Material behavior

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Where innovation starts

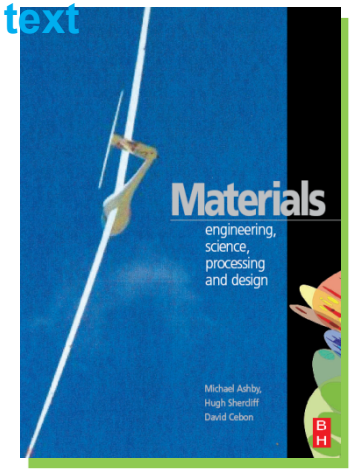
Literature

- M. Ashby, H. Shercliff, D. Cebon, Materials. Engineering, Science, Processing and Design, Elsevier, 2007.
- M. Ashby, Materials Selection in Mechanical Design, Elsevier, 2005.
- W.D. Callister Jr., Materials Science and Engineering. An Introduction John Wiley & Sons, Inc., 2007. (Excellent book)
- M.P. Groover, Fundamentals of Modern Manufacturing, Prentice Hall.

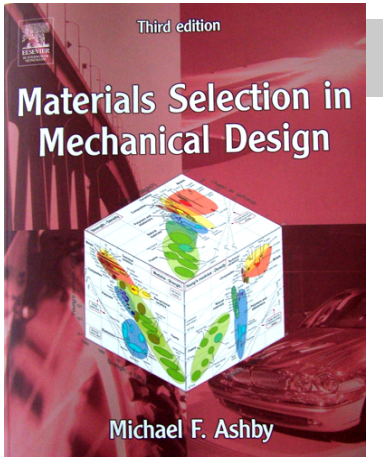
Ashby M.F. literature

- Software

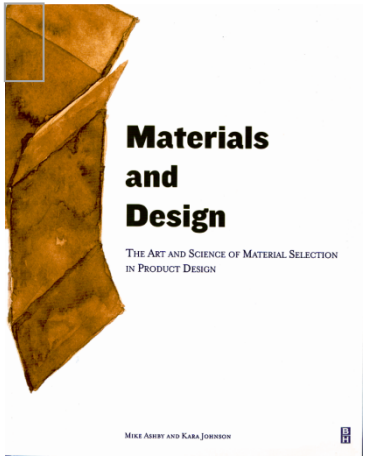
- Elementary text



- Advanced text



- Industrial design text

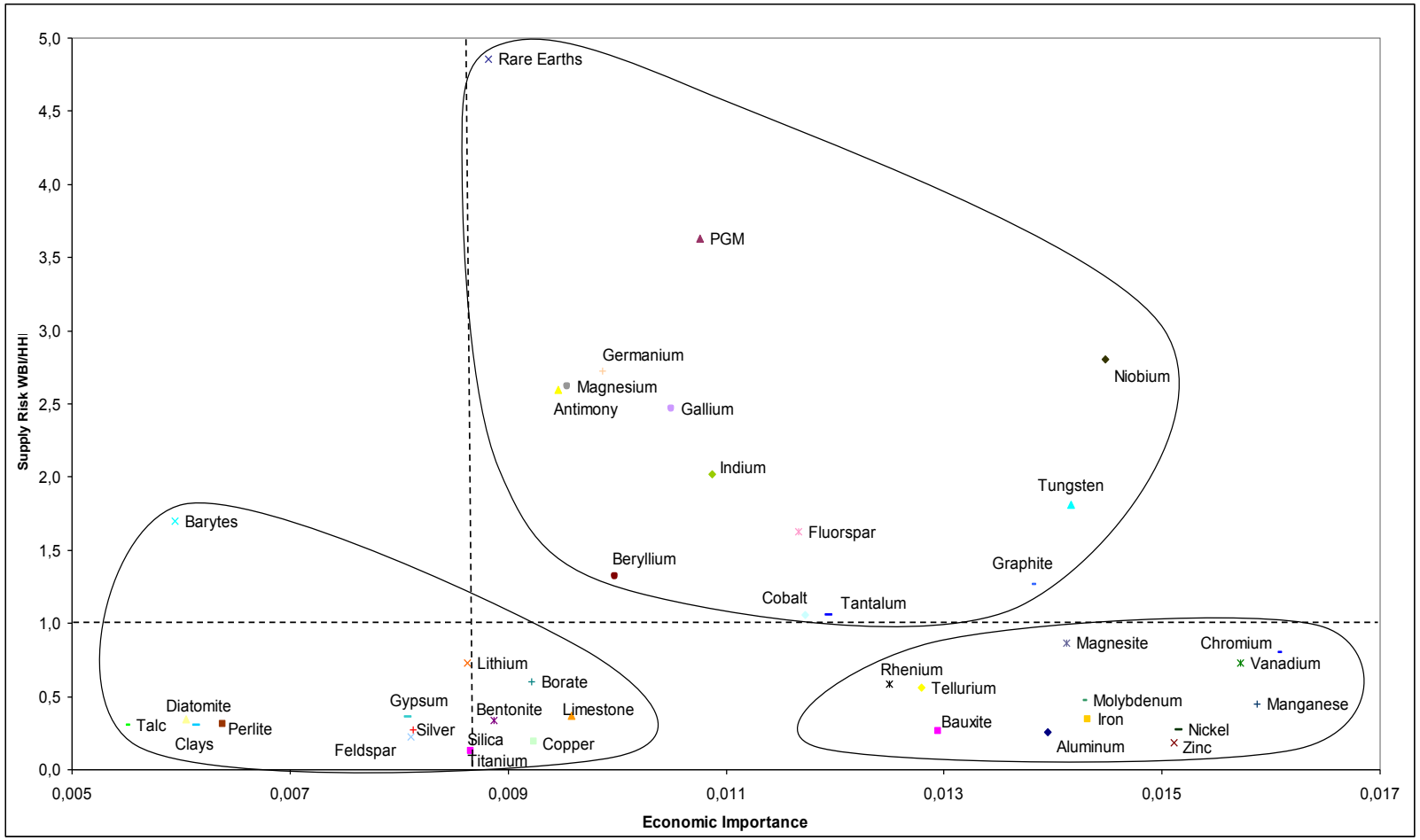


If you think knowledge is expensive, try ignorance.

“The only thing more expensive than education is ignorance.”

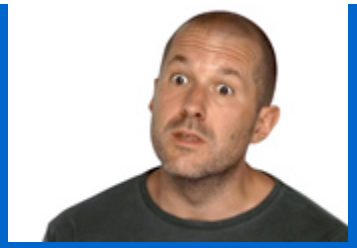
Benjamin Franklin

The economic importance and supply risk of 41 materials (EU MEMO/10/263, 17 June 2010)



Raw material is labelled “critical” when the risks for supply shortage and their impacts on the economy are higher.

Jonathan Ive (Apple), 2010/06/30
On materials and manufacturing



- **"A big part of the experience of a physical object has to do with the *materials*, we experiment with and explore materials, *processing* them, learning about the inherent properties of *the material–and the process of transforming it* from raw material to finished product; for example, understanding exactly how the processes of machining it or grinding it affect it. That understanding, that preoccupation with the materials and processes, is very essential to the way we work."**

First meeting (today)

- Introduction Mechanical Behavior of materials
- Explanation of the experiments to perform
- Assignment literature:
  1. M. Ashby, H. Shercliff, D. Cebon, Materials. Engineering, Science, Processing and Design, Elsevier, 2007. (Pictures available in PPT presentation)
  2. CES EduPack software (http://w3.id.tue.nl/nl/intranet/ict/software/)
     1. Material and Process Selection Charts (PDF)
     2. Material cards (PDF)

Second “meeting”

- No joint meeting but
  - Performance of tensile experiments at Mechanical Engineering (Mr. C. Meesters).
- Perform bending test yourself at the ID Atelier.
  - Do not forget to inform the atelier personnel on beforehand.

Third meeting

- Every group of students (2-3 persons) presents:
  1. The topics studied from:
     - M. Ashby, H. Shercliff, D. Cebon, Materials. Engineering, Science, Processing and Design, Elsevier, 2007
  2. The experience gained from the experiments
     - Not your choice of material for the product!
- Hand in the report with an individual material choice for the product

Fourth “meeting”

- No joint meeting.
- Individual interviews (+/- 15 minutes)
  - Material behaviour in general
    - What did you learn?
    - Can you apply it?
  - Your choice of material for the product chosen

Programme today

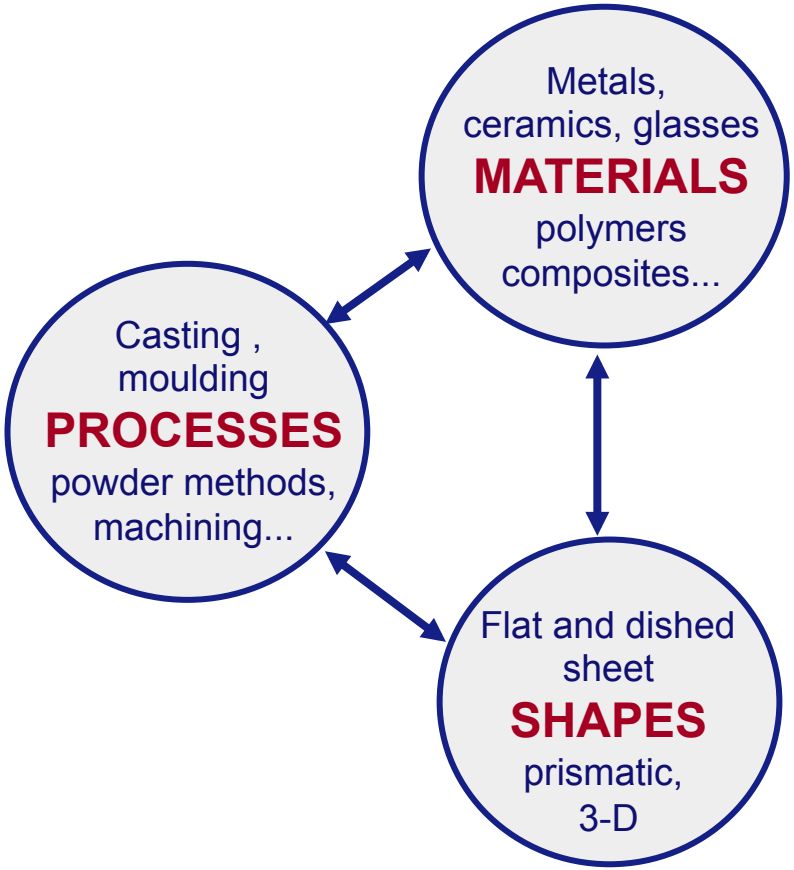
- Goal
- Introduction.
- Examples of visible material behavior
- Material behavior and properties in general
- Material testing
  - Tensile test
  - Bending test
- Desired material properties
- Conclusion

Goal:

- Study the behavior and properties of 5 different materials
  - Perform relevant measurements
- Choose the most suitable material for a car body
  - Extensively justify your choice of material

Material behavior and properties

Material & processes & shapes interactions



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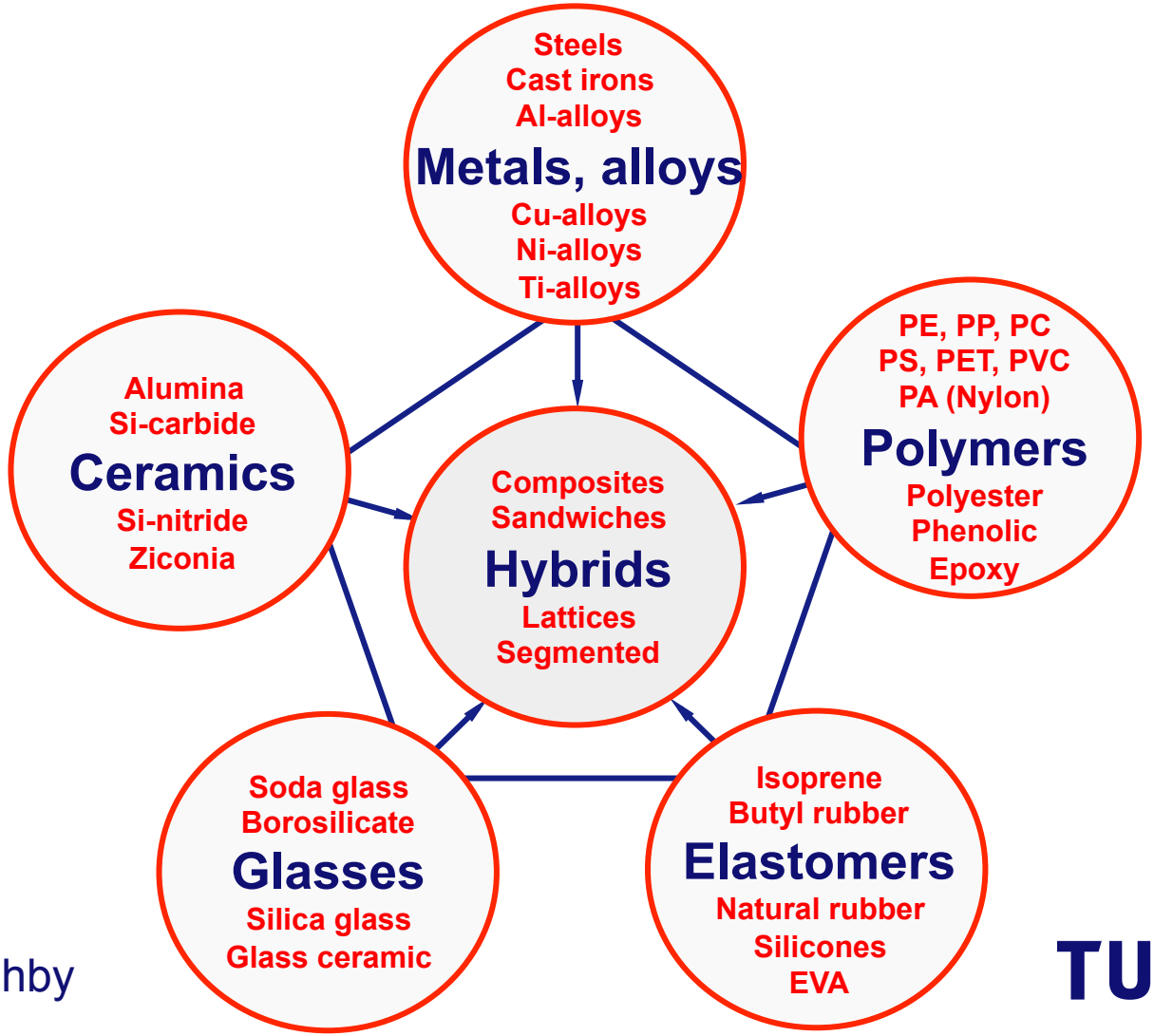
Material classes



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Material properties and behavior

All materials react, when loaded, by deforming!

