FM0819

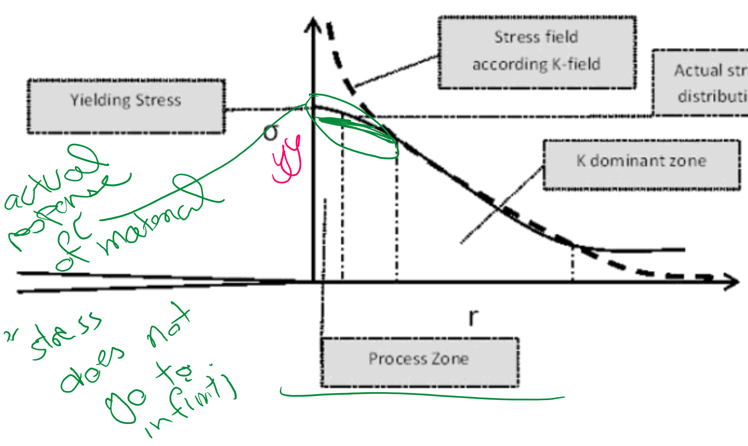
Sunday, August 18, 2024 5:21 PM

Course requirements

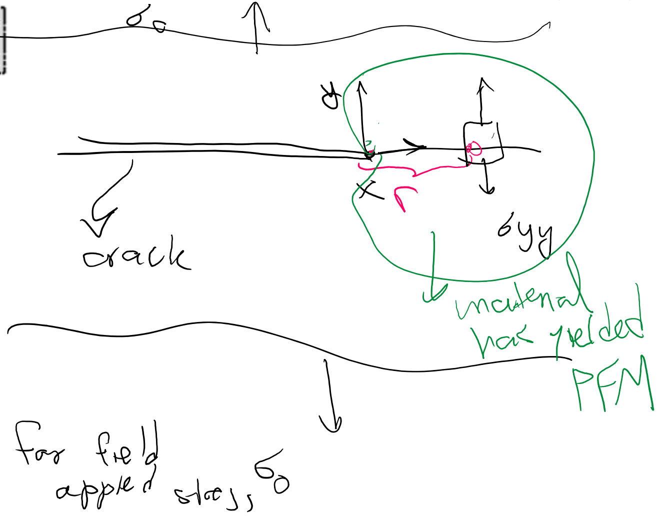
- Homework 34% + 5% (extra credit)
- Exams: Midterm + final: 34%
- Term project 16%: Use commercial software to evaluate stress intensity factor; Simple computations with cohesive and damage models.
- Report and presentation on a topic on fracture 16%: 4-page report and 10-12 minute presentation at the end of the semester. Individual topics and references will be chosen by the instructor and the student.

From <http://rezaabedi.com/teaching/fracture-mechanics/>

Course content:

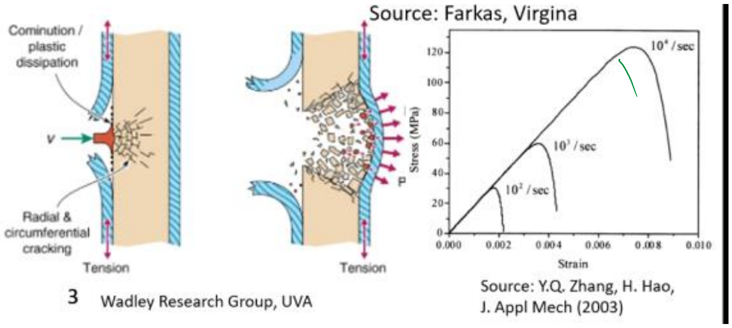


Linear Elastic Fracture Mechanics (LEFM)



$$\sigma_{yy} = \frac{K_I}{\sqrt{2\pi r}}$$

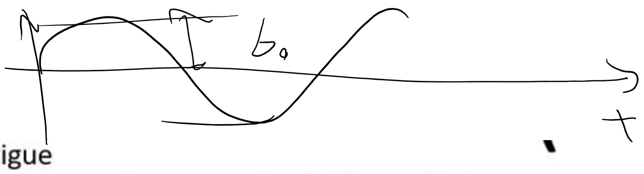
1. Intro to fracture mechanics
2. LEFM
3. Plastic Fracture Mechanics (PFM)
4. Dynamic Fracture Mechanics

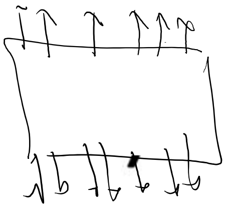


Source: Farkas, Virgina

Wadley Research Group, UVA

Source: Y.Q. Zhang, H. Hao, J. Appl Mech (2003)



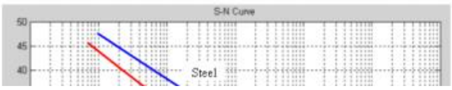


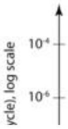
σ(t)

