Designing new materials:

Filling the materials-property space

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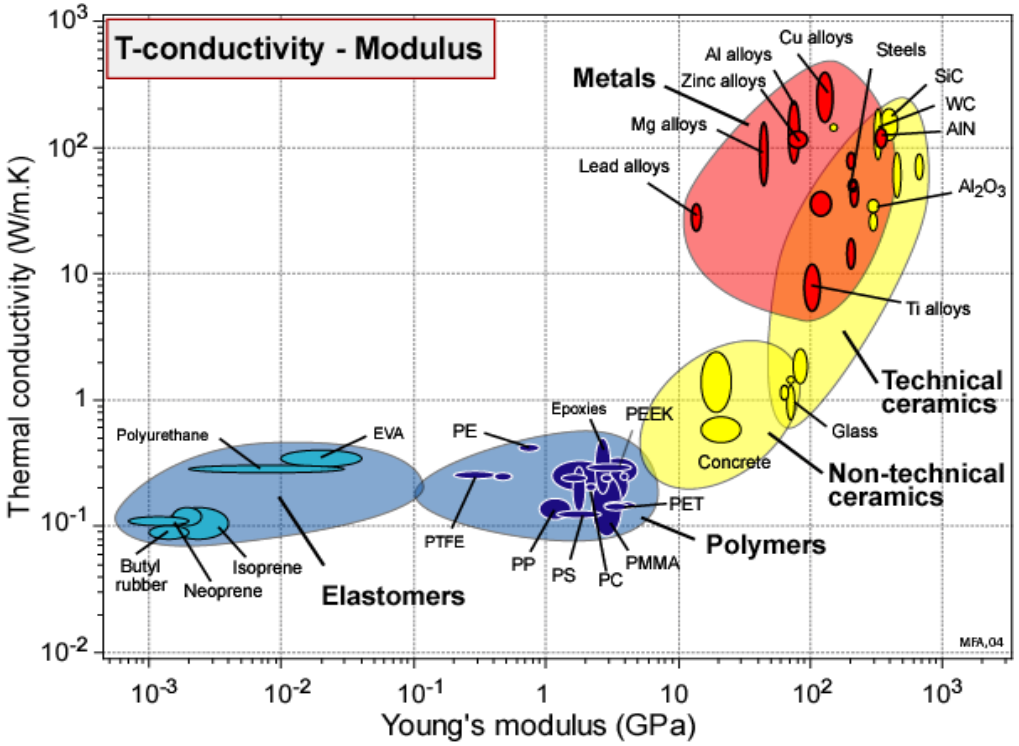


Learning objectives for this lecture unit

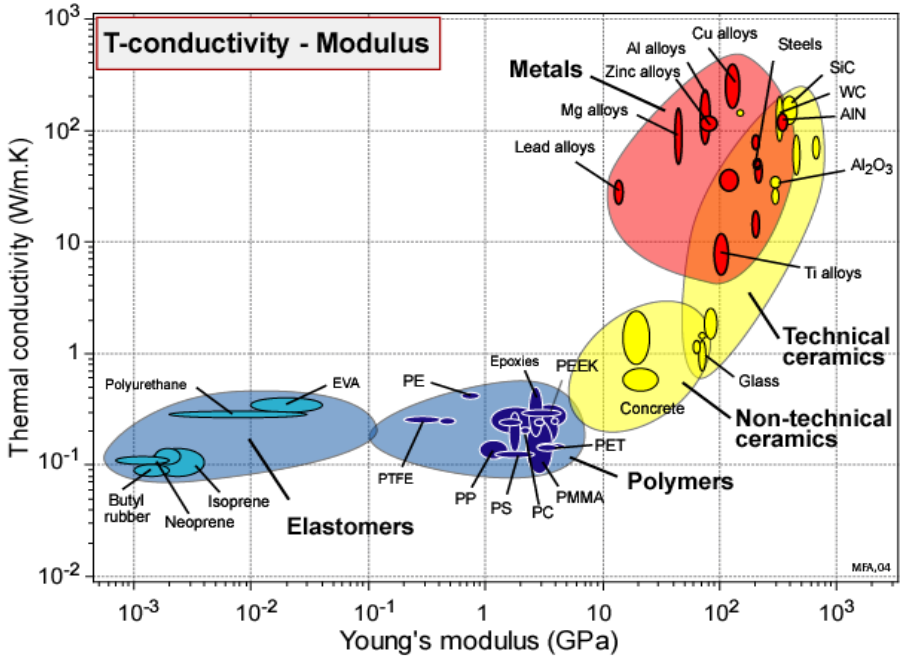
Ansys software mentioned	• Ansys Granta EduPack™, a teaching software for materials education

Intended Learning Outcomes	
Knowledge and Understanding	Knowledge about structural and architecture materials
Skills and Abilities	Ability to fill holes in the property space of materials
Values and Attitudes	Realization of the potential for material development