Elastic material behavior

- Material deformation under moderate loads is reversible:
  - When removing the load the deformation disappears!
  - This is called elastic deformation

- Examples:
  - rubber but also steel or ceramics

Plastic material behavior

- Above a certain load an *irreversible* deformation will be generated
  - The so-called *plastic* deformation
  - After the elastic deformation!

- When removing the load after plastic deformation
  - The plastic deformation stays! (manufacturing!!)
  - The elastic deformation disappears

Material failure

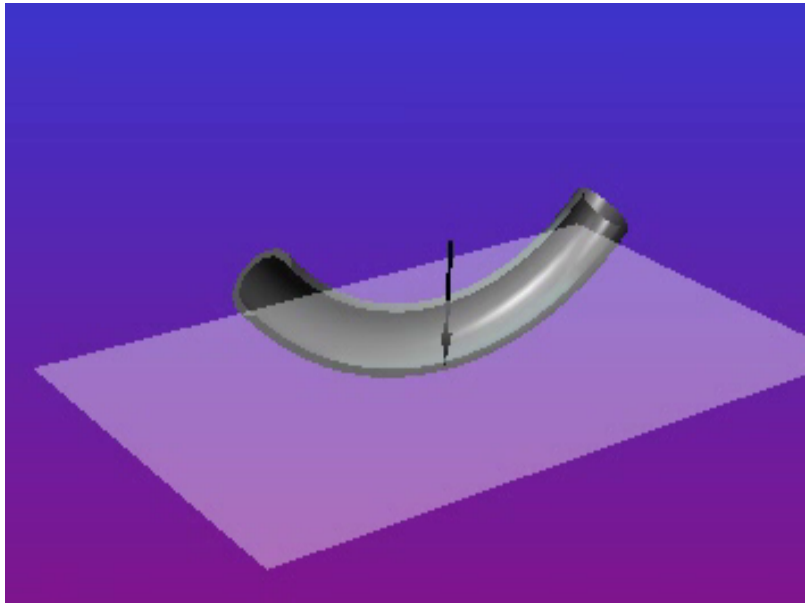
- Above a certain plastic deformation the material fails
  - Is material type dependend!
    - Metal, ceramic, polymer, elastomer, hybrid
  - Is load type dependend
    - Tension, compression, bending, torsion, cyclic loading

Material behavior recapitulation

Always the sequence:

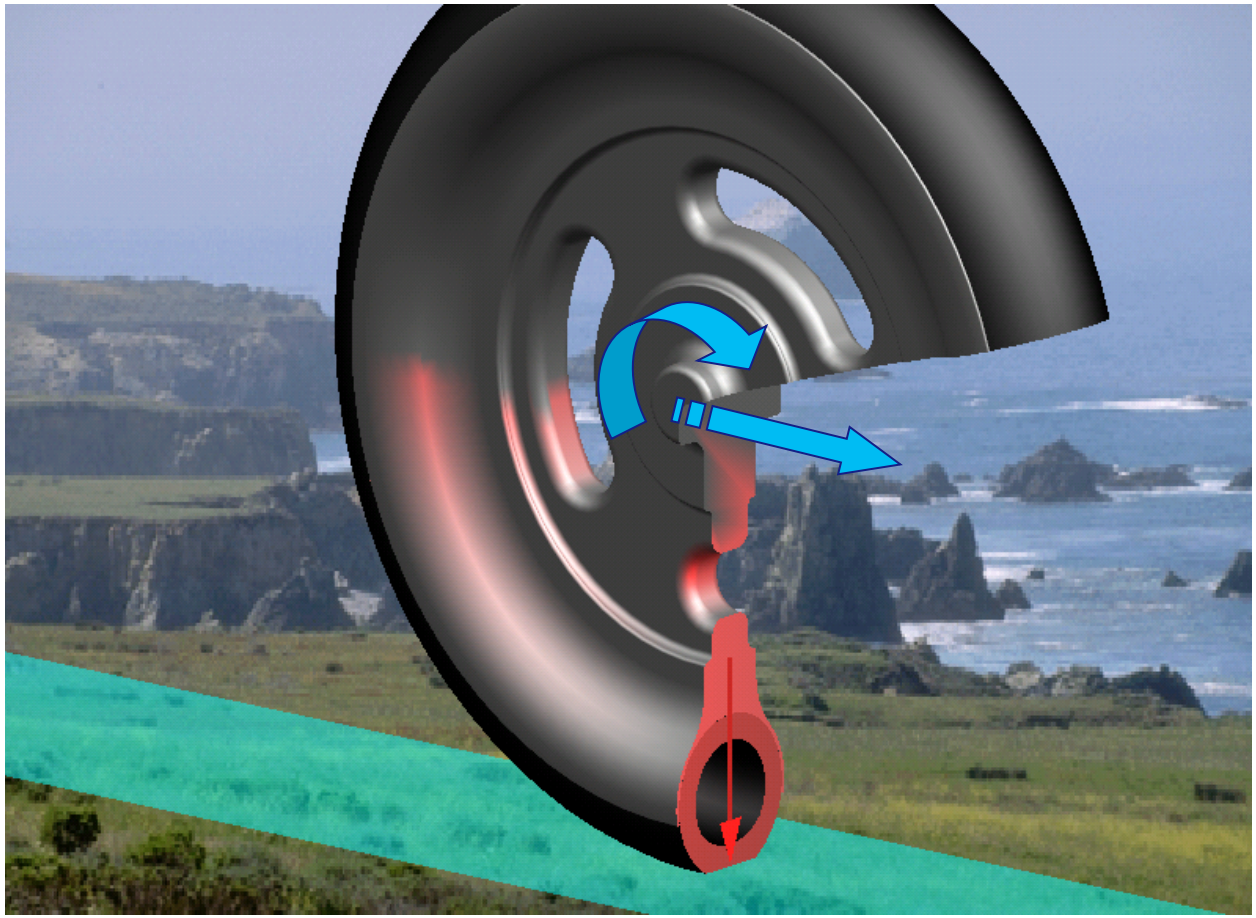
1. Elastic deformation
2. Plastic deformation
3. Failure

Example of a desirable elastic product property: a car tyre



- A tyre deforms elastically
- No point contact
  - A larger contact surface
  - Point contact → infinite stress→ failure
- +Friction

Thus traction!



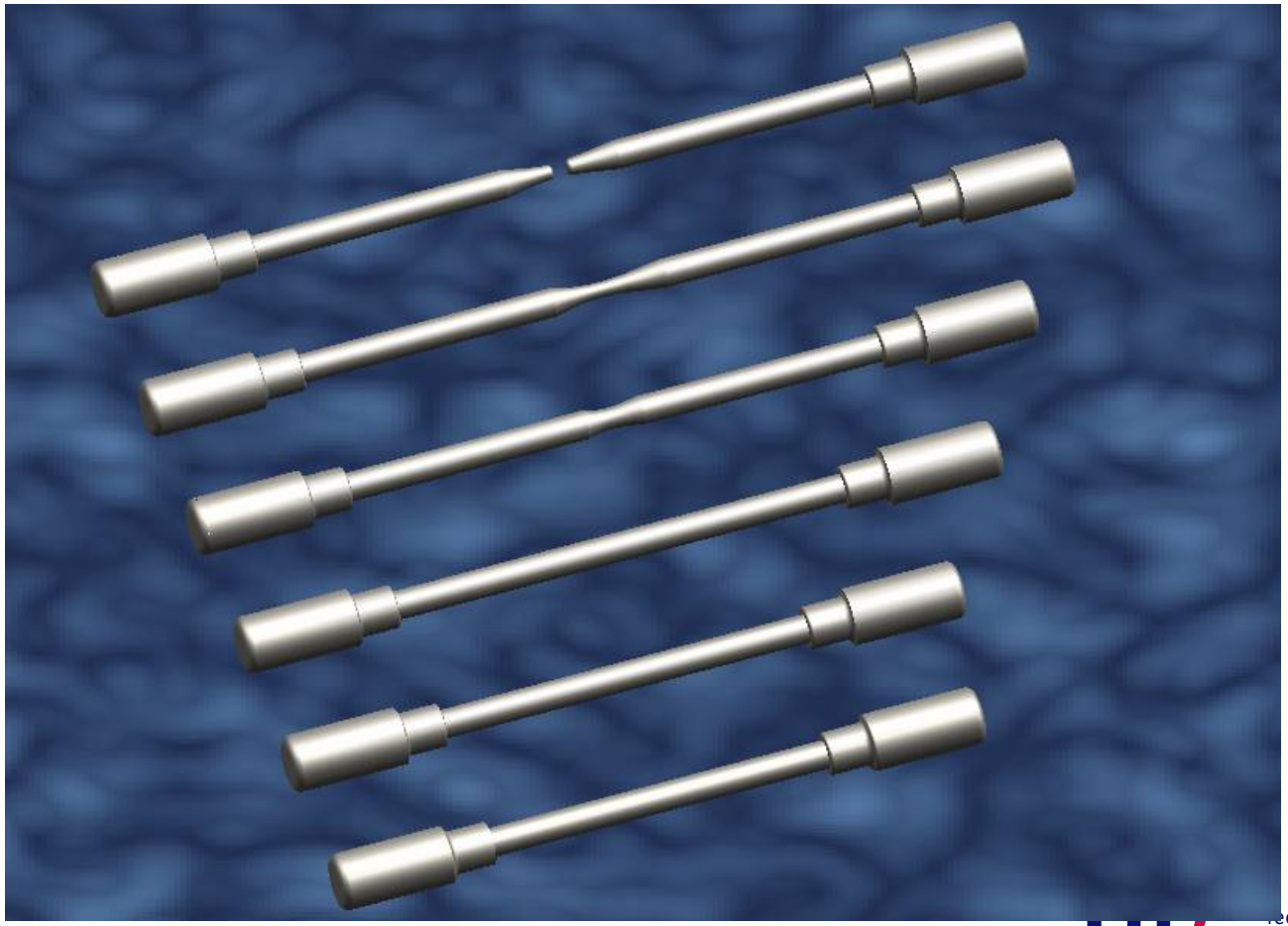
Mechanical material behavior

Mechanical material behavior is:

