Unified Engineering

Lecture M21 12/2/2003

Materials Selection

Objective

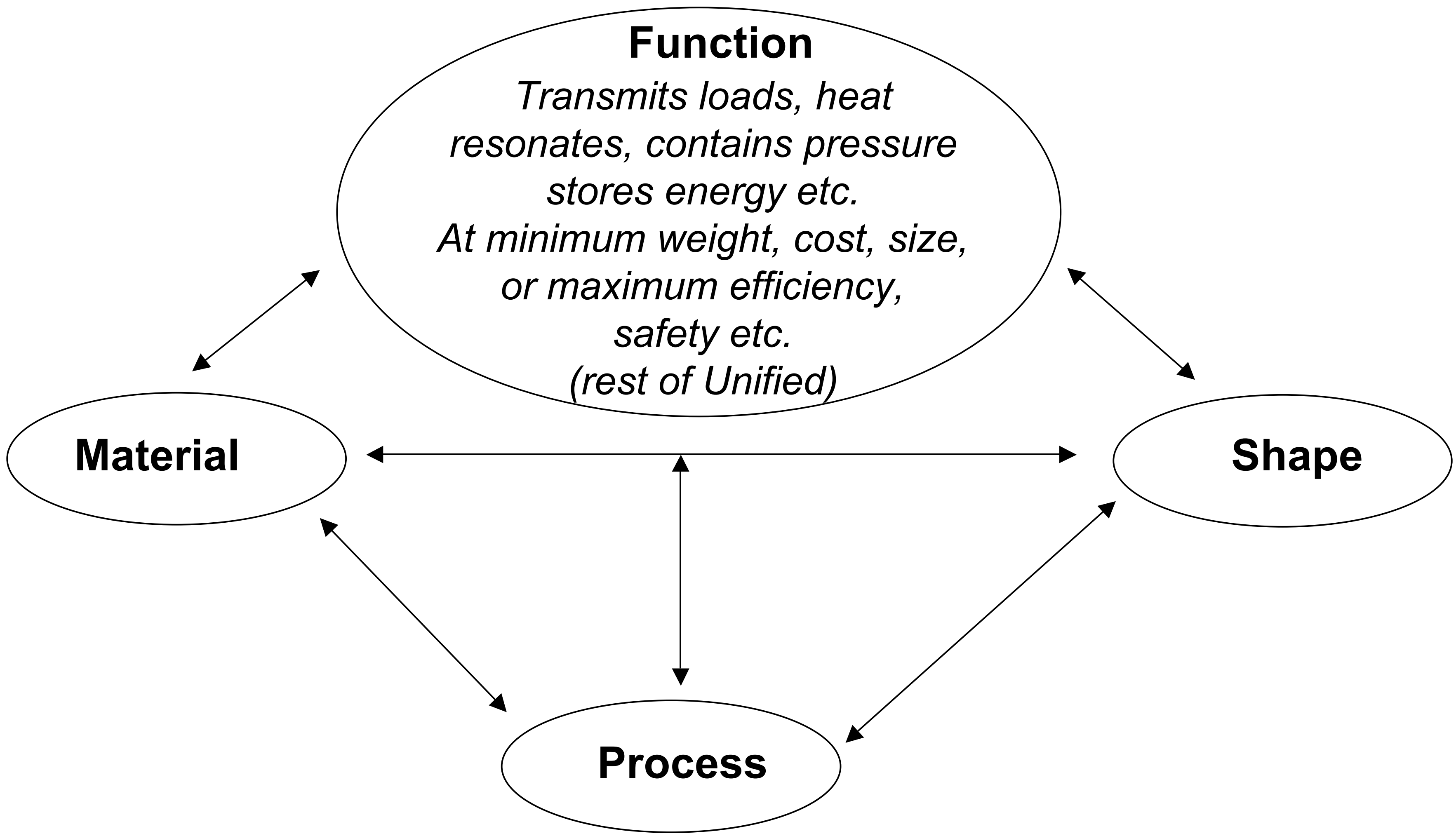
- **Aim to provide coherent overview of material selection**
  - **Materials (and structural configurations and processes) should be selected for applications based on measurable criteria**

Key Ideas

- It is possible to compare the suitability of materials for a given application according to quantifiable performance metrics based on material properties
  – Properties (such as Young's modulus, density, strength) quantify material performance

- Some materials properties are more invariant than others
  – Role of scale, role of manufacturing, microstructure
  – Fiber composite allow flexibility
  – Important to know what you can change - or not!

Central Problem - Interaction of Function, Material, Process and Shape



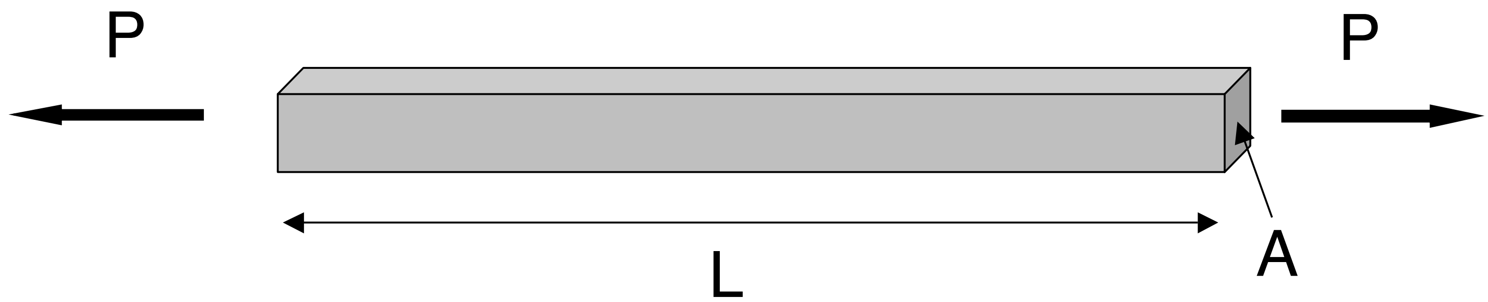
References

- Material Selection in Mechanical Design, M.F Ashby, Pergamon Press, Oxford, 1992
- Ashby and Jones, Engineering Materials I, Chapter 6

Materials for Mechanical Elements - performance indices

- **Design of a structural element is specified by three parameters, or groups of parameters (performance indices):**
  - **Functional requirements (F), Geometry (G) and Material Properties (M)**
- **We can quantify the interdependence if we can specify performance, p, as a function of F, G and M:**
  - » $p = f(F, G, M)$
- **We can simplify further if the three groups of parameters are separable, i.e:**
  - » $p = f_1(F) \, . \, f_2(G) \, . \, f_3(M)$

Ex: Lightweight stiff rod - tensile load



Material, modulus E, density ρ - note these are a property of the material, and cannot be independently selected

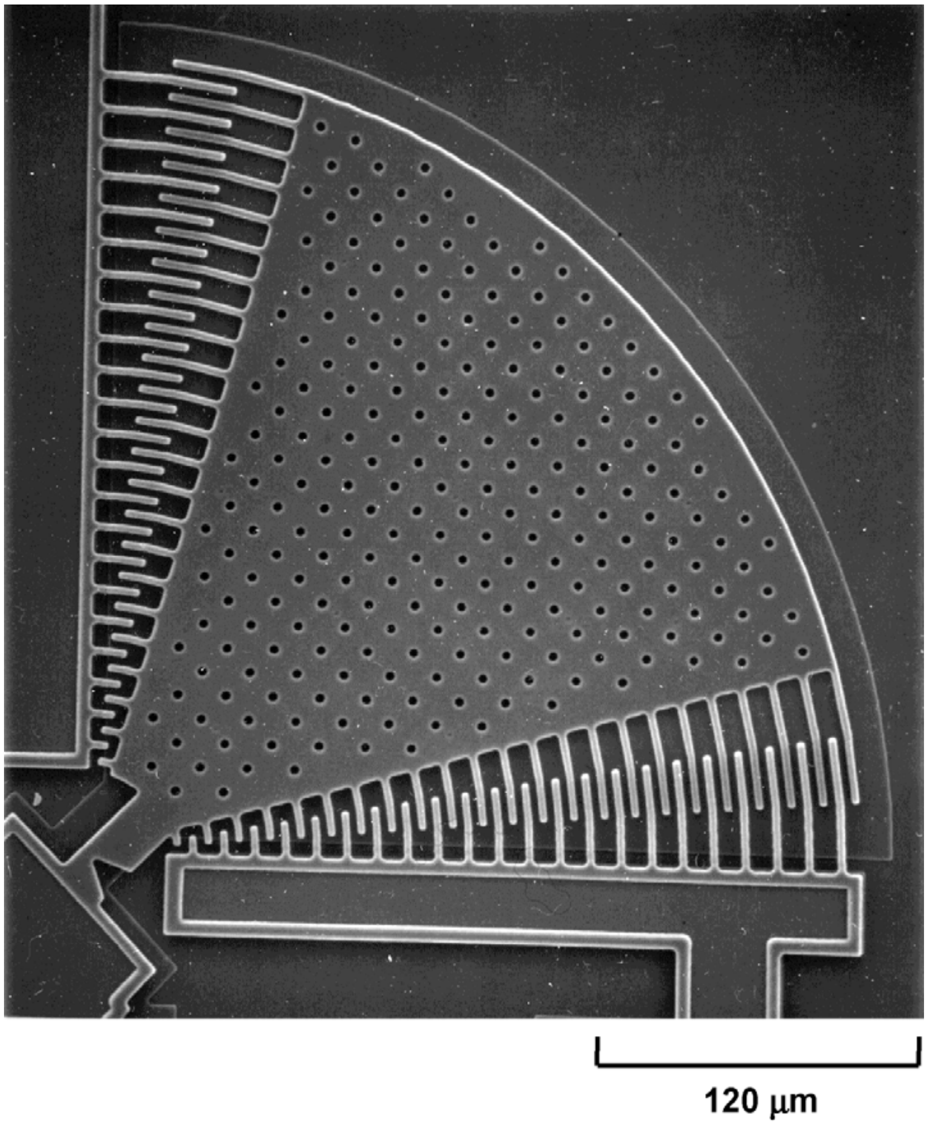
- **Mass of rod given by** $m = \rho A L$
- **Stiffness of rod, given by** $k = \frac{P}{\delta} = \frac{AE}{L}$
- **Combining, by eliminating free variable, A:**

$$m = \frac{kL^2\rho}{E} = k \cdot L^2 \cdot \frac{\rho}{E}$$

F G M

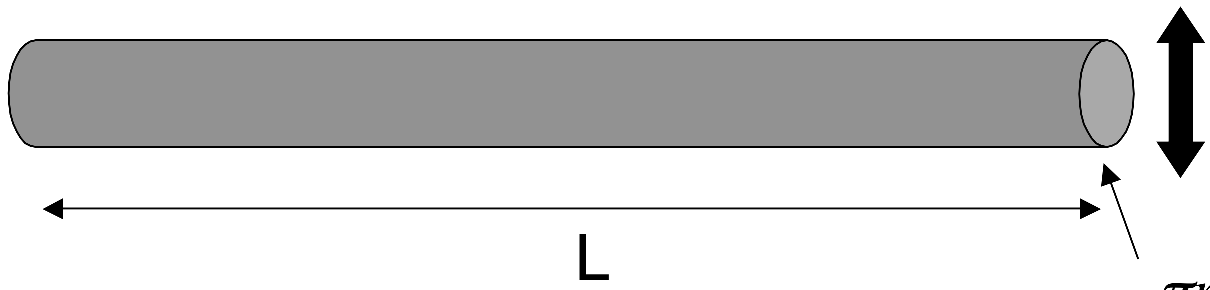
Choose material with low ρ/E ratio!!!

MATERIAL SELECTION FOR A MICROMECHANICAL RESONATOR



Fatigue test device
(Courtesy of Stuart Brown. Used with permission.)

Example 2 - High f Beam Resonator



$$\delta = A_0 \sin \omega t$$

Material, modulus E, density ρ

$$I = \frac{\pi r^4}{4}$$

- **Natural (resonant) frequency, f**

$$f \propto \sqrt{\frac{EI}{ML^3}} \Rightarrow \beta_1 \sqrt{\frac{Er^2}{\rho L^4}} = \beta_2 \sqrt{\frac{E}{\rho}} \cdot \frac{r}{L^2} \qquad \beta_n = f(B.C\ s)$$

- **For high frequency resonator select high E/ρ**
- **Note frequency** $f \propto \frac{1}{L}$ **for given** $\frac{r}{L}$ **implies scale effect**

Choose material with low ρ/E ratio,
MEMS allow high frequencies

MODULUS - DENSITY RATIOS OF SOME MEMS MATERIALS

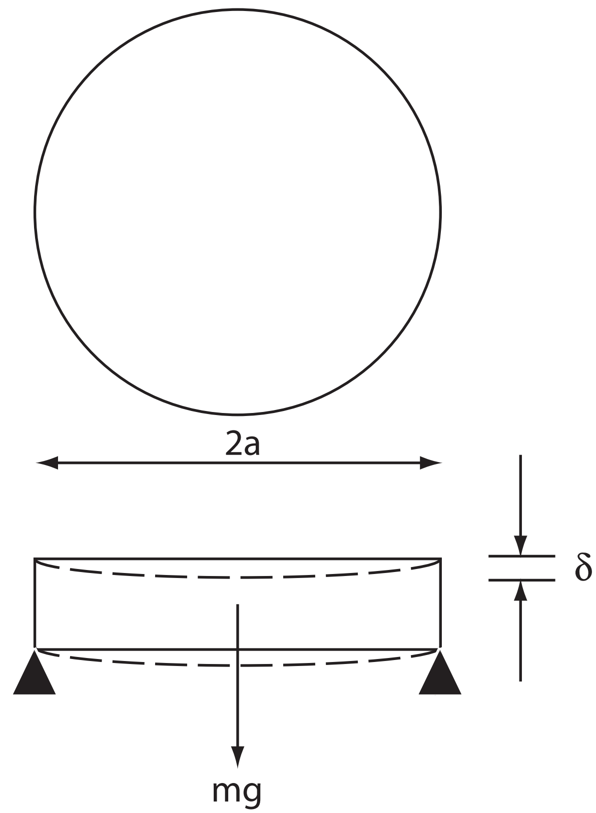
Material	Density, ρ, Kg/m^3	Modulus, E, GPa	E/ ρ GN/kg-m
Silicon	2330	165	72
Silicon Oxide	2200	73	36
Silicon Nitride	3300	304	92
Nickel	8900	207	23
Aluminum	2710	69	25
Aluminum Oxide	3970	393	99
Silicon Carbide	3300	430	130
Diamond	3510	1035	295