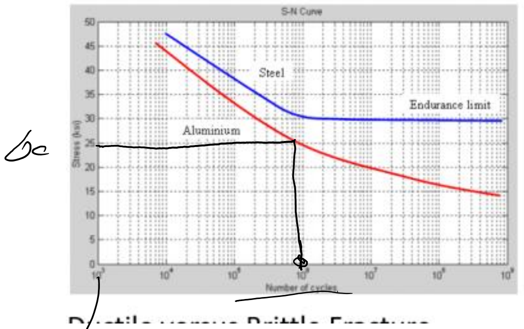
5. Fatigue

Fatigue

- Fatigue crack propagation & life prediction
- Paris law

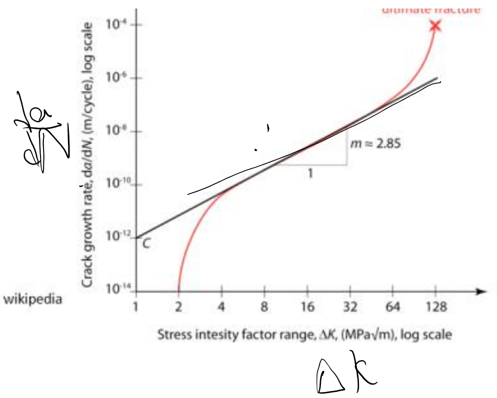






wikipedia

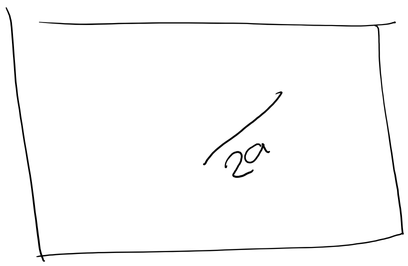
old approach



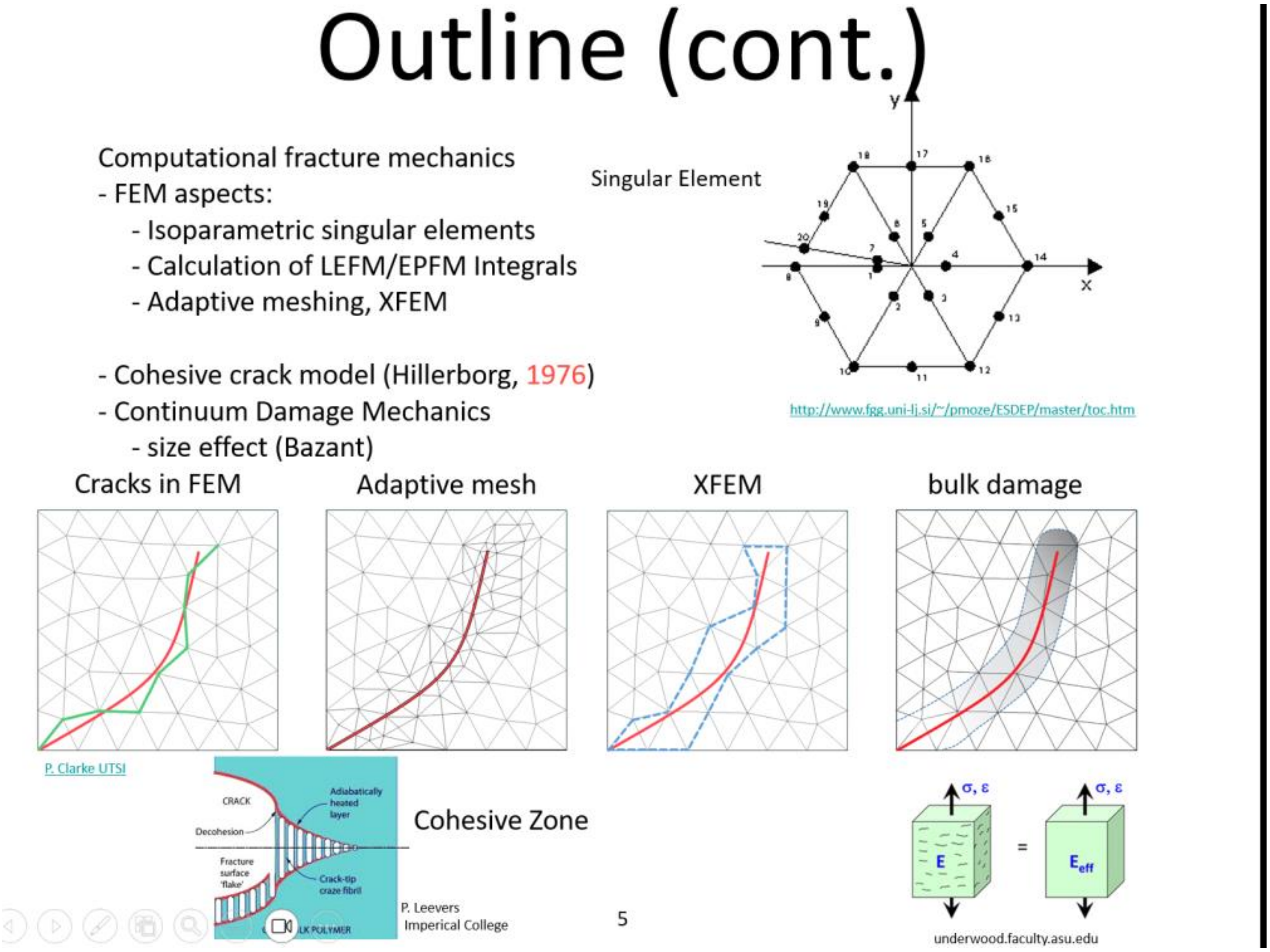
Paris law

crack length

$$\underset{\#\text{cycles}}{\frac{da}{dN}} = C\,\underbrace{\Delta K}_{\text{change in stress intensity factor}}^{m}$$



New design philosophy: we consider defects in the material and design such that the cracks don't become critical



Outline (cont.)