Resources

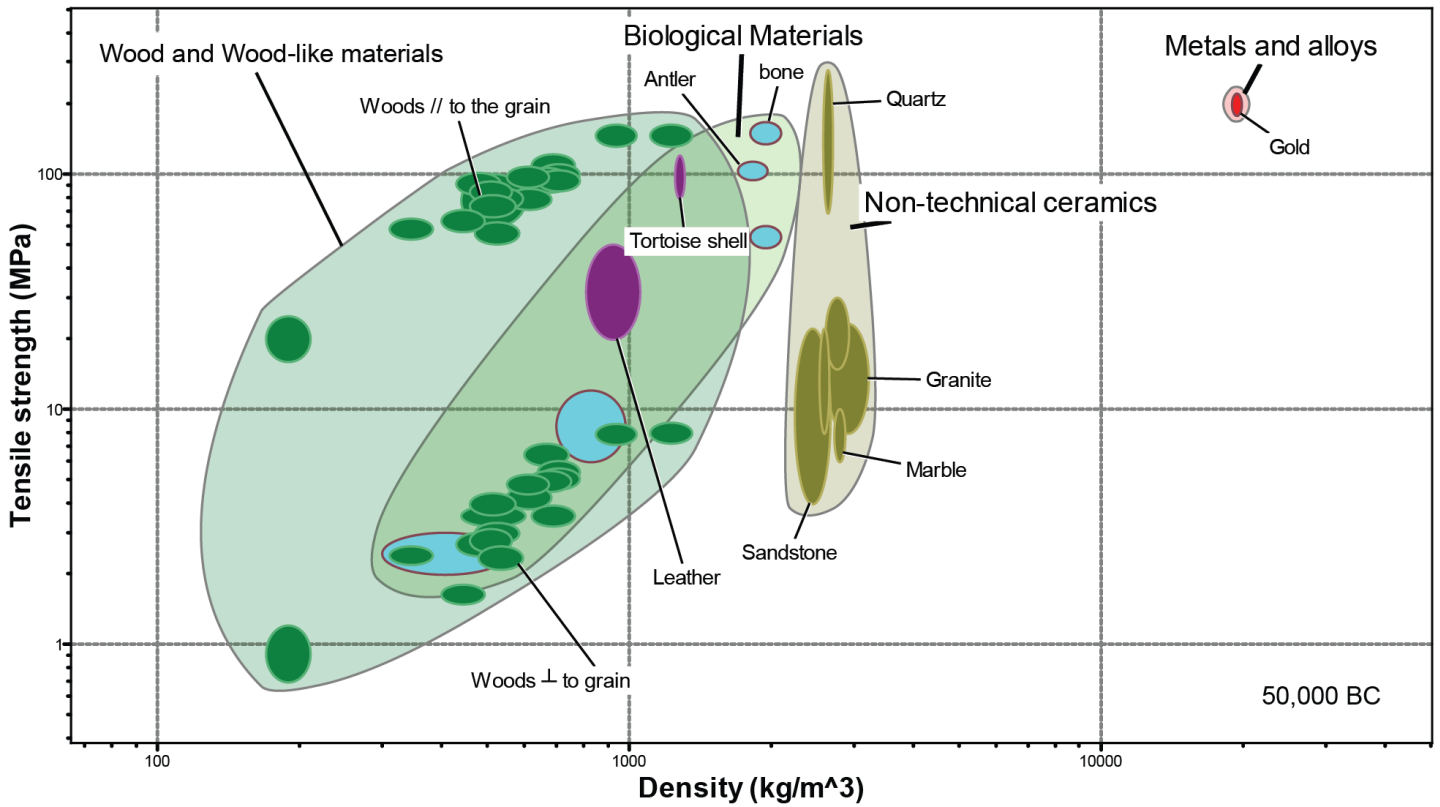
- **Text:** "Materials Selection in Mechanical Design", 5th edition by M.F. Ashby, Butterworth Heinemann, Oxford, 2016, Chapters 12-13

Outline



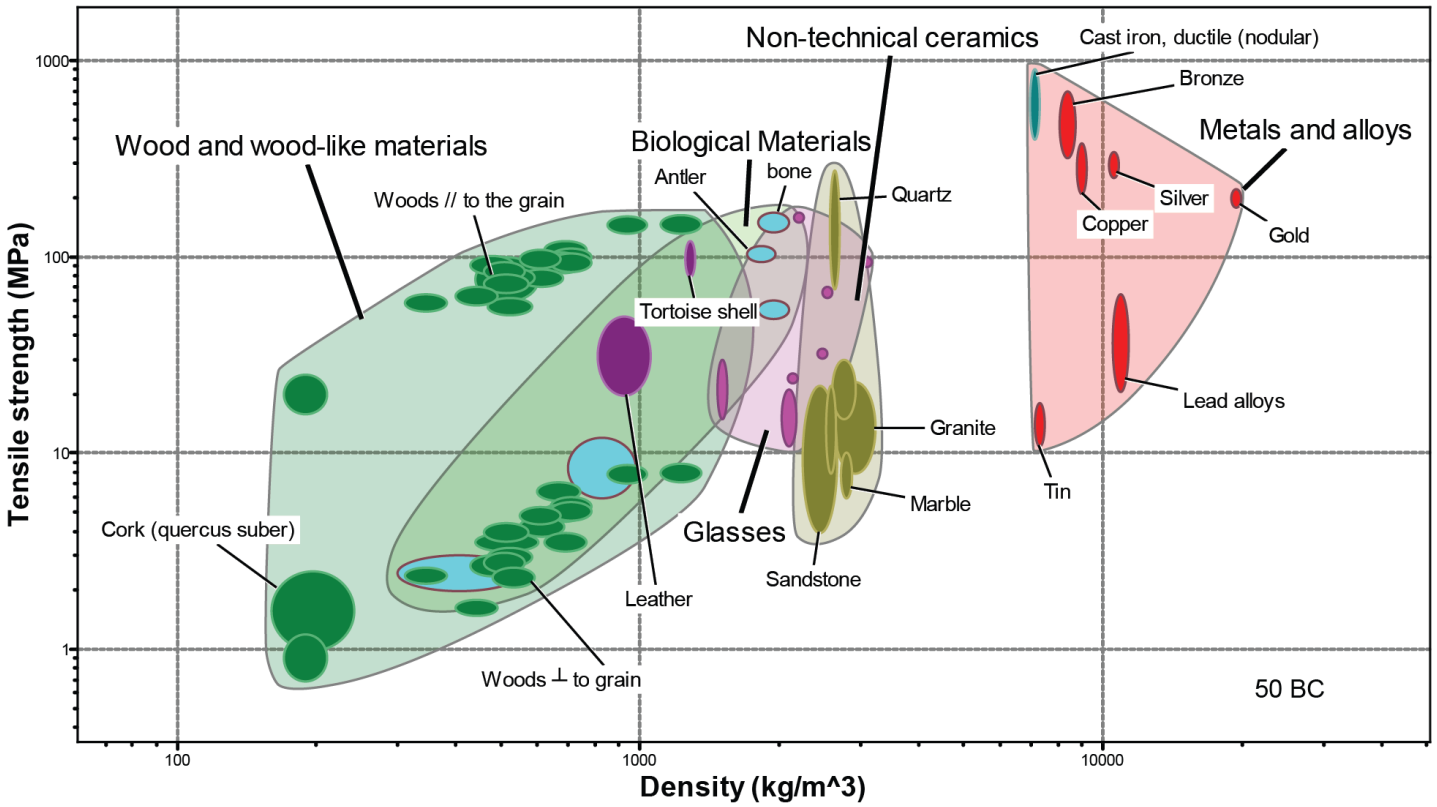
- History of structural materials
- Holes in material property space
- Fundamental limits
- Hybrid materials as a way forward

