrosion
  - Occurs where the surface is exposed to an electrolytic environment where the concentration of the corrosive fluid or the dissolved oxygen varies.
  - Often combined with stagnant fluid or in areas with low fluid velocity.

- ## Graphitic Corrosion
  - Cast iron loosing iron in salt water or acids.
  - Leaves the graphite in place, resulting in a soft weak metal.

*Crevice: a long narrow opening [syn: crack*Crevice: a long narrow opening [syn: crack, cleft*Crevice: a long narrow opening [syn: crack, cleft, fissure*Crevice: a long narrow opening [syn: crack, cleft, fissure, scissure]

Electrochemical corrosion

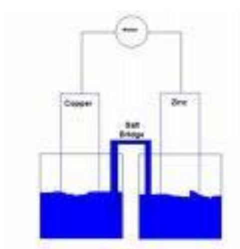
- Four conditions must exist before electrochemical corrosion can proceed:

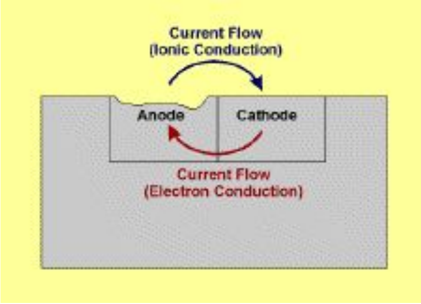
  (1) there must be something that corrodes , the metal ____________, where the oxydation reaction takes place

  (2) there must be a ___________, where the reduction reaction takes place

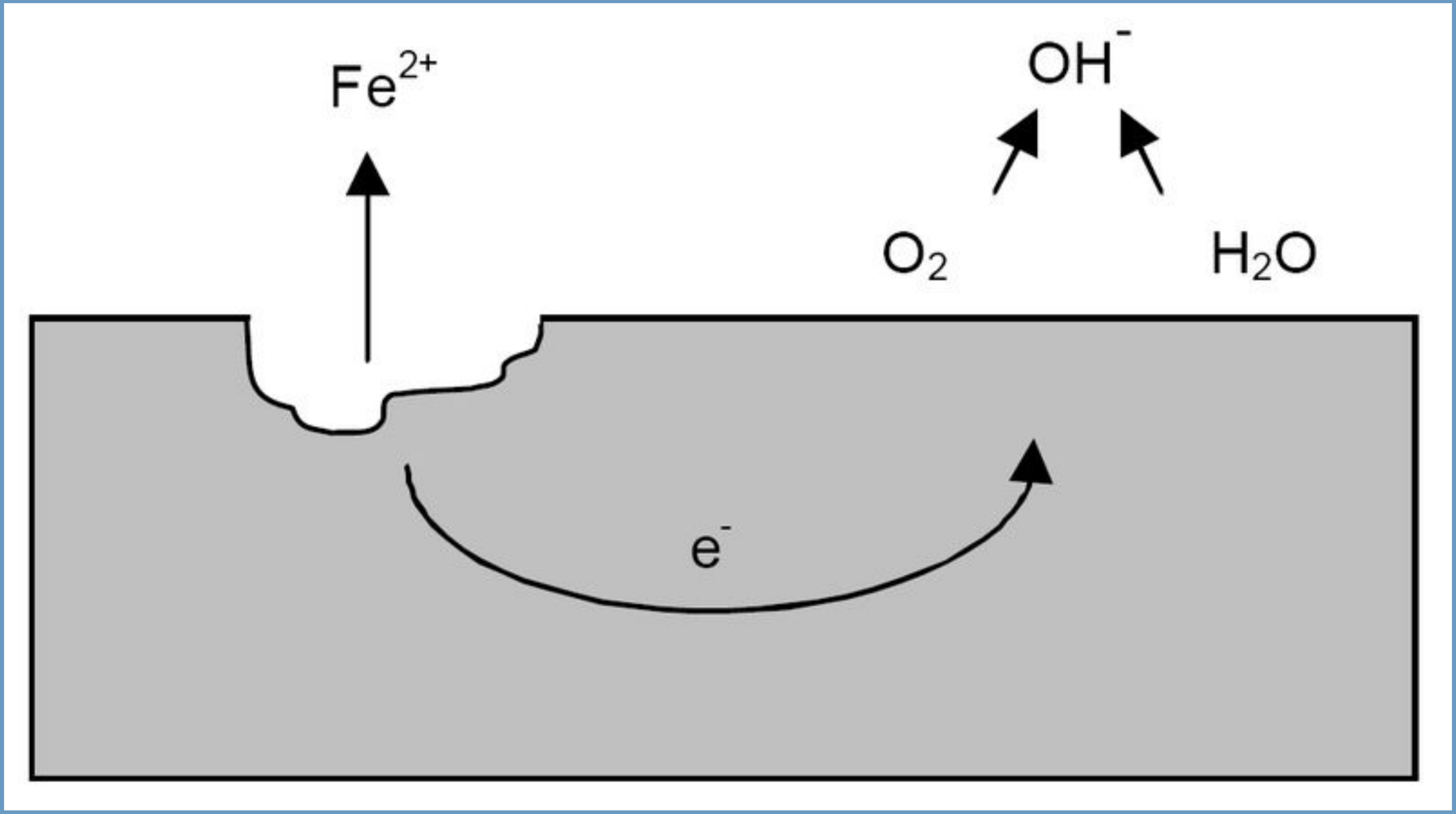
  (3) there must be continuous conductive liquid _______________ (electrolyte, usually condensate and salt or other contaminations), for example: water, seawater, condensing water, humidity..

  (4) there must be a ________________ to carry the flow of electrons from the anode to the cathode.





E.g. Electrochemical corrosion of iron due to contact with water



- This conductor is usually in the form of metal-to-metal contact such as in bolted or riveted joints.

  The elimination of any one of the four conditions will remote the conditions that causes corrosion. An unbroken (perfect) _______________ on the surface of the metal will prevent the electrolyte from connecting the cathode and anode so the current cannot flow.

  Therefore, no corrosion will occur as long as the coating is unbroken.

- Corrosion is a normal, natural process. Corrosion can seldom be totally prevented, but it can be _______________ or controlled by proper choice of material, design, coatings, and occasionally by changing the environment.

- Various types of metallic and nonmetallic coatings are regularly used to protect metal parts from corrosion.

CORROSION CONTROL

- There are a number of means of controlling corrosion. The choice of a means of corrosion control depends on
  - economics,
  - safety requirements, and
  - a number of technical considerations.

- Failure to control corrosion can lead to:
  - Increase costs
  - reduced safety
  - Negative environmental impact

CORROSION CONTROL

- Protective _______________,
  - Can be metallic, such as the galvanized steel or they can be applied as a liquid "__________."
- ______________ protection,
  - Cathodic protection is an electrical means of corrosion control. It can be applied using sacrificial (galvanic) anodes.
- Corrosion inhibitors
  - Corrosion inhibitors are ____________ that are added to controlled environments to reduce the corrosivity of these environments.

INTRODUCTION TO CREEP

- When a material is subjected to a stress that is greater than or equal to its yield stress, the material deforms *plastically*. When the stress is below this level, then in principle it should only deform elastically.

- However, **provided the ________________________ is relatively ____________, plastic deformation can occur even when the stress is lower than the yield stress.** This deformation is time-dependent and is known as *creep*.

CREEP OF METALS

- High temperature progressive deformation of a material at constant stress is called creep. High temperature is a relative term that is dependent on the materials being evaluated.

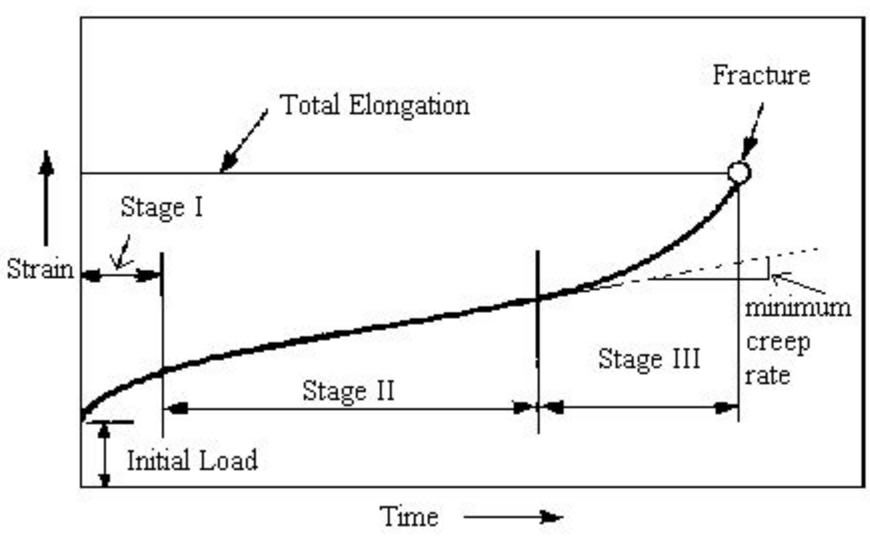
- Creep occurs under load at high temperature. Boilers, gas turbine engines, and ovens are some of the systems that have components that experience creep.

- For a low melting point metal like lead, creep becomes significant at about $27^{0}C$, i.e. on a hot day. This may cause drainage piping made from lead to sag between its supports or lead plates to creep in a battery.

- For a high melting point metal like tungsten, temperatures above $1500^{0}C$ would be needed to produce creep.

CREEP CURVE

- A typical creep curve is shown below:



Effect of High Temperature on Metals:

I. _____________ strength.

II. Greater atomic and dislocation mobility, assisting dislocation climb and diffusion.

III. New __________________ mechanisms, such as new slip systems or grain boundary sliding.

IV. Recrystallisation and grain growth.

V. Age hardened alloys will _________________ by particle coarsening and lose strength.

VI. Oxidation and intergranular penetration.

REFERENCES

- http://www.materialsengineer.com/CA-corrosion.htm
- http://www.tis-gdv.de/tis_e/misc/korro.htm
- http://www.engineeringtoolbox.com/corrosion-d_986.html
- http://www.tech.plym.ac.uk/sme/mats340/cpintro.pdf