Computational fracture mechanics
- FEM aspects:
  - Isoparametric singular elements
  - Calculation of LEFM/EPFM Integrals
  - Adaptive meshing, XFEM

- Cohesive crack model (Hillerborg, 1976)
- Continuum Damage Mechanics
  - size effect (Bazant)

Singular Element

http://www.fgg.uni-lj.si/~/pmoze/ESDEP/master/toc.htm

Cracks in FEM

Adaptive mesh

XFEM

bulk damage

P. Clarke UTSI

Cohesive Zone

P. Leevers
Imperical College

5

underwood.faculty.asu.edu

Design philosophies

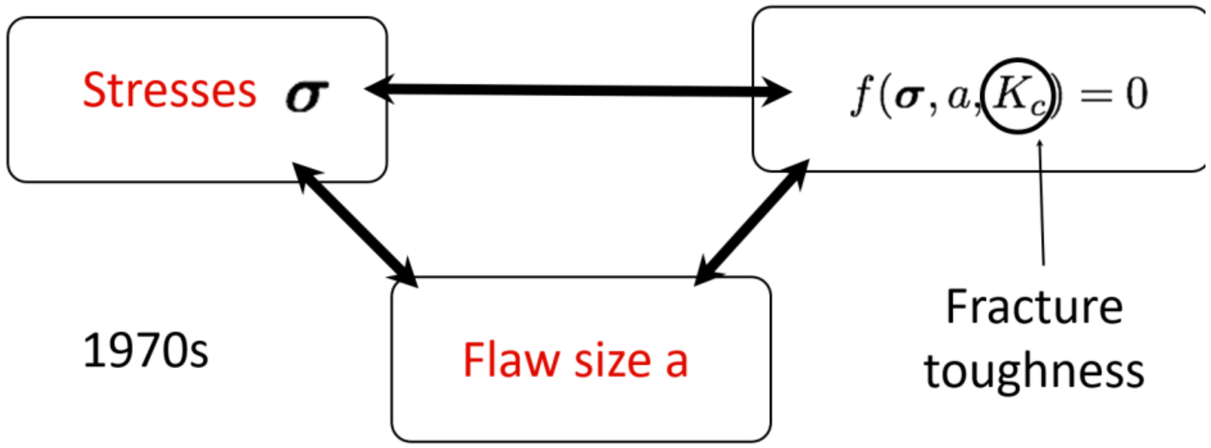
- Safe life

  The component is considered to be free of defects after fabrication and is designed to remain defect-free during service and withstand the maximum static or dynamic working stresses for a certain period of time. If flaws, cracks, or similar damages are visited during service, the component should be discarded immediately.

- Damage tolerance

  The component is designed to withstand the maximum static or dynamic working stresses for a certain period of time even in presence of flaws, cracks, or similar damages of certain geometry and size.

New Failure analysis



Stresses $\boldsymbol{\sigma}$

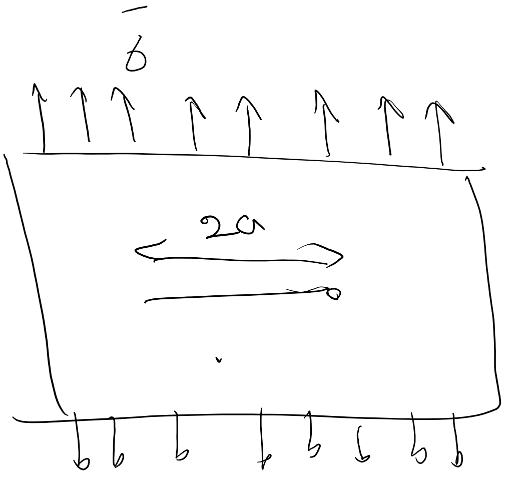
$f(\boldsymbol{\sigma}, a, \boxed{K_c}) = 0$

Fracture toughness

1970s

Flaw size a

Fracture Mechanics (FM)



1. applied load $\bar{\sigma}$
2. Material properties

   E, ν, K_{Ic} critical stress intensity factor

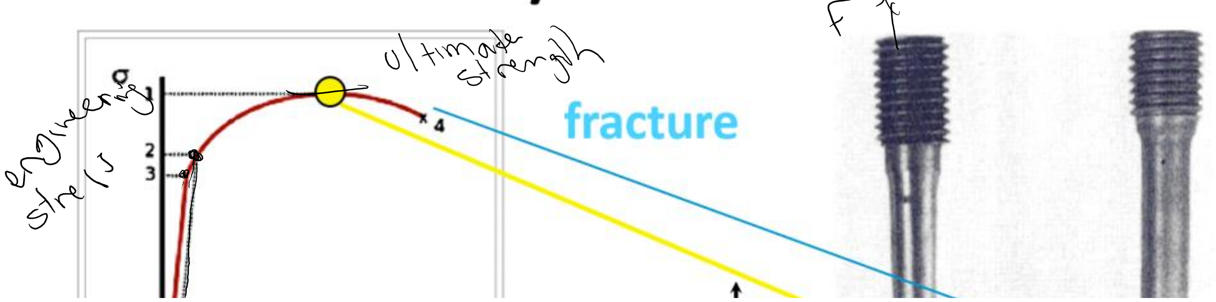
3. Defect geometry : a

1&2 given → a = ? for safe operation

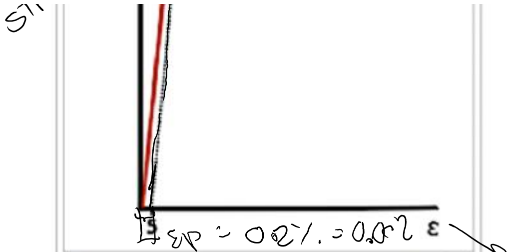
2, 3 → what's the safe load $\bar{\sigma}$

