2020/08/19

Wednesday, August 19, 2020 11:23 AM

http://rezaabedi.com/

Course webpage:
http://rezaabedi.com/teaching/fracture-mechanics/

Course syllabus can be access through the link above

> http://www.rezaabedi.com/wp-content/uploads/Courses/FractureMechanics/SYLLABUS-FEM_524.pdf

This document has a more detailed overview of what will be covered in this course:
http://www.rezaabedi.com/wp-content/uploads/Courses/FractureMechanics/TopicsDetails.pdf

Fracture Mechanics Topics & References

Color Code: Covered, Brief Discussion, Not Covered

1. Preliminaries: Tensors; Kinematics (displacement, strain); Stress; Balance laws; Constitutive equations
   Saouma 5.1-5.4; Anderson A2.1
2. History
   Anderson 1.2.1-1.2.5
3. Fracture modes
   - 3.1. Classification
     Murakami 1.1.1, 1.1.2, **1.1.3**; Saouma **4.1-4.4** (buckling, fracture, yielding, etc.); Schreurs 2.1.
   - 3.2. Ductile fracture
     - 3.2.1. Dislocation dynamics
       Hertzberg 2 (theory), 3 (slip and twinning)
     - 3.2.2. Void nucleation, growth, and coalescence
       Anderson **5.1**
   - 3.3. Brittle fracture
     Anderson 5.2; Lawn
   - 3.4. Ductile-brittle transition
     - 3.4.1. Temperature
       Anderson 5.3

Useful online courseware and links

1. Presentation on Fracture Mechanics by Dr. N. V. Phu from University of Adelaide. With special thanks to Dr. Phu, the majority of course presentations are based on Dr. Phu's presentations.
2. S. Suresh, Fracture and Fatigue, MITOpen courseware.
3. V.E. Saouma, Fracture Mechanics lecture notes, University of Colorado, Boulder.
4. P.J.G. Schreurs, Fracture Mechanics lecture notes, Eindhoven University of Technology (2012).
5. A.T. Zender, Fracture Mechanics lecture notes, Cornell University.
6. K. Ramesh, Engineering fracture mechanics lecture videos, IIT, Madras, India.
7. L. Zhigilei, MSE 2090: Introduction to the Science and Engineering of Materials, University of Virginia: Excellent lecture notes on material preliminaries such as atomic structure (ch2), crystalline solids (ch3), imperfections (ch4), mechanical properties (ch6), dislocation (ch7), and **failure (ch8)**.

Selected Bibliography

1. T. L. Anderson, Fracture Mechanics: Fundamentals and Applications, 3rd Edition, CRC Press, USA, 2004 (**main textbook**).
2. D. Broek, Elementary Engineering Fracture Mechanics, 4th Revised Edition, Springer, 1982 (or reprint 2013).
3. B. Broek, The Practical Use of Fracture Mechanics, Springer, 1998.
4. S. Murakami, Continuum Damage Mechanics: A Continuum Mechanics Approach to the Analysis of

Damage and Fracture, Springer Netherlands, Dordrecht, 2012.
5. S. Suresh, Fatigue of Materials. 2nd ed. Cambridge University Press, 1998.
6. L.B. Freund, Dynamic Fracture Mechanics, Cambridge University Press, 1998.
7. B. Lawn, Fracture of Brittle Solids, Cambridge University Press, 1993.
8. M.F. Kanninen and C.H. Popelar, Advanced Fracture Mechanics, Oxford Press, 1985.
9. R.W. Hertzberg, Deformation and Fracture Mechanics of Engineering Materials. 5th ed. John Wiley & Sons, Inc., 2012 (material focus).
10. S Al Laham, Stress Intensity Factor and Limit Load Handbook, British Energy Generation Limited, 1998.
11. H Tada, P.C. Paris, G.R. Irwin, Stress Analysis of Cracks Handbook, 3rd ed., ASME Press. 2000

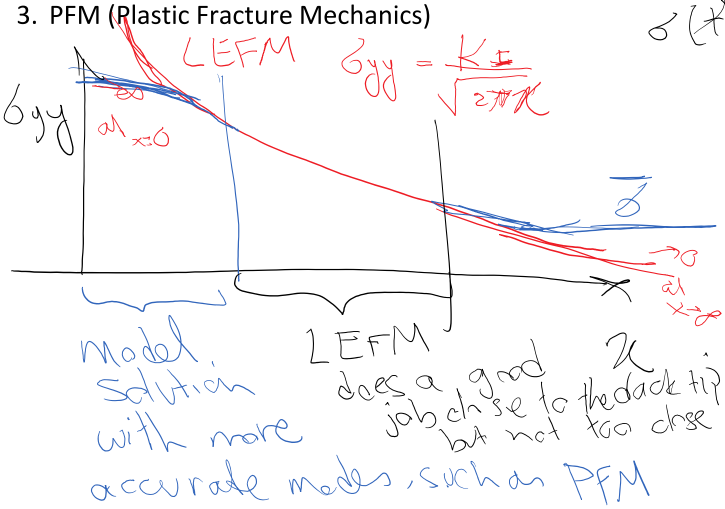
http://www.rezaabedi.com/wp-content/uploads/Courses/FractureMechanics/FractureMechancisME524.pdf

