Aalto University
School of Engineering

MEC-E6007 Mechanical Testing of Materials

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March 4, 2024

Mechanical Testing of Materials

Image from "Alice's Adventures in Wonderland" by Lewis Carroll, 1865 (public domain)

Mechanical:

- related to mechanisms or machines
  - *Greek μηχανή = a tool or a device*
- involving forces and motion

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Mechanical Testing of Materials

Testing:

- determining the quality or correctness
  - *from Latin testa (an earthenware pot) by way of the crucibles used for melting metal to see if it was adulterated (cfr.* French *tête* = head)

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Mechanical Testing of Materials

Materials:

- “The stuff that stuff is made of”

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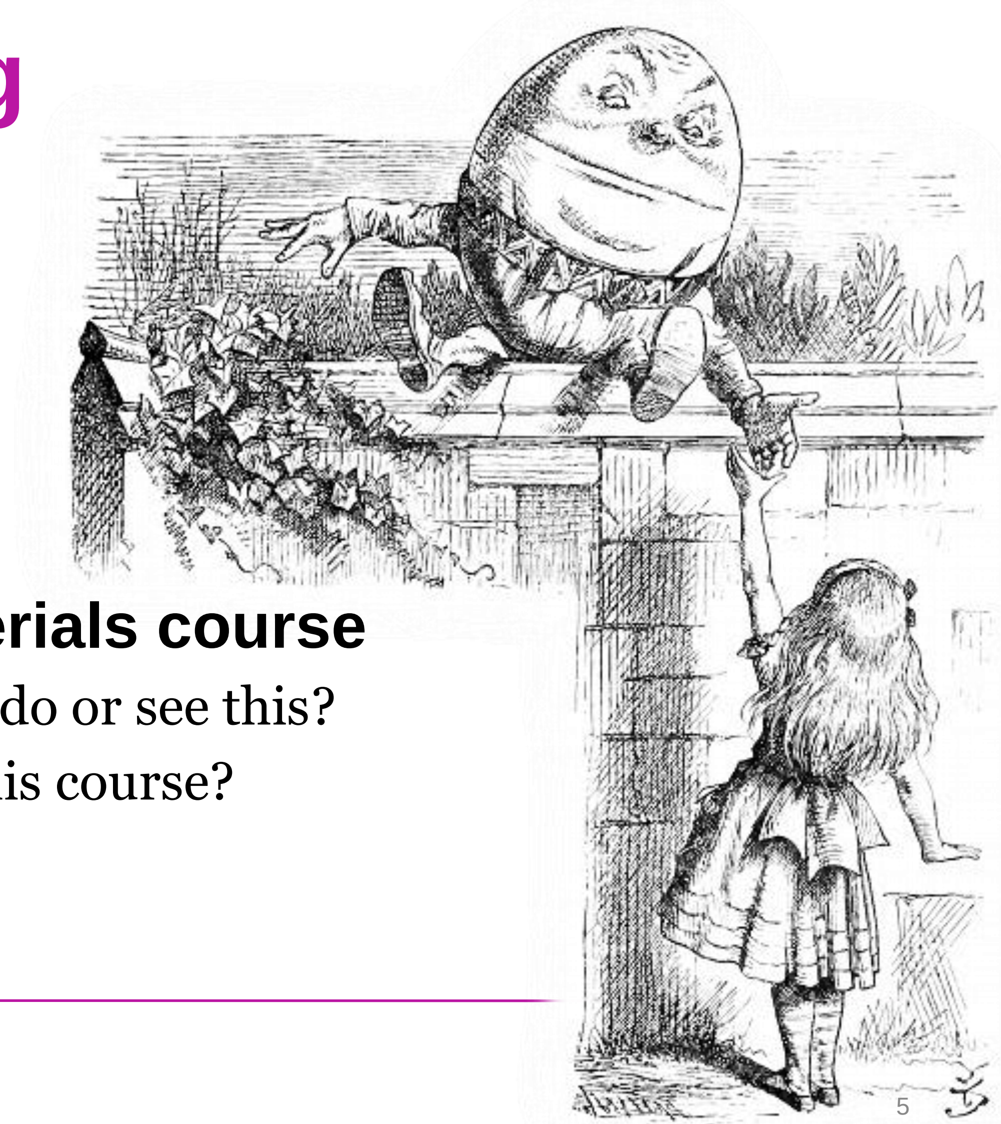
Mechanical Testing of Materials



mechanical testing of materials course

- In what context do you expect to do or see this?
- What do you expect to learn in this course?

http://presemo.aalto.fi/mtom

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Past years' presemo responses for MEC-E6005:
What does engineering materials mean to you?

- "non-bulk" materials, somehow special stuff.
- Materials which work in an efficient way with the engineering problem in hand +1
- Building blocks of modern society
- To find innovative solutions for the current problems
- Materials used in major engineering products
- Engineered materials, materials made "better" by thought and by human labor +2
- Incorporate the usage of material in engineering applications.
- materials for a new and innovative progress
- Materials which help in solving an existing problem which is the basis for engineering +2
- Materials that are used in engineering, and their processing
- The materials which is used for the engineering application by modifying their properties. A material that is widely used in different engineering applications
- Understanding the basic characteristic of commonly used materials in engineering
- Tailoring properties of the elements or combinations on the microstructure level, studying the effects and comparing them to the macro level, exploration and design for new materials

Last year’s presemo responses:

In what context do you expect to see or do mechanical testing yourself?

- I dont have an exact answer for this but for me the interest came from the fact that i have interest in alumina based membranes and carbon nano tubes used for water purification
- Test and measuring the quantities that cannot be measured easily. like force, or small displacements of mechanical devices.
- I have some experience and knowledge on fatigue of materials. So maybe applying tensile load on materials.
- General knowledge for testing different materials, in particular lattice structures.
- Create a new type of composite and test is under mechanical loads
- checking the mechanical properties/behavior of the materials
- I expect to to do and see different mechanical tests in lab conditions. If possible I would be conducting these test or a parts of them myself.
- Investigation the timber beams under bending
- I think it is about test something using mechanics, like by applying forces and analyzing effects.
- Working in the fields of solid mechanics, validating the results from simulations
- Using machines/mechanisms to test the qualities/attributes of materials
- I'm personally sutdying mehcnaical properties of nuclear waste disposal canisters and mehcnical testing is essential for that.
- strength, elasticity, pressure
- Working with the metallurgy department of a manufacturing company, maybe in the future being employed in such a team.

Last year's presemo responses:
What do you expect to learn in this course?

- Learning different methods for mechanical testing
- I think we would learn about different techniques to test materials. We have studied some tests at our bachelor's so I am looking for some new testing techniques.
- Learning more about the testing procedure and devices, also how to examine the mechanical behaviour of materials and structures.
- Methods to perform mechanical testing of materials
- What will be the mechanical testing ine should be done before use it in the practical environment
- I expect to learn about different mechanical testing methods.
- testing methods and techniques. equipment used for them and modern or upcoming innovations in the field of mechanical testing
- DIC method
- I would love to learn different kind of material testings. The relationship between different testing and different material will be very interesting to know.
- The basics of mechanical testing, to have get an understanding of how to tests are done.
- I expect to learn different testing methods and application of those methods to engineering materials research
- More about advanced testing methods such as DIC
- Practical experience in relation to how tests are performed. Writing reports, planning a test.

Learning Outcomes

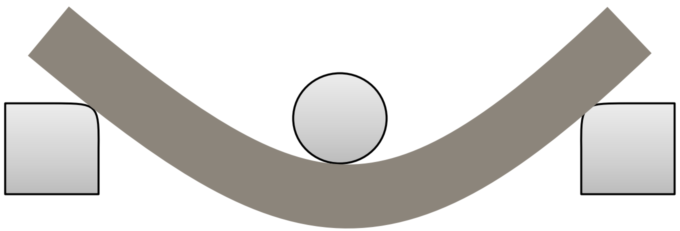
- After the course, the student can
    1. distinguish different purposes of mechanical testing in different contexts
    2. understand the operating principles of typical measurement techniques used in mechanical testing of materials, and the resulting limitations of the techniques
    3. analyze the requirements and possibilities for measurements to characterize the deformation behaviour of materials
    4. compare the specifications of mechanical testing equipment with the requirements of a measurement
    5. recognize and quantify sources of error and uncertainty in measurement results
    6. choose appropriate testing methods in different situations
    7. carry out some standard mechanical tests and evaluate the results
    8. study other methods in mechanical testing independently

Course Content

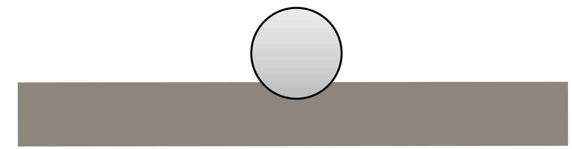
- The course includes theory and practice of mechanical testing, with deeper emphasis on methods used in engineering materials research at Aalto University and on topics of special interest to the students in the course. The target audience includes master's degree students in Mechanical Engineering, in Building Technology, and in Chemical, Biochemical and Materials Engineering, as well as doctoral students.
- Main topics:
  1. measurement of force, displacement, and strain
  2. loadframes, actuators, and grips
  3. quasi-static, dynamic, and cyclic loading
  4. selected special challenges in mechanical testing
  5. digital image correlation and other full-field measurement techniques
  6. introduction to inverse problem methodologies in experimental mechanics

Mechanical Properties

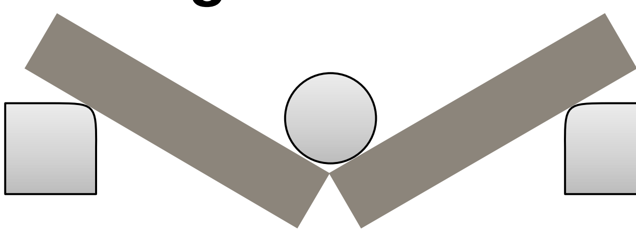
Stiffness



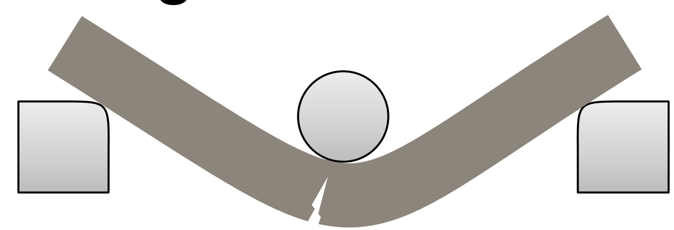
Hardness



Strength

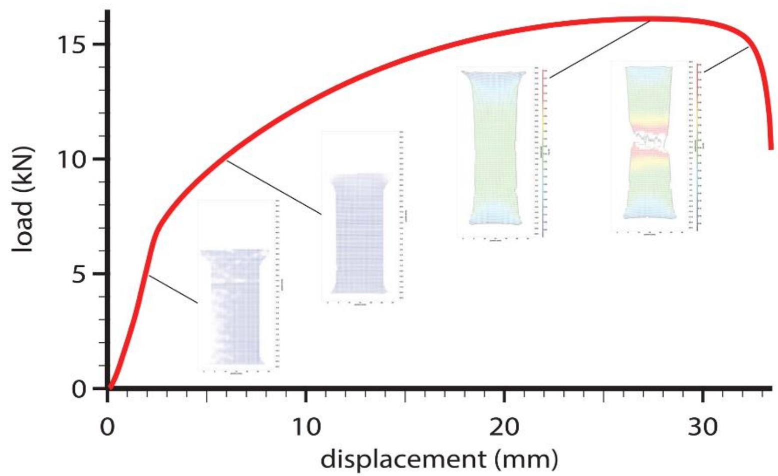


Toughness



Course Content: *learning from breaking things*

- Load
  - *loadframes, actuators, and grips*
  - *quasi-static, dynamic, and cyclic loading*
- Measure
  - *measurement of force, displacement, and strain*
  - *digital image correlation and other full-field measurement techniques*
- Analyse
  - *selected special challenges in mechanical testing (ask for yours!)*
  - *introduction to inverse problem methodologies in experimental mechanics*



Course Concept

lectures with general principles and theoretical background

- *attendance is voluntary*
- *discussion and questions encouraged*
- *glossary of technical terms in English, Finnish, and Swedish*
  - constructed collaboratively in MyCourses

laboratory exercises for hands-on experience

- *feel free to propose bringing your own materials to test*
- *written reports for your own records and for grading*
- *"poster gallery walk" with verbal presentation for discussion and feedback*

case study in lieu of exam

- *about materials testing for your own needs or about published results from others*
- *should demonstrate learning outcomes of the course*

Laboratory Exercises

hardness mapping

- *indentation hardness of metals*
- *variation of microstructure and properties across weld and heat-affected zone*

full-field measurement with digital image correlation

- *specimen geometry resulting in non-uniform strain*
- *trade-off between strain resolution and spatial resolution*
- *compare equipment from different vendors*

“dog-bone” specimen with strain gauges

- *practicalities of specimen gripping to apply load*
- *signal acquisition and measurement accuracy*

Timetable

- weekly lectures
  - *Mondays at 14:15, until March 25 (week 10-13)*
  - *Wednesday, March 6, at 10:15 (travel)*
  - *Thursday, April 4, at 10:15 (spring break)*
- laboratory exercises in weeks 11, 14–15, and 17
  - *March 12–15, April 4–12, and April 22–26*
  - *arranged separately in small groups*
- feedback and discussion week after the exercises
  - *lab reports are due then*
  - *March 27, April 26, and May 10*
- case study due at end of period V
  - *presentations on May 31*
  - *report due June 7*

Practical Issues

Administration

- registration in SISU
  - *limited spaces for lab safety reasons*
- course updates in MyCourses
- submissions in MyCourses

COVID safety

- If you feel sick, stay home!
  - *Individual arrangements can be made as needed*
- Vote for in-person lectures or online

Contact information

- Sven Bossuyt <sven.bossuyt@aalto.fi>
  - *please include course code MEC-E6007 at the start of the subject line*
  - *online "office hours" by appointment*

Assessment criteria

Lab Reports

- conciseness and completeness
- correctness
- clarity
- reflection
- presentation

Case Study

- as for lab reports
- + difficulty and originality

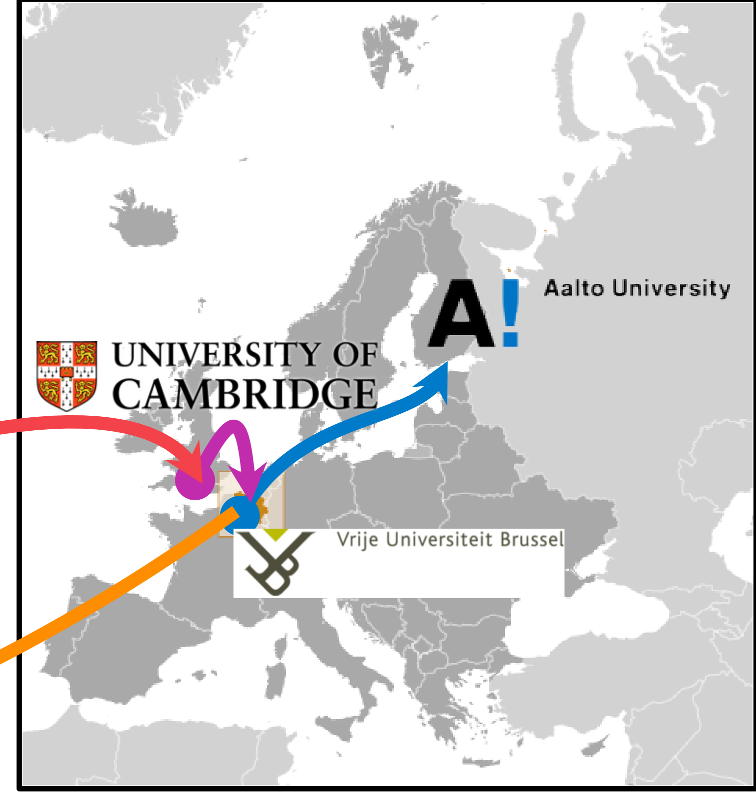
constructive feedback

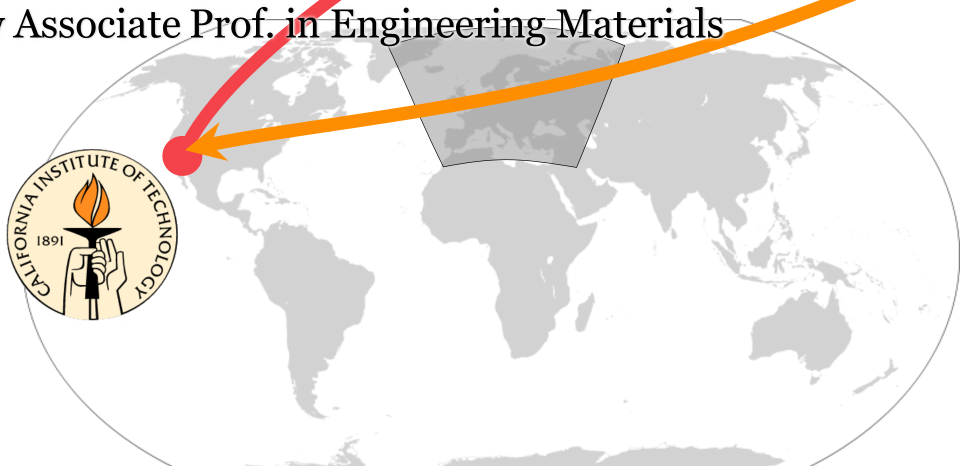
PDF document

This is an extract from a slide set by Päivi Kinnunen about giving and receiving feedback, with a word cloud based on people's descriptions of feedback they found useful, and some concepts about what makes feedback constructive.

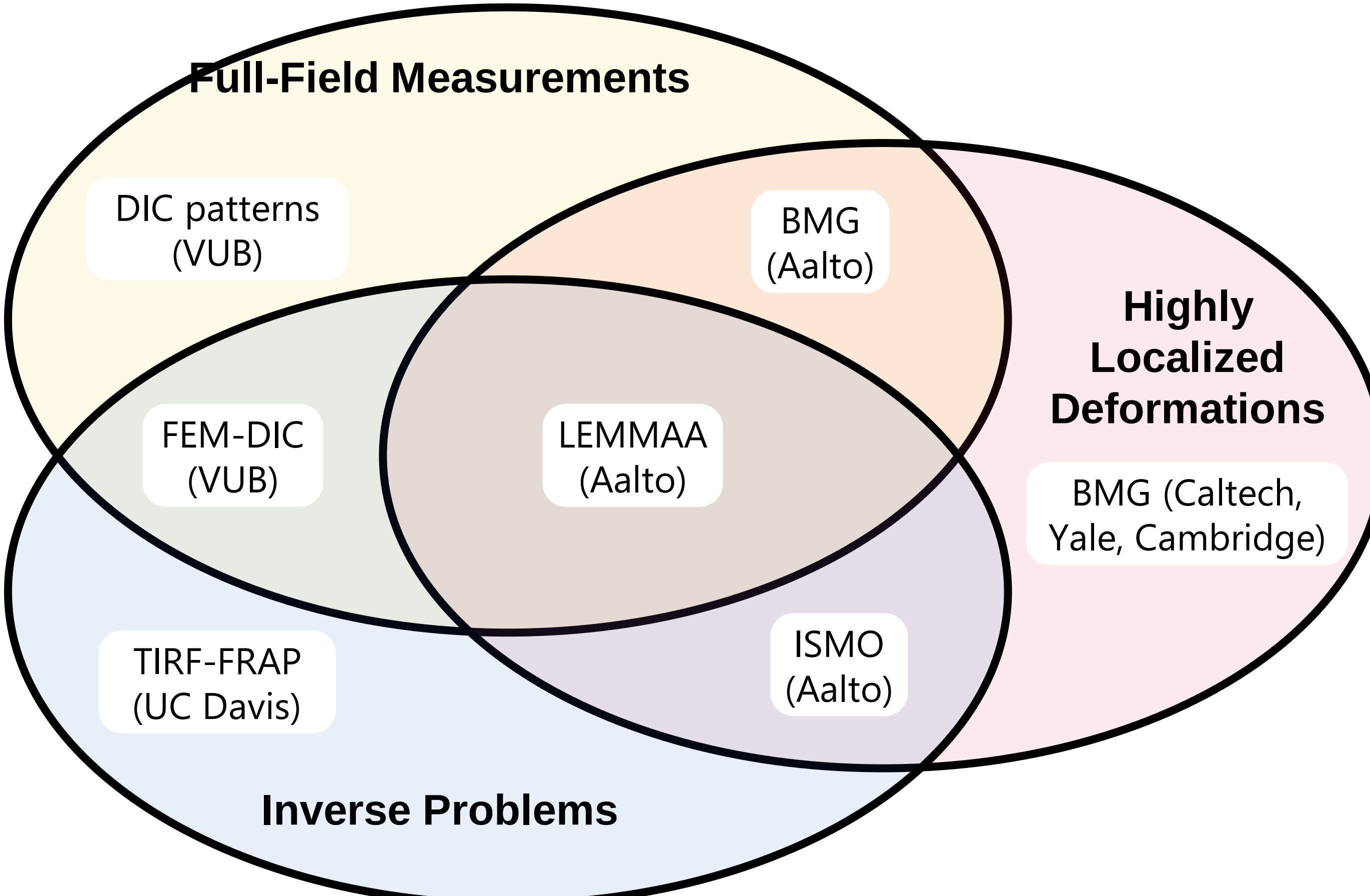
Introductions

- from Belgium originally
  - *Engineering degree in Materials Science*
- Ph.D. in Applied Physics from Caltech
  - *"Crystallization behavior of glass-forming alloys"*
- postdoc in Cambridge
  - *electrochemical de-oxygenation*
- return grant to Belgium
  - *mechanics of materials and constructions*
  - *inverse methods visit TKK institute of mathematics*
- Academy Research Fellow at TKK/Aalto
  - *"Localization Phenomena in Experimental Mechanics Measured using Appropriate Assumptions"*
  - now Associate Prof. in Engineering Materials





Sven's Research:
Multi-Disciplinary and International



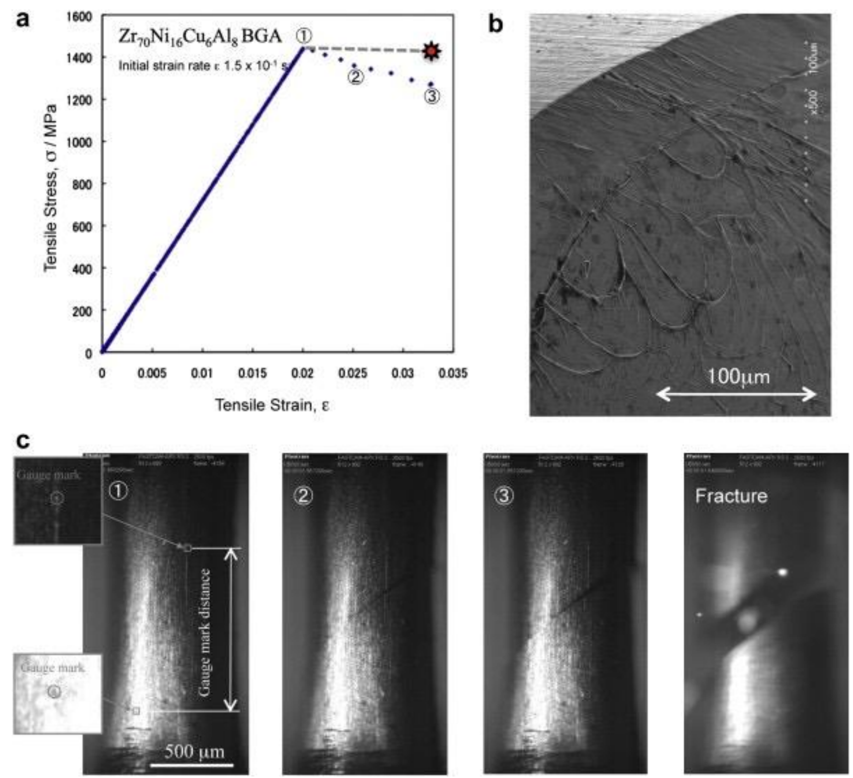
Highly Localized Deformations:
Shear Banding in Bulk Metallic Glasses

BMG's are novel, highly processable materials with ultra-high strength

- net-shape casting or thermoplastic forming
- amorphous atomic structure of liquid retained in solid below glass transition
- microscopically perfect elasto-plastic
- lack of work hardening allows deformation to localize into (~100 nm) narrow bands

experimental challenge to measure highly dynamic highly localized deformation

- universal problem when ultra-high strength reaches theoretical limit
- BMG's as model material for engineering of extrinsic toughening mechanisms in future ultra-high strength materials



Amorphous Metal Alloys

disordered structure

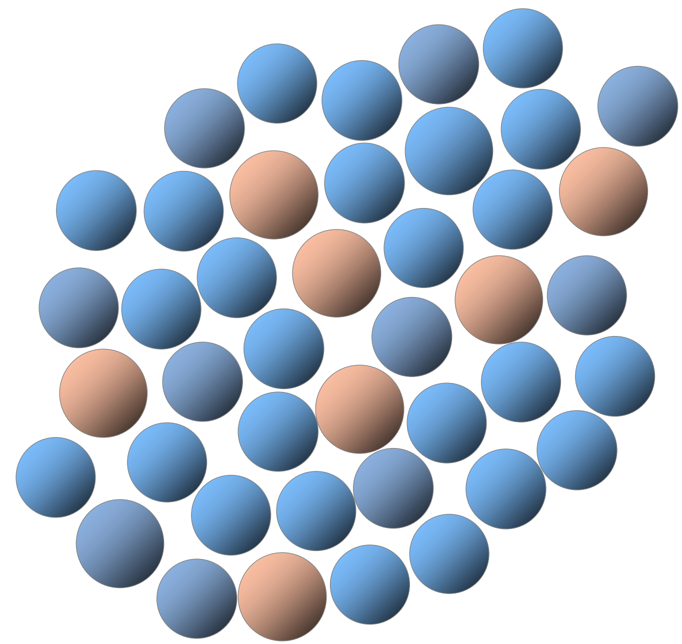
- no long-range order
- equilibrium structure of liquid phase

persists in solid by:

- quenching the liquid
- vapor phase condensation
- electrochemical deposition

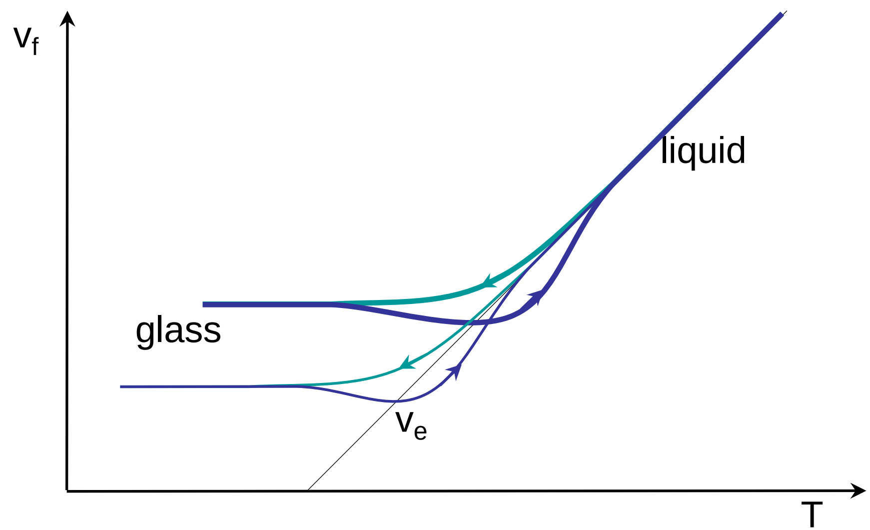
or induced by:

- solid-state amorphization
- mechanical deformation
- ion mixing



Glass Transition

- relaxation time depends on structure
- glass transition depends on cooling rate



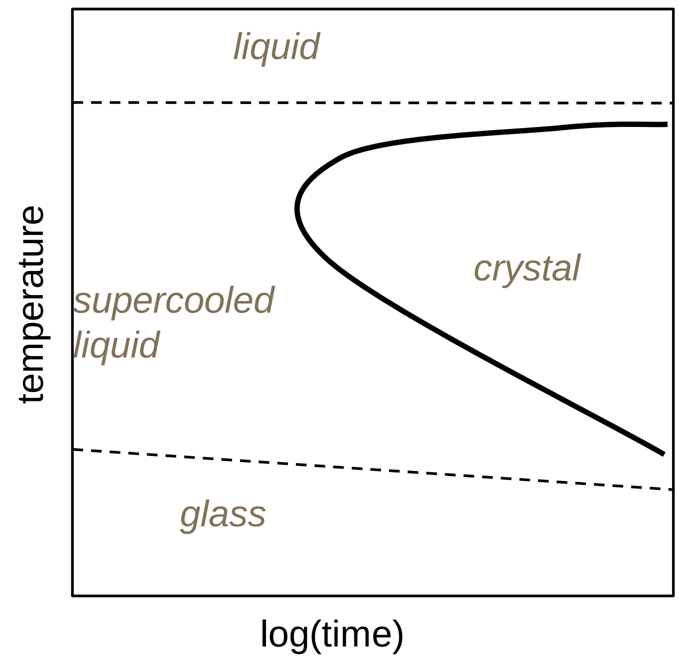
Glass Formation

glass is a liquid cooled below its glass transition

- material behaves as a solid
- atomic structure of liquid is “frozen in”

avoid crystallization

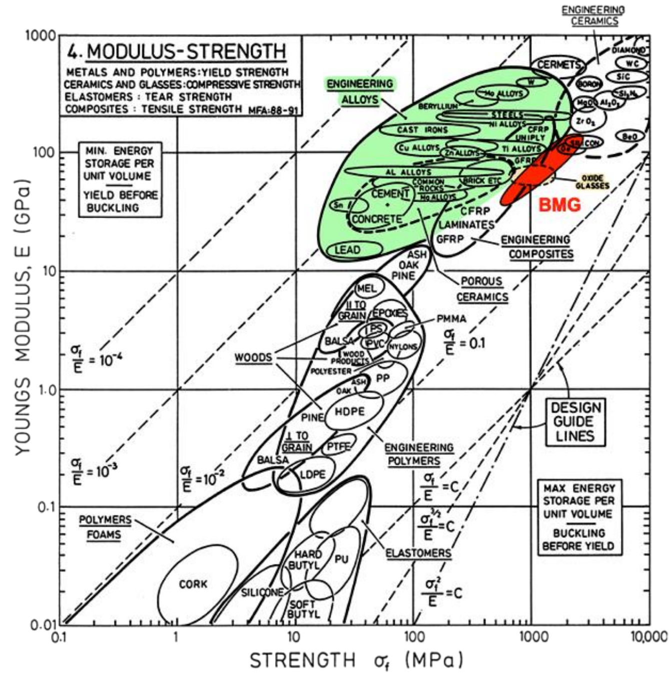
- extremely high cooling rates required for most metals



Mechanical Properties

no dislocations

- high strength
- large elastic strain
- final properties without further heat treatment
- elastic – perfectly plastic
- failure can be catastrophic due to shear localization
- partial crystallization can be used to increase toughness



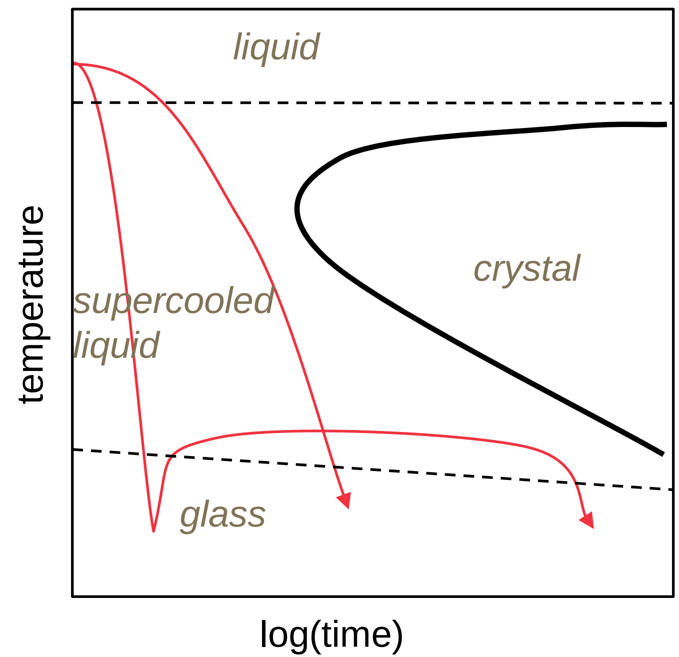
Bulk Metallic Glass Processing

easily shaped in supercooled liquid state

- net-shape forming
- suitable for mass production
- excellent surface finish

die casting

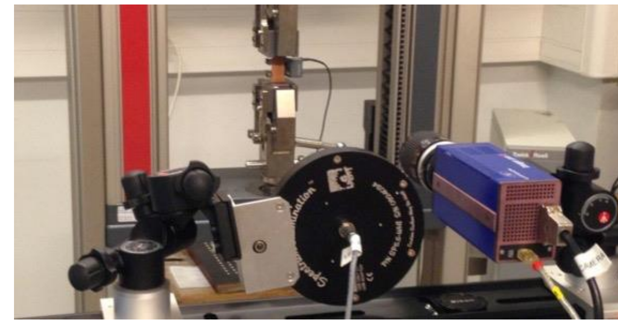
semi-fabricated products



Full-Field Measurements:
Digital Image Correlation

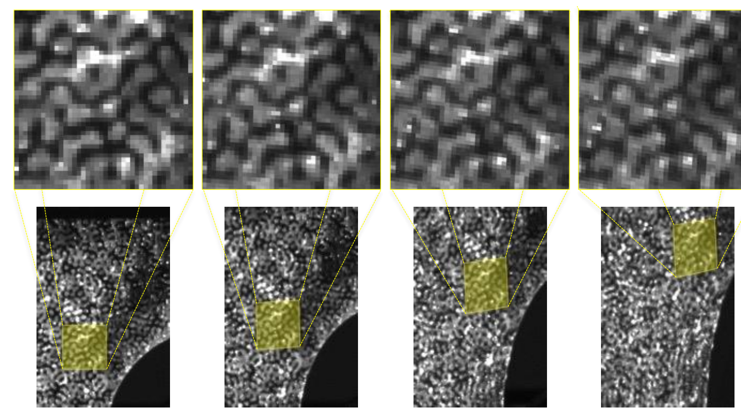
match images of deformed object to reference image of that object

- cross-correlation via FFT
  - *peak amplitude indicates how well it matches*
- Lucas-Kanade
  - *deform reference image with hypothetical displacement fields, then interpolate and calculate sum of squared differences*
- find the displacement field that gives the best match with observed image



advantages:

- instantaneous non-contact optical full-field measurement
- leverage advances in digital cameras and computers
- sub-pixel resolution (due to peak fitting or interpolation)
- 3D displacements from stereo image pairs



t_0 t_1 t_2 t_3

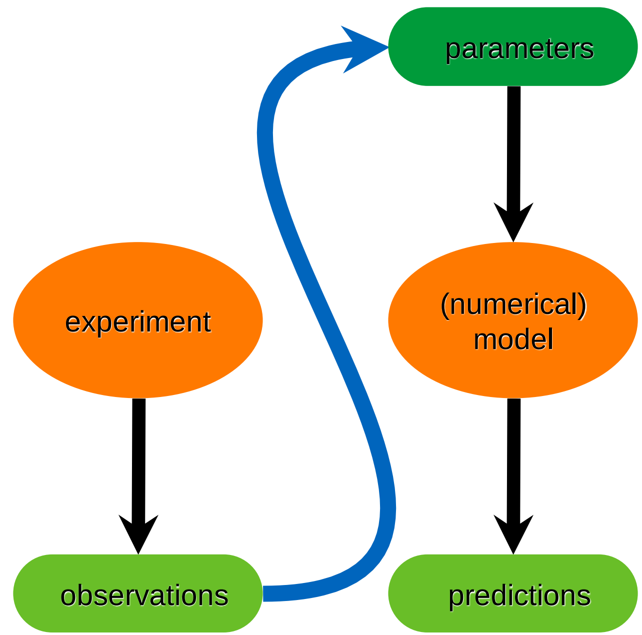
issues:

- calibrating camera geometry and distortions
- contrast and feature spacing in image
- implicit assumptions in algorithm and in discretization method of fields
  - *e.g., cracks and shear bands replaced by unrealistically high but smooth localized strain*

Inverse Problems:
Mixed Numerical Experimental Techniques

determine model parameters from observed data

- forward problem predicts observations for given model parameters
  - *iterative solution to find model parameters that agree with observations*
- inverse problem is often ill-posed
  - *regularisation, preferably using a priori knowledge about actual experiment*



Inverse Problems
in Experimental Mechanics

parameter identification

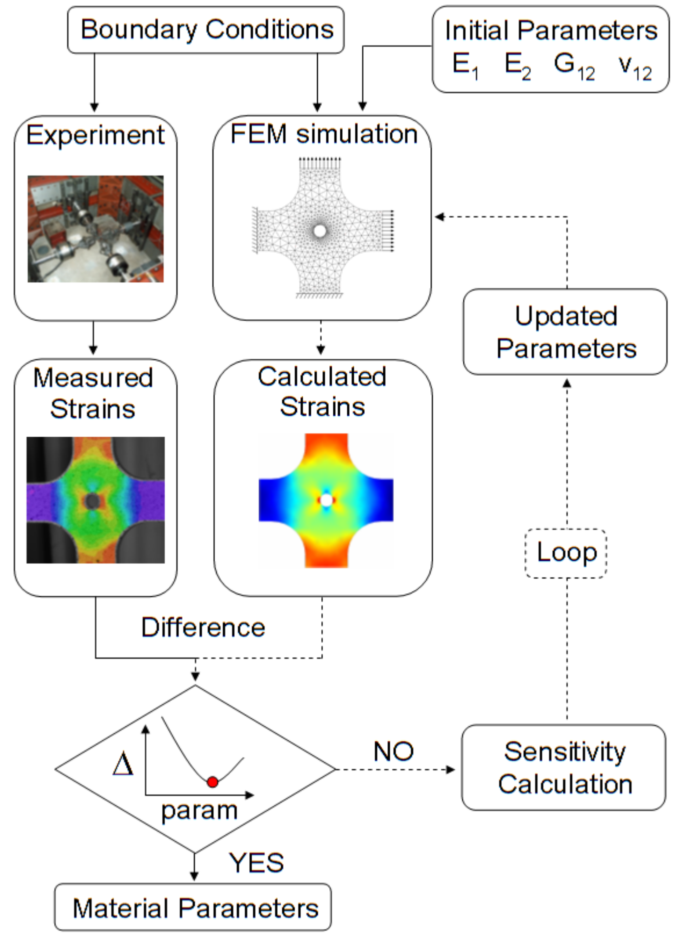
- over-determined
- ill-posed only with non-linearities

full-field measurements

- under-determined
- excessive regularization causes artifacts

forward problems solved by finite element models

- computationally intensive
- shape functions act as regularization
- finer mesh requires more computation and gives less regularization



Roundtable Introductions

I introduced myself

Who are you?

- which degree programme
- previous classes in engineering materials
- prospective employment or research interests
- requests for special challenges

What is your proposed case study?

- why that topic
- how does it relate to other work

Scope of the course

Includes

- basic principles of mechanical testing applicable in different situations
- digital image correlation
- identification of material properties
- some special requests

Excludes

- tribology (friction and wear)
- in-depth coverage of specific issues with
  - *high-speed testing*
  - *fatigue loading*
  - *testing of structures*
  - *specimen preparation*
- except by special request