LAB AT KEMPER 1120

Contents

1 Creep

Objectives:

1. Explain stages of environmental fracture
2. Explain mechanisms of crack growth in SCC
3. Explain mechanisms of crack growth in HIC
4. Explain stages of Creep
5. Identify creep fracture surface features
6. Use creep deformation map to Identify the dominant creep mechanism
7. Predict creep failure time using Larson-Miller Parameter

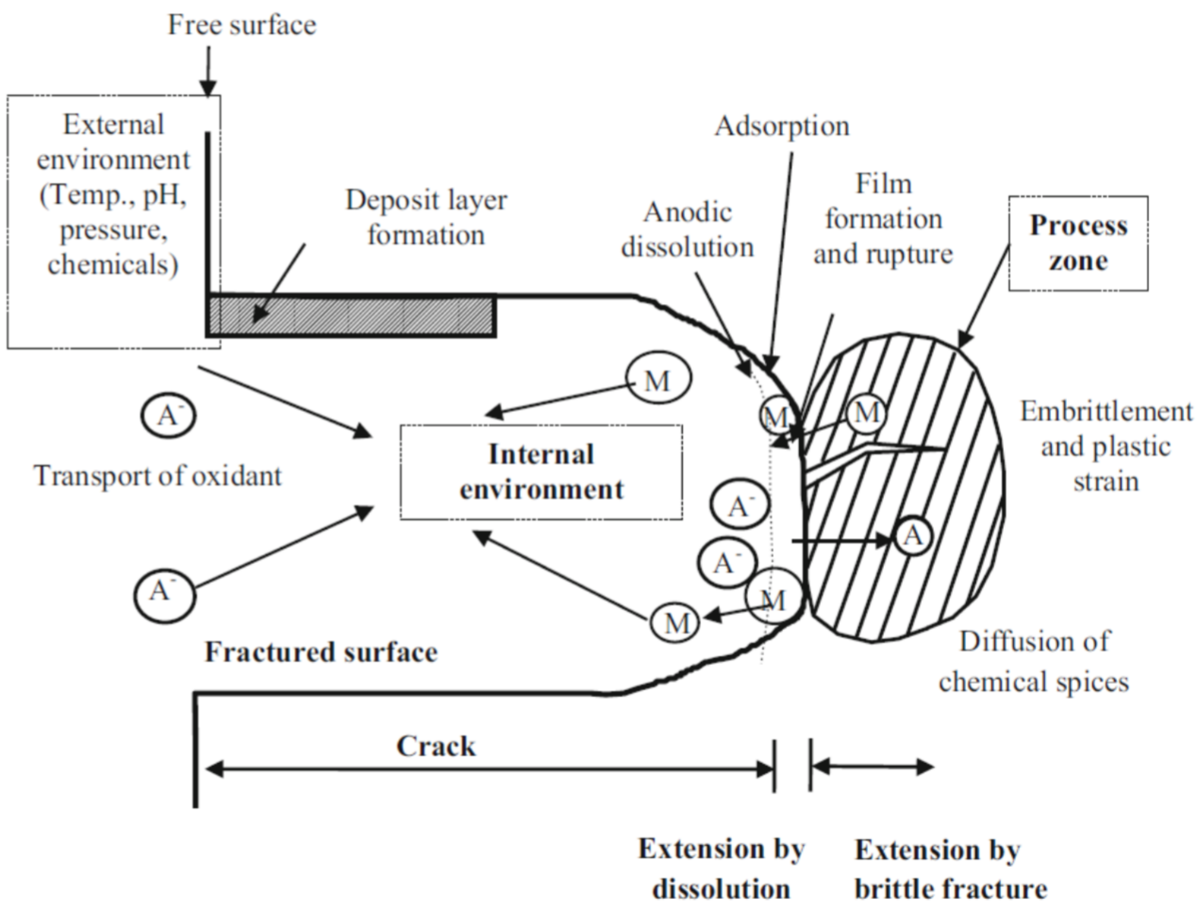
1.1 Stages of environmental fracture

A slow or stable fracture due to combined action of loads and the environment in a susceptible material