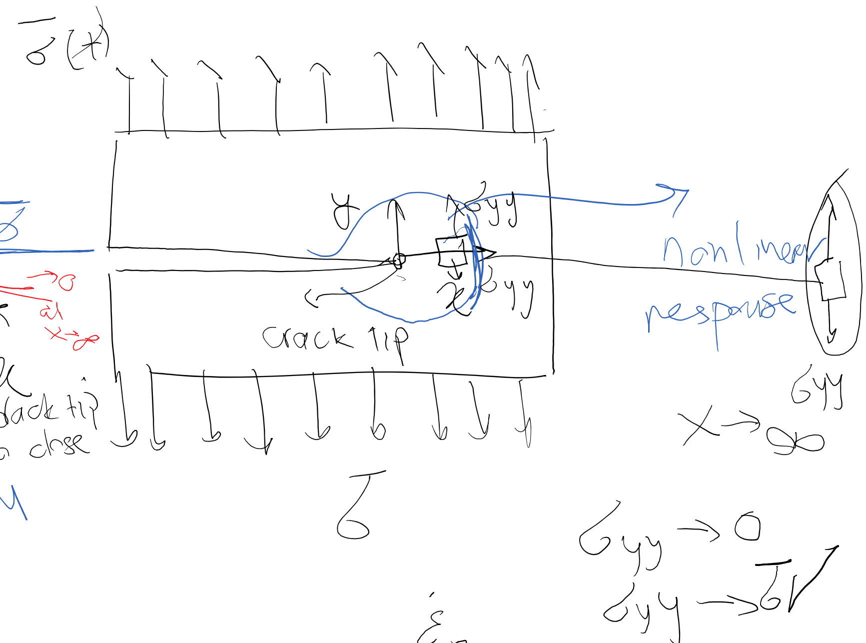
Breakdown of your grade:

HW: 34%
Midterm exam: 22%
Final exam: 12%
Computational Project: 16% : You will calculate stress intensity factor using a commercial code (Ansys will be used by the instructor)
Final Project 16%: Presentation on a fracture mechanics topic that will be communicated with the instructor. Can also do a computational / theoretical / experimental fracture project.

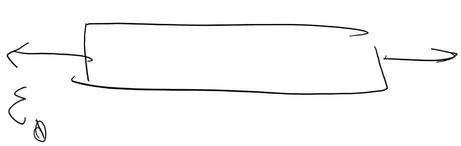
Course outline:

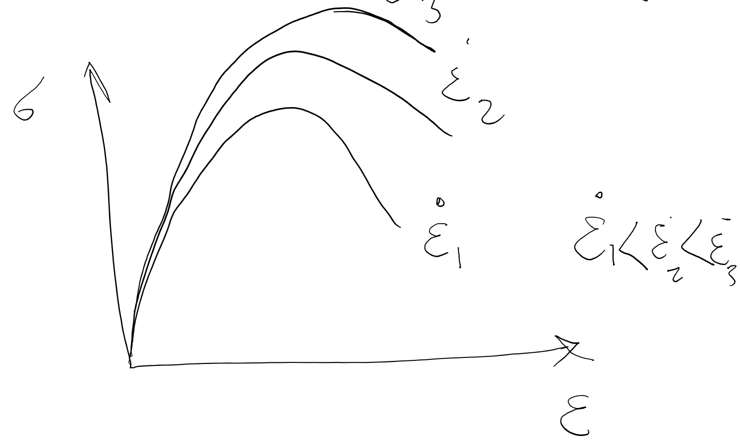
1. Brief introduction to fracture mechanics (ductile and brittle materials and the transition between two failure modes)
2. LEFM theory
3. PFM (Plastic Fracture Mechanics)