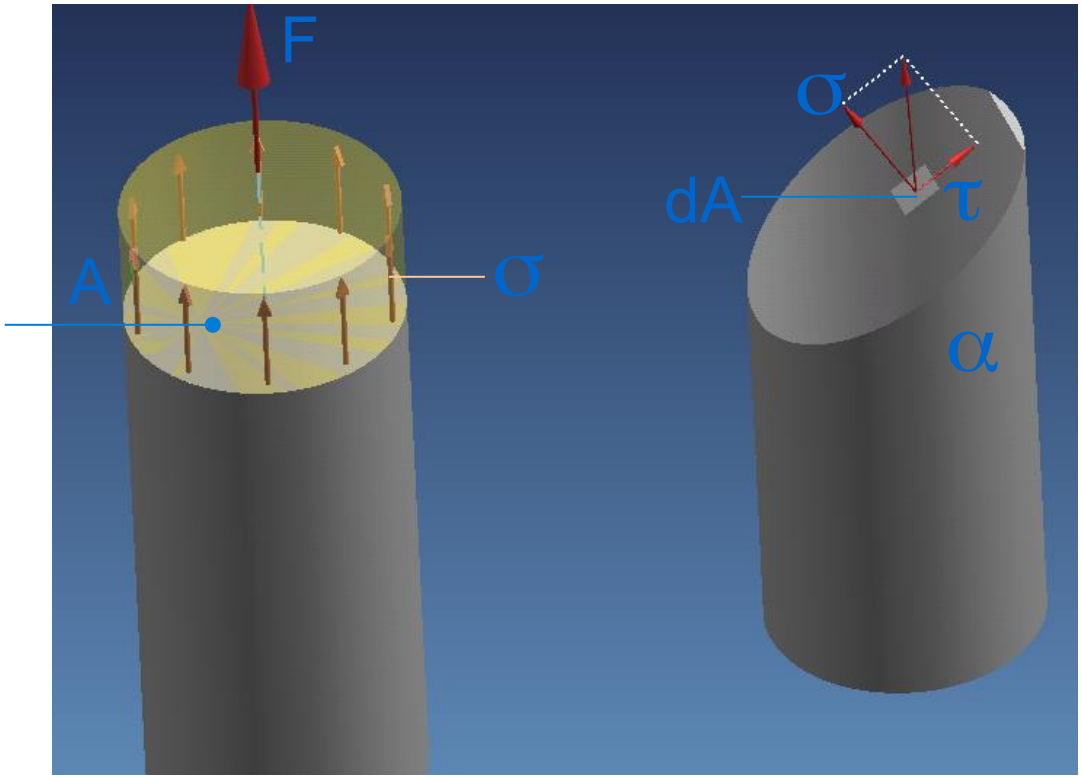
the relation between

- **The load on the material**
- **and the resulting deformation or failure**

Tensile properties



Stress



Normal stress:

$$\sigma = \frac{F_{normal}}{A_{normal}} \text{ in } \frac{N}{m^2}$$

Shear stress:

$$\tau = \frac{F_{shear}}{A_{shear}} \text{ in } \frac{N}{m^2}$$

$$\tau = \frac{F_{normal} \cdot \sin\alpha}{A_{normal} / \cos\alpha}$$

$$= \sigma \sin\alpha \cdot \cos\alpha$$

$$\tau_{45^0} = \frac{\sigma}{2}$$

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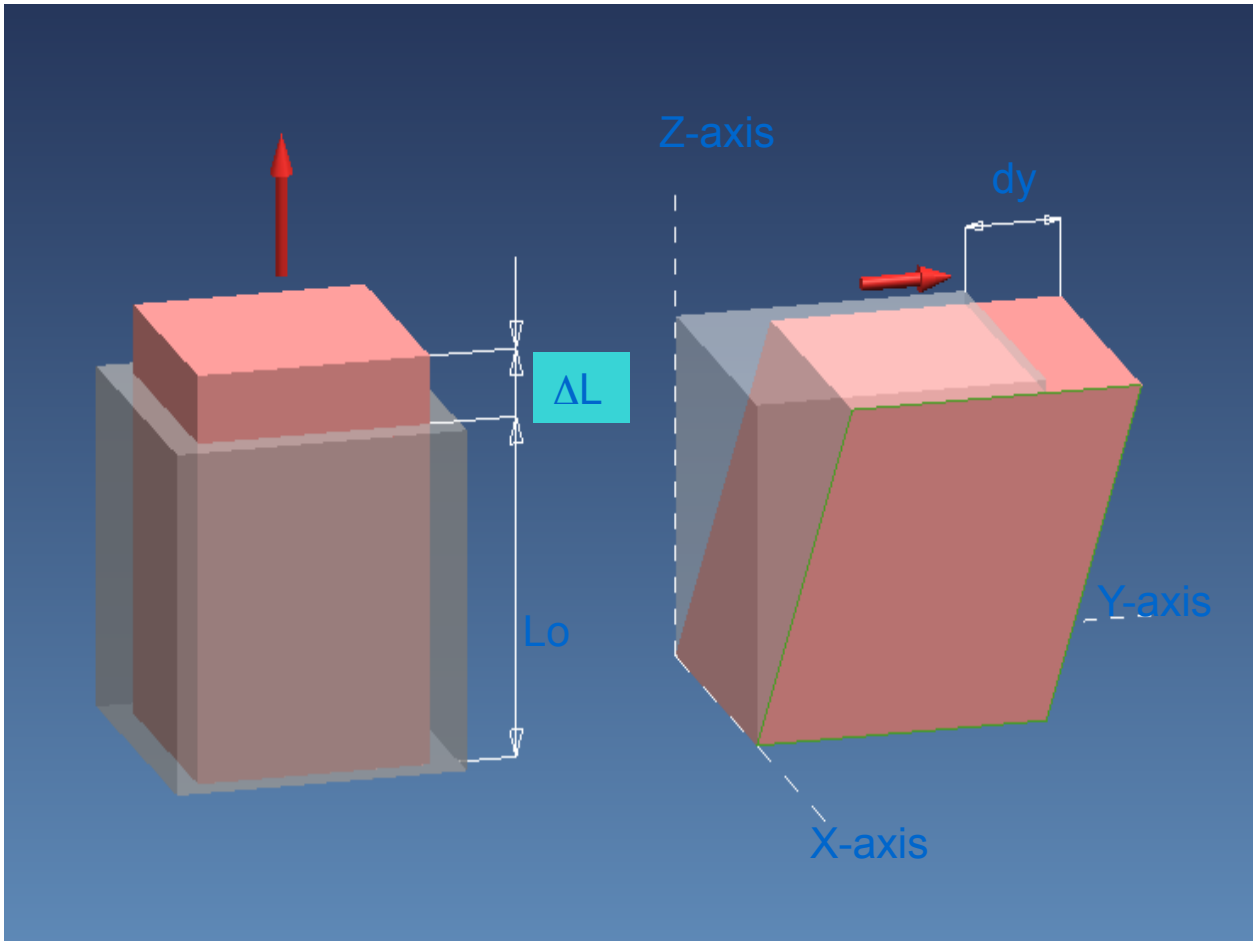
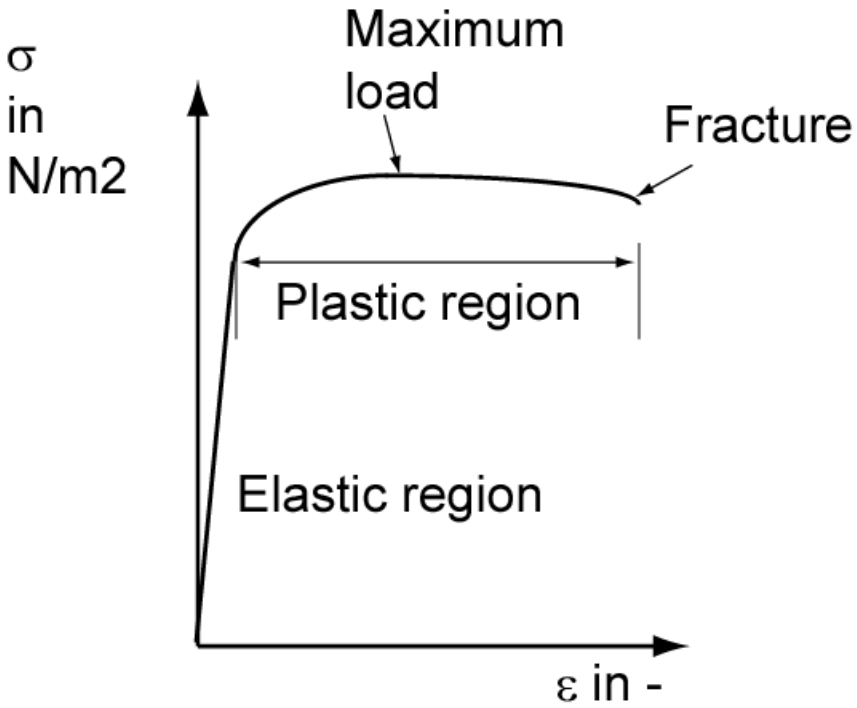
Strain

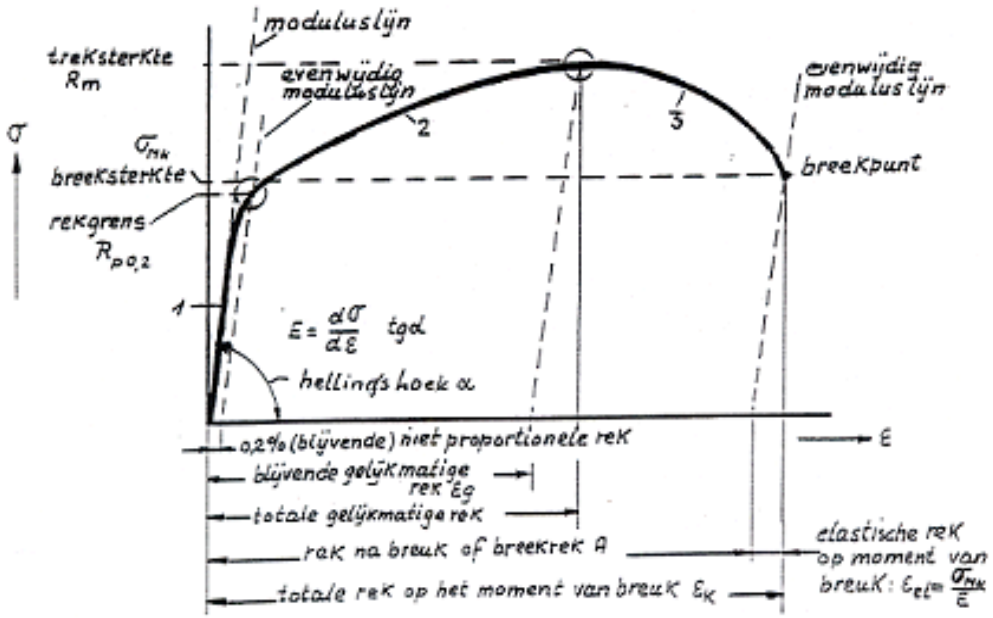


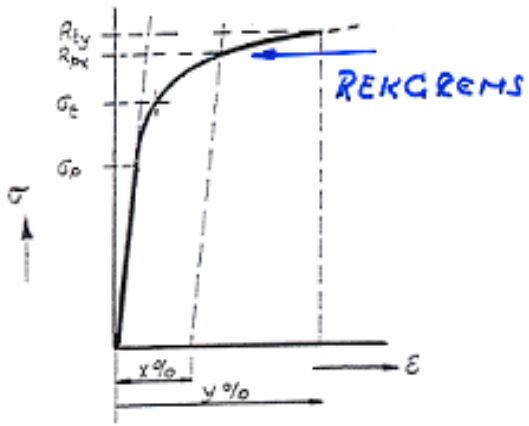
$$\varepsilon = \frac{\Delta L}{L_0} \text{ in } -$$

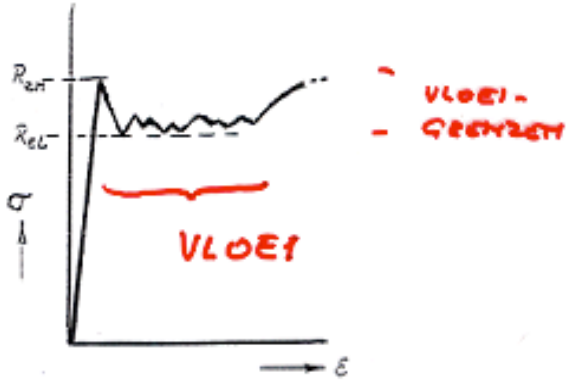
$$\text{tg}\,\gamma = \frac{dy}{dz} \text{ in } -$$

Tensile test

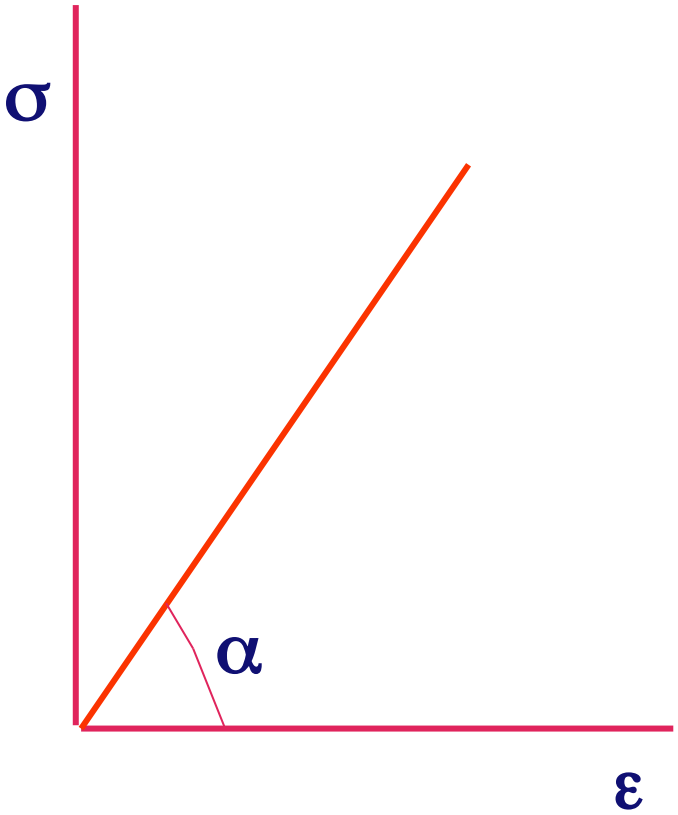



modulus lijn
treksterkte
Rm
evenwijdig modulus lijn
evenwijdig modulus lijn
σ
σmk
breeksterkte
breekpunt
rekgrens
Rp0,2
1
2
3
E = dσ/dε tgα
hellingshoek α
0,2% (blijvende) niet proportionele rek
ε
blijvende gelijkmatige rek εg
totale gelijkmatige rek
rek na breuk of breekrek A
elastische rek op moment van breuk: εel = σmk/E
totale rek op het moment van breuk εk