1. Crack nucleus formation
   - mechanical strength reduction(Temperature dependent)
   - formation of microstructural defects or surface micro-cracking
2. Nucleated crack turns into macroscopic crack
   - load opens the crack
   - corrosion is dominant
3. Fracture
   - not entirely mechanical
   - can happen at $K < K_{IC}$

1.2 Mechanisms of crack growth in SCC

Stress corrosion cracking causes:



1. Slip
   -External stress causes dislocation and create slip steps

2. film rupture
   -Slip steps ruptures oxide film at the crack tip

3. anodic dissolution
   -ruptured oxide film causes exposes material to anodic dissolution (corrosion)

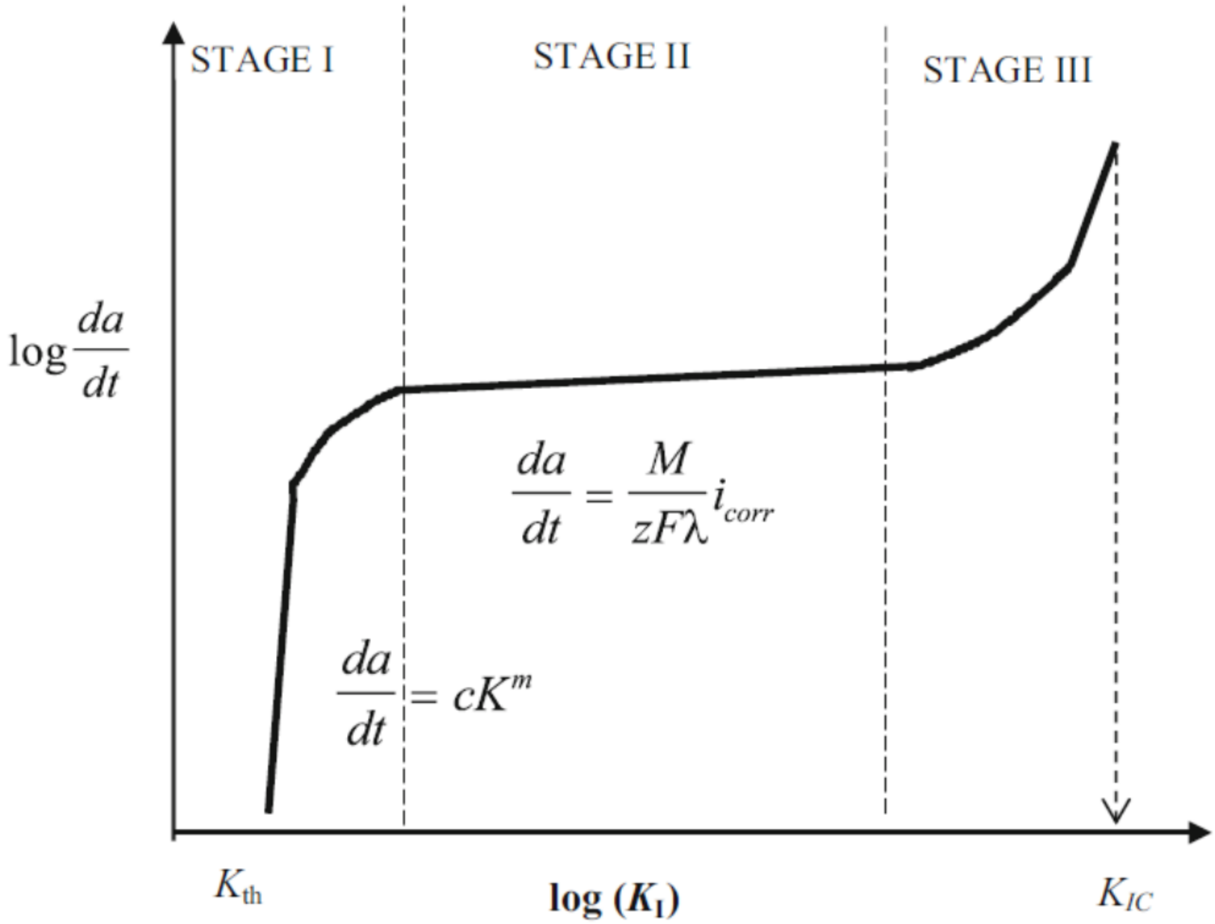
4. repassivation
   -new oxide film forms