1, 3 load & crack length given ⟹ good material

Stress/strain curve



$\sigma = \frac{F}{A_0}$

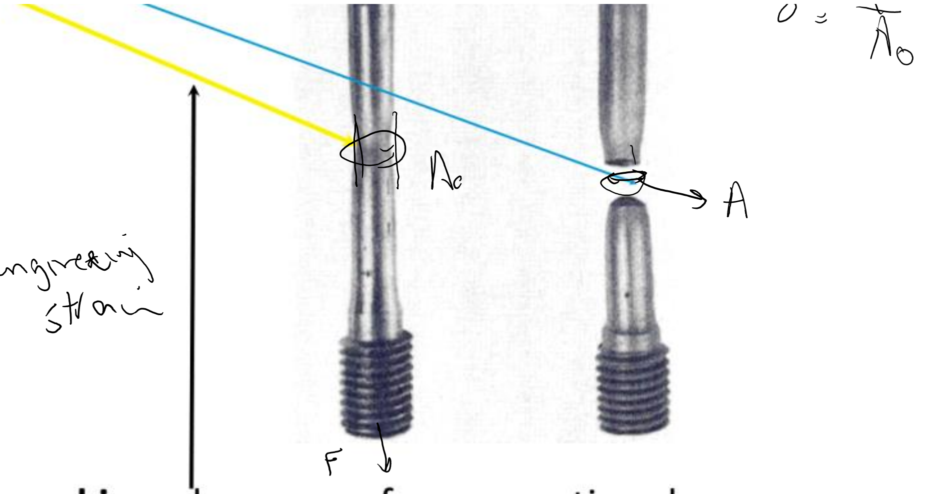


engineering strain

Stress vs. Strain curve typical of aluminum

1. Ultimate strength
2. Yield strength
3. Proportional limit stress
4. Fracture
5. Offset strain (typically 0.2%)

Wikipedia



necking=decrease of cross-sectional area due to plastic deformation

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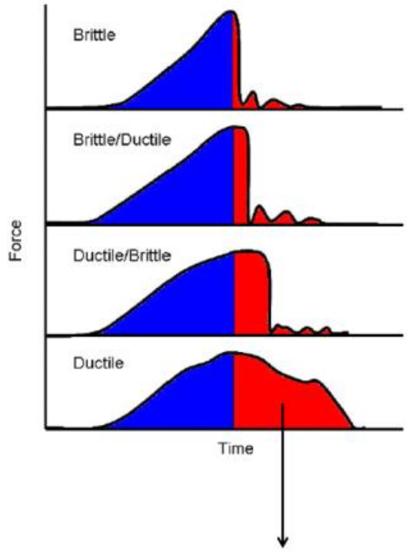
Ductile versus Brittle Fracture

- **Ductile fracture** - most metals (not too cold):
  - Extensive plastic deformation ahead of crack
  - Crack is "stable": resists further extension unless applied stress is increased
- **Brittle fracture** - ceramics, ice, cold metals:
  - Relatively little plastic deformation
  - Crack is "unstable": propagates rapidly without increase in applied stress

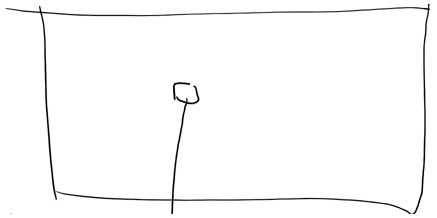
Ductile fracture is preferred in most applications



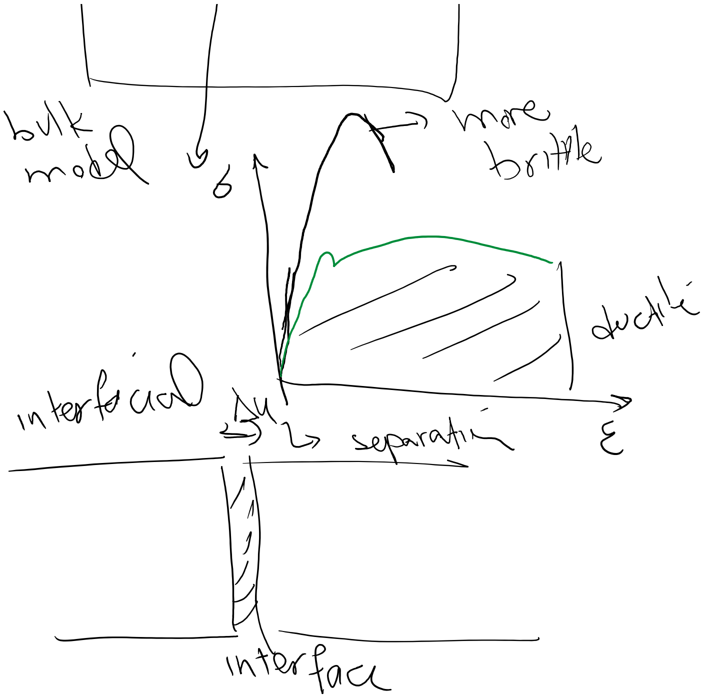
After crack commencement

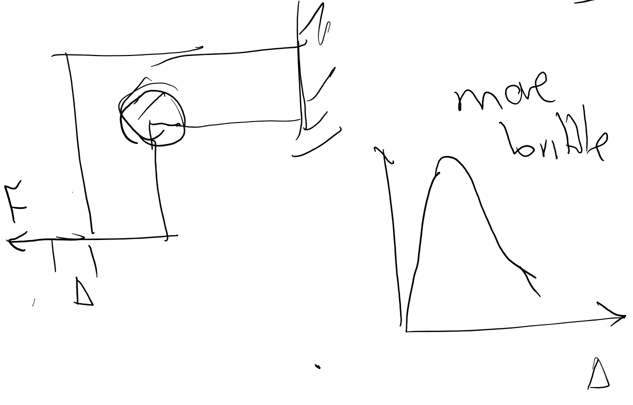
Ductile versus brittle response can be discussed from material model and structure prespectives