4. Dynamic fracture mechanics and rate effects



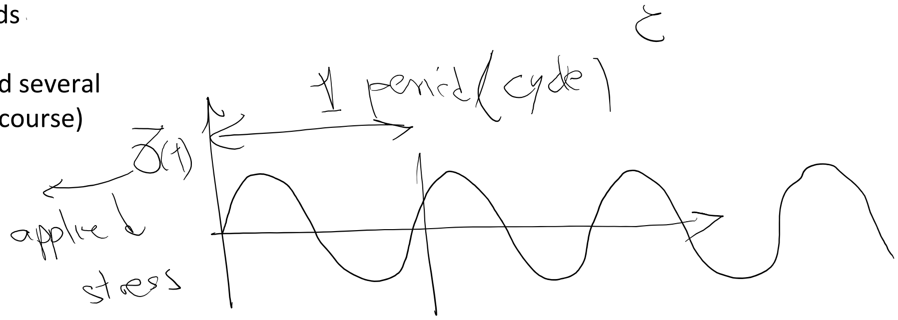


Pulling the ends of a bar with different speeds

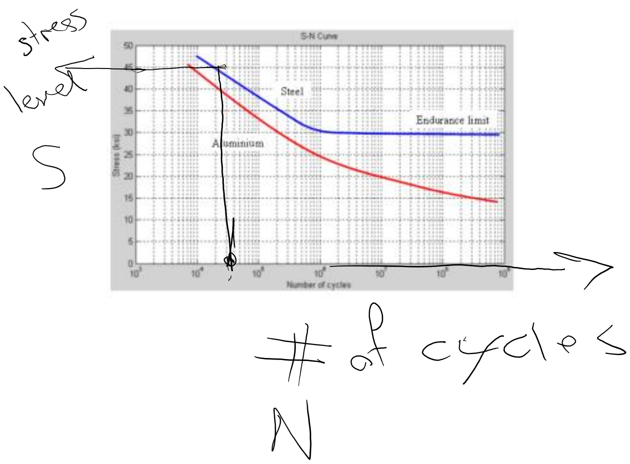
We will also look at dynamic LEFM theory and several

Pulling the ends of a bar with different speeds

We will also look at dynamic LEFM theory and several rate dependent models (near the end of the course)

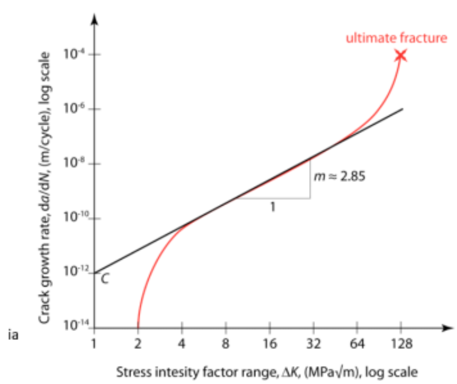


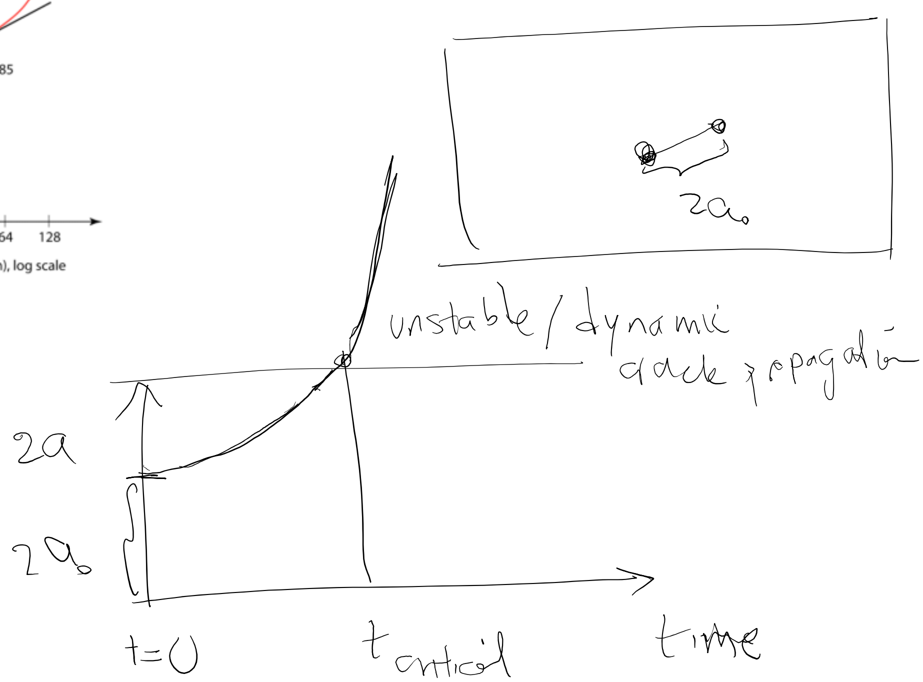
5. Fatigue



older approach

More modern approach for modeling fatigue:
We will allow the material to have cracks and model the progress (elongation) of the crack as the number of cycles increase



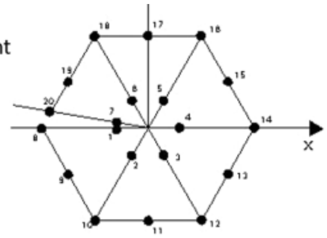


6. Computational Fracture Mechanics
Learn how to extract important fracture mechanics parameters (for example stress intensity factor) from finite element (or other numerical methods') solutions.