The evolution of structural materials



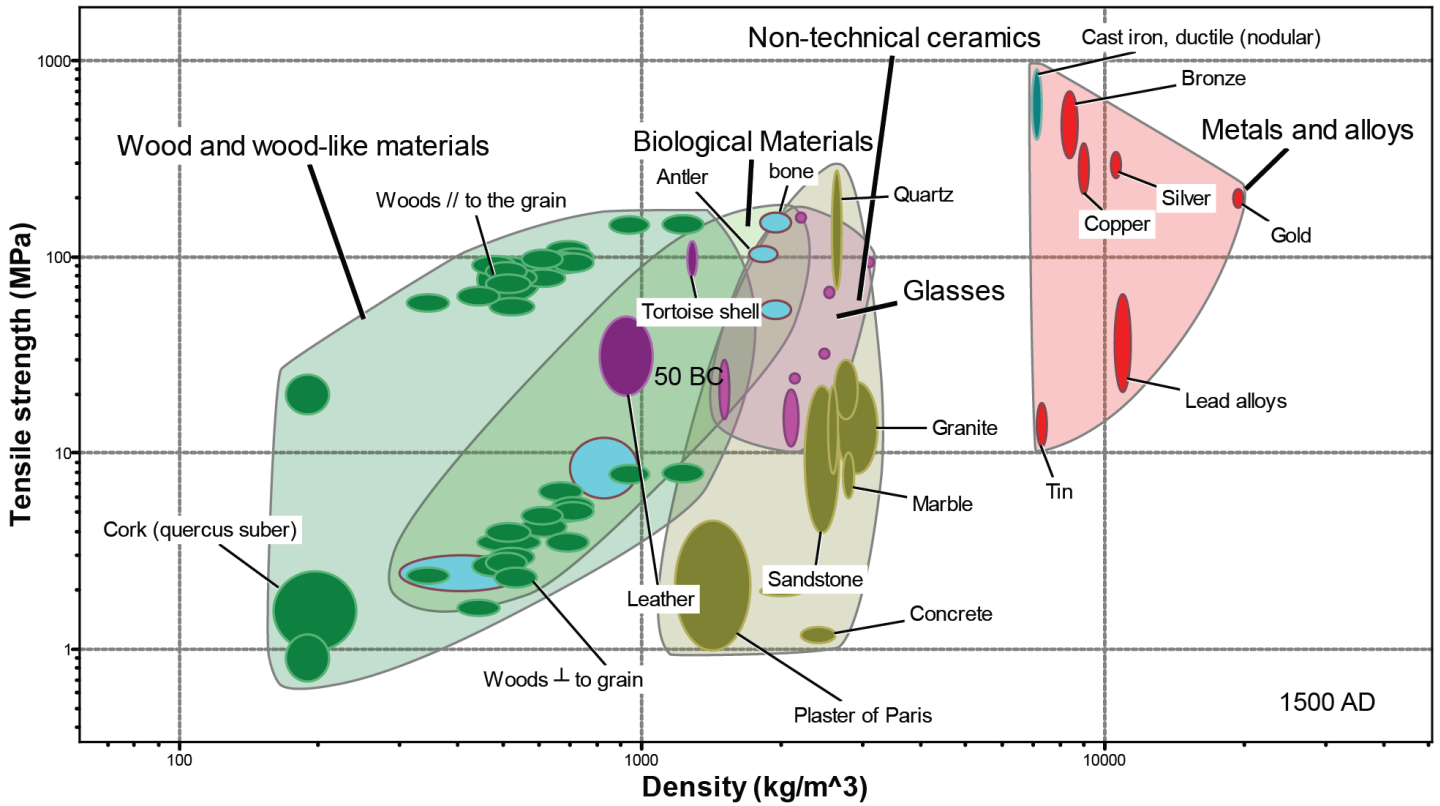
Egyptian Pyramids

The evolution of structural materials



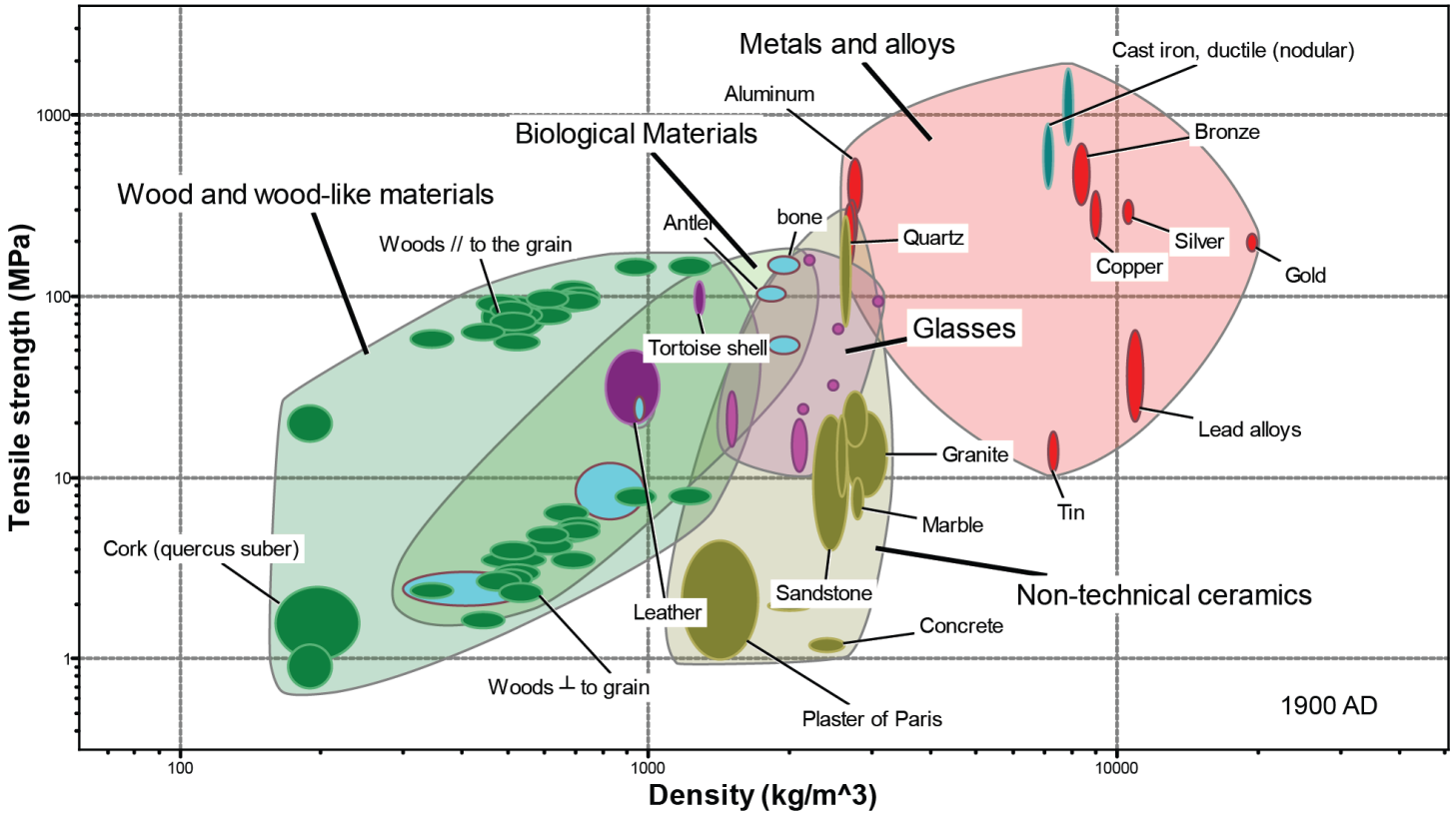