1.2.1 Two types of SCC Mechanisms

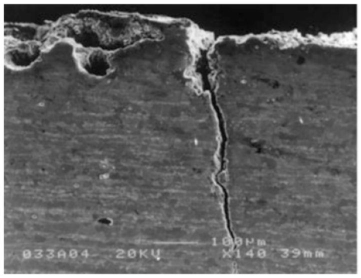
1. Controlled by Environment:
   - Predominant mechanism is anodic dissolution

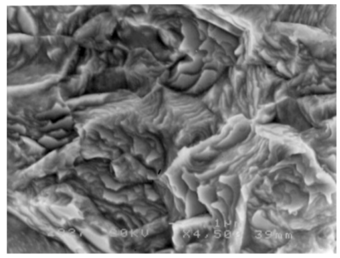
2. Controlled by Stress:
   - Predominant mechanism is brittle fracture
   - Thin film of corrosion products

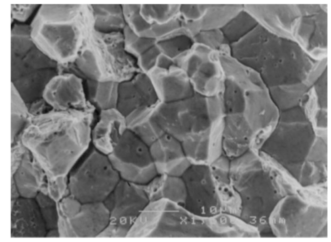
1.2.2 Stages of SCC



1. Formation and rupture of passive layer
2. crack tip anodic dissolution
3. Static fracture

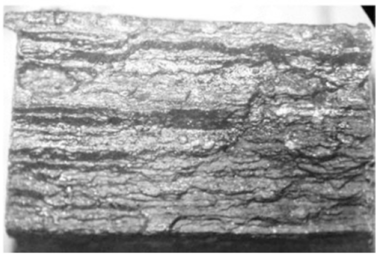


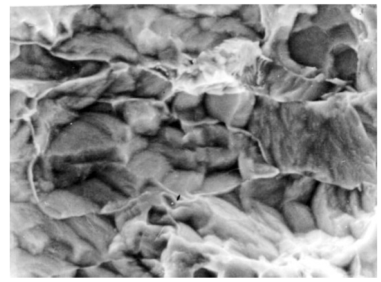




SCC cracks nucleated at corrosion pits

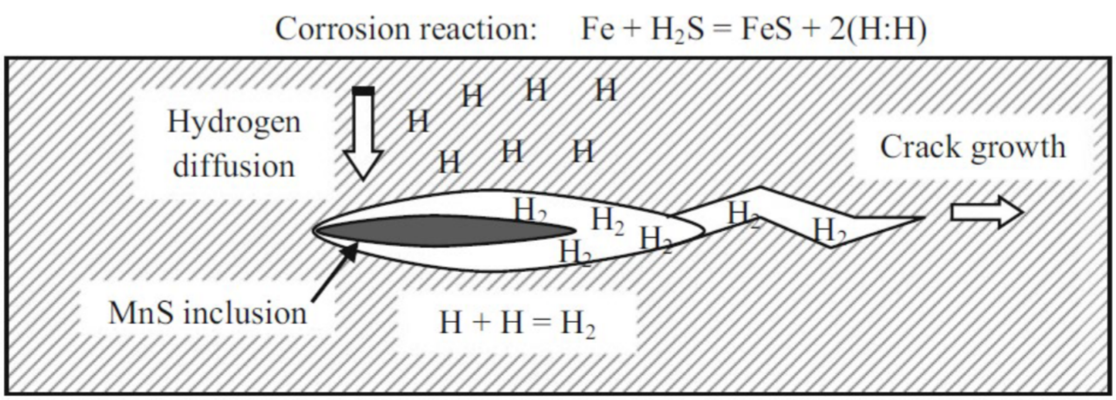
Crack can be IG or TG, or mixed.
It depends on which being anodic.