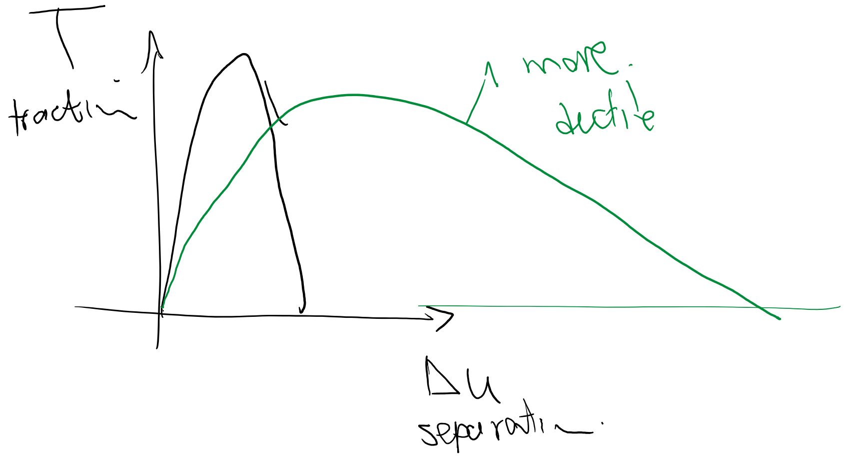
Material



structure

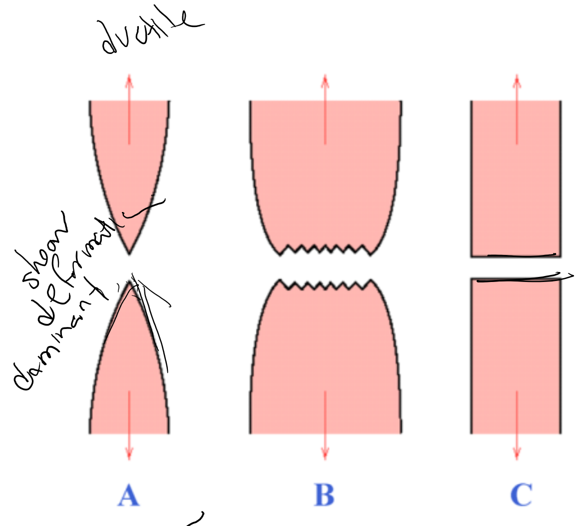






Traction separation law (TSL)
relation (TSR)

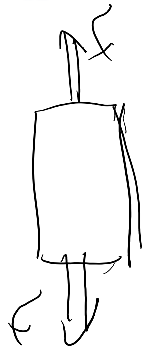
Brittle vs. Ductile Fracture

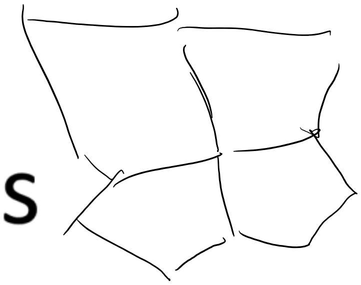


A. Very ductile, soft metals (e.g. Pb, Au) at room temperature, other metals, polymers, glasses at high temperature.

B. Moderately ductile fracture, typical for ductile metals

C. Brittle fracture, cold metals, ceramics.





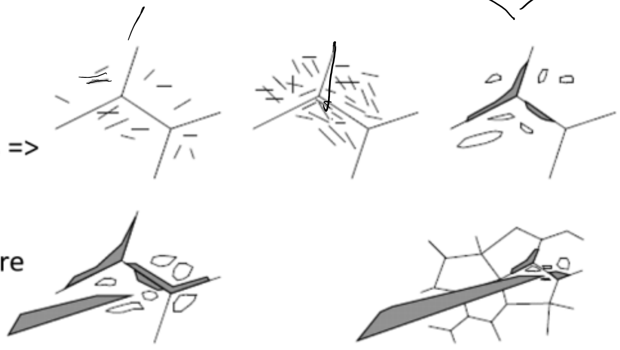
Why do we get necking for ductile materials?

Fracture Types

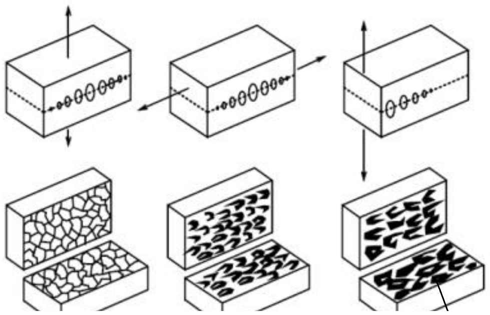
Shearing

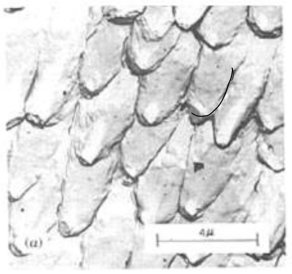
- Applied stress =>
- Dislocation generation and motion =>
- Dislocations coalesce at grain boundaries =>
- Forming voids =>
- Voids grow to form macroscopic cracks
- Macroscropic crack growth lead to fracture

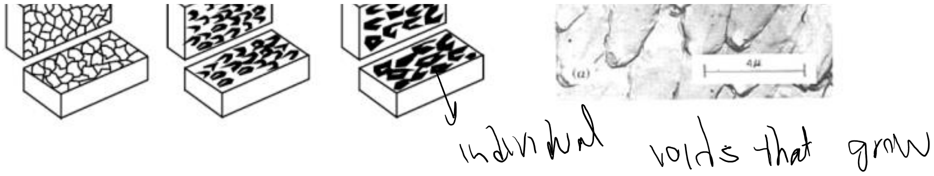
Plastic deformation (ductile material)



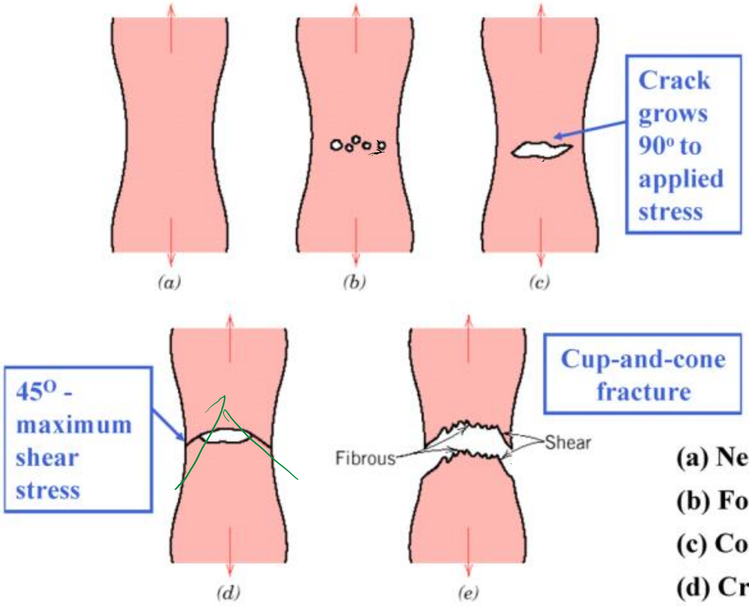
Dough-like or conical features







Ductile Fracture (Dislocation Mediated)