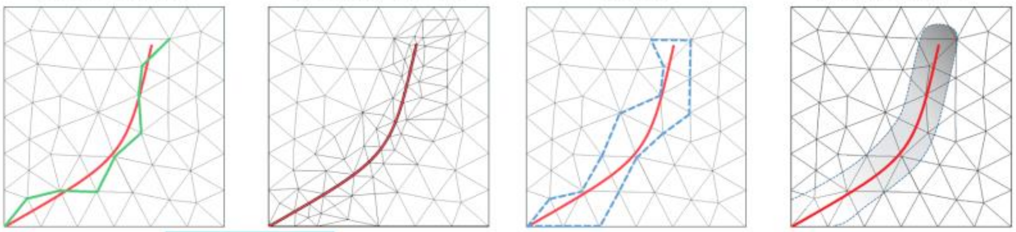
Computational fracture mechanics
- FEM aspects:
  - Isoparametric singular elements
  - Calculation of LEFM/EPFM Integrals
  - Adaptive meshing, XFEM

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

Singular Element



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



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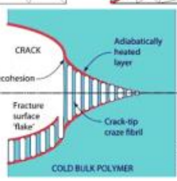

Cohesive Zone

P. Leevers
Imperical College

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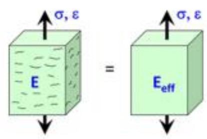
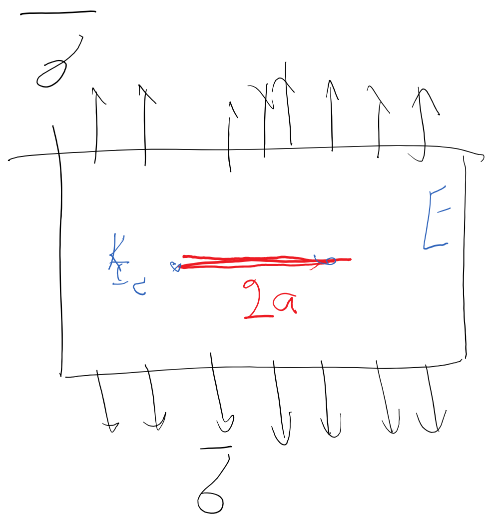


underwood.faculty.asu.edu

Today's material

Some background and ductile vs. brittle fracture

Three main problems are encountered in fracture mechanics:



Model parameters:

(1) Applied/Design loads $\bar{\sigma}$

(2) Material properties

E: elastic modulus

K_{Ic}: fracture toughness

(3) Defect geometry (e.g. crack size)

In design / analysis problems we generally have 2 of these and want to obtain the third one.

a. 1 and 2 given (load and material properties are known) and want to find 3, meaning that what crack length is safe.

b. 1, 3 are given (load and crack length are known) -> what material is needed to withstand the given load. This may not always have a reasonable solution / the original design space may not be reasonable.
c. 2, 3 are given (material and crack size), want to find the safe design load.

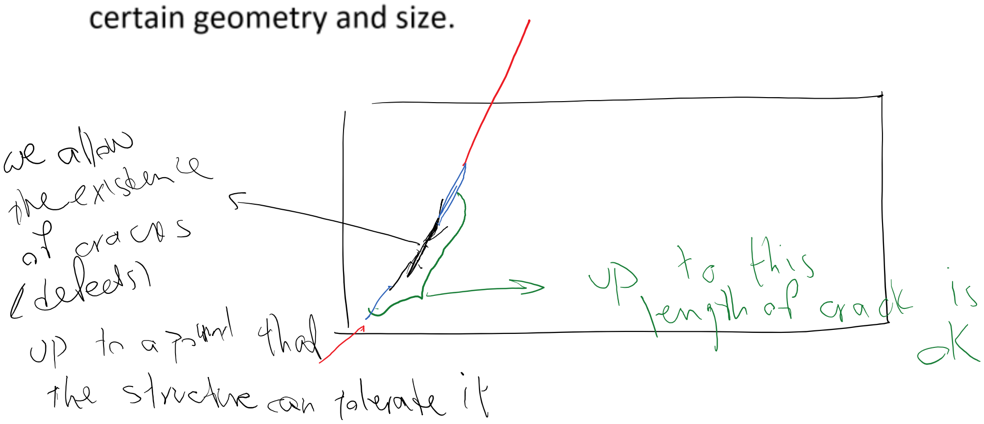
Design philosophies

- Safe life

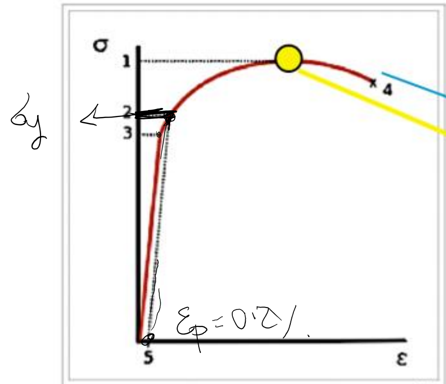
  The component is considered to be free of defects after fabrication and is designed to remain defect-free during service and withstand the maximum static or dynamic working stresses for a certain period of time. If flaws, cracks, or similar damages are visited during service, the component should be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