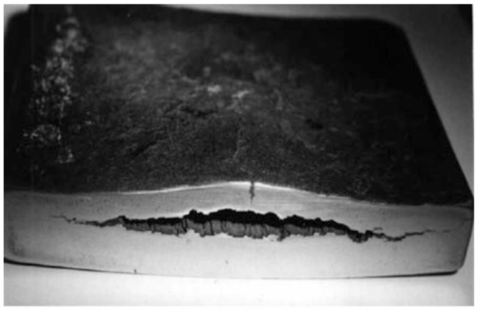


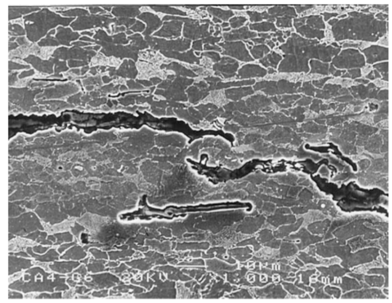
Brittle appearance, and there is clear evidence of corrosive attack on the fractured surface

1.3 Hydrogen induced cracking (HIC)



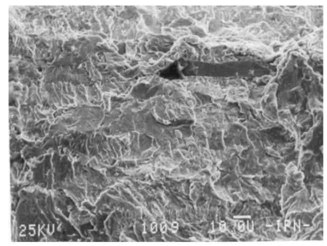
- Reported in low and medium carbon steels exposed to sour environments
  - Sour environments contain hydrocarbon H_2S, carbon dioxide, and water(l).
- atomic hydrogen dissolves in material
- gashouse hydrogen inside the metal, near the inclusion is formed and creates stress concentration at the edge of the trapping creating cracks





The cracks move toward each other.

Near surface: Blister



Brittle appearance.

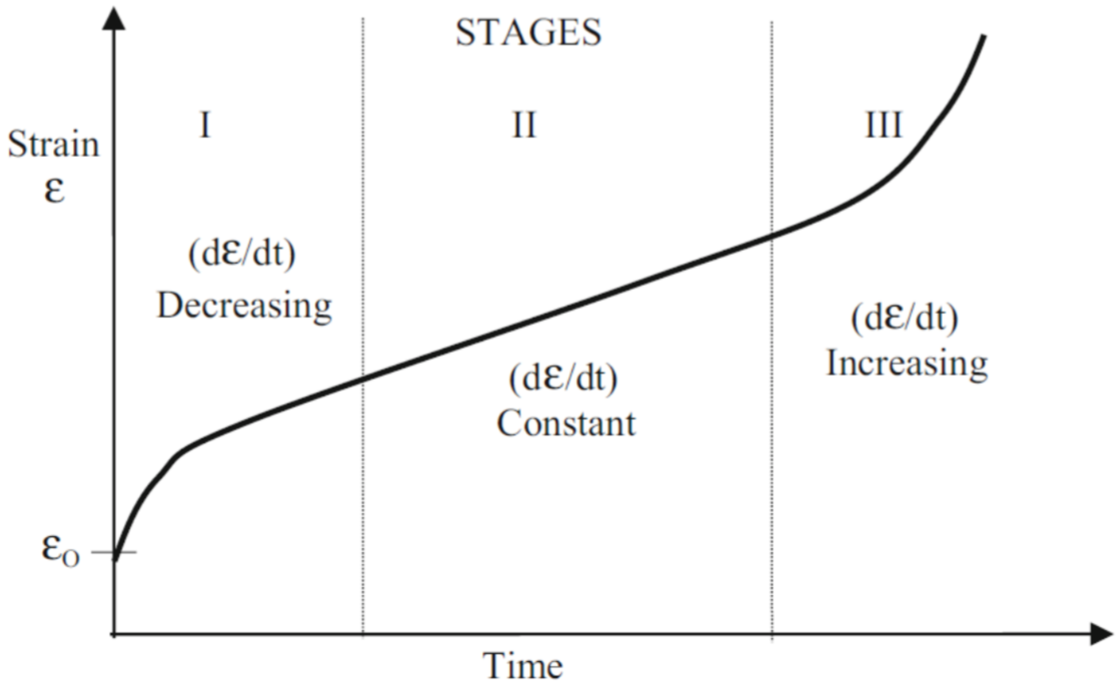
In the midlle: Lamination

1.4 Stages of creep

Creep refers to plastic deformation leading to fracture of a material under stress when subjected to high temperature. $T > (0.3 \text{ to } 0.5)T_{melting}$
Creep leads to loss of tolerance and component/structural failure.
Used in engine components, turbine blades, Boilers, pipelines, etc.

Effect of high temperature:

- Reduction of yield and tensile strength
- increase in dislocation mobility(diffusion)
- Recovery and recrystallization and grain growth.
- Dissolution and precipitation of second phases



Stages of creep:

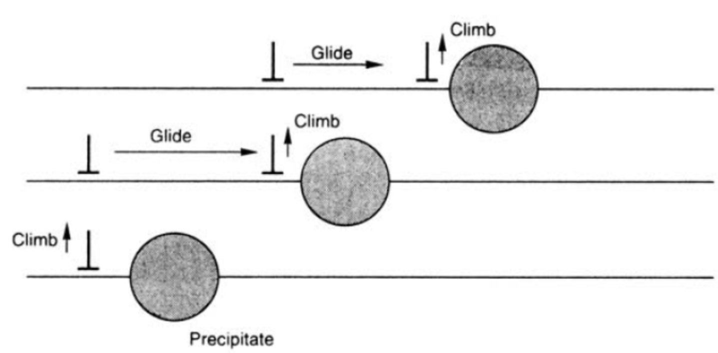
1. The strain decreased due to work hardening phenomena associated to dislocation density increase
2. Strain rate is constant due to balance between hardening and recovery or softening mechanisms
3. The strain rate increases due to onset of creep damage, characterized by microvoid nucleation and growth mechanisms

1.4.1 Dislocation-controlled Creep mechanism

- Creep rate in climb:
  - Independent of grain size
  - Dependent on the stress

$$\dot{\varepsilon}_{ss} = \frac{AGb}{kT}\left(\frac{\sigma}{G}\right)^n$$

G: Modulus of rigidity
B: Burger's vector
K: Boltzmann constant
A: Constant



2 Wear

2.1 Three types of wear

2.2 Abrasive Wear

1. Occurs when a harder material is pressed against a softer one
2.

2.2.1 Abrasive wear mechanisms

1. Plowing
2. Cutting
3. Fracture

2.2.2 Types of Abrasive Wear

1. two body
2. three body
   -Occurs when theres a particle involved in between two podies

2.3 Adhesive Wear

2.4 Fretting

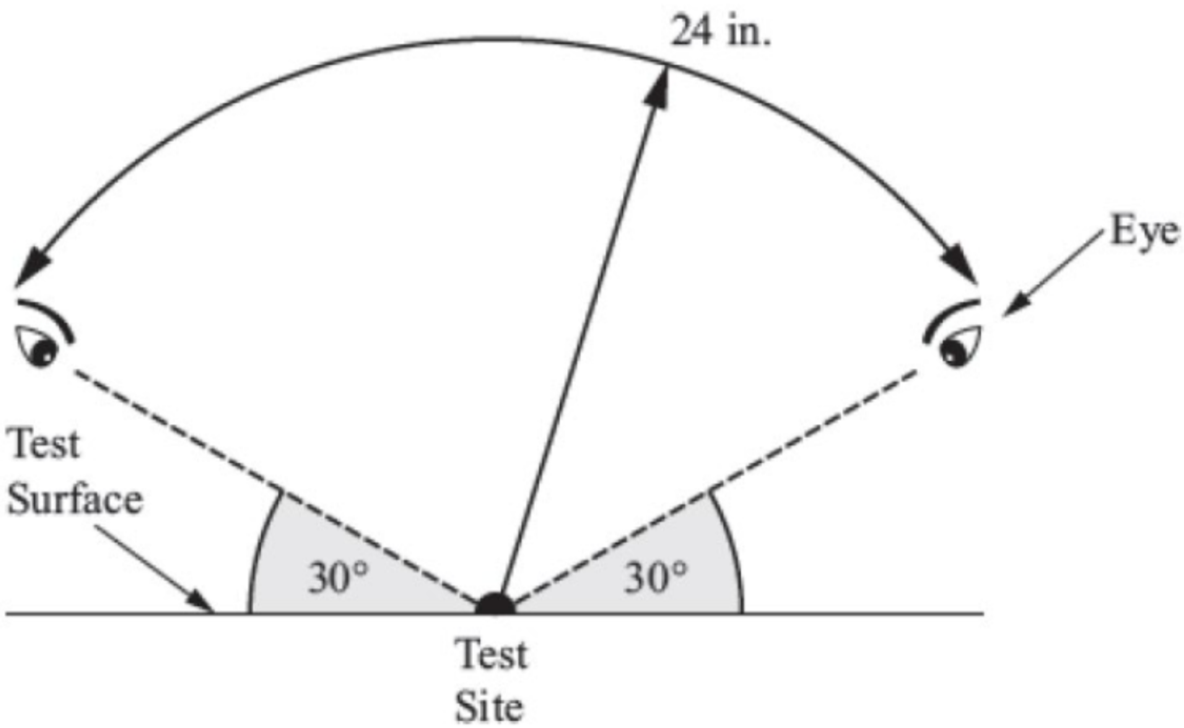
3 Non destructive testing(NDT)

Evaluation of an object without changing it or altering it in any fashion.

3.1 Objectives

1. Define NDT and name some NDT techniques
2. Principles and steps in penetrant testing
3. Principles of magnetic particle testing
4. Name advantages and disadvantages of NDT's

3.1.1 NDT Technique: Visual Inspection



3.1.2 NDT Technique: Penetrant testing (PT)

Take advantage of capillary action of Penetrant

- Good for surface discontinuities
- Can be used in production-type environment
- Flaws as fine as 1 micron can be detected
- Fluorescent dye can be used
- Portable

Advantages:

- Inexpensive
- Sensitive
- Minimal equipment
- Can be applied to irregular shapes
- Versatile and Portable
- Minimal training required
- Ease of interpretation

Disadvantages:

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3.1.3 NDT Technique: Magnetic-Particle Inspection

Disadvantages:

- Crack direction matters

3.1.4 NDT Technique: Eddy-Current inspection

3.2 Destructive testing

Advantages:

- Generates useful data for design purposes
- Data can be used to establish standards and specifications
- Data achieved through ?destructive? testing ususally quantitative.
- Service conditions can be measured
- Useful life can be predicted

Disadvantages:

- specimens cant be used after testing
- expensive

3.3

4 NDT (II)

Objectives:

1. Principles of ultrasound inspection
2. principles of radiography inspection
3. advantages and disadvantage of NDTs

4.1 Advantages and disadvantages of NDT

Advantages:

- part not changed or altered after examination. (can be reused)
- can be examined for conditions internal and at the surface
- parts can be examined while in service
- many NDT methods are portable

- cost effective

Disadvantages:

- operator dependent
- do not generally provide quantitative data
- orientation of discontinuities must be considered
- evaluation of some test results are subjective and subject to dispute
- some are expensive(radiography)
- defined procedures

5 NDT SUMMARY

Summary of methods:

- Visual testing
  - Working principles: Direct observation of the surface with or without optical aids to detect visible defects
  - Detects Surface discontinuity
  - Advantages: Simple, low cost, quick process.
  - Limitations: Limited to visible surface defects. Dependence on inspector skill. No quantitative data.
- Penetrant testing
  - Working principles: Low-viscosity liquid die applied to a clean surface. Seeps through surface cracks and flaws via capillary action. Developer draws out dye.
  - Surface or internal discontinuity? Surface
  - Advantages: Inexpensive, Can be applied to complex shape, High sensitivity to very fine surface cracks
  - Limitations: Does not work with porous materials, post-cleaning, chemicals can be hazardous
- Magnetic particle testing
  - Working principles: Part is magnetized; surface or near-surface discontinuities affect magnetic flux which attracts fine ferromagnetic particles forming an indication
  - Surface or internal discontinuity? Surface and near-surface
  - Advantages: Effective in detecting surface and shallow subsurface cracks
  - Limitations:
- Radiographic testing
  - Working principles:

  - Surface or internal discontinuity?
  - Advantages:
  - Limitations:

- Ultrasonic testing
  - Working principles:
  - Surface or internal discontinuity?
  - Advantages:
  - Limitations:

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1. Visual Testing (VT)

Orientation effects

- VT relies on reflected light reaching the eye.

- Cracks that are perpendicular to the viewing/lighting direction cast small shadows or specul

- Cracks parallel to the line of sight (very tight, in the same direction as brushing or machi

- Inspectors often change viewing angle and use oblique lighting (flashlight at a low angle) t

Why the limitations?

- Surface only: visible light cannot penetrate opaque solids, so internal defects do not affec

- Human-eye resolution: the eye typically cannot reliably resolve features below ~0.1{0.2 mm w

- Access and line of sight: if the surface cannot be seen directly (internal bores, complex we

- Operator dependence: fatigue, eyesight, experience, and lighting strongly influence detectio


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2. Penetrant Testing (PT)

Orientation effects

- PT detects any surface-breaking discontinuity, largely independent of crack direction, as lo

- Very tight, closed, or oxidized cracks limit capillary penetration → weak or no indication.

- Gravity can slightly affect performance (penetrant may drain out of upward-facing openings),

Why the limitations? (e.g., porous materials)
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- Doesn’t work on porous/rough materials:
 - Penetrant is drawn by capillary action into every small pore and surface cavity, not just c

 - During development, dye seeps back out from everywhere, creating a uniformly stained backgr

- Surface-breaking flaws only:
 - Penetrant must physically enter the defect; subsurface flaws have no open path to the surfa

- Requires clean, non-contaminated surfaces:
 - Oil, paint, scale, or dirt can block crack mouths, preventing penetrant ingress.

 - Residual penetrant left on the surface after removal will bleed out everywhere, creating fa

- Post-cleaning and environmental issues:
 - Chemicals (solvents, emulsifiers, developers) must be removed to avoid corrosion/contaminat

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3. Magnetic Particle Testing (MT)

Orientation effects

- Sensitivity depends strongly on the angle between the magnetic field lines and the disconti

- A flaw is detected when it interrupts or distorts the magnetic flux, creating leakage fields

- Maximum indication occurs when the discontinuity is approximately perpendicular to the magne

- If a crack is parallel to the field, flux lines bypass it with minimal leakage → the crack m

- In practice, parts are often magnetized in two or more directions (e.g., longitudinal and ci

Why the limitations?

- Only ferromagnetic materials:
 - MT relies on a strong difference between the high permeability of the component and the sur

 - Non-ferromagnetic metals (aluminum, austenitic stainless, copper alloys) do not concentrate

- Limited depth of detection:
 - Magnetic leakage fields decay rapidly with depth; deep internal flaws do not produce strong

- Geometry and accessibility:
 - Sharp corners, varying thicknesses, and holes distort the magnetic field and create non-rel

- Residual magnetization:
 - After testing, components can retain magnetism, which may cause problems (e.g., attracting

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4. Radiographic Testing (RT)

Orientation effects

- RT records material thickness and density along the X-ray/gamma-ray beam path.

- Volumetric defects (voids, porosity, inclusions) show clearly due to path length or density

- Planar defects (cracks, lack of fusion) are best detected when the crack plane is nearly per

- If a crack is parallel or almost parallel to the beam, the beam passes along the crack with

- To mitigate this, inspectors may use multiple exposure angles.

Why the limitations?

- Radiation safety:
 - X-rays and gamma rays are ionizing; exposure can cause serious health effects. Extensive sh

- Need access to both sides (conventional RT):
 - Source on one side and detector/film on the other → thick or inaccessible structures (e.g.,

- Poor sensitivity to very tight, planar cracks:
 - If a crack does not produce a significant change in either thickness or density along the b

- Thickness and material limitations:
 - Very thick or dense materials require high-energy sources to penetrate; this reduces image

- Relatively slow and costly:
 - Requires careful setup, exposure, film processing or digital handling, and interpretation.

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5. Ultrasonic Testing (UT)

Orientation effects

- UT uses specular reflection of sound.

- Planar defects oriented perpendicular to the sound beam act like mirrors and reflect a strong

- If the defect plane is tilted, much of the sound is reflected away from the transducer → weal

- Angle-beam probes are used to steer the beam so that it strikes weld flaws and laminations a

- Rough, branched, or irregular cracks scatter sound, producing diffuse echoes that can be har

Why the limitations?

- Couplant requirement:
 - At an air{solid interface, acoustic impedance mismatch is huge; almost all incident energy

 - A liquid or gel couplant is needed to \bridge" the gap; without it, sound cannot effectivel

- Surface condition and geometry:
 - Rough or curved surfaces scatter and deflect the beam, reducing signal-to-noise ratio and m

- Near-surface \dead zone":
 - After a transmit pulse, the transducer rings for a short time; echoes from very close to th

- Material structure:
 - Coarse-grained or highly attenuative materials (e.g., some cast steels, austenitic welds) c

- Operator skill and interpretation:
 - Raw A-scan signals require experience to distinguish between backwall echoes, geometry refl

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6. Eddy Current Testing (ECT)

Orientation effects

- Eddy currents flow parallel to the surface in loops beneath and around the probe.

- Defects are best detected when they interrupt many current paths, typically when the crack is

- If a crack runs parallel to the current lines, only a small fraction of the currents is distu

- Different coil geometries and scanning directions are used to vary the current flow directio

Why the limitations?

- Only electrically conductive materials:
  - Eddy currents are induced by changing magnetic fields in conductors. Nonconductive material

- Limited penetration depth (skin effect):
  - At typical test frequencies, current density decays exponentially with depth (skin depth).
  - Higher frequencies → stronger signals but shallower penetration (good for surface cracks).
  - Lower frequencies → deeper penetration but reduced sensitivity and more susceptibility to n

- Sensitivity to lift-off, geometry, and material variations:
  - Small changes in probe distance (\lift-off"), edges, thickness variations, and changes in c
  - This makes interpretation more complex and can require reference standards and sophisticate

- Not ideal for very rough or highly curved surfaces:
  - Irregular lift-off and changing geometry cause rapidly varying background signals, masking

6 Slide 1

1. Stages of environmental fractures
2. Creep
3. Third item

7 Slide 2 - Environmental Fracture

slow or stable fracture due to combined action of loads and the environmentin a susceptible material

7.1 example: Rolled up plastic hoses

8 Slide 3 - Stages of Environmental Fracture

- Stage 1: Accumulation of internal damage
- Stage 2: Nucleated crack turns into a macroscopic crack
- Stage 3: Rapid fracture, can happen $K < K_{IC}$

9 Slide 4 - Creep

10 Stress corrosion cracking (SCC) Mechanism

- Slip-dissolution mechanism involves 4 stages: slip, film rupture, anodic dissolution, repassivation
- External stress causes dislocations to move and create slip steps, increasing plastic strain, and breaking the oxide film at the crak tip.

11 SCC Mechanisms

11.1 Stress corrosion cracking SCC

For stage I: $log(da/dt) = cK^m$
For stage II: $log(da/dt) = M/(zF\lambda)i_{curr}$

11.2 SCC - Effect of Microstructure

11.3 Example problem

$PLM = (500 + 273)[17 + log(28 * 365 * 24)]$
$PLM = 17190$
using the graph, $\sigma = 400MPa$