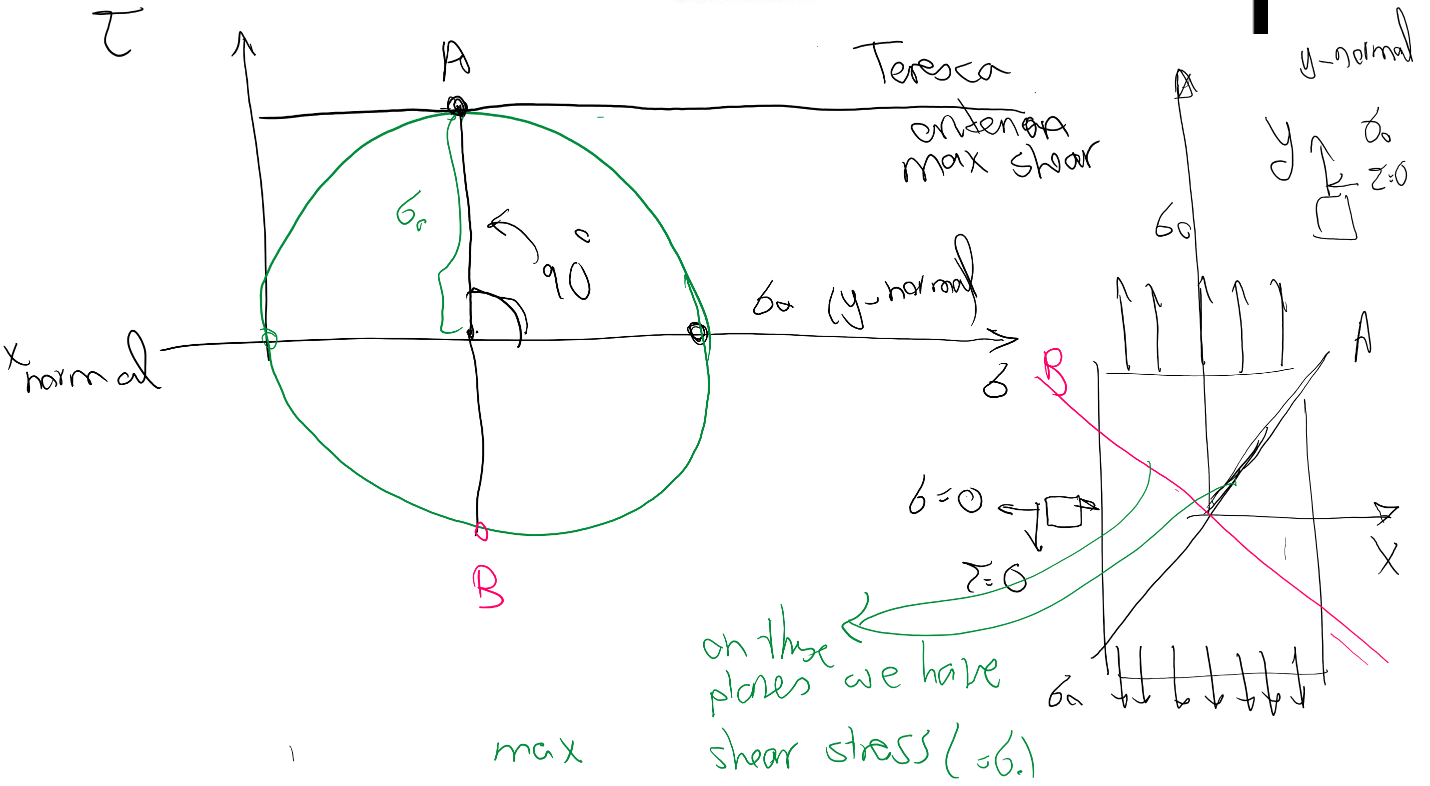
(a) Necking

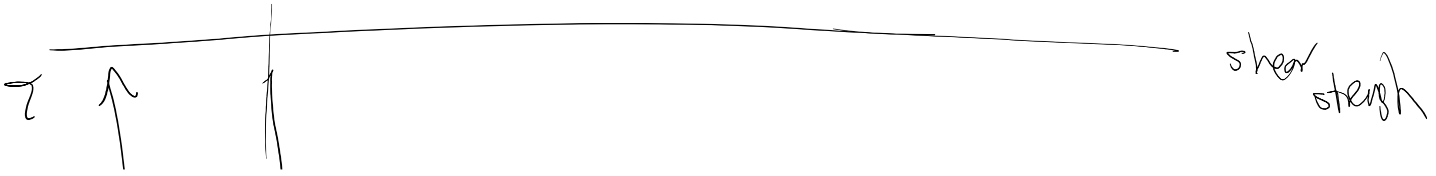
(b) Formation of microvoids

(c) Coalescence of microvoids to form a crack

(d) Crack propagation by shear deformation

(e) Fracture





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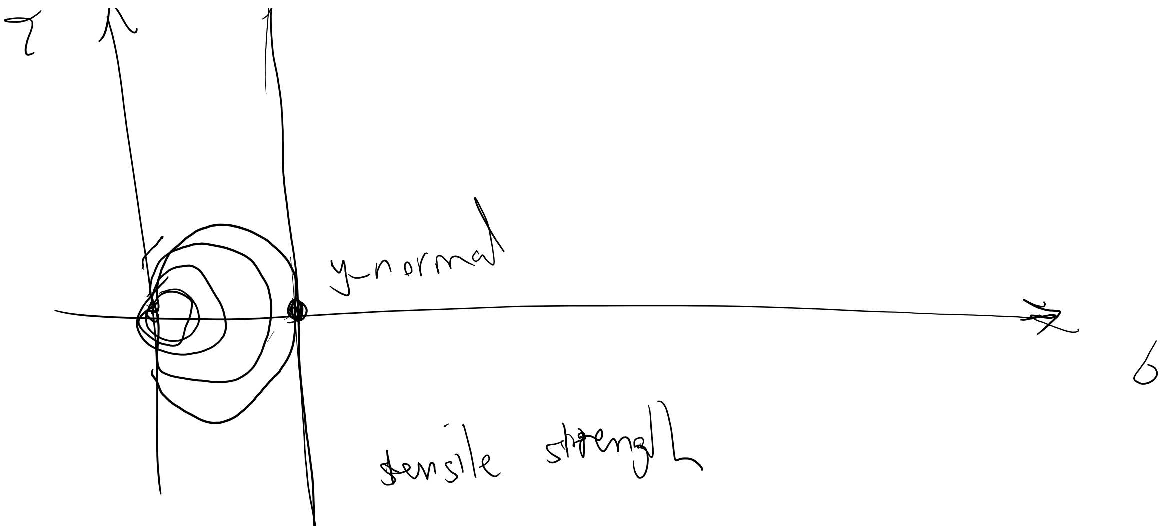
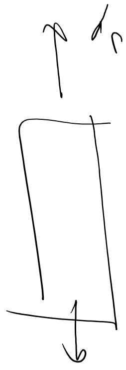
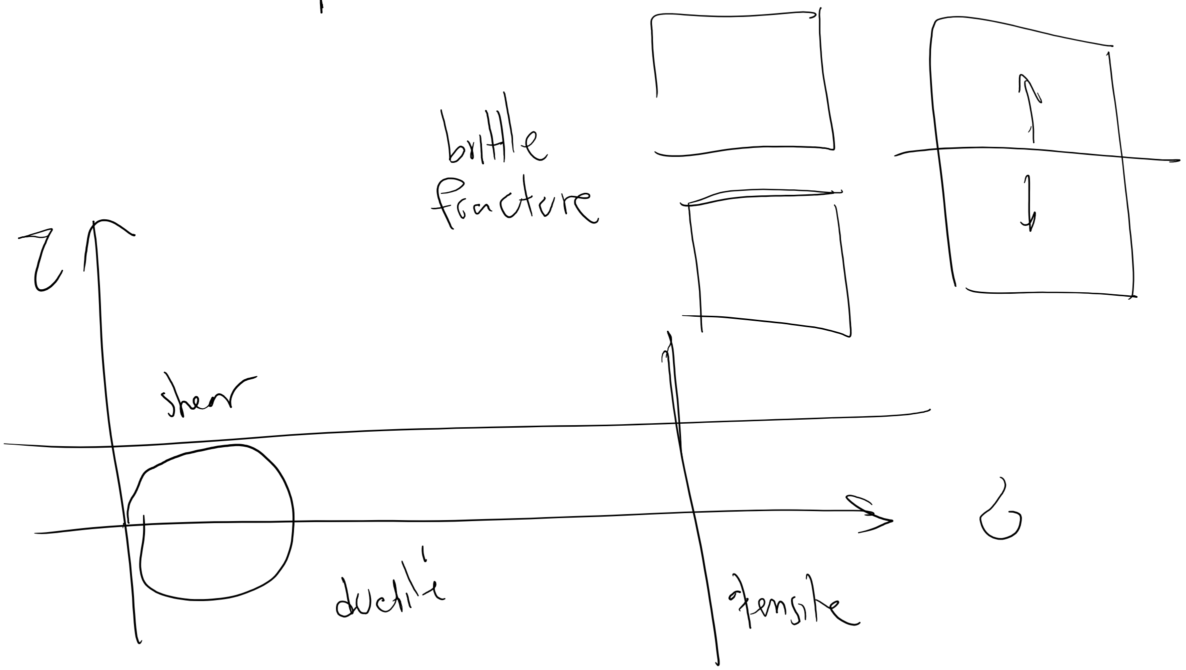
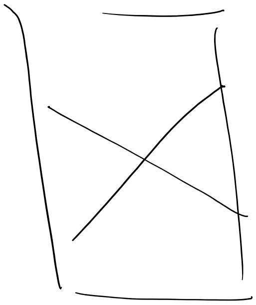
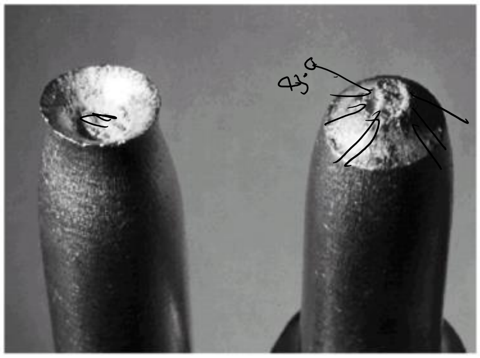

