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## Chapter 1 Introduction

### 1.1 Common causes of Failure in Machines and Structures.

\* Yielding

\* Excessive deformation or large deflections

\* Buckling

\* Creep

\* Fracture

- The separation of an object into two or more pieces under action of stresses

\* Fatigue

- Failure due to a damage to an object caused by long-time repeated loading (stresses)

### 1.2 Histories - Fracture mechanics

\* 1943 - Failure of a liberty ship which broke during sailing Siberia and Alaska. - Liberty ships: Cargo ships produced by the United States using welding instead of riveting. 2700 ships made and 400 failed.

\* 1953 - Failure of a Comet commercial airplane. First commercial airplane (Pressurized cabin and large square windows). Three

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Comets were lost within 12 months after suffering catastrophic inflight break-ups.

\* Causes of the failure of Liberty ships.

1. Poorly welded parts contain crack-like flaws

2. Stress concentration at the crack tip

3. Use of materials of poor toughness \* Brittle fracture under cold temperature

\* Cause of the failure of Comet Jet plane

1. A small crack initiated near an opening in the fuselage

2. High tensile stress in the pressurized cabin in high altitude (over 10,000 m)

3. Propagation of the crack under fluctuating loading

\* The failures in both cases are sudden and catastrophic.

\* A.A. Griffith (1920) - Developed fracture theory based on a simple "Energy Balance Approach" for a brittle material (glass). No convenient parameter was introduced for prediction of the load conditions that would cause the growth of a crack.

\* G.R. Irwin (1948) - Formulated fracture mechanics. Introduced workable parameters like "Stress Intensity Factor" and "Energy Release Rate" for brittle and less ductile materials.

\* A.A. Wells (1961) - Developed the CTOD (Crack Tip Opening Displacement) as a parameter

\* J.R. Rice (1968) - Developed J-integral as a parameter

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C TOD and J-integral are to account for the large plastic zone at the crack tip in ductile materials.

Figure 1.1: Liberty ship failure: T2 tanker Schenectady after failure in January 1943. Poor welding procedure caused the cracks in welded ship hulls [courtesy B.B. Rath, Naval Research Laboratory]

Figure 1.2: BOAC comet 1 before its flight in 1953

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Figure 1.3: Reconstruction of the Elba fuselage wreckage recovery

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### What is fracture mechanics

\* Fracture mechanics was developed in an effort to answer the question asked "What causes the failure?"

\* Fracture mechanics is based on the implicit assumption that there exists a crack in a work component

\* Existence of a crack in a work piece;

1. Holes, notches, slots, and reentrance corners

2. Manufacturing defects - voids, foreign particles, and cracks created during manufacturing process.

\* Fracture mechanics deals with the question - "Is a known crack likely to grow under a certain loading condition?"

### Approaches

\* In applied mechanics approaches (\(\leftrightarrow\)material science approaches)

1. Energy-based approach - Energy Release Rate (G) for brittle and less-ductile materials

2. Stress based approach - Stress Intensity Factor (K) for brittle and less-ductile materials

3. J-integral approach - Both for brittle and ductile materials

4. Crack Tip Opening Displacement (CTOD) approach - For ductile

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materials

\* Critical values of these parameters define "\*\*Fracture Toughness.\*\*" - What is the upper limit of a parameter that would not cause catastrophic failure of a component under given geometry and loading conditions

\*\*Figure 1.4\*\* Comparison of the fracture mechanics approach to design with the traditional strength of materials approach: (a) the strength of materials approach and (b) the fracture mechanics approach.

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### Brittle fracture and ductile fracture

1. Brittle fracture

2. A crack moves easily through components made of brittle materials.

3. No significant plastic deformation.

4. The material near the crack is not much affected by the crack growth.

5. Affected depth is shallow.

6. A thick plate of a regular ductile material may allow the growth of a crack in a brittle manner: A crack inside a thick plate is constrained from all sides, and large plastic deformation is not allowed.

7. Ductile fracture

8. In ductile materials, there exists substantial plastic deformation and creations of micro voids in the vicinity of crack tip.

9. Fractured surfaces are rather rough looking

10. The growth of a crack is slow. - Large absorption of energy from plastic deformation and coalescence of voids.

11. Brittle fracture of normally ductile materials

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Figure 1.5: Schematic representations of tensile stress-strain behavior for brittle and ductile materials

Figure 1.6: Fractured surfaces of a (a) brittle fracture and a (b) ductile fracture

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<!-- image -->

## 1.5 Brittle fracture and ductile fracture

- i. Brittle fracture

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- ⚫ Brittle fracture of normally ductile materials

Figure 1.5 Schematic representations of tensile stress-strain behavior for brittle and ductile materials

<!-- image -->

Figure 1.6 Fractured surfaces of a (a) brittle fracture and a (b) ductile fracture

<!-- image -->

<!-- image -->

Image: figure-3-1.jpg

The image shows a large ship with a significant structural damage, as it appears to be bent or broken in the middle. The ship is floating on calm water, and there are no visible people or activity on board. The background is clear, with no additional structures or objects visible. There is no text present in the image.

Image: figure-3-2.jpg

The image shows a vintage airplane on a runway. The text visible on the aircraft includes "G-ALYP" on the tail and "COMET" on the fuselage. The airplane appears to be an early model of a jet airliner, likely from the mid-20th century. The overall setting is an airport with a flat, open area in the background.

Image: figure-4-3.jpg

The image appears to be a diagram or analysis of a damaged aircraft fuselage section. The text includes:

- "DIRECTION OF PROPAGATION OF FATIGUE FAILURES"

- "FORWARD"

- "SECONDARY FAILURES AND TEAR ALONG RIVET LINES"

- "PORTION OF FUSELAGE FROM WHICH MAJOR IMPACT WAS TO TEAR IT LOOSE"

The image shows a section of an aircraft with visible damage, including tears and missing pieces, likely used to analyze the failure points and the direction of damage propagation.

Image: figure-4-4.jpg

The image shows the remains of an aircraft fuselage, which appears to be heavily damaged and stripped down to its framework. The tail section is partially intact, displaying the registration "D-AL..." with the rest obscured. The structure is mostly skeletal, with significant portions of the outer skin missing, revealing the internal framework and components.

Summary: The image depicts a severely damaged aircraft fuselage with visible framework and partial tail markings.

Image: figure-6-5.jpg

The image contains two diagrams labeled (a) and (b).

Diagram (a) shows a relationship between "Applied Stress" and "Yield or Tensile Strength," connected by a double-headed arrow, indicating a direct relationship.

Diagram (b) illustrates a triangular relationship among "Applied Stress," "Flaw Size," and "Fracture Toughness." Each element is connected by double-headed arrows, suggesting interdependence among these factors.

Overall, the diagrams depict relationships between stress, material strength, flaw size, and fracture toughness in materials.

Image: figure-8-6.jpg

The image is a stress-strain graph comparing brittle and ductile materials.

- The y-axis is labeled "Stress."

- The x-axis is labeled "Strain."

- The curve for brittle materials is steep and peaks at point B, with a shaded area under it.

- The curve for ductile materials is more extended and peaks at point B', with a larger shaded area.

- Points A, B, C, B', and C' are marked on the graph.

- The region under the brittle curve is labeled "Brittle."

- The region under the ductile curve is labeled "Ductile."

The graph illustrates how brittle materials break with less strain compared to ductile materials, which can withstand more deformation.

Image: figure-8-7.jpg

The image shows two pairs of metal rods with different fracture surfaces.

- \*\*(a)\*\*: The rods have flat, rough surfaces, indicating a brittle fracture. The left rod has a threaded section.

- \*\*(b)\*\*: The rods have more irregular, cup-and-cone shaped surfaces, suggesting a ductile fracture.

The image is likely illustrating the difference between brittle and ductile fracture characteristics in materials.