Roman Temples

The evolution of structural materials



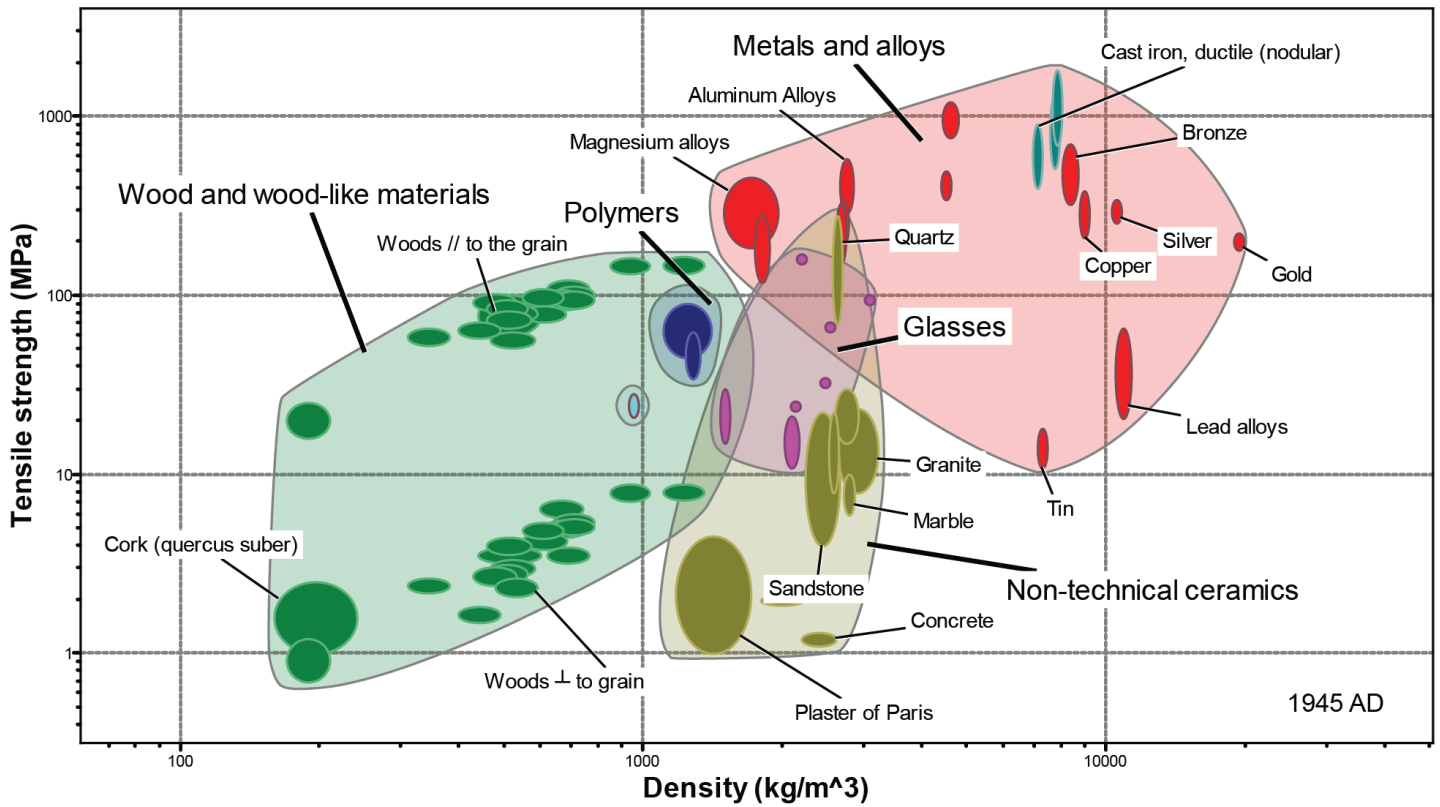
Medieval Castles

The evolution of structural materials