τ
y-normal
tensile strength
σ


σr

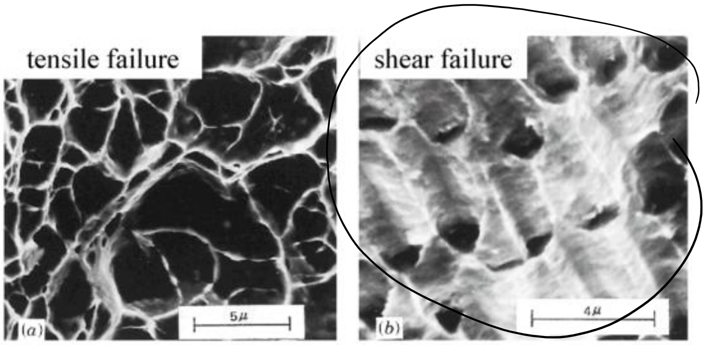

brittle fracture
τ
shear
ductile
tensile
σ



Ductile Fracture



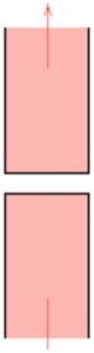
(Cup-and-cone fracture in Al)

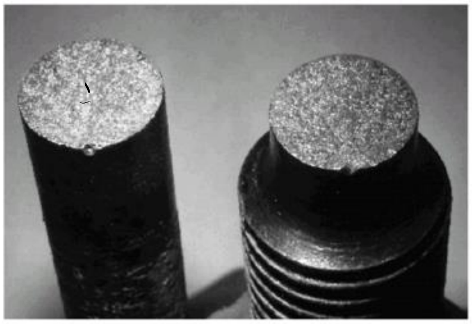


Scanning Electron Microscopy: *Fractographic* studies at high resolution. Spherical "dimples" correspond to microvoids that initiate crack formation.

Brittle Fracture (Limited Dislocation Mobility)

- No appreciable plastic deformation
- Crack propagation is very fast
- Crack propagates nearly perpendicular to the direction of the applied stress
- Crack often propagates by cleavage - breaking of atomic bonds along specific crystallographic planes (cleavage planes).

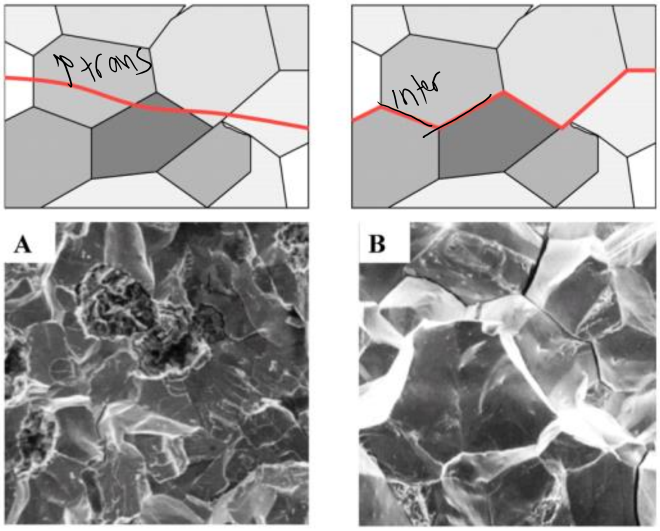


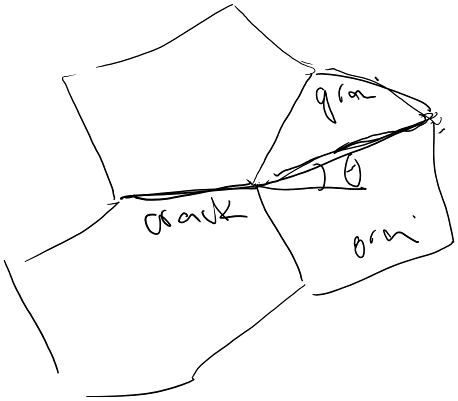


Brittle fracture in a mild steel

A. Transgranular fracture: Fracture cracks pass through grains. Fracture surface have faceted texture because of different orientation of cleavage planes in grains.

B. Intergranular fracture: Fracture crack propagation is along grain boundaries (grain boundaries are weakened or embrittled by impurities segregation etc.)





deflection angle θ high

or

Grain boundary strength high →

make the crack more likely to go through grains