Rty
Rpk
σt
σp
σ
REKGRENS
x %
y %
ε


ReH
ReL
σ
VLOEI-GRENZEN
VLOEI
ε

Relation normal stress and strain (in the elastic region)



$$\sigma = E \cdot \varepsilon$$

$$E = \tan \alpha$$

- E (N/m^2)
  - Modulus of elasticity (Young's modulus)
  - Material property

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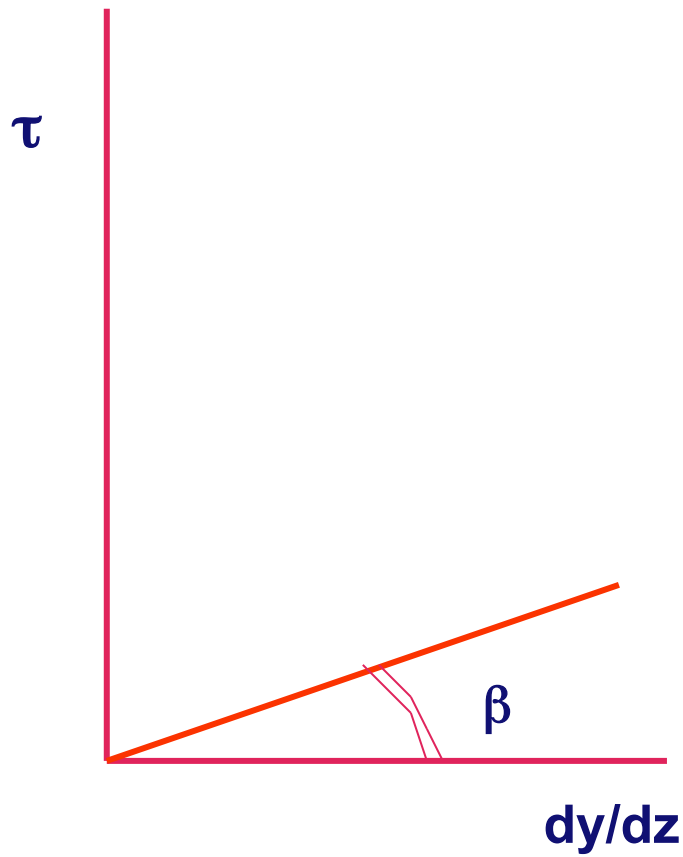
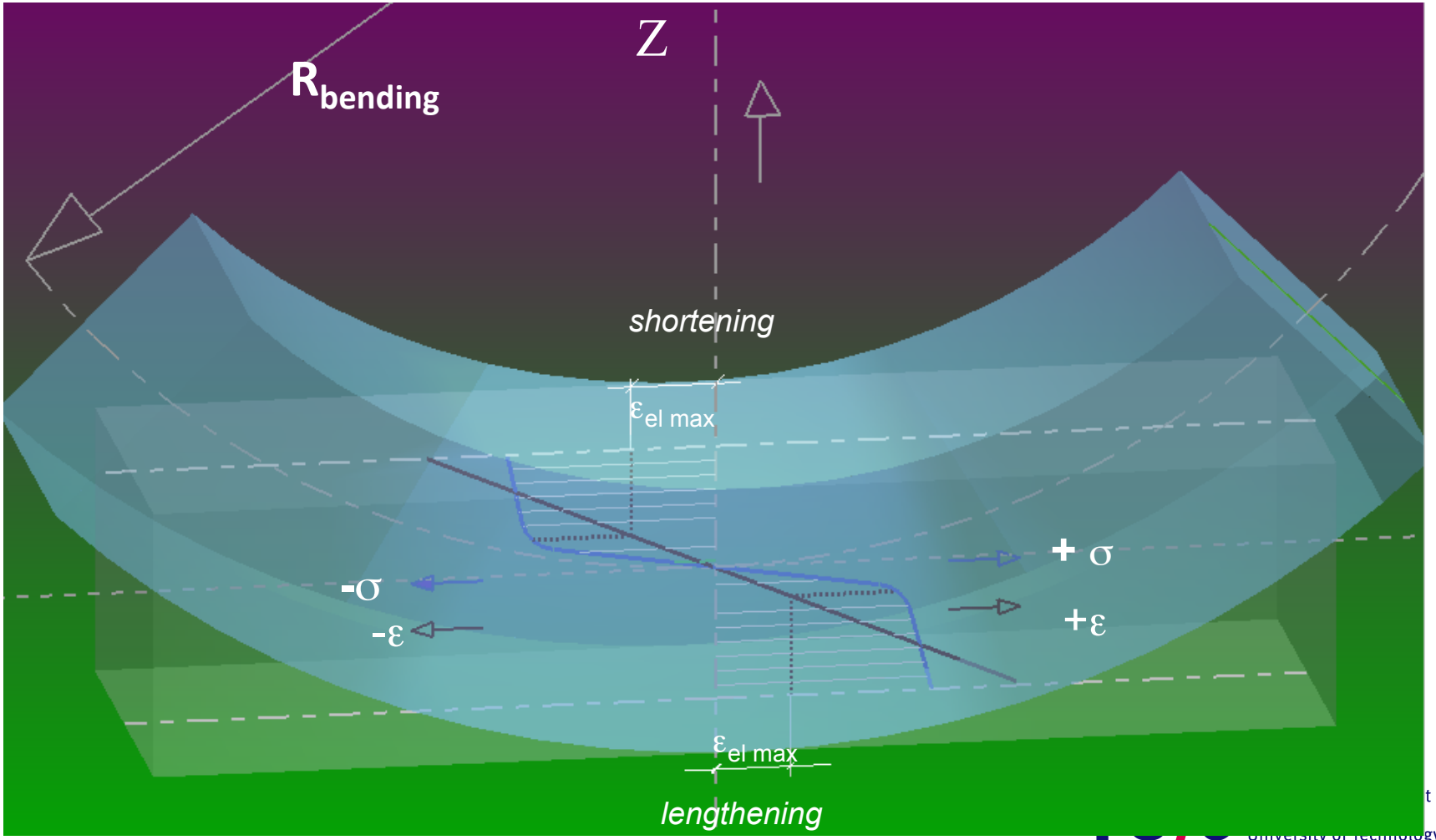
Relation shear stress and shear strain (in the elastic region)



Bending, stress and strain



In general only 4 very important mechanical material properties

1. Strength
   - Specific resistance to deformation
2. Toughness
   - Plastic deformation until failure
3. Stiffness
   - Ratio between stress and strain (in the elastic region)
4. Wear

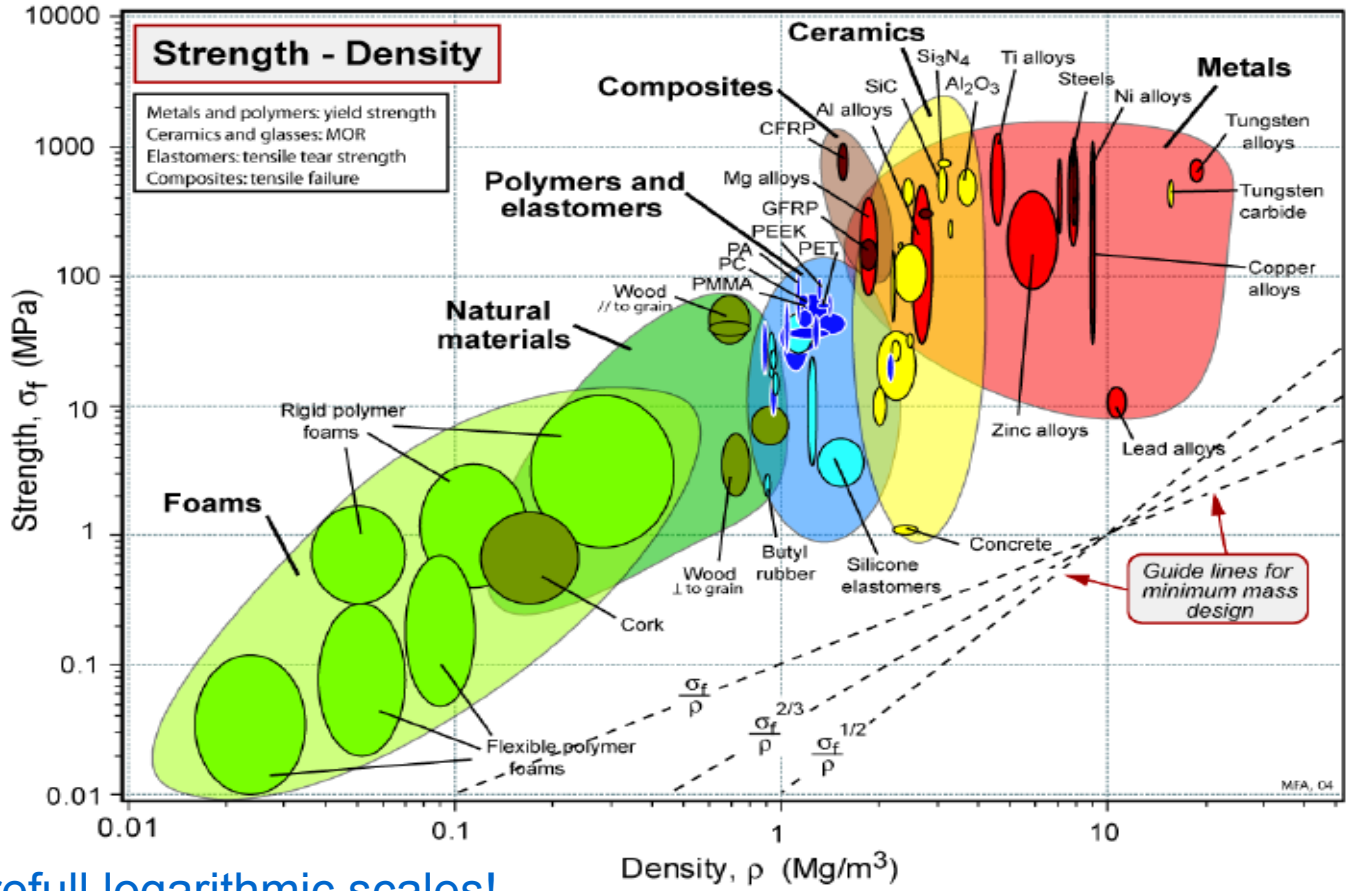
Mechanical quantities

- Are defined based on their test methods
  - Tensile tests
    - E modulus, tensile loading, plasticity, failure
  - Bending tests
    - E-modulus, tensile/compression/shear loading, plasticity, failure
  - Hardness tests
    - Resistance against wear
  - Brittleness tests
    - Failure
  - Fatigue tests
    - Failure under dynamic loading

Very important mechanical properties

1. Strength:
   - Strong versus weak
2. Toughness:
   - Tough versus brittle (<2% strain)
3. Stiffness:
   - Stiff versus not stiff
4. Wear

Material properties charts



Be carefull logarithmic scales!