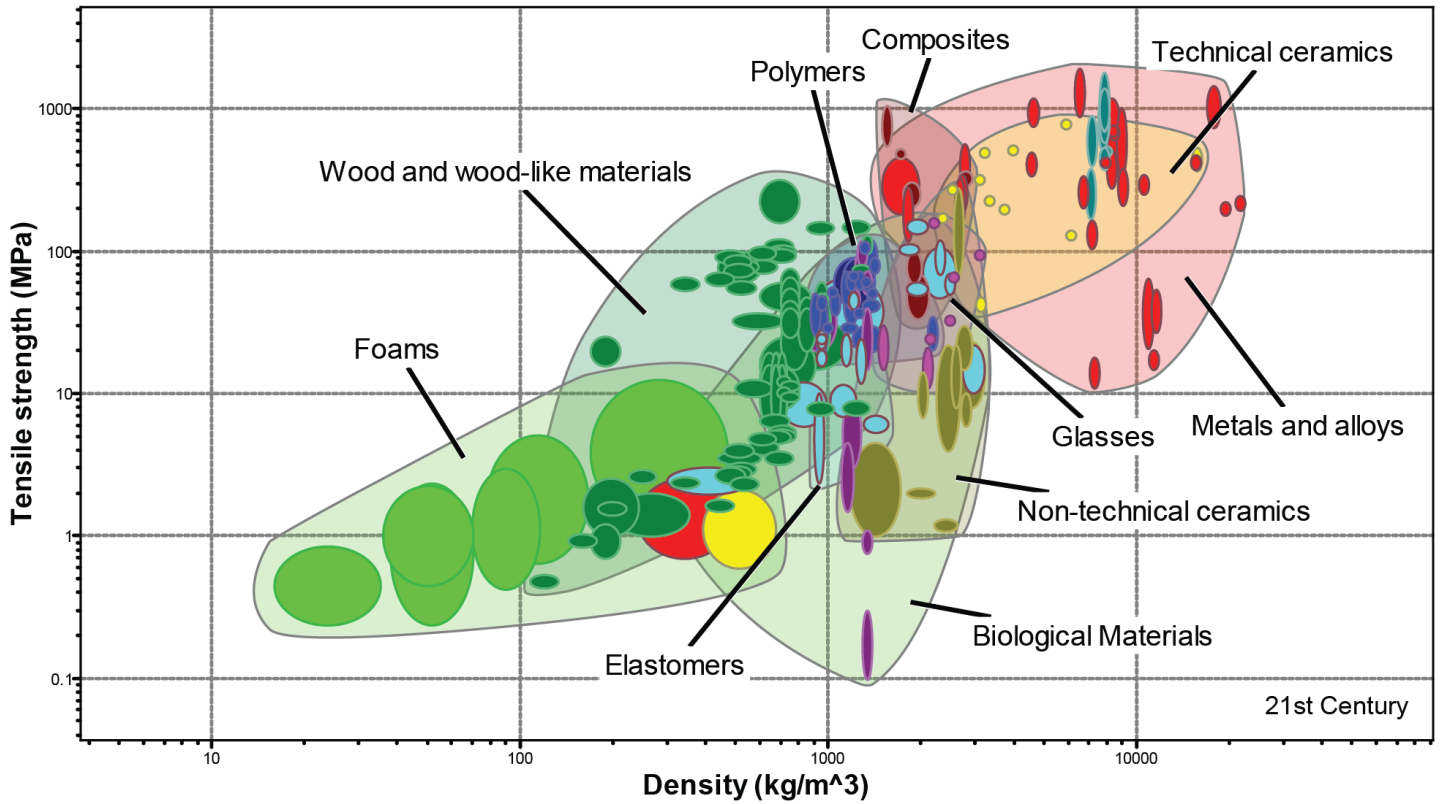
Art Nouveaux

The evolution of structural materials



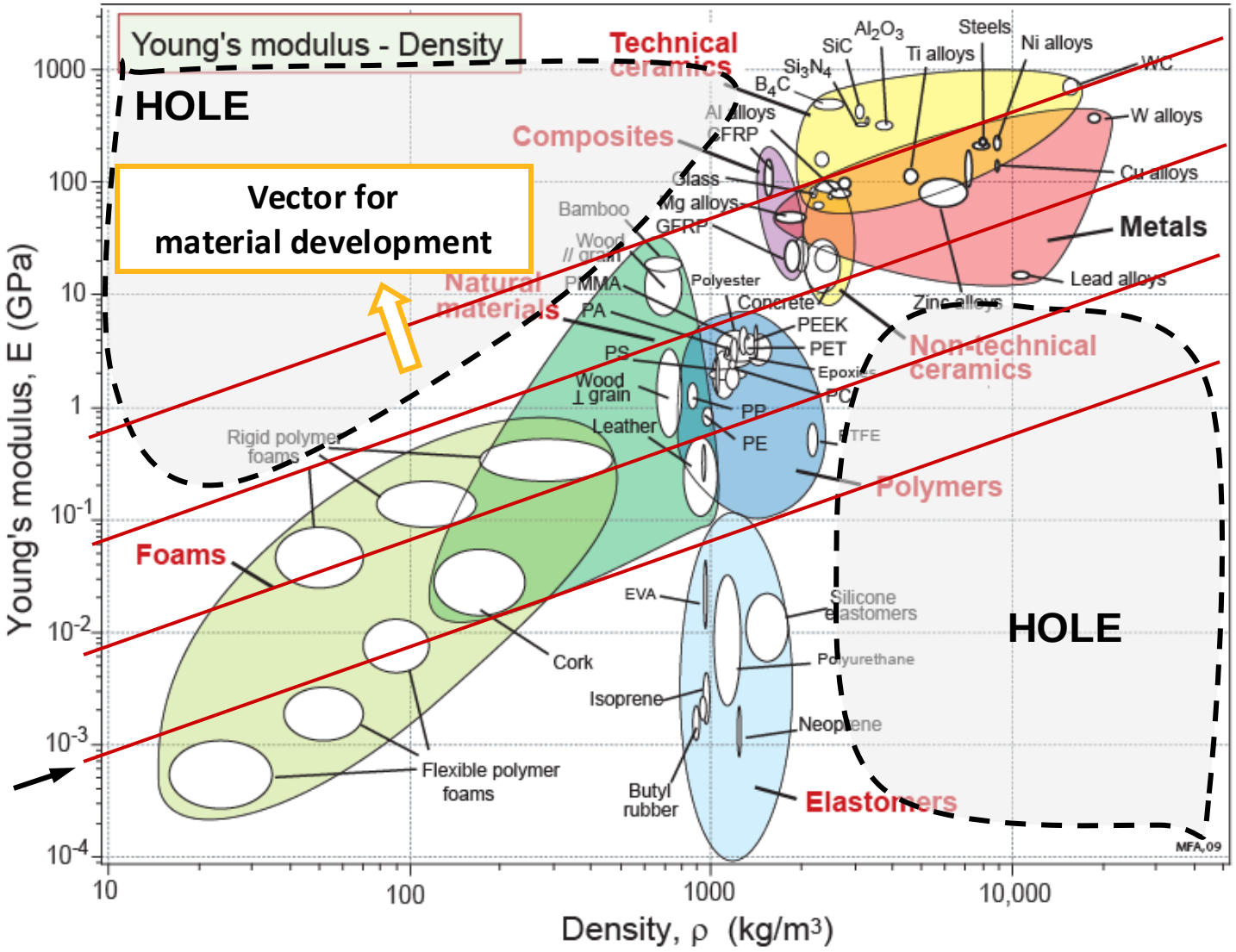
Skyscrapers

The evolution of structural materials



