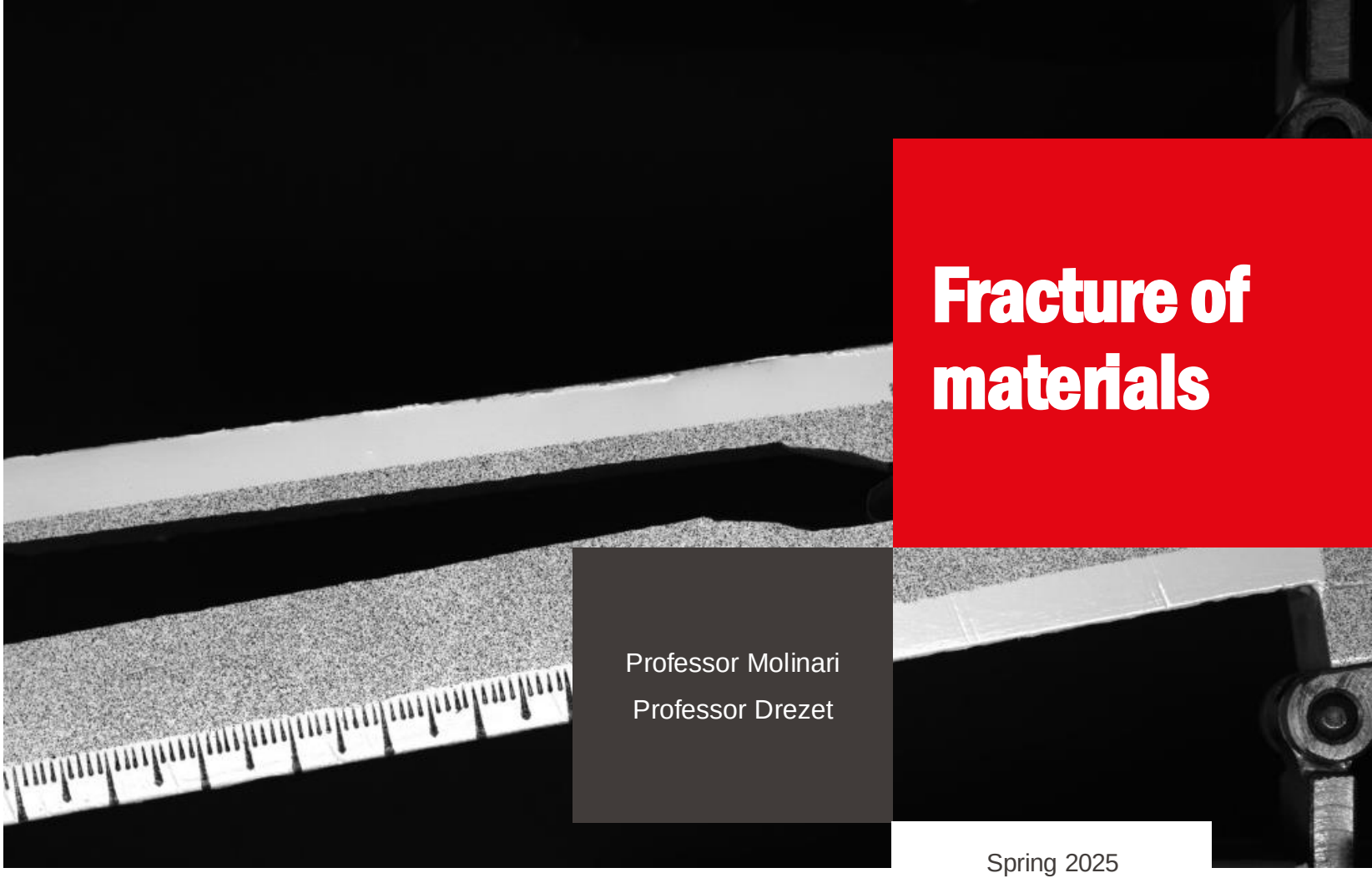


Fracture of materials

Professor Molinari
Professor Drezet

Spring 2025

Teaching team

Professor Jean-François Molinari

Computational solid mechanics laboratory

Dr Jean-Marie Drezet
MER

Materials science institute

PhD. Student Gaëtan Cortes

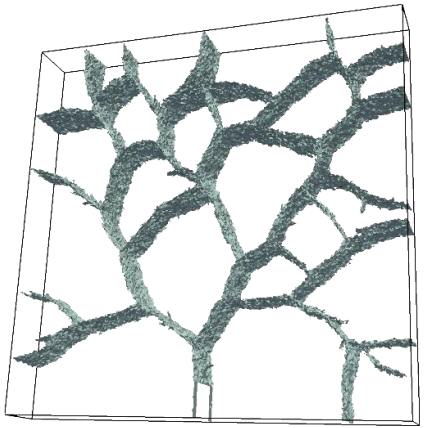
Computational solid mechanics laboratory

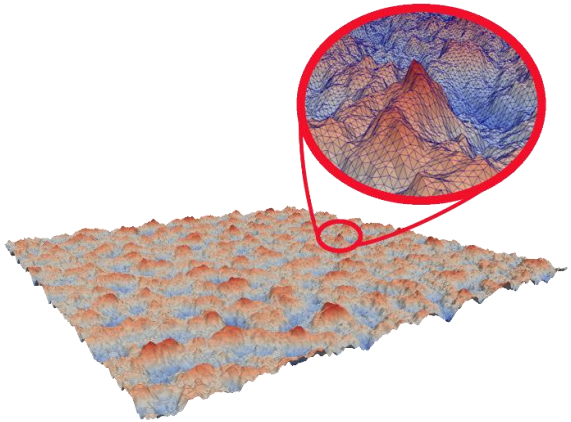
MSc. Student Allegra Magnetti

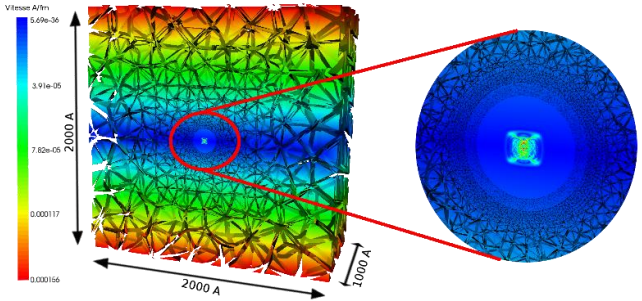
Materials Science and Engineering

LSMS Research group

- Mechanics of materials and structures
- Interdisciplinary research (mechanics, materials science, geophysics, scientific computing, applied mathematics)
- Theory and simulations (and experiments through collaborations)
- Alumni LSMS – LSMS - EPFL
- Two main areas: damage mechanics and tribology across scales

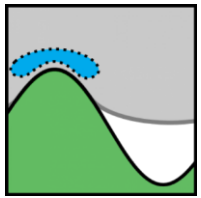


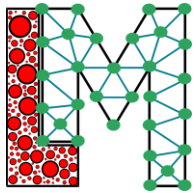




LSMS Research group

- Track record of development of novel numerical methods and open-source software (extensive V&V; all on GitLab; demonstrated HPC capabilities)
- Akantu Cracklet Tamaas Libmultiscale





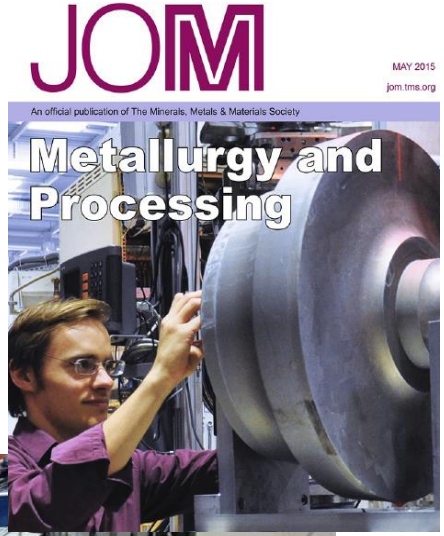
- Open-source software for granular materials, ex LAMMPS
- Two in-house codes examples:
  - Akantu: general purpose FE software (statics and dynamics, contact detection, cohesive elements, non-local continuum damage, phase-field fracture)
  - Cracklet: spectral boundary element code for elastodynamics of cracks and sliding friction (Geubelle and Rice 1995; Breitefeld and Geubelle 1998); very fast (discretization of interface only; semi-infinite elastic bodies in contact)

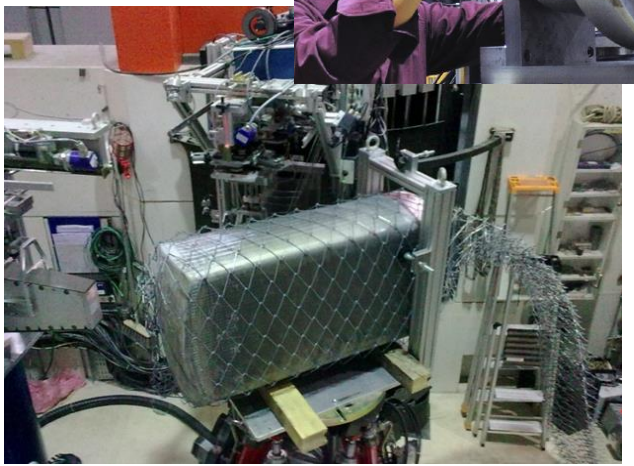
LSMS Research group

- Swiss National Science Foundation, “Adhesive wear across scales”,
- Innosuisse, “Surface design for improved frictional properties to lower CO2 footprint and foster formability”, J.F. Molinari (EPFL), Christian Leppin (Novelis Switzerland SA)
- ENAC interdisciplinary research grant, “An open-source platform for geomechanical assessment of CO2 geological storage”, PI: Brice Lecampion (50%), Co-PI: J.F. Molinari (50%)
- Swiss National Science Foundation/France ANR lead agency project, “CLIP: Dynamic fragmentation with the cohesive Lipschitz approach”, PI: J.F. Molinari, Co-PI: N. Moës (ECN, Nantes, France)
- Federal Department of the Environment, “What is the maximum magnitude of fluid INduced EARTHquake in Geo-reservoirs: a coupled numerical and experimental study”, PI: M. Violay, Co-PI: J.F. Molinari
- EPFL Global leader fellowship: Jacopo Bilotto with Bühler Group

Dr J.-M. Drezet (Materials science institute)

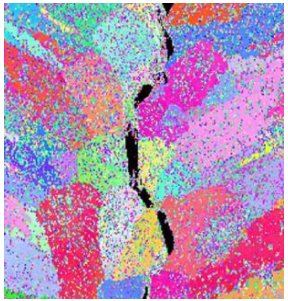
- 1996, PhD at EPFL (Physical Metallurgy, MX)
- Two European Research Projects (Empact and Vircast) dedicated to **aluminum continuous casting** and product quality.
- In 2009, neutron diffraction to measure **internal stresses** post-mortem in as-cast industrial aluminum billets and large ingots and in-situ in solidifying aluminum alloys to study hot tearing (solidification cracking)
- Since 2011 (MER), (co)-supervision of seven PhD students.

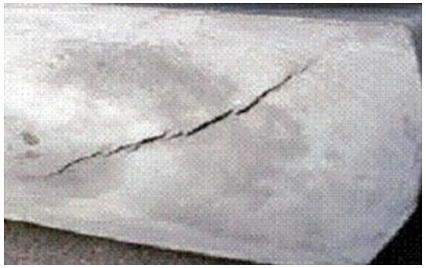


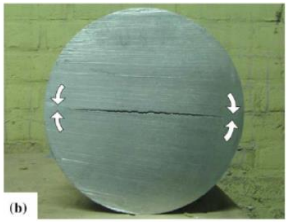


Dr J.-M. Drezet (Materials science institute)

- Hot tearing in casting and welding: a crack that initiates between growing grains … (limited liquid feeding) and might propagate further in zones of tensile stresses … (cold cracking).







- **Young Scientist ESAFORM Prize 2000,** European Scientific Association for Material Forming (Esaform), April 2000, Stuttgart, Germany.
- **Grand Prix Constellium 2012,** Académie des Sciences de l'Institut de France, Paris.
- **2014 Light Metals Award – Warren Peterson -** Cast Shop for Aluminum Production

Course organization

- 2h classes per week (Monday 8-10am)

- 2h exercises per week (Tuesday 3-5pm)
  - Corrections will be online on Wednesday

- Ed Discussion forum available for questions
  - We encourage you to post the questions in public so everyone can see them and learn from them !

- Office hours (TA) : Wednesday, 1-4pm, GC A2 495

Course organization

Week	Subject	Teacher
17-21.02	Introduction, 1D waves	JFM + JMD
24-28.02	Dispersion, 3D waves	JFM
03-07.03	Helmholtz decomposition, reflection/refraction, Rayleigh waves	JFM
10-14.03	Introduction to fracture, LEFM, Irwin solution	JFM
17-21.03	Griffith energy (global approach), energy release rate, R-curve	JFM
24-28.03	Local approach, fracture modes, crack tip, stress intensity factor	JFM
31.03-04.04	Relation between local and global, crack tip plasticity, K-controlled rupture	JFM
07-11.04	Mixed-mode rupture, crack propagation, J-integral	JFM

Week	Subject	Teacher
14-18.04	Dynamic crack propagation	JFM
21-25.04	Easter break !	Yourself
28.04-02.05	Fracture of brittle materials, Weibull statistics	JMD
05-09.05	Fracture of polymers	JMD
12-16.05	Fracture of metals	JMD
19-23.05	Fracture of heterogeneous materials	JMD
26-30.05	Course summary, research, Q&A	JFM+JMD
02-22.06	Revision weeks	Yourself

Exam organization

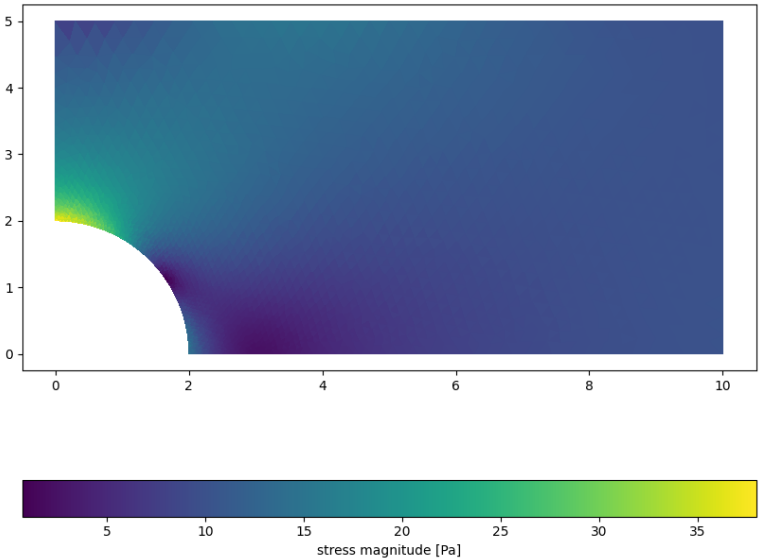
- Final written exam in the exam session
  - 1/3 of the grade : Class theory questions, without notes
  - 2/3 of the grade : Practical questions, with formula sheet
    - The formula sheet will be provided for the preparation and the examination

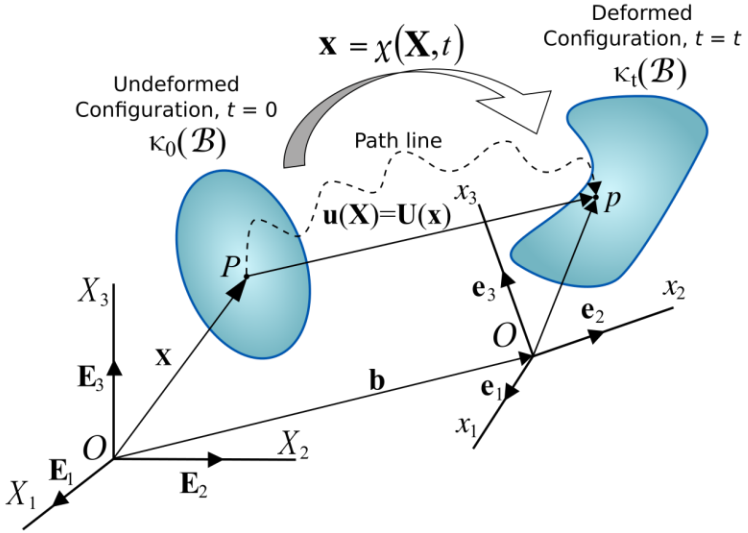
Introduction to fracture

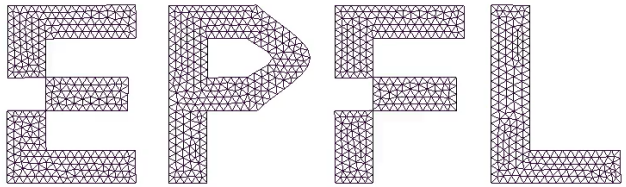
Where is it coming from ?

Why is it important ?

From Continuum...

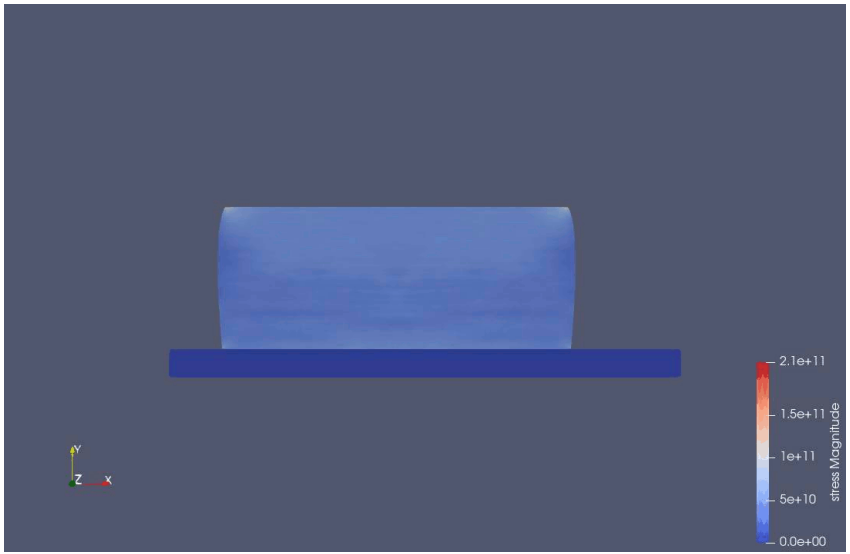


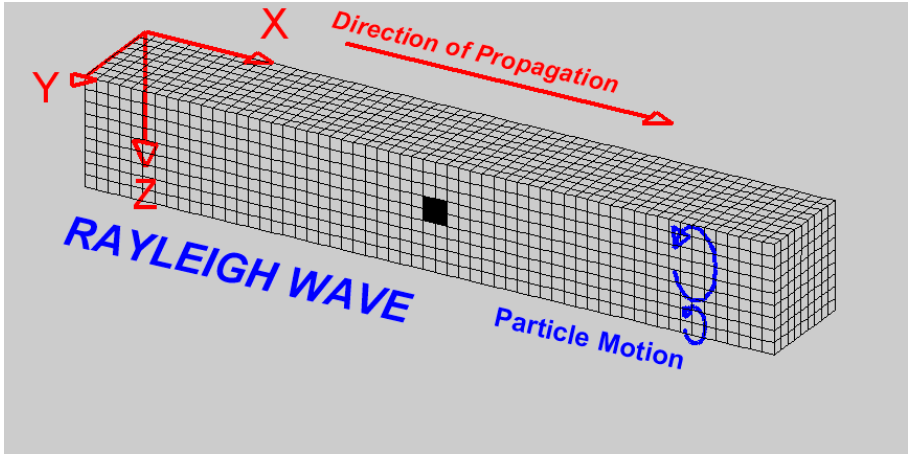




Prof. Drezet/Molinari

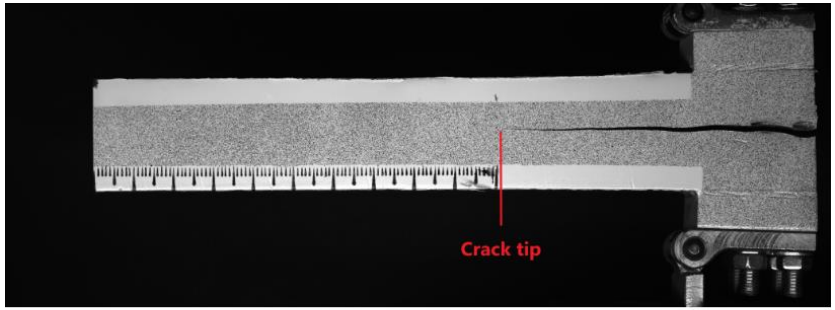
To Dynamic...



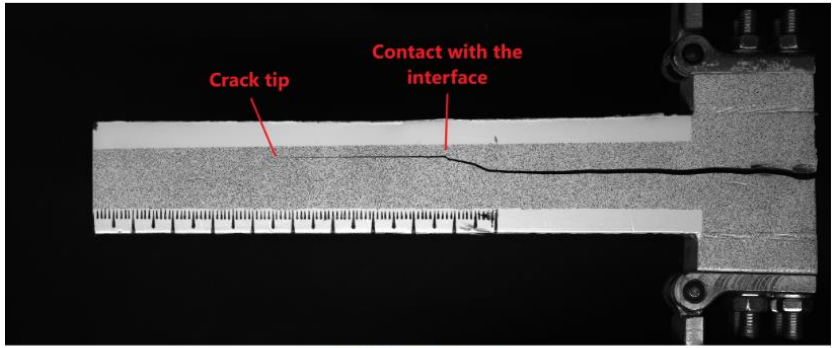


Michigan Technological University, UPSeis

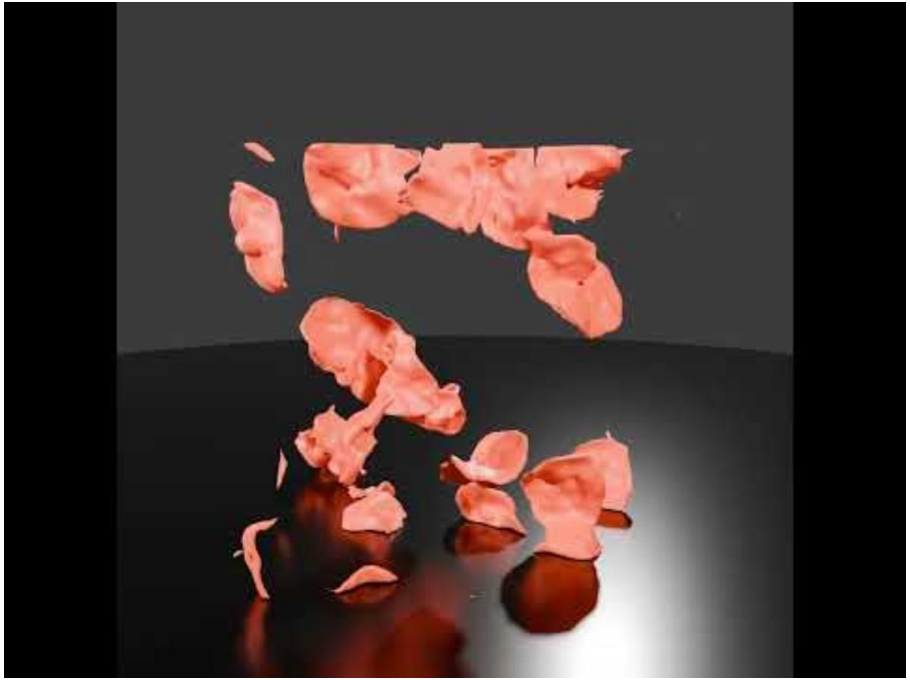
To fracture !



(A) Before crack propagation

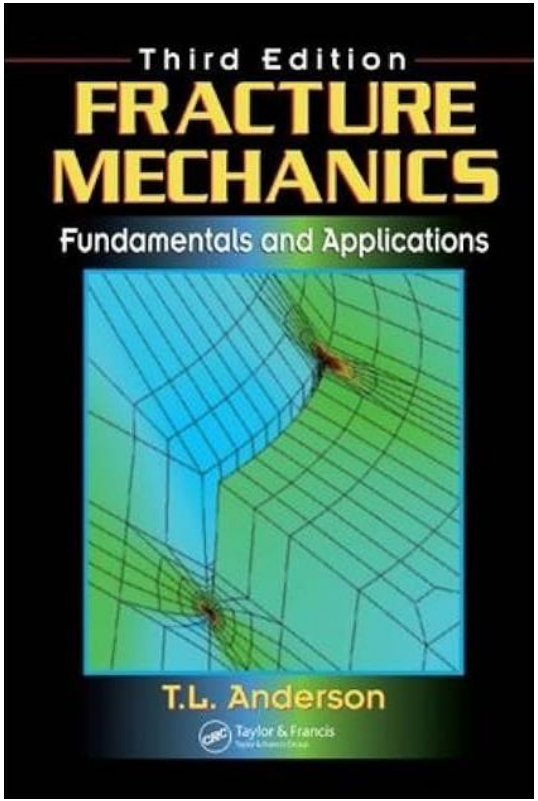


(B) After crack propagation



Fracture mechanics : Reference book

- Fracture mechanics
- T.L. Anderson
- Available at EPFL library and online
  - Be sure to be connected to VPN for accessing online version
  - https://www.epfl.ch/campus/library/



Why do we study fracture ?

- Increase the security of machines and structures with
  - Design
  - Choice of materials

- Historical perspective
  - Roman era
  - Industrial revolution
    - Massive use of metallic structures

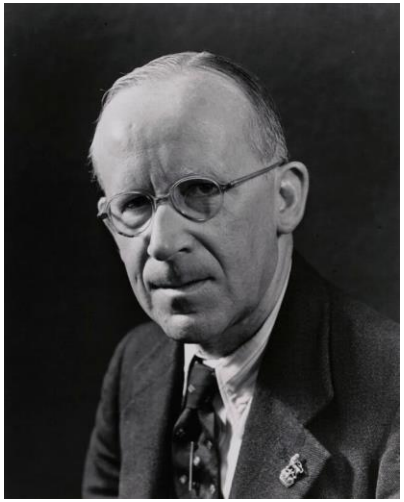
Catastrophic consequences

- Boston Molasses Disaster

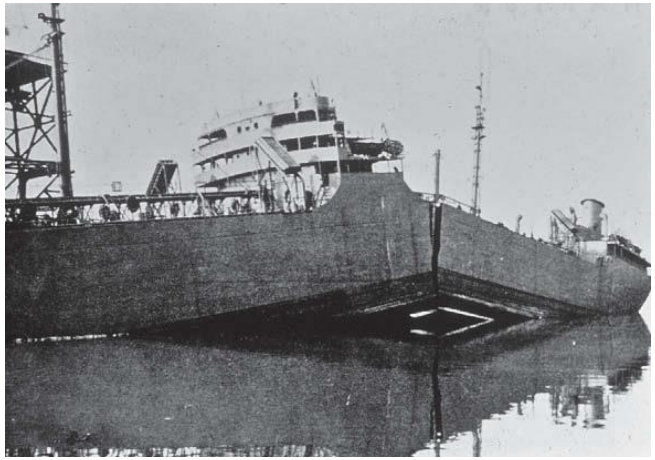
- 200 dead/year due to rupture of axis of wheels in 1920
  - Even recent example : Eschede train disaster (1998)

Significant progresses

- 1920 : Griffith's theory on fracture



- 1939-1945 : The Liberty Ships
  - Two parts of the hull welded in the center
  - Faster building rate
  - Appearance of cracks in the weld



- Multiple reasons identified :
  - Defects in weld
  - Stress concentration
  - Low toughness steel at low temperature

Significant progresses

- 1946 : George Rankine Irwin is made responsible of the project on brittle fracture at the US Naval Research Laboratory
- 1960-1980 : Multiple developments in fracture understanding
- Today : Research is still very active on fractures

Prof. Drezet/Molinari

State of the art

- Defects/Cracks in each structure
  - This does not necessarily imply end of service !

- Nondestructive evaluation methods have been developed

- Balance between cost of reparation and risks
  - Concept of damagae tolerance
  - Need of fracture analysis !