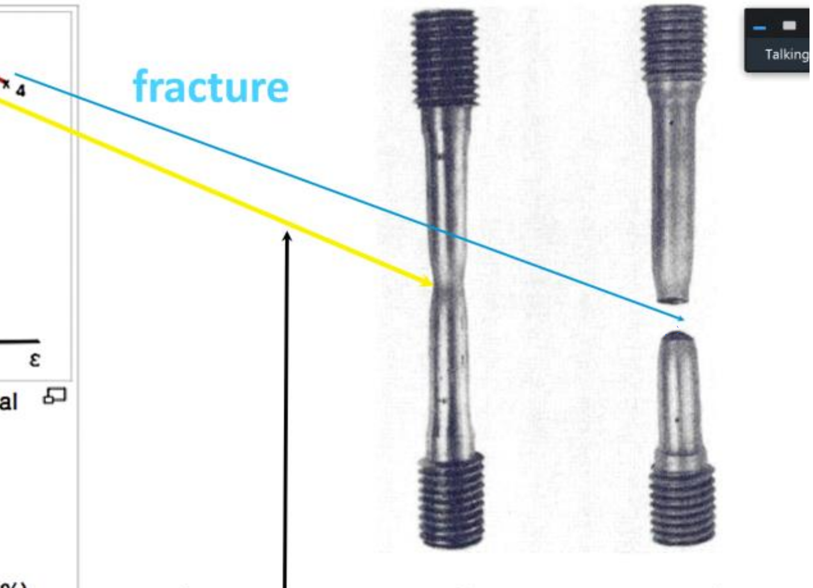
Ductile vs. brittle fracture
Starting point for this discussion:



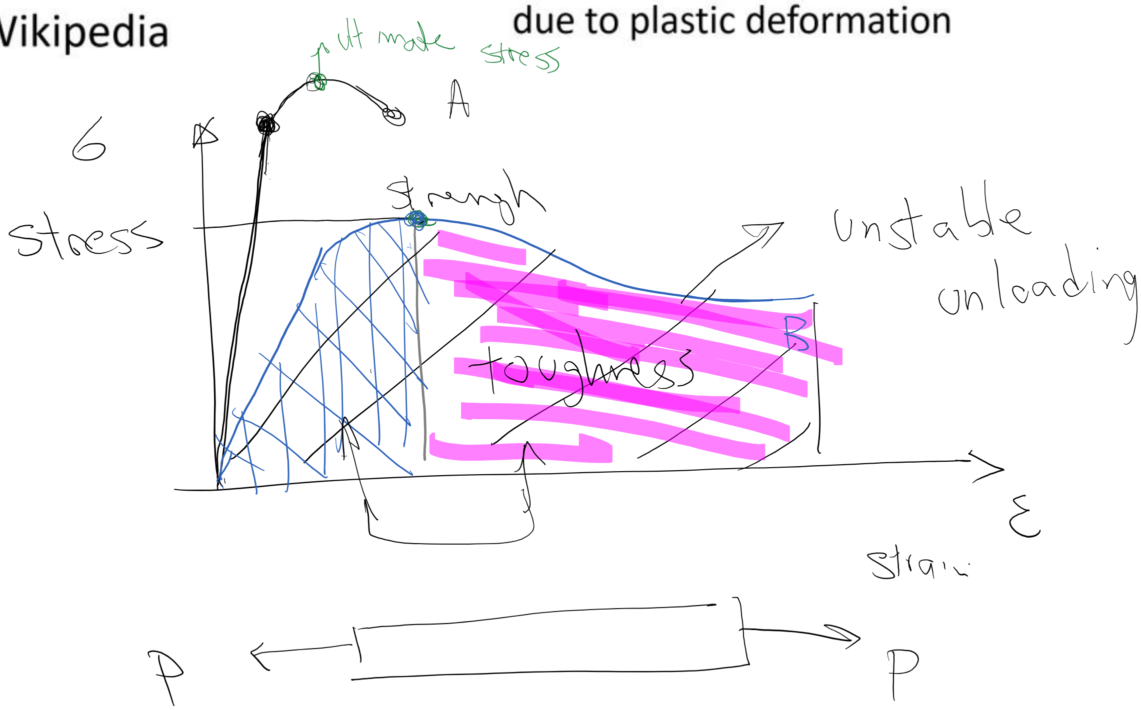
Stress vs. Strain curve typical of aluminum

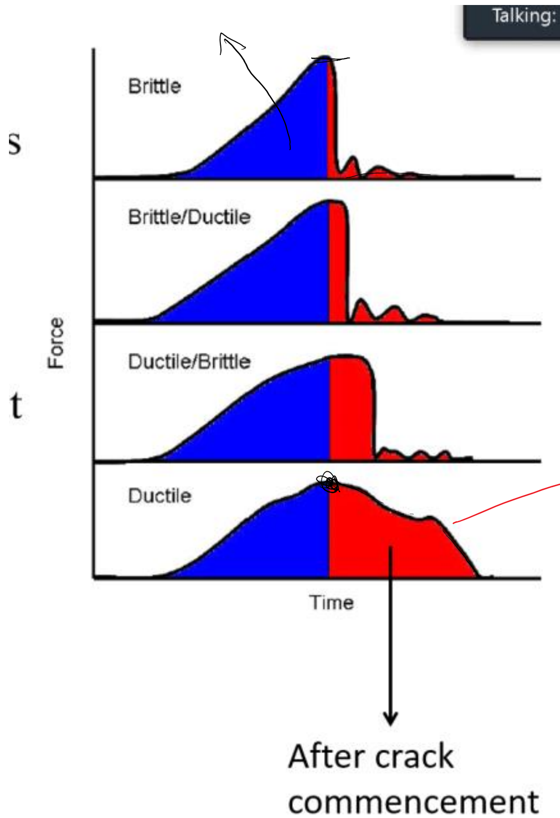
1. Ultimate strength
2. Yield strength
3. Proportional limit stress
4. Fracture
5. Offset strain (typically 0.2%)

Wikipedia



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



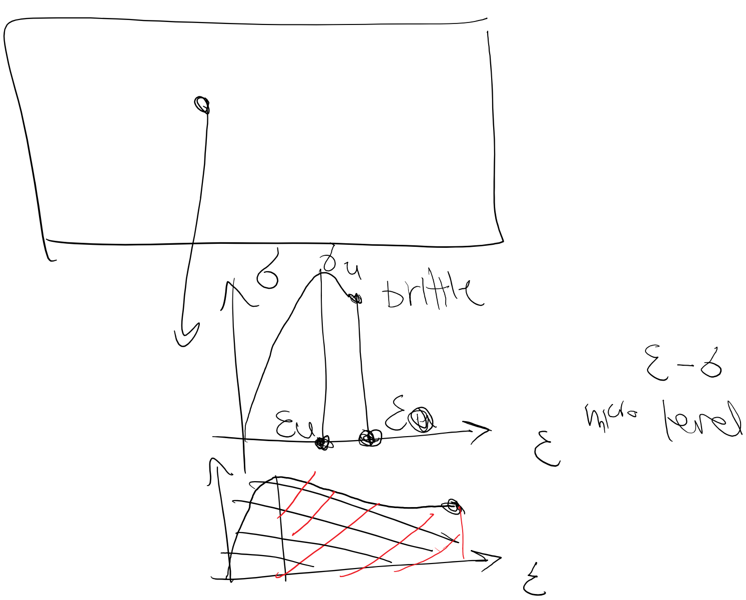


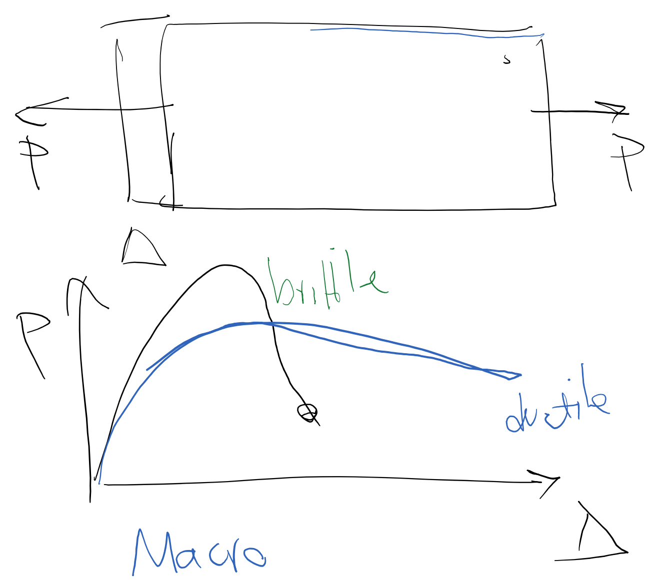
we want to have more time (strain, displacement) in unloading phase

Ductile vs. Brittle is defined in

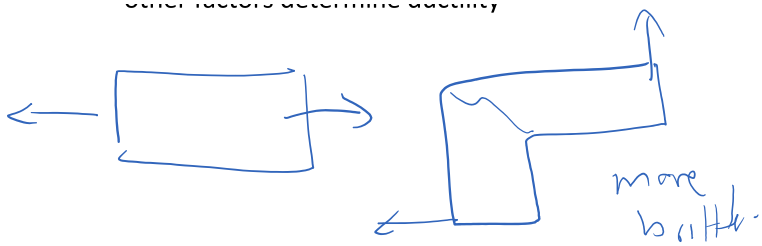
micro vs macro scale.

bulk vs interfacial models



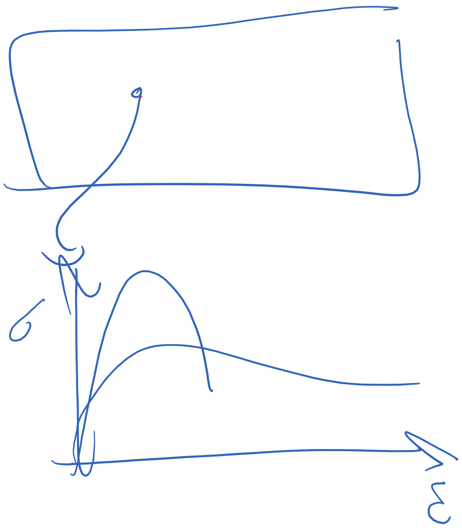


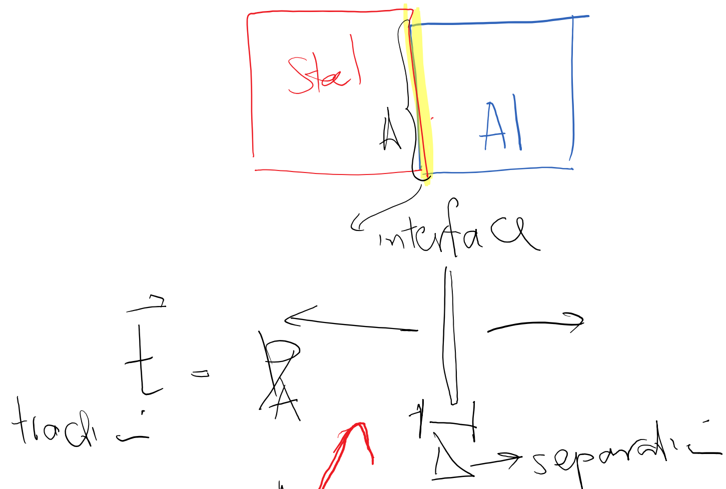
At the macroscale, the constitutive equation of the material, e.g. how brittle it is, and the geometry, plus other factors determine ductility other factors determine ductility

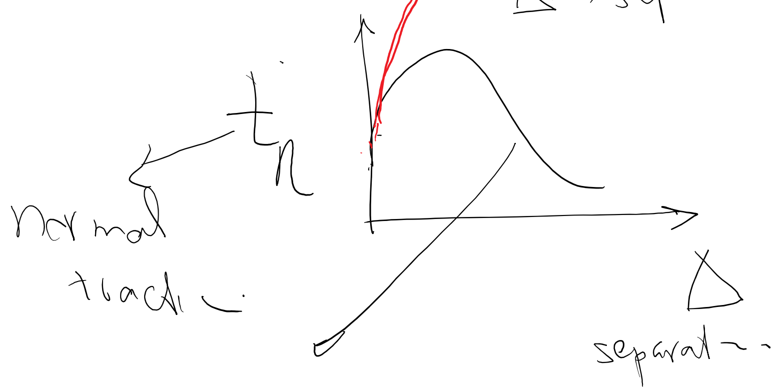


Micro scale

Bulk vs. interface

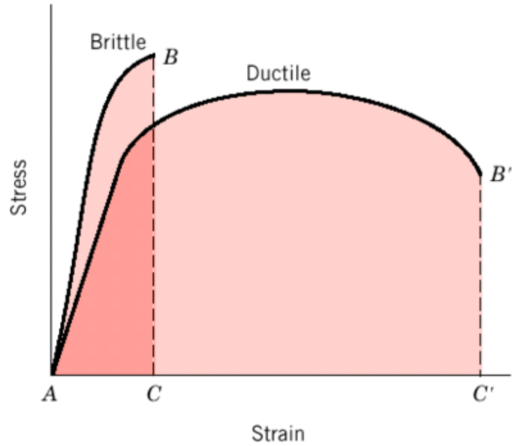






Traction-separation Relation (TSR)

- **Ductile materials** - extensive plastic deformation and energy absorption ("toughness") before fracture
- **Brittle materials** - little plastic deformation and low energy absorption before fracture

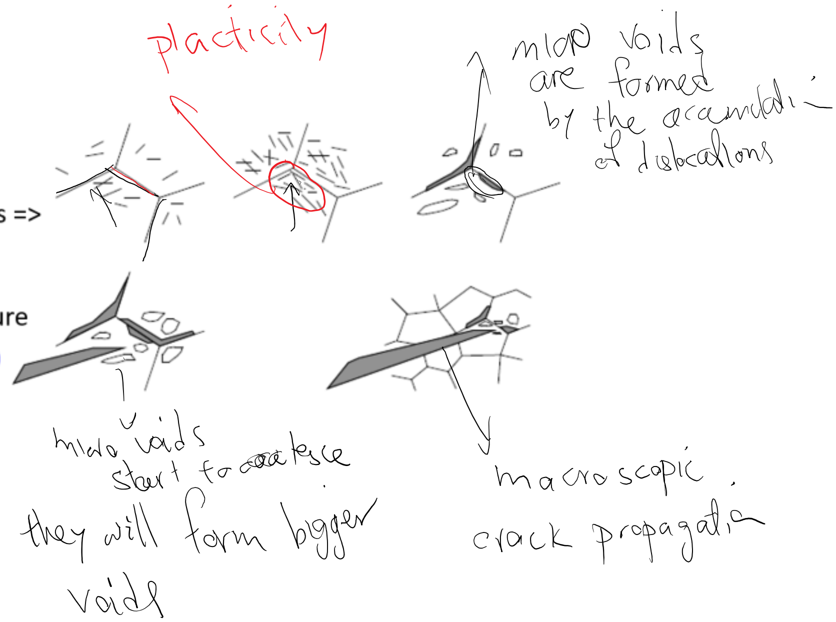


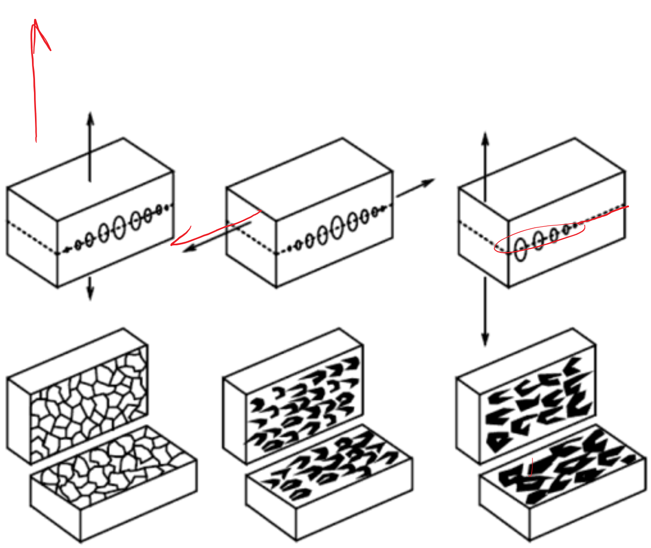
How does ductile fracture happen?

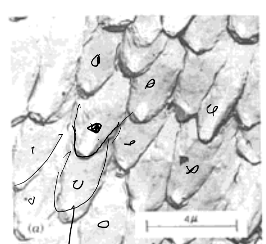
Shearing

- 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)

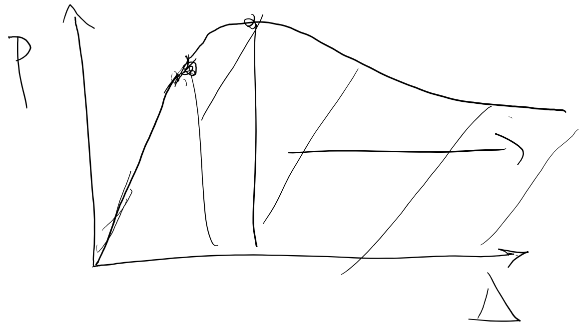






On the surface of ductile fracture

ductile fracture surface is very rough

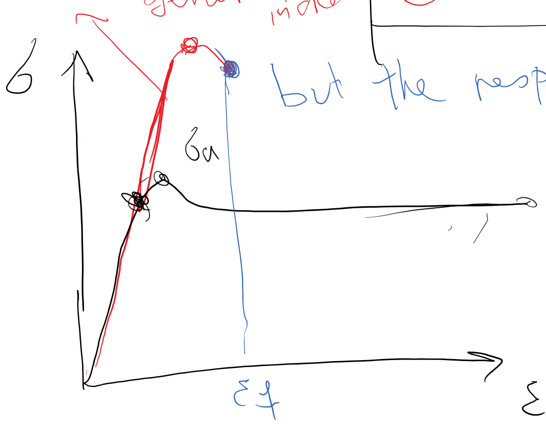


All these processes (dislocation motion, pile-up against grain boundary, micro void formation, …) contribute to:

1. Rough fracture surface
2. High fracture energy

A common feature of ductile fracture is ease of motion of dislocations

by inhibiting dislocation motion strength generally increases :)



but the response becomes more brittle

"not much energy reserve beyond peak stress"