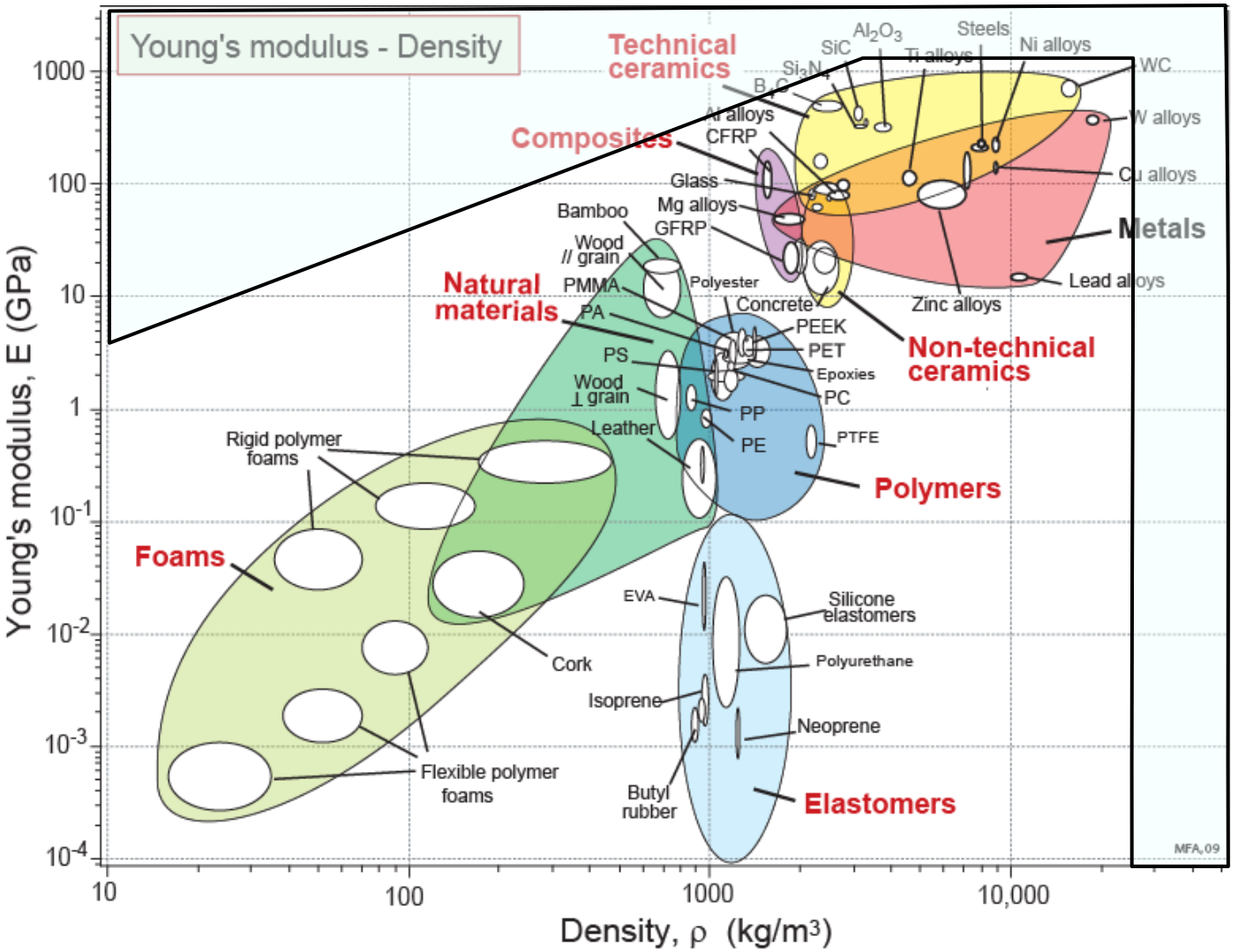
21st Century

Modulus and density

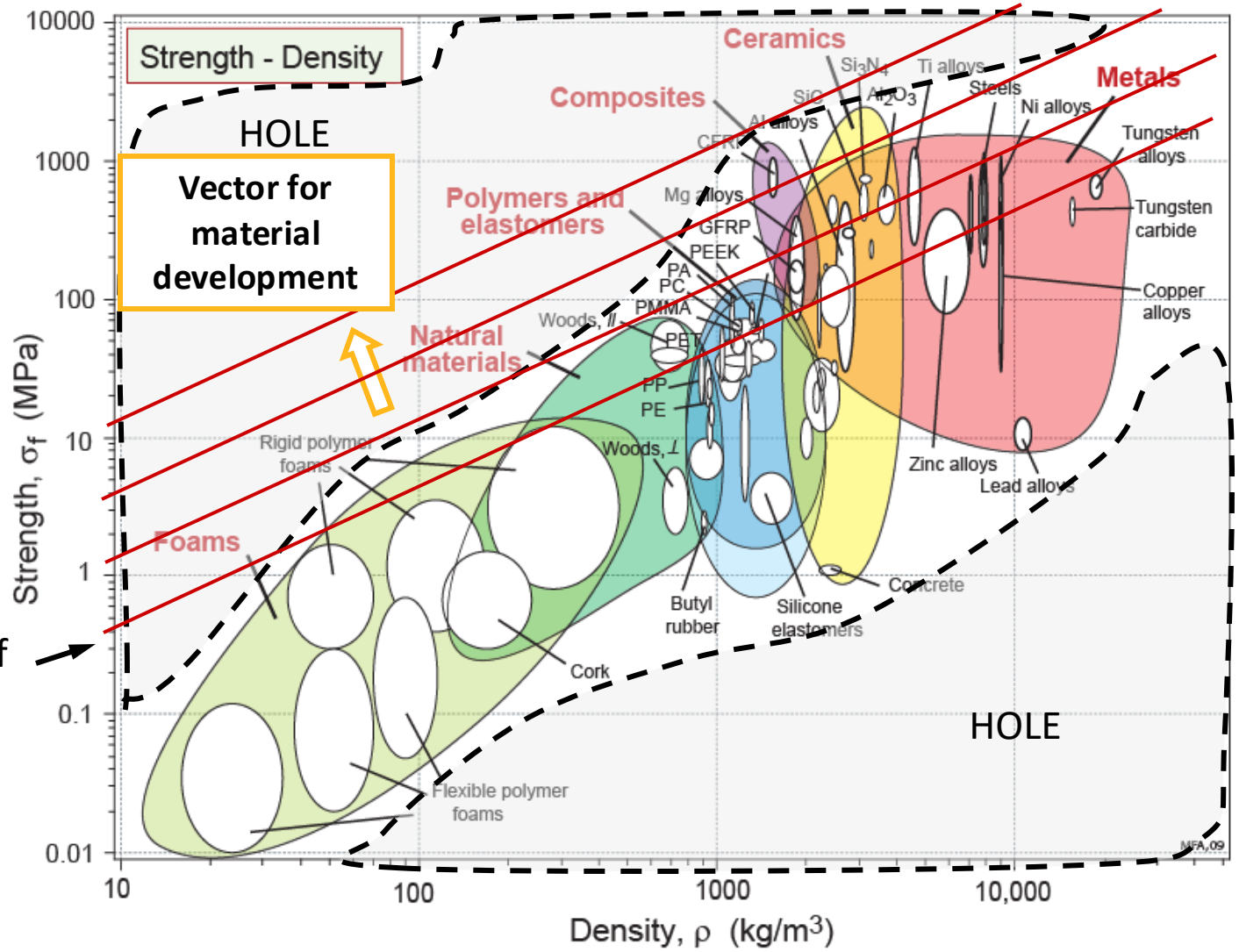


Contours of E/ρ

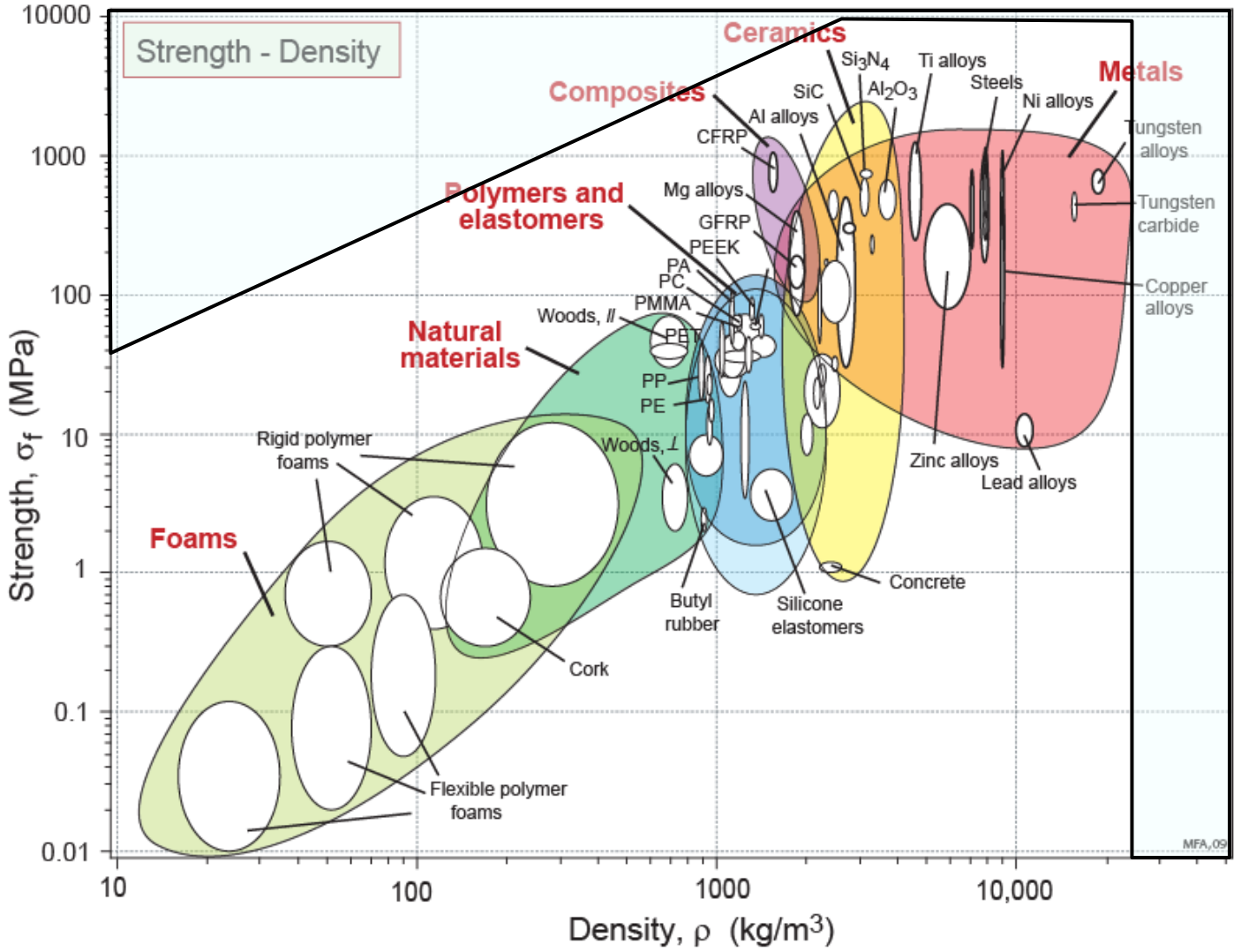
Limits: modulus - density



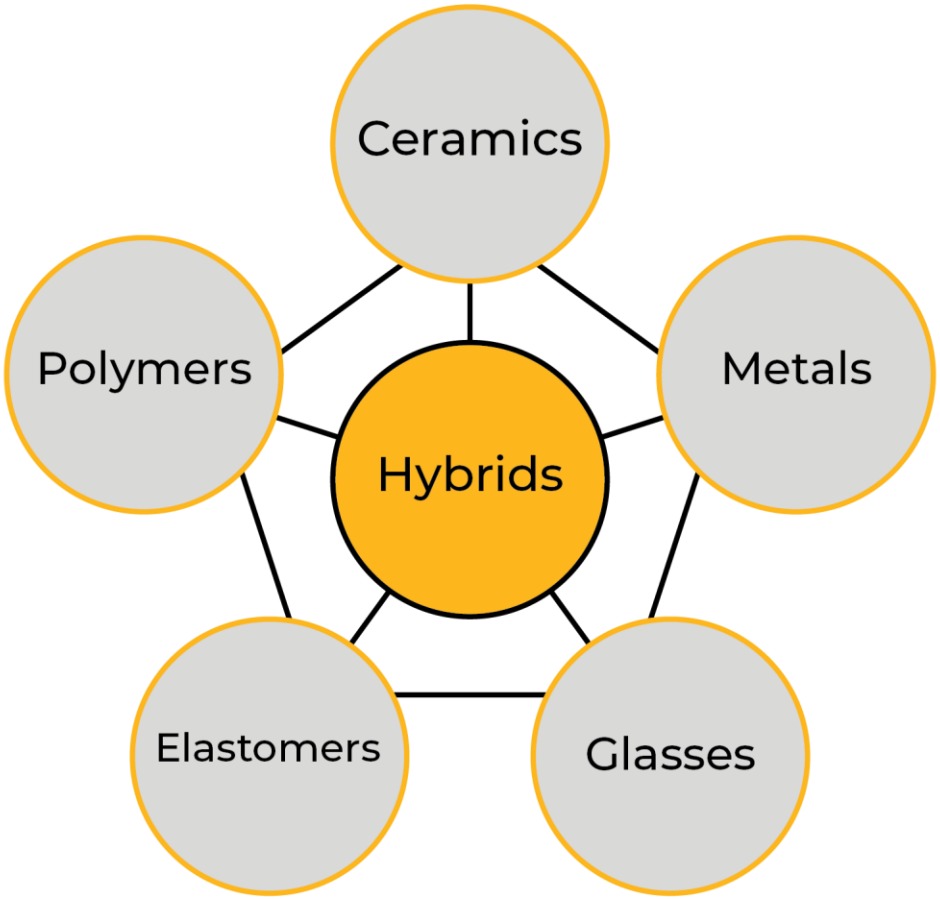
Strength - density



Limits: strength - density



Hybrid materials



Design variables:

- Choice of materials
- Volume fractions
- Configuration
- Connectivity
- Scale

The good and the bad about Hybrids

Hybrid corn

Improved yield, hardiness

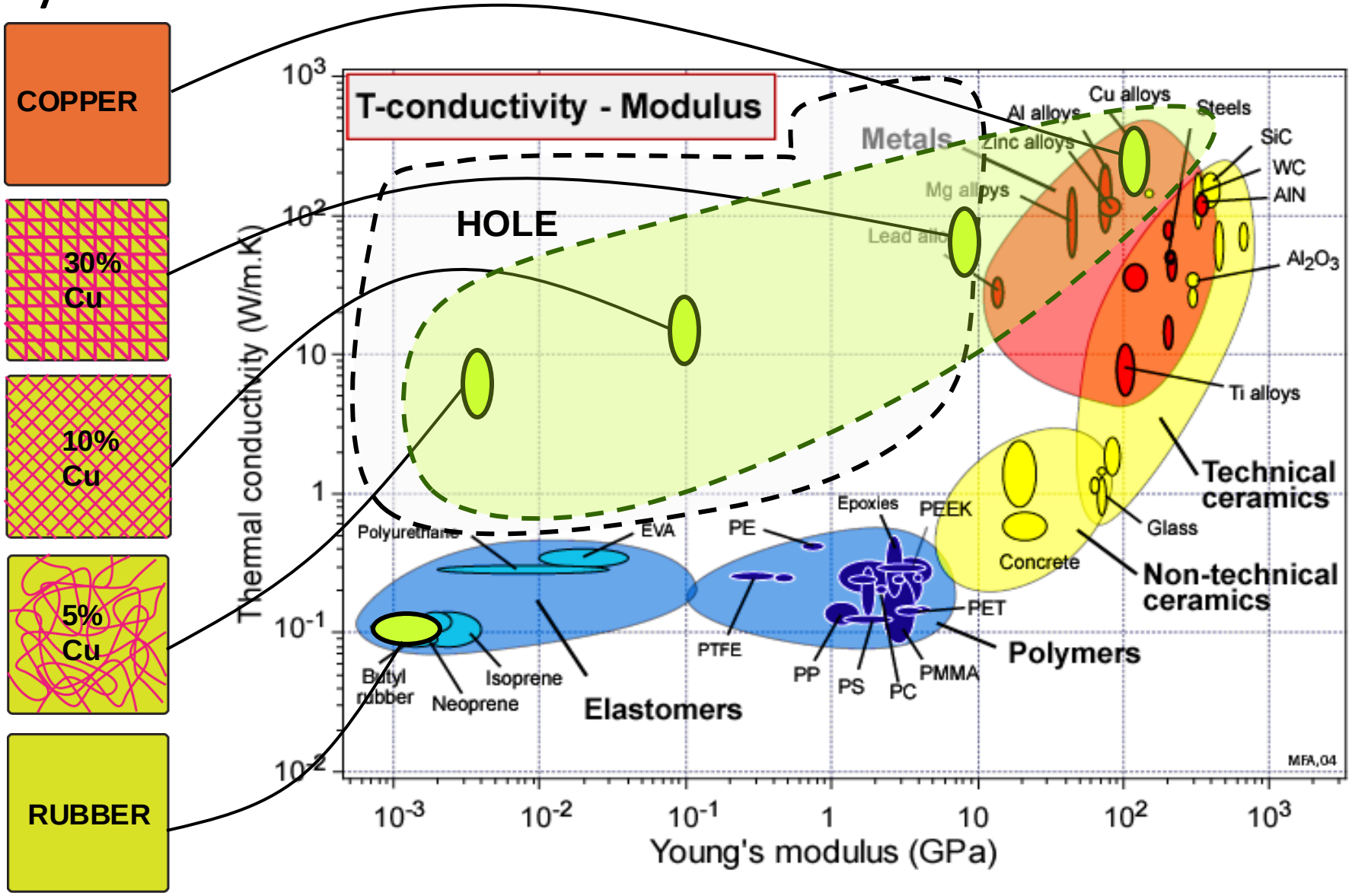
…… but… **Infertile**

Hybrid cars

Low fuel consumption, emissions

…… but… **Expensive**

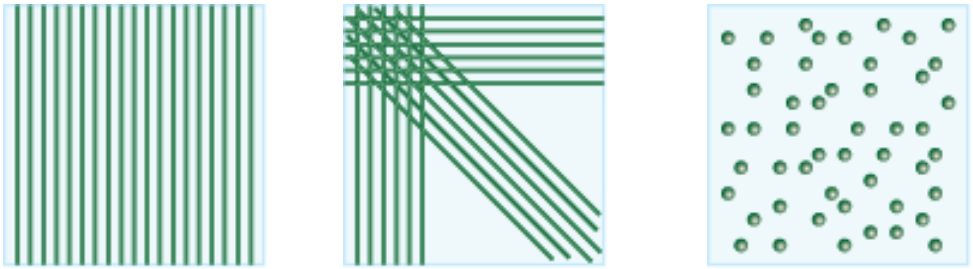
Using Hybrids to fill holes



Familiar architectures

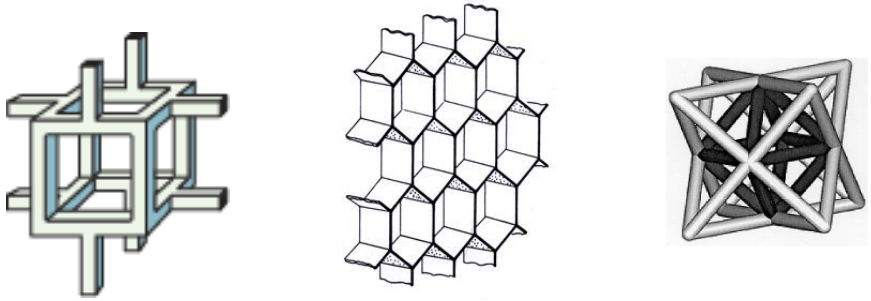
Composites

- *Unidirectional*
- *Quasi-isotropic*
- *Particulate*



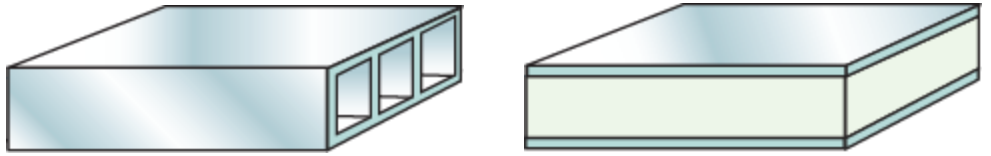
Cellular structures

- *Foams*
- *Honