The University of Tennessee at Martin

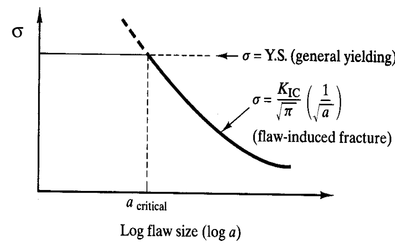
MARTIN School of Engineering

Fracture Mechanics and Steady Load Failure Theory Summary

Lecture 9

Engineering 473
Machine Design

Critical Crack Size



For a given crack size, there is a corresponding stress that will cause the crack to propagate in a catastrophic manner.

Non-destructive Testing

Testing methods exist that can detect cracks or flaws in metallic parts without destroying them. These methods are called **non-destructive testing** (NDT).

If the flaw size can be established in a part through NDT, and the stress state at the location of the crack is known through analysis or test, then an analysis can be performed to determine if the crack is close to the critical crack size for the particular stress state.

The combination of analysis to determine the stress state and NDT to establish the maximum flaw size are critical components of fracture prevention programs.

Fracture Mechanics Cases

(NDT Inspected Part)

Case 1: The machine element is inspected and no cracks are found.

All Nondestructive Testing (NDT) methods have a minimum crack size that can be detected. In this case, the crack length is taken to be the minimum detectable crack.

$$\sigma_f = \frac{K_{IC}}{Y\sqrt{\pi \cdot a}}$$

Crack geometry factor (Y)

Minimum detectable crack length (a)

Fracture Mechanics Cases

(Part has been tested)

Case 2: The part is tested and does not fail under a known load.

In this case, the crack size is assumed to be slightly smaller than the critical crack size associated with the stress state caused by the test load.

$$a = \frac{1}{\pi}\left(\frac{K_{IC}}{Y\sigma_f}\right)^2$$

Possible crack size (a)

Stress caused by the test load (σ_f)

Fracture Mechanics Cases

(Crack is detected)

Case 3: The part is inspected and a crack is found.

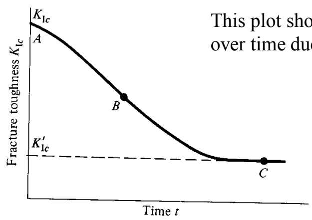
The size of the crack is compared to the critical crack size obtained from the following formula. The stress used is that to be encountered during service.

$$a_{crit} = \frac{1}{\pi}\left(\frac{K_{IC}}{Y\sigma}\right)^2$$

Expected service stress (σ)

Stress-Corrosion Cracking

Parts subjected to continuous static loads in certain corrosive environments may, over a period of time, develop cracks.



This plot shows a reduction in K_{IC} over time due to stress-corrosion.

Shigley, Fig. 5-27

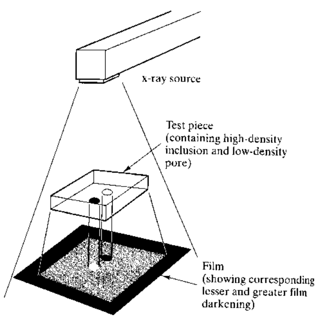
Non-destructive Testing

NDT is the examination of engineering materials with technologies that do not affect the object's future usefulness.

Common NDT Methods

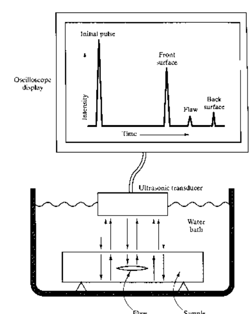
X-radiography	Magnetic particle
Ultrasonic	Liquid penetrant
Eddy current	Acoustic emission

X-radiography



Shackelford, Fig. 8-22.

Ultrasonic Testing



Schakelford, Fig. 8-23.

Summary of Steady Load Failure Theories

Ductile Materials	Brittle Materials	Fracture Mechanics
Distortion Energy (von Mises)	Maximum Normal Stress	Linear Elastic Fracture Mechanics (LEFM)
Maximum Shear Stress (Tresca)	Internal Friction (Coulomb-Mohr)	
	Modified Internal Friction	

When do I apply these failure theories?

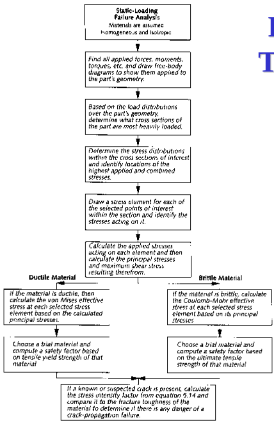
Design Governed by Industry Design Standard

- Follow formulas in standard.
- Formulas can often be derived based on a knowledge of the failure theory incorporated in the standard.
- Factor of safety is included in the standard.

Design Not Governed by Industry Design Standard

- Choose a factor of safety that the design is to be based on.
- Use appropriate failure theory during the design of machine elements.
- Compute failure margins at all critical locations.

Flow Chart for Typical Analysis



Norton, Fig. 5-22

Material Failure Mechanisms

Ductile fracture – failure that involves a significant amount of plastic deformation prior to fracture

Brittle fracture – failure without a significant amount of macroscopic plastic deformation prior to fracture.

Fatigue failure – failure associated with slow crack growth due to changing stress states.

Corrosion-fatigue failure – failure due the combined actions of changing stress and corrosive environments.

Stress-corrosion cracking – failure in which a steady tensile stress leads to the initiation and propagation of fracture in a relatively mild chemical environment.

Material Failure Mechanisms
(Continued)

Wear failure – broad range of relatively complex, surface-related damage phenomena.

Liquid-erosion failure – type of wear failure in which liquid is responsible for removal of material.

Liquid-metal embrittlement – involves the material losing some degree of ductility below its yield strength due to its surface being wetted by a lower-melting-point liquid metal.

Hydrogen embrittlement – notorious cause of catastrophic failure in high strength steels exposed to hydrogen environment which leads to lose of ductility (few parts per million of hydrogen is enough).

Material Failure Mechanisms

Creep and stress rupture failures – failure due to continued strain growth under steady load.

All of these mechanisms are associated with the failure of the material. They do not include one of the most important structural failure mechanisms that must be considered in compressive stress environments – **Buckling**.

Assignment

A high - strength steel has a yield strength of 1,460 Mpa and a K_{IC} of 98 Mpa $\sqrt{m}$. Calculate the size of a surface crack that will lead to catastrophic failure at an applied stress of 0.5 S_y.

An NDT inspection is used that can ensure that a structural ceramic part will have no flaws greater that 25 μm in size. Calculate the maximum service stress that can be used. $K_{IC} = 9$ Mpa$\sqrt{m}$.