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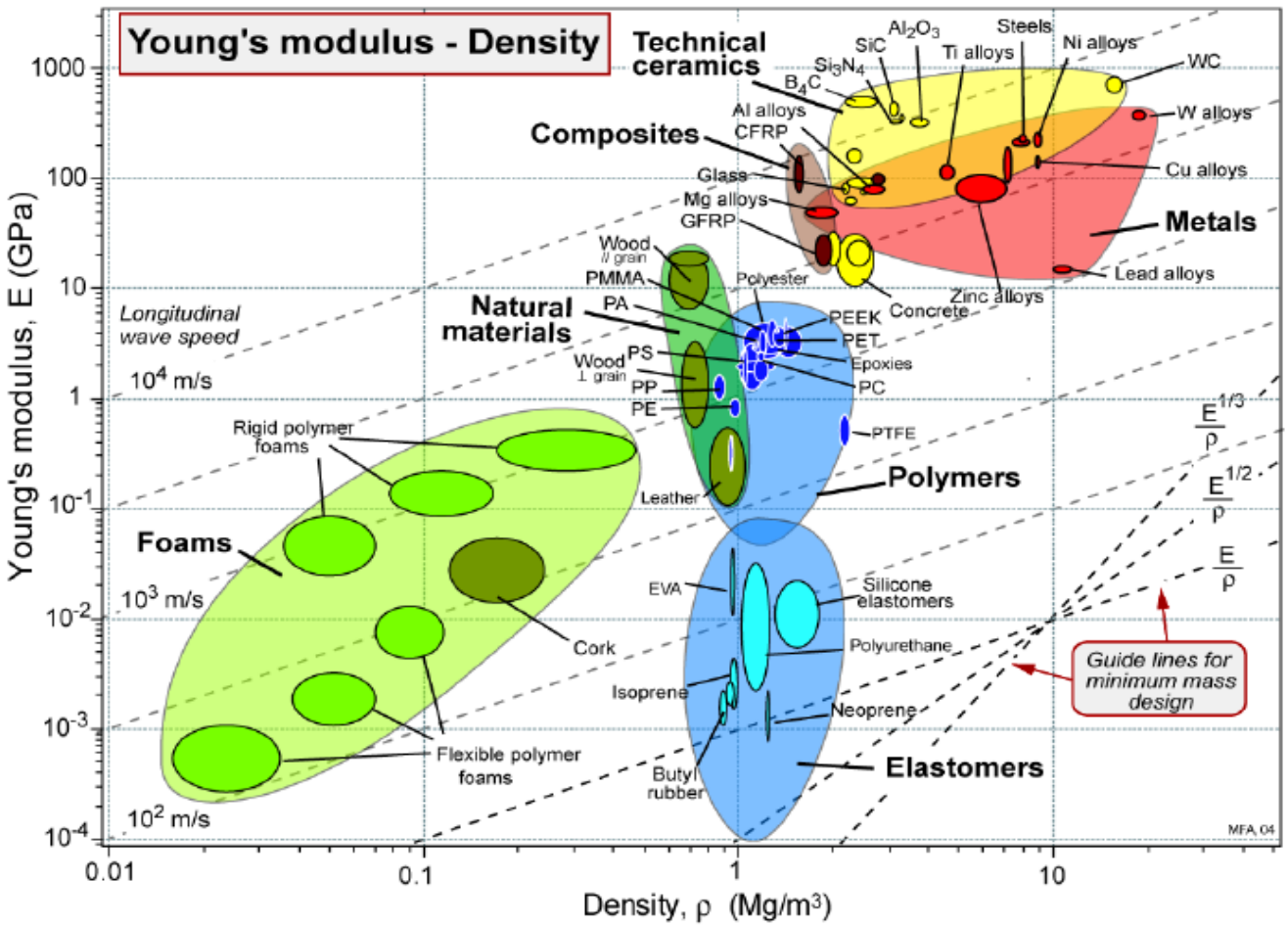
Young's modulus - Density
Technical ceramics
Composites
Natural materials
Metals
Polymers
Foams
Elastomers
SiC
Al_2O_3
Steels
Ni alloys
Si_3N_4
Ti alloys
WC
B_4C
W alloys
Al alloys
CFRP
Cu alloys
Glass
Mg alloys
GFRP
Lead alloys
Wood // grain
PMMA
Polyester
Zinc alloys
PA
PEEK
Concrete
PET
Epoxies
PS
Wood ⊥ grain
PC
PP
PE
PTFE
Leather
Rigid polymer foams
Cork
EVA
Silicone elastomers
Polyurethane
Isoprene
Neoprene
Butyl rubber
Flexible polymer foams
Longitudinal wave speed
10^4 m/s
10^3 m/s
10^2 m/s
$\frac{E^{1/3}}{\rho}$
$\frac{E^{1/2}}{\rho}$
$\frac{E}{\rho}$
Guide lines for minimum mass design
Young's modulus, E (GPa)
Density, ρ (Mg/m³)
1000
100
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.01
0.1
1
10
MFA 04

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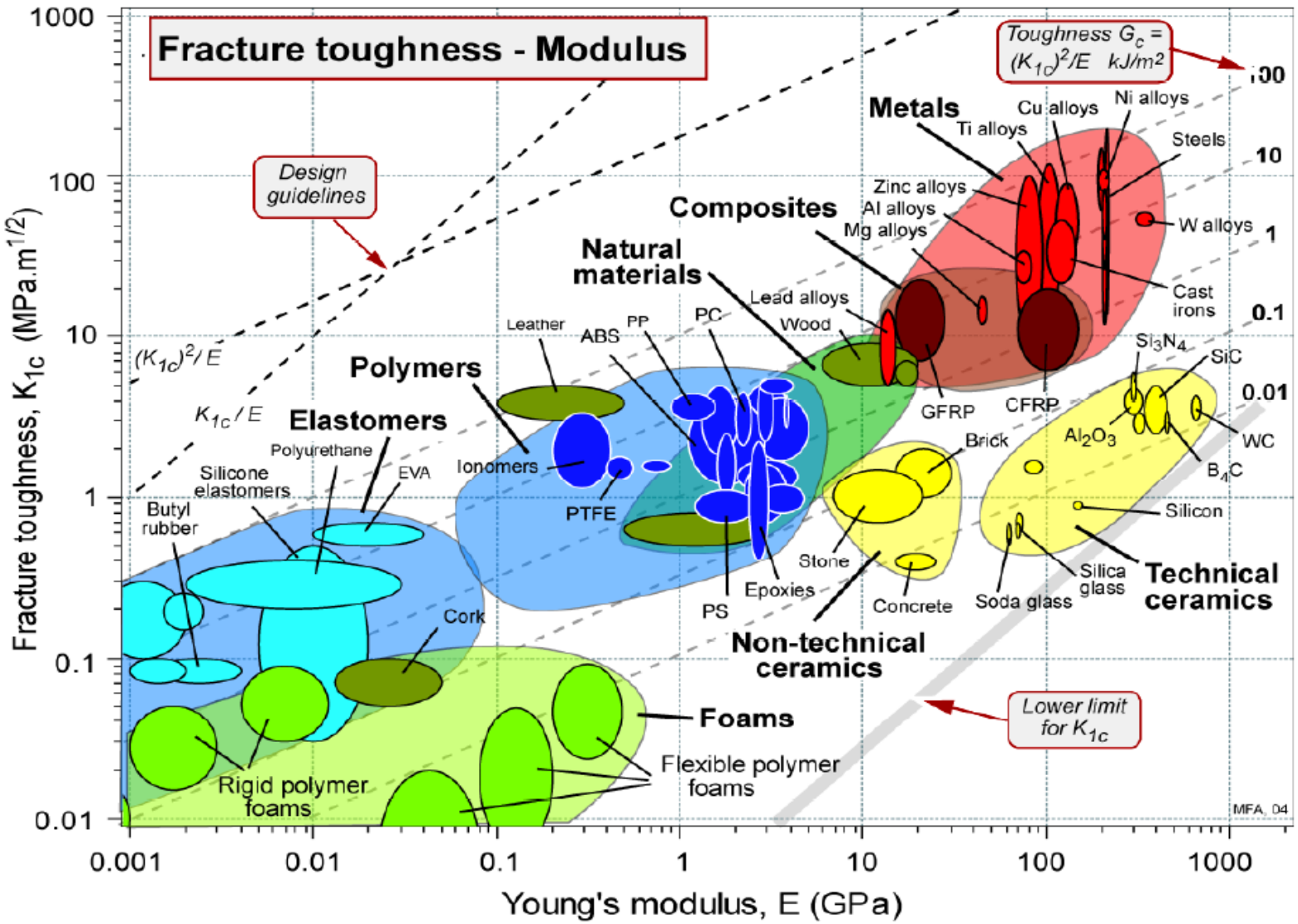
Fracture toughness - Modulus
Toughness G_c = $(K_{1c})^2/E$ kJ/m²
Design guidelines
Metals
Ti alloys
Cu alloys
Ni alloys
Steels
Zinc alloys
Al alloys
Mg alloys
W alloys
Composites
Natural materials
Lead alloys
Wood
Cast irons
Leather
ABS
PP
PC
Polymers
Elastomers
Polyurethane
EVA
Silicone elastomers
Butyl rubber
Ionomers
PTFE
PS
Epoxies
Stone
Brick
GFRP
CFRP
Concrete
Soda glass
Silica glass
Silicon
Si_3N_4
SiC
Al_2O_3
WC
B_4C
Technical ceramics
Non-technical ceramics
Cork
Foams
Rigid polymer foams
Flexible polymer foams
Lower limit for K_{1c}
$(K_{1c})^2/E$
K_{1c}/E
Fracture toughness, K_{1c} (MPa.m$^{1/2}$)
Young's modulus, E (GPa)
MFA, 04

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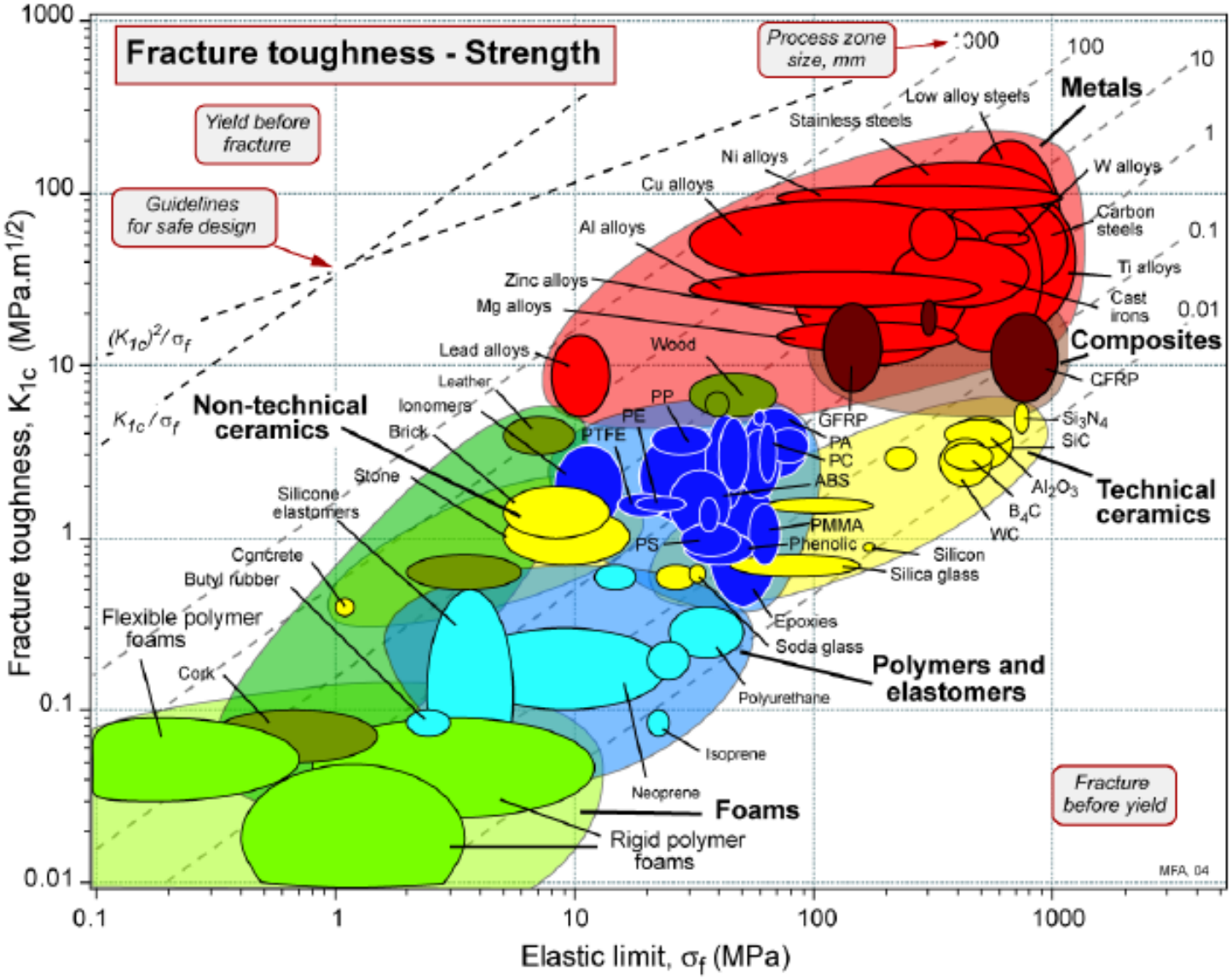
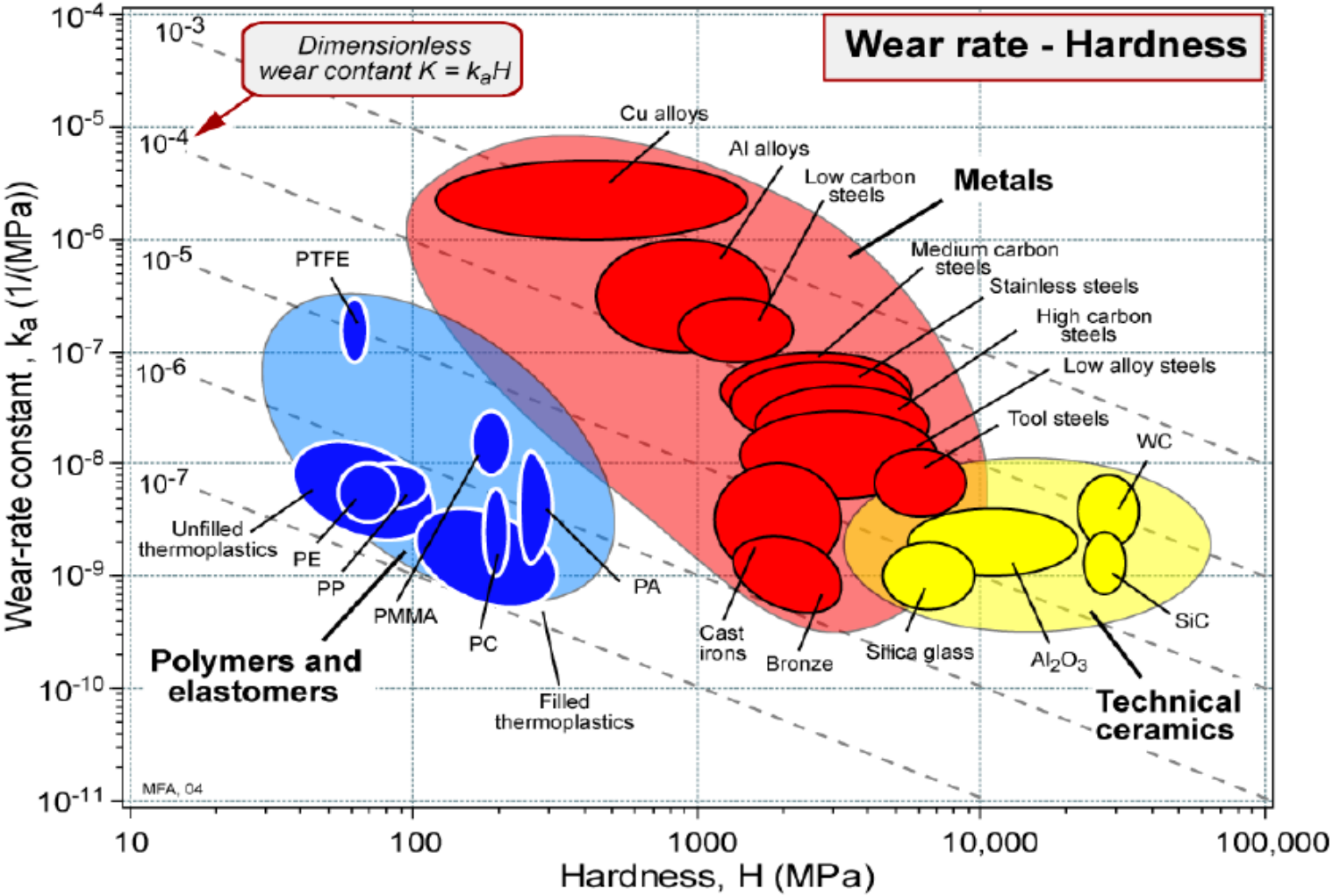

Fracture toughness - Strength
Process zone size, mm
1000
100
10
1
0.1
0.01
Yield before fracture
Guidelines for safe design
$(K_{1c})^2/\sigma_f$
K_{1c}/σ_f
Metals
Low alloy steels
Stainless steels
Ni alloys
Cu alloys
Al alloys
Zinc alloys
Mg alloys
Lead alloys
W alloys
Carbon steels
Ti alloys
Cast irons
Composites
CFRP
GFRP
Wood
Leather
Ionomers
Brick
Stone
Non-technical ceramics
Silicone elastomers
Concrete
Butyl rubber
Flexible polymer foams
Cork
PP
PE
PTFE
PA
PC
ABS
PMMA
Phenolic
PS
Epoxies
Soda glass
Polyurethane
Isoprene
Neoprene
Polymers and elastomers
Foams
Rigid polymer foams
Si_3N_4
SiC
Al_2O_3
B_4C
WC
Technical ceramics
Silicon
Silica glass
Fracture before yield
MFA, 04
Fracture toughness, K_{1c} (MPa.m$^{1/2}$)
Elastic limit, σ_f (MPa)
0.1
1
10
100
1000


Wear rate - Hardness
Dimensionless wear contant K = k_aH
Wear-rate constant , k_a (1/(MPa))
Hardness, H (MPa)
Metals
Cu alloys
Al alloys
Low carbon steels
Medium carbon steels
Stainless steels
High carbon steels
Low alloy steels
Tool steels
Cast irons
Bronze
Polymers and elastomers
PTFE
Unfilled thermoplastics
PE
PP
PMMA
PC
PA
Filled thermoplastics
Technical ceramics
WC
SiC
Silica glass
Al_2O_3
MFA, 04

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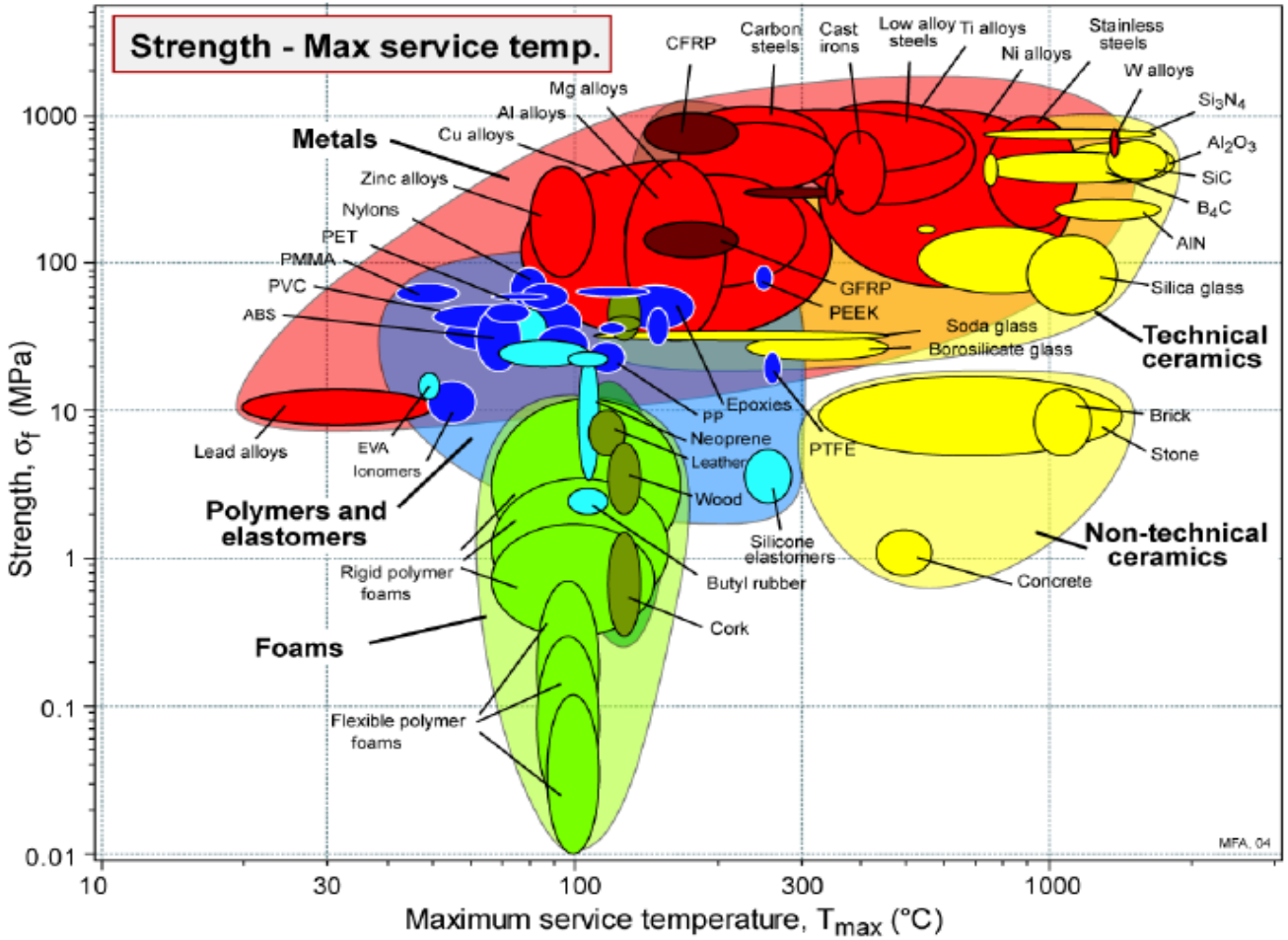
Strength - Max service temp.
Metals
Polymers and elastomers
Foams
Technical ceramics
Non-technical ceramics
CFRP
Carbon steels
Cast irons
Low alloy steels
Ti alloys
Ni alloys
Stainless steels
W alloys
Mg alloys
Al alloys
Cu alloys
Zinc alloys
Nylons
PET
PMMA
PVC
ABS
Lead alloys
EVA
Ionomers
Rigid polymer foams
Flexible polymer foams
Cork
Butyl rubber
Silicone elastomers
Wood
Leather
Neoprene
PP
Epoxies
PTFE
GFRP
PEEK
Soda glass
Borosilicate glass
Silica glass
AlN
B4C
SiC
Al2O3
Si3N4
Brick
Stone
Concrete
MFA, 04
Strength, σf (MPa)
Maximum service temperature, Tmax (°C)
1000
100
10
1
0.1
0.01
10
30
100
300
1000

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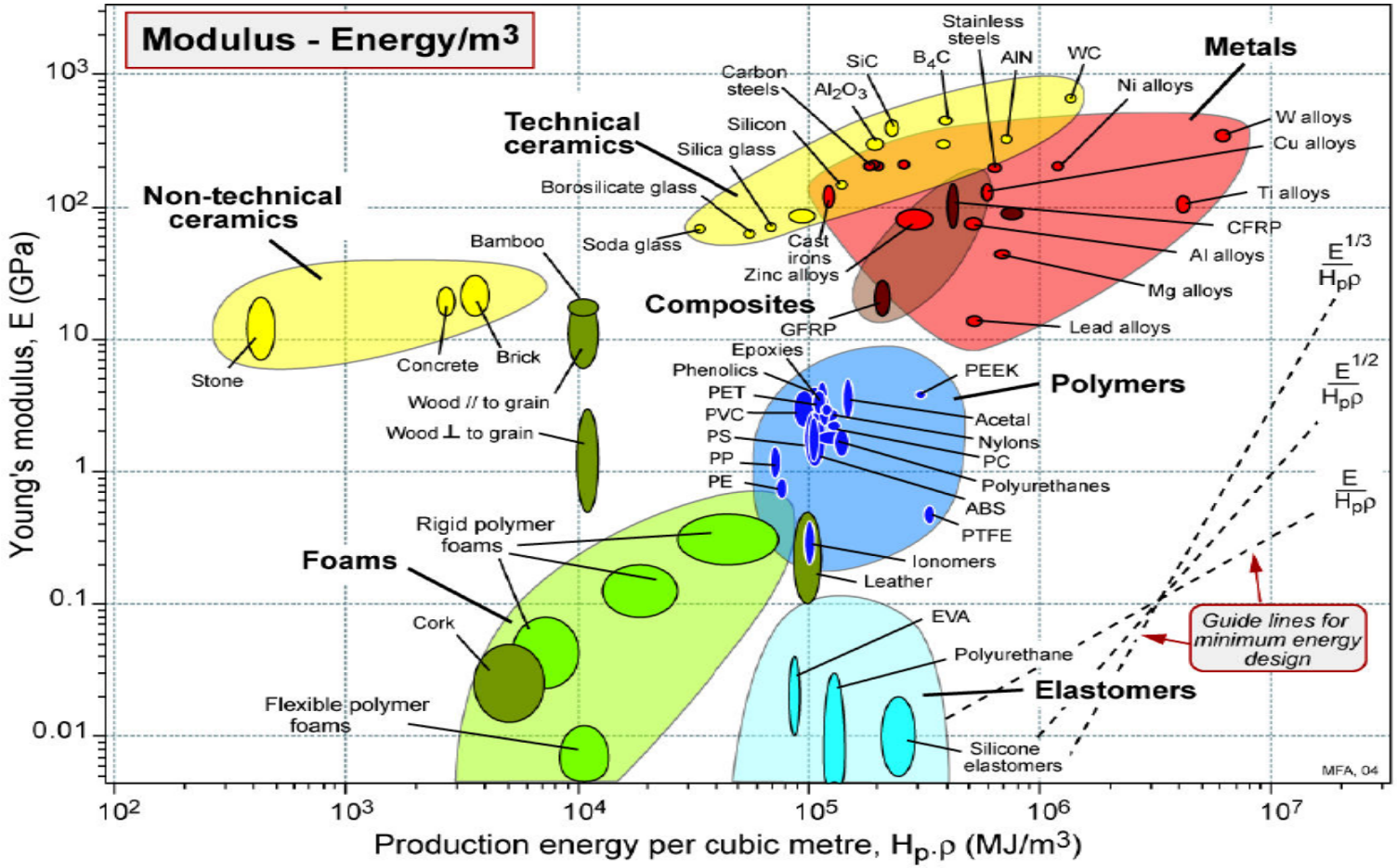
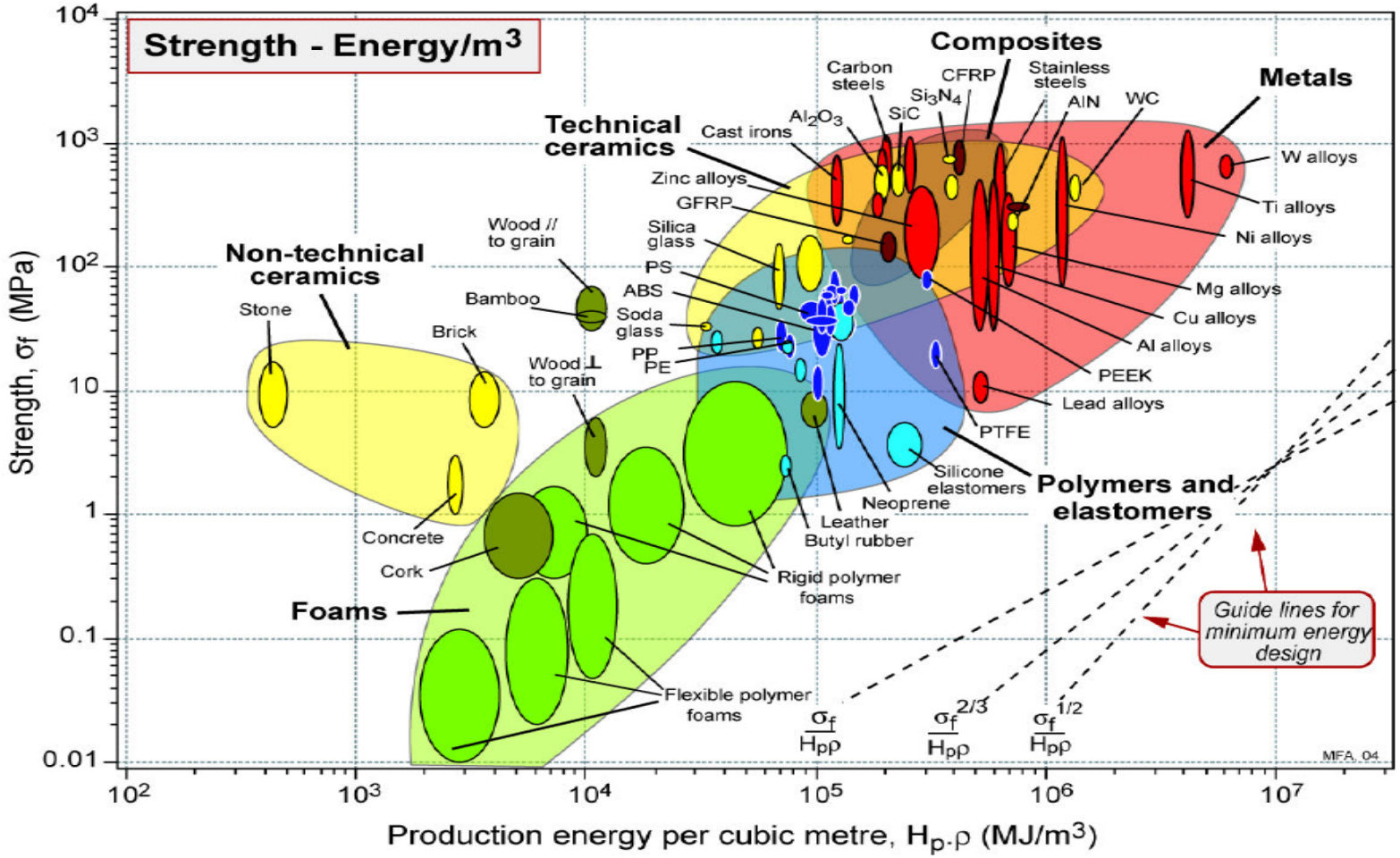
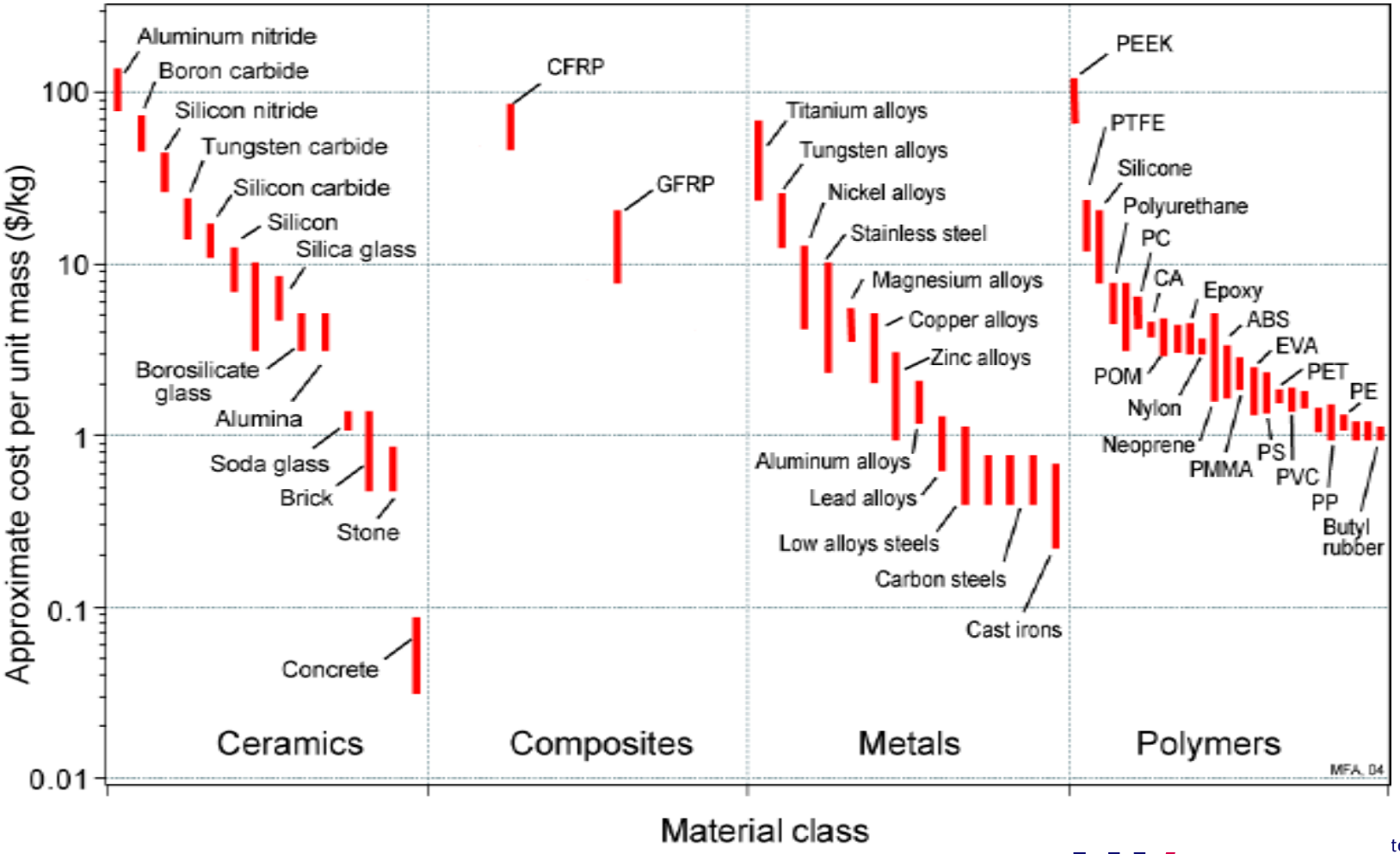
ECO properties of materials, production energy.



Eco properties of materials



Approximate material prices (2008)



Material behavior recapitulation

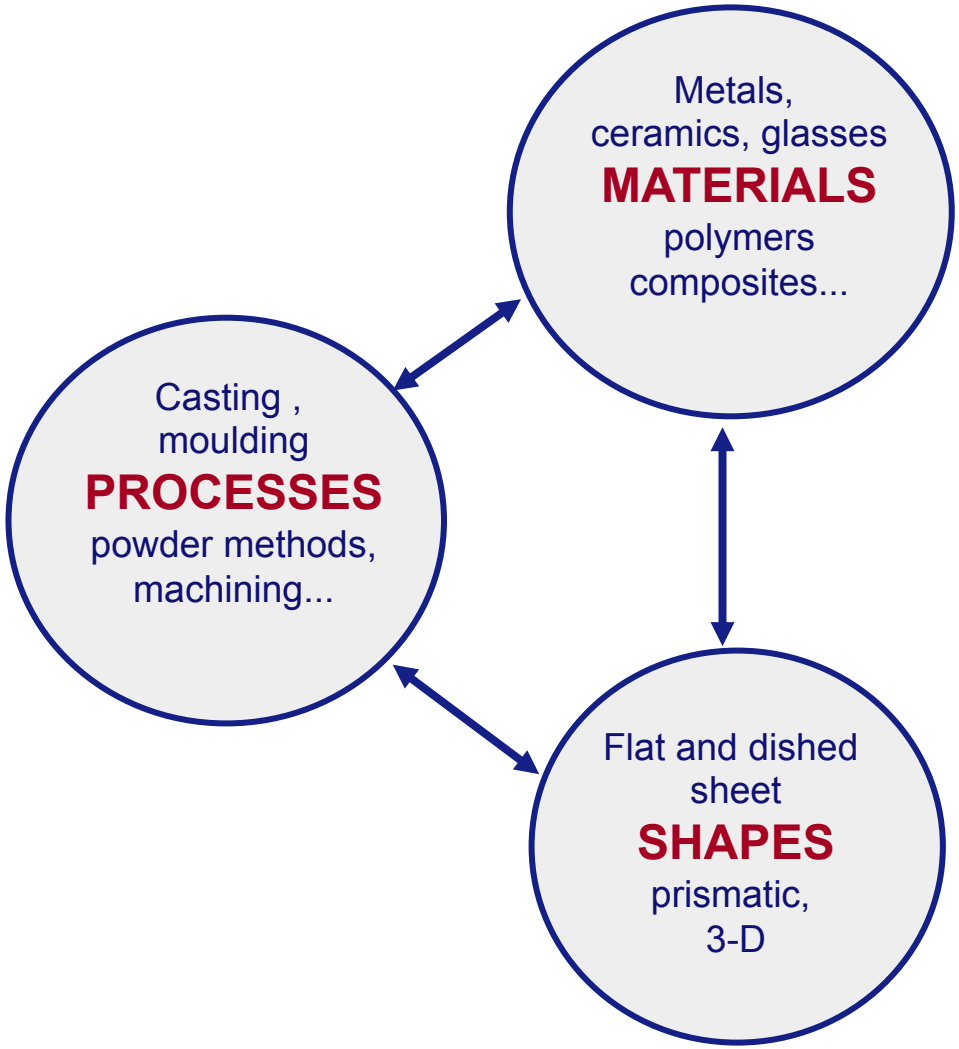
- Tough behavior:
  - Elastic deformation → plastic deformation → failure

- Very brittle behavior:
  - Elastic deformation → failure

Conclusions

- Four general mechanical material properties
  - Strength, toughness, stiffness, wear
- Tough: large plastic deformation
- Describing mechanical behavior with
  - Stress and strain
    - Stress increases:
      - Elastic deformation → plastic deformation → failure
    - Elastic: $\sigma = E.\ \varepsilon$;
    - plastic: σ = Rp0.2 + something

Materials and manufacturing relations



CES EduPack materials database available for free!

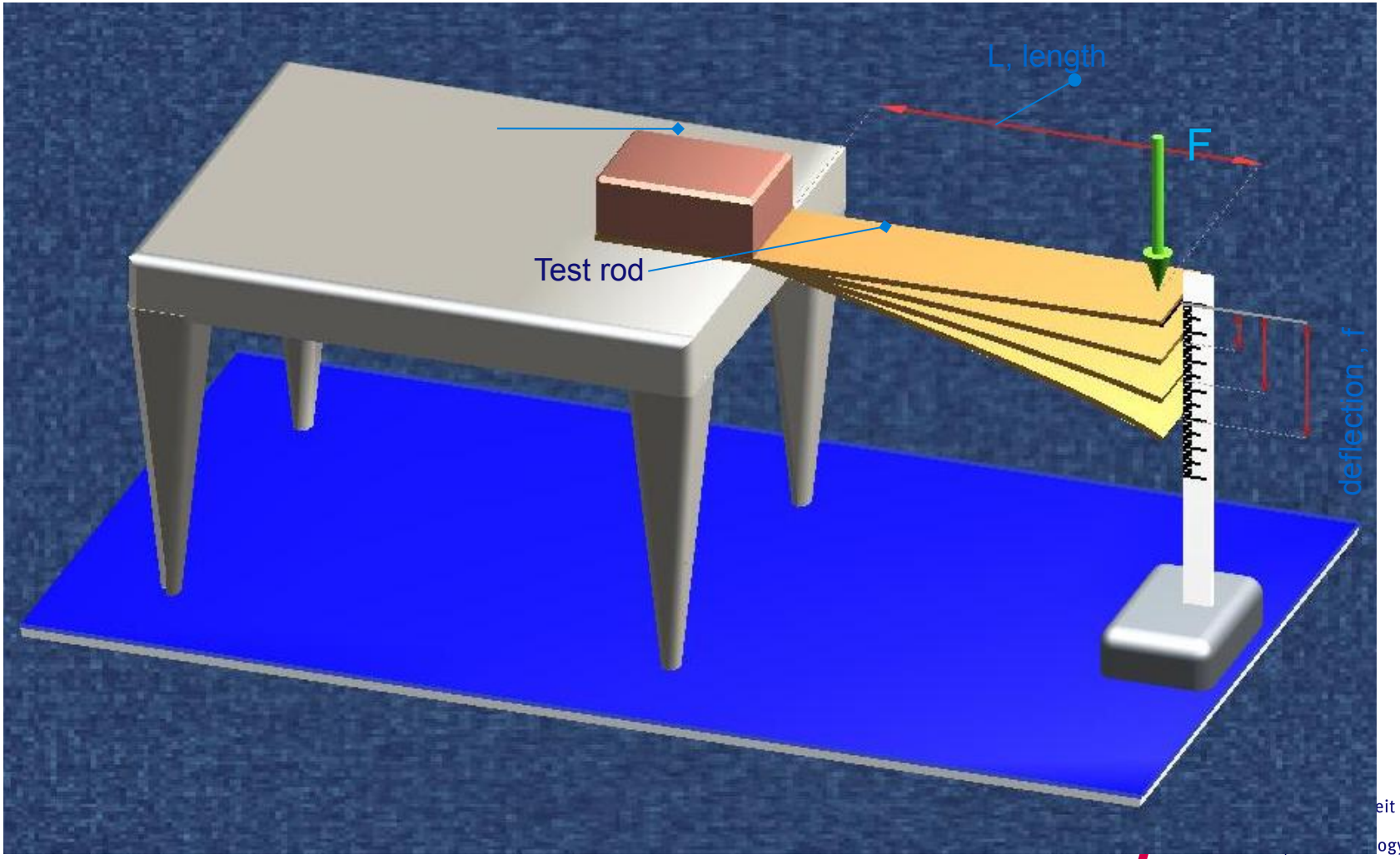
- **Install (sorry only for windows):**
  - http://w3.id.tue.nl/nl/intranet/ict/software/
- **A Shortcut "CES EduPack 2009" will appear on your desktop**
- **Use Level 2 as starting level.**

Experiments to perform

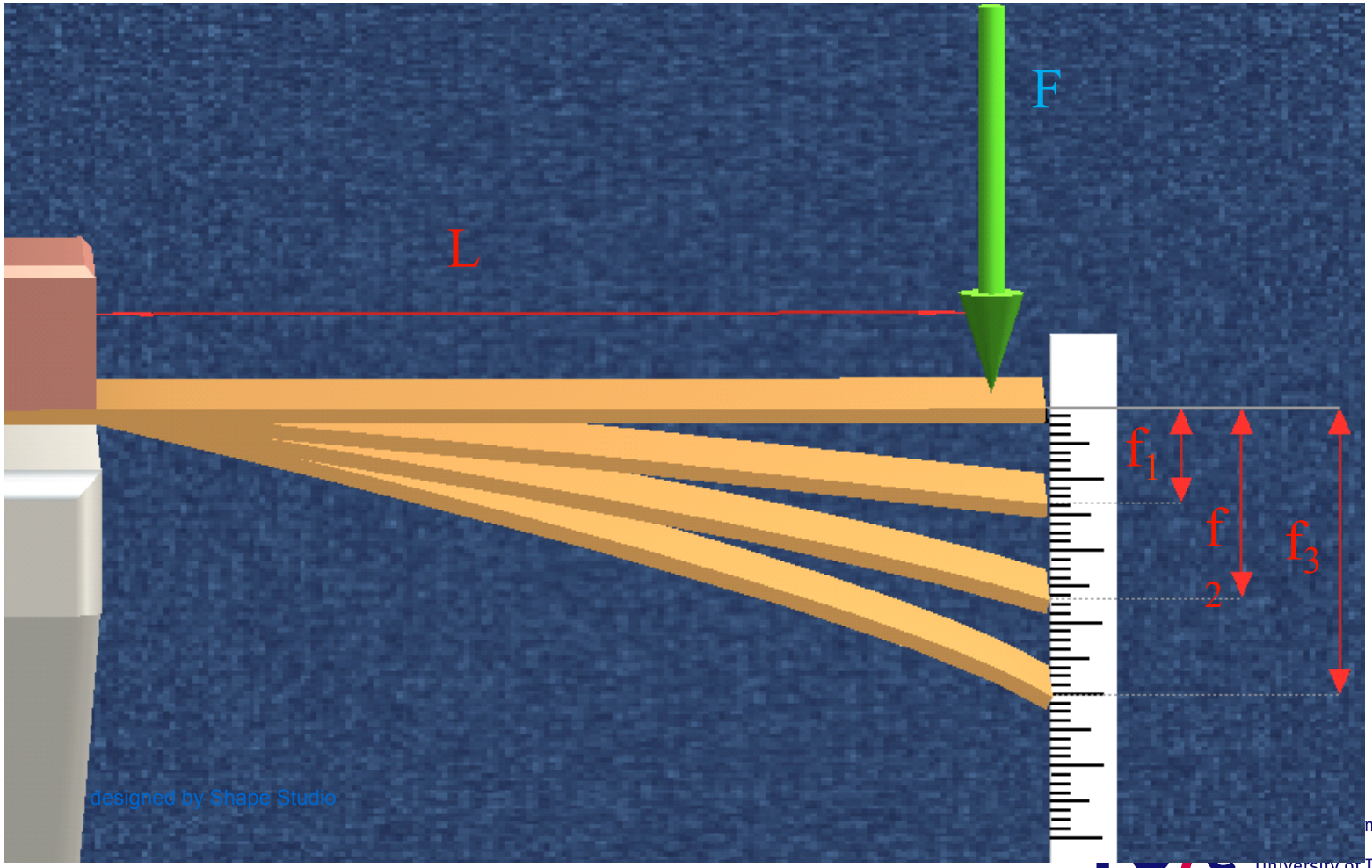
- **Tensile tests (together with mr. C. Meesters)**
  - **C. Meesters is an expert in materials**

- **Bending tests (do yourself)**

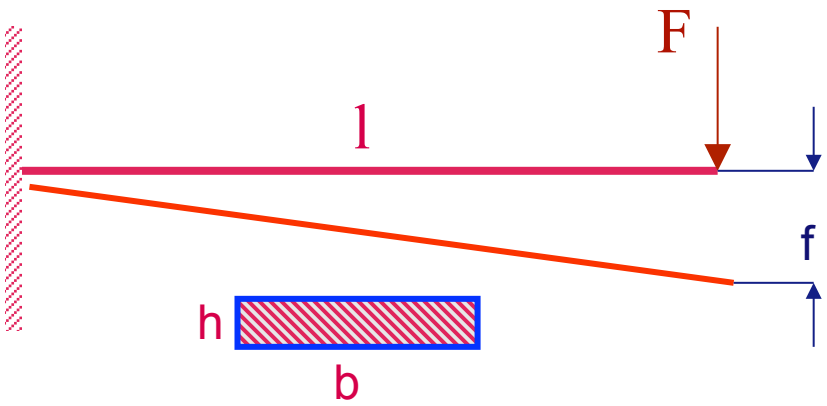
Bending test



In detail



Calculating the E-Modulus



F [N]	f [mm]

Elasticity limit

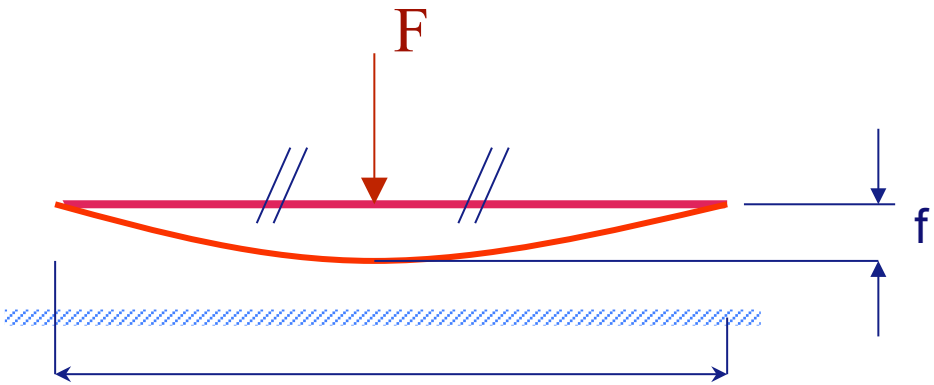
$$f = \frac{F \cdot l^3}{3 \cdot E \cdot I} \text{ in } m$$

$$E = \frac{F \cdot l^3}{3 \cdot f \cdot I} \text{ in } \frac{N}{m^2}$$

$$I = \frac{b \cdot h^3}{12} \text{ in } m^4$$

Moment of inertia

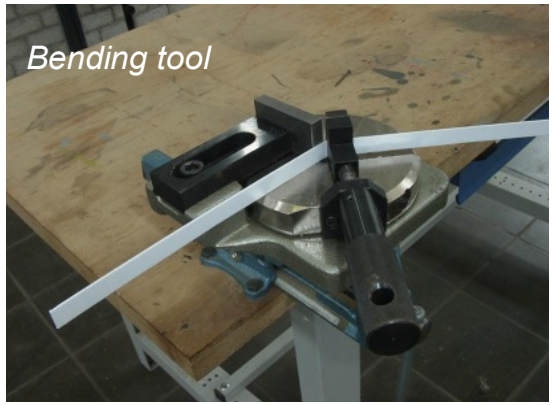
Calculating the E-Modulus, better method

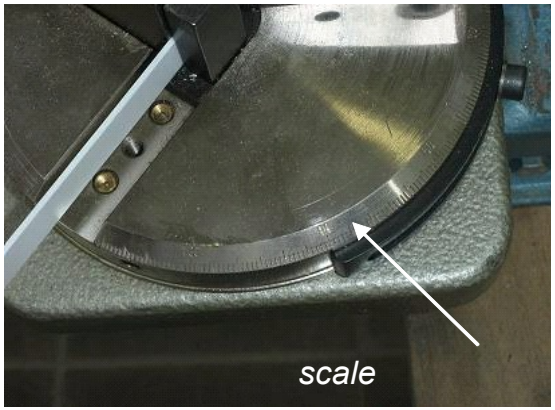


$$f = \frac{F \cdot l^3}{48 \cdot E \cdot I} \text{ in } m$$

$$E = \frac{F \cdot l^3}{48 \cdot I \cdot f} \text{ in } \frac{N}{m^2}$$

Measuring equipment

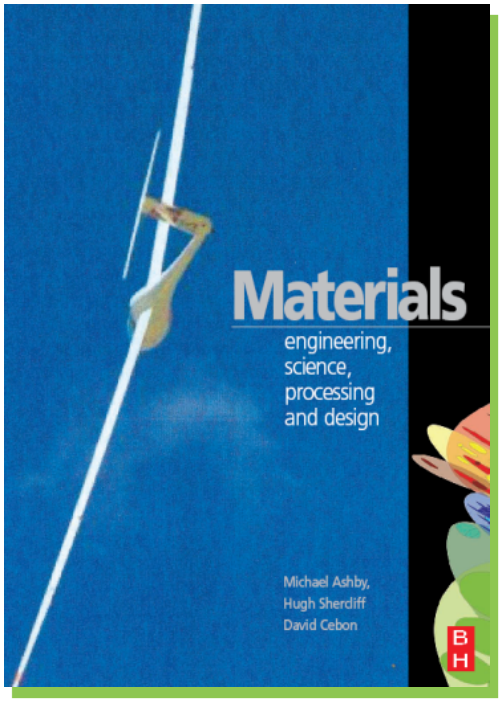




Topics to be studied:

- Everybody: study Chapters 1, 2 and 3

- Group 1: Chapters 4 and 9
- Group 2: Chapters 5 and 10
- Group 3: Chapters 6 and 11
- Group 4: Chapters 7 and 17
- Group 5: Chapters 8 en 20



Deliverable: report per group

- Common part
  - Measurement result of tensile and bending tests
  - Description of the studied part of M.F. Ashby et al., Materials. Engineering, science, processing and design.

- Individual part
  - Material choice for a car body, based on the experiments and the knowledge gained. Well justified!

Topics to be studied

- Everybody: study chapters 1, 2 and 3
- Group 1: Chapters 4 and 9
- Group 2: Chapters 5 and 10
- Group 3: Chapters 6 and 11
- Group 4: Chapters 7 and 17
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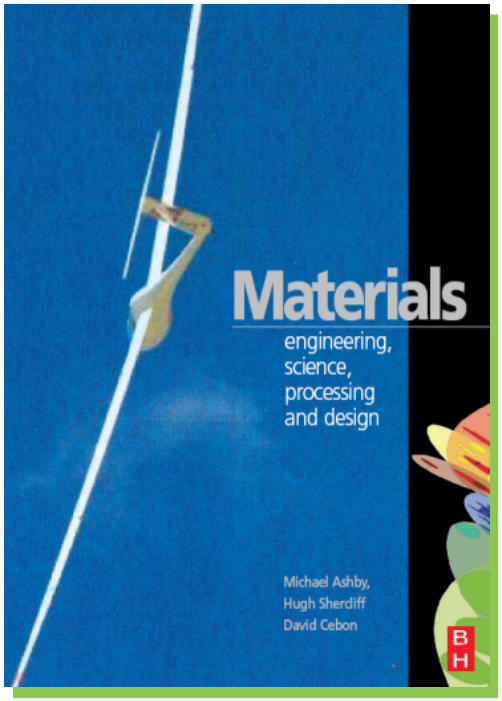

- Presentation max. 15 minutes:
  - 10 minutes 1th chapter,
  - 5 minutes 2nd chapter of each group

  - Pictures available for use.