Silicon performs well, diamond, SiC and SiN significantly better

DEFLECTION OF CIRCULAR PLATE

$$\delta = \frac{0.67}{\pi}\frac{mga^2}{Et^3}$$

$$m = \pi a^2 t\rho$$



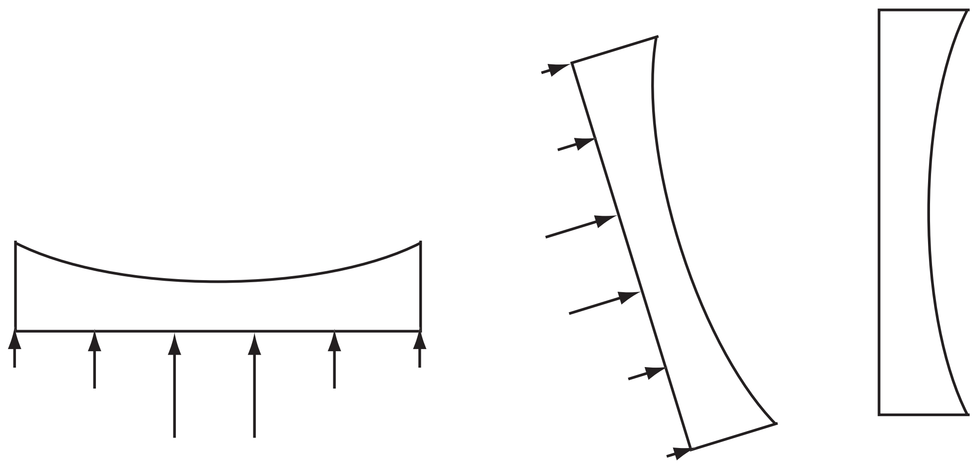
The elastic deflection of a telescope mirror (shown as a flat disc), under its own weight. (Adapted from Ashby.)

$$m = \left(\frac{0.67/g}{\delta}\right)^{1/2} \pi a^4 \left(\frac{\rho^3}{E}\right)^{1/2}$$

$$M = \frac{\rho^3}{E}$$

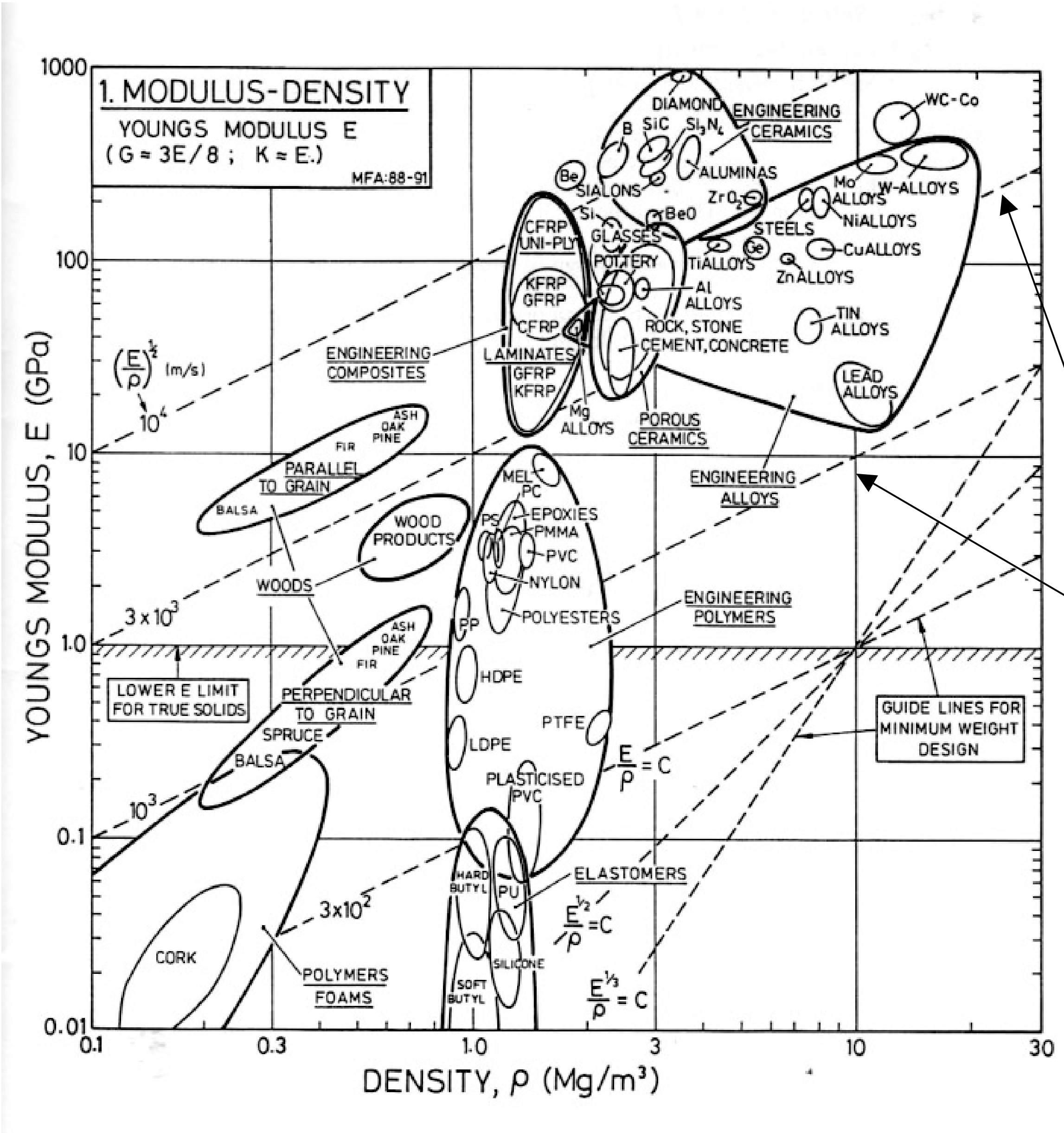
Example 3 - Telescope Mirror

- **Choose materials with high** $M = \frac{\rho^3}{E}$



The distortion of the mirror under its own weight can be corrected by applying forces to the back surface. (Adapted from Ashby.)

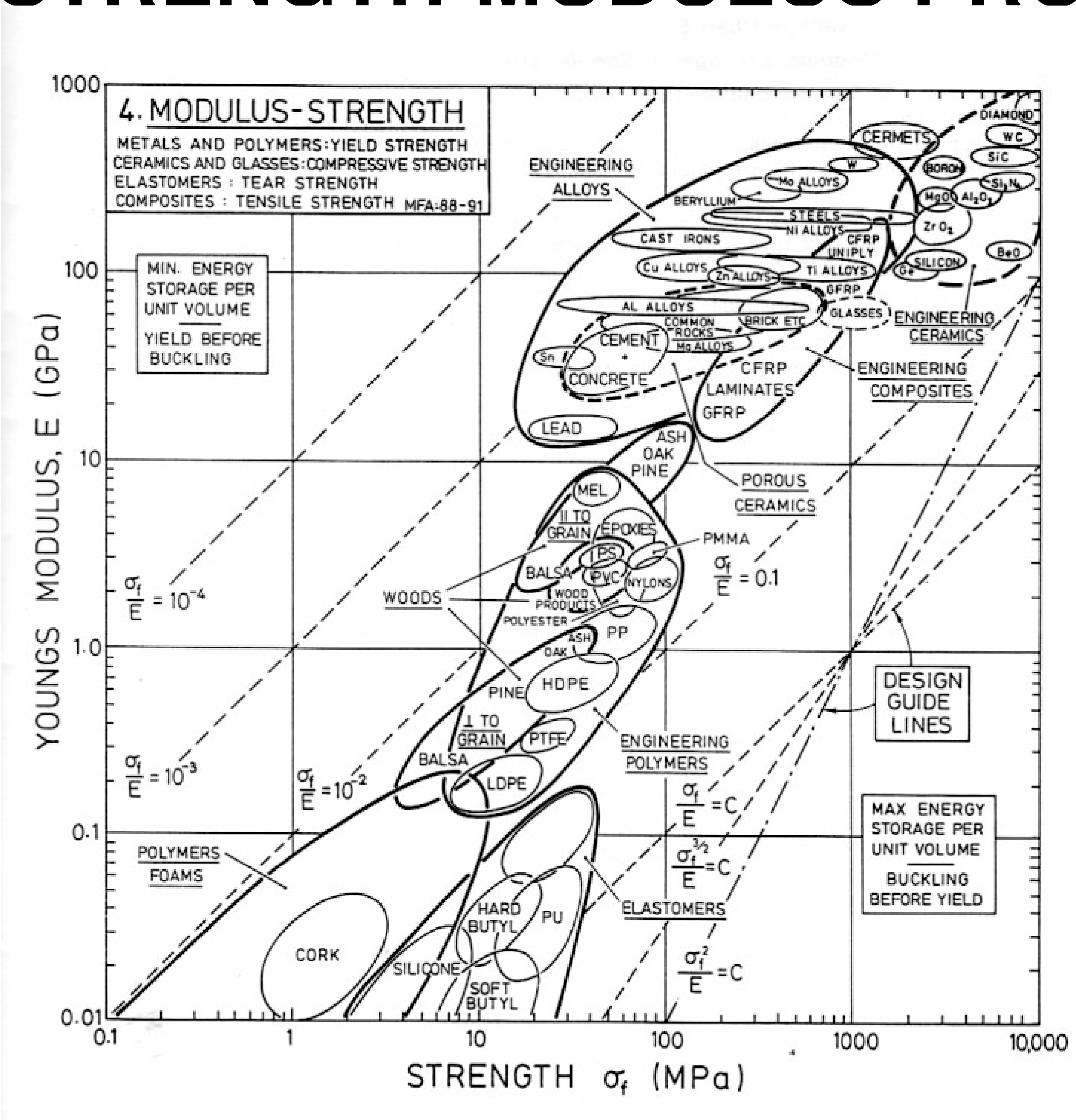
MODULUS - DENSITY PROPERTY MAP



Note contours of equal performance

Ashby

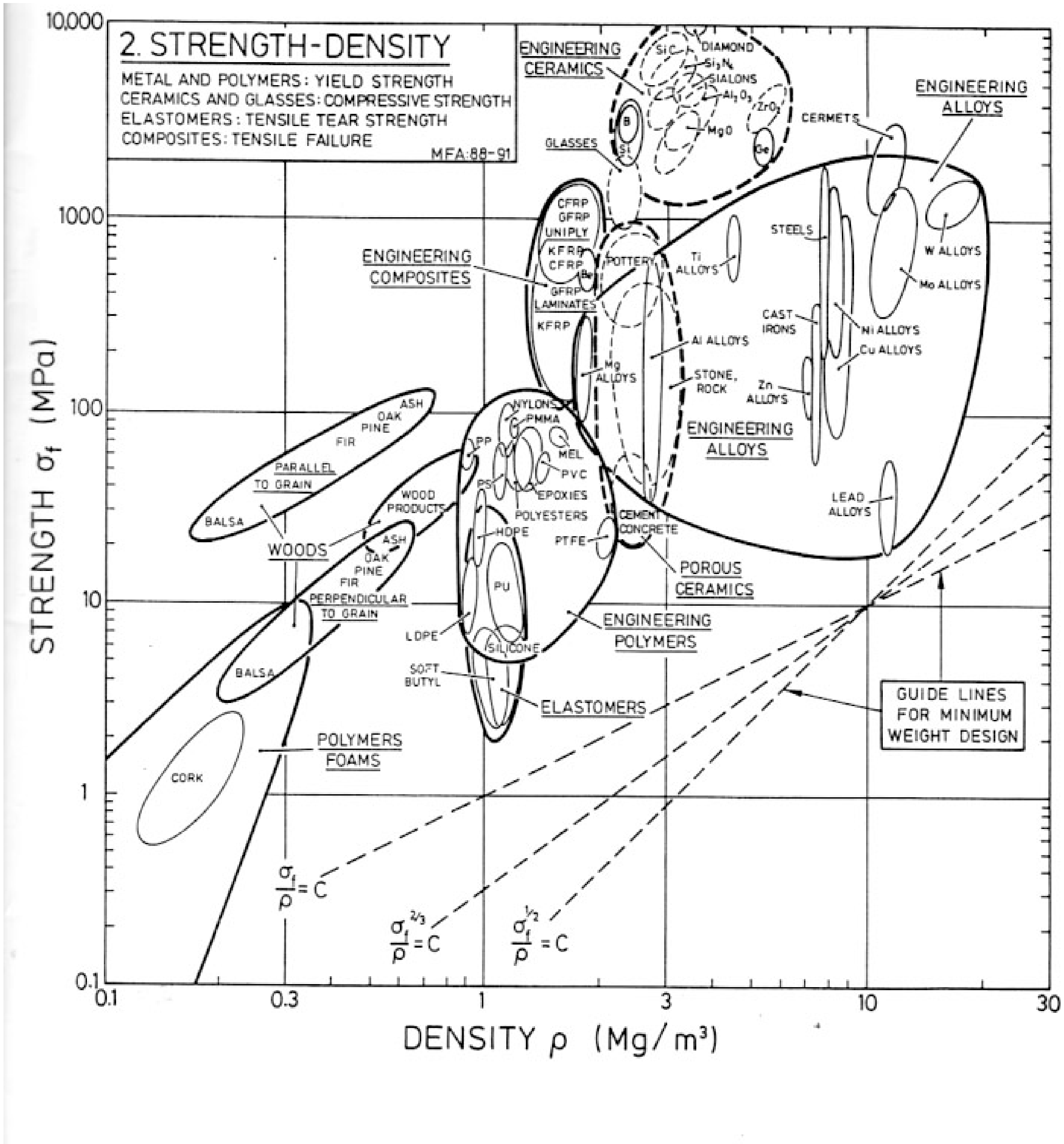
STRENGTH-MODULUS PROPERTY MAP



Might also want Deflection at minimum force - polymers would appear more attractive

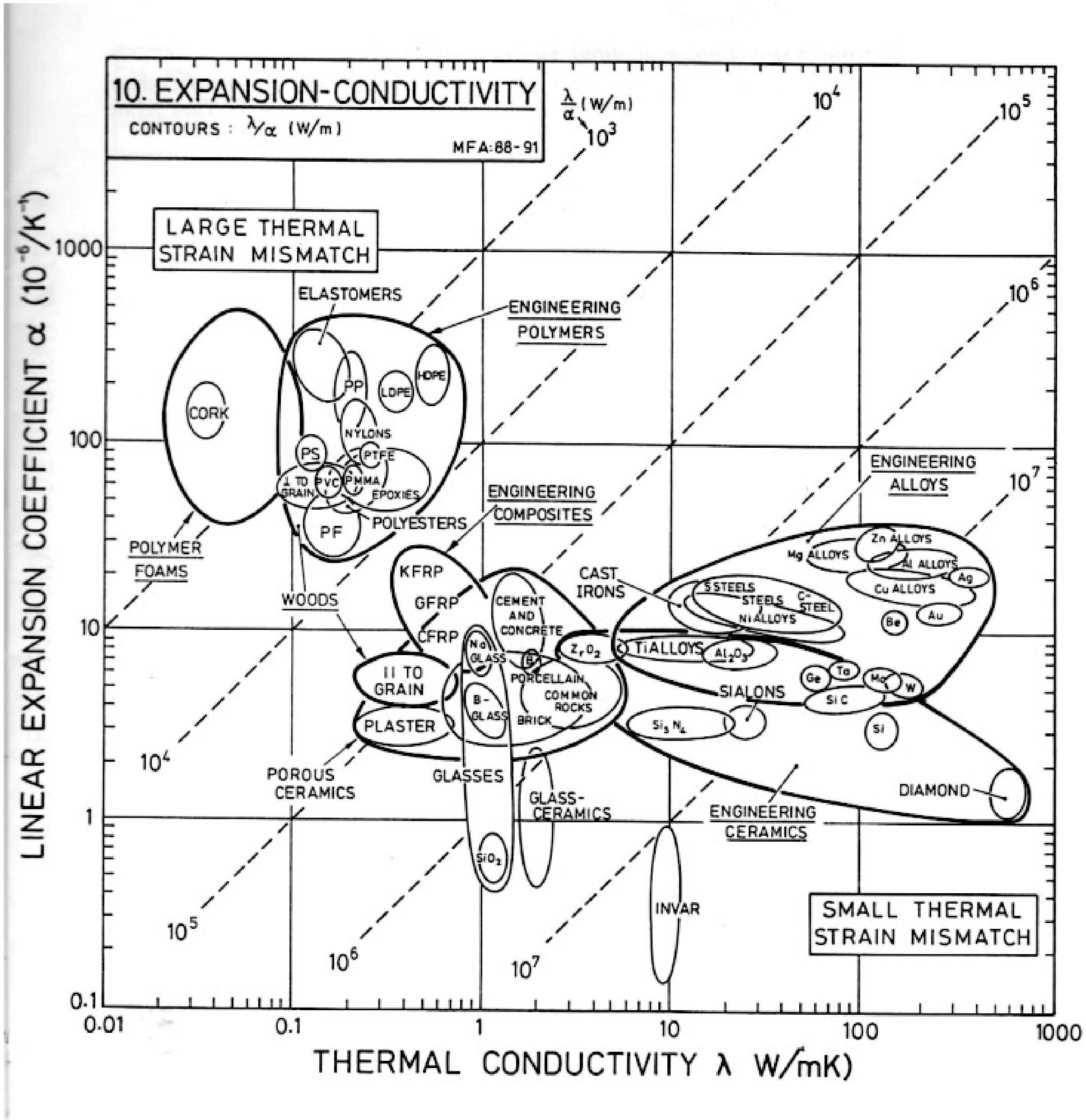
Ashby

STRENGTH-DENSITY MAP



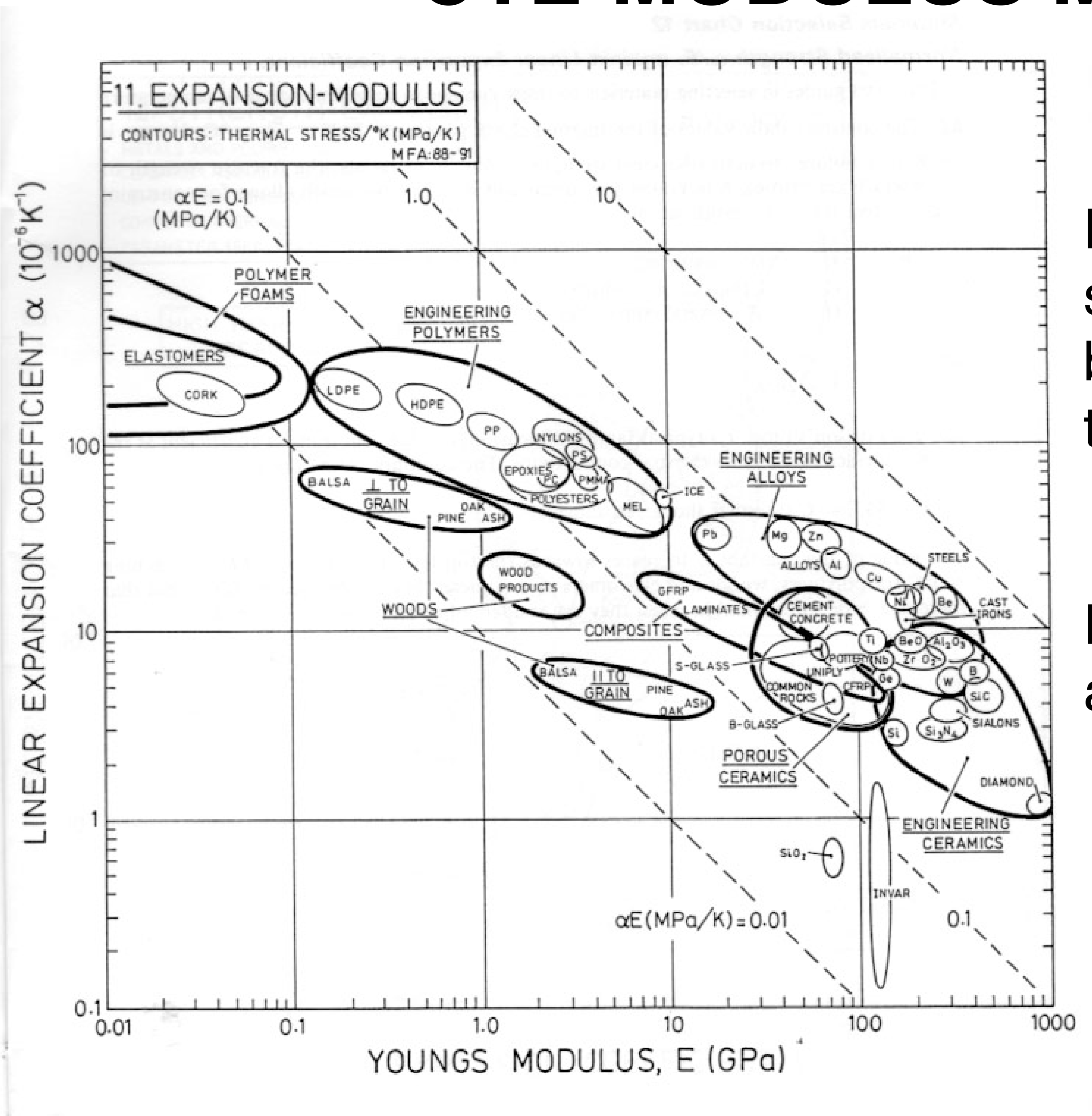
Ashby

CTE-THERMAL CONDUCTIVITY



Ashby

CTE-MODULUS MAP



Determines thermal stress, thermal buckling limits for thin tethers,

also

Feasibility of thermal actuation

Ashby

SUMMARY

- **Aimed to provide coherent overview of material selection**
  - **Materials (and structural configurations and processes) should be selected for applications based on measurable criteria**
  - **Often combinations of material properties**
- **Material properties group according to class of material**
  - **Metal, ceramic, polymers**
  - **Engineered materials (composites, foams)**
  - **Natural materials (wood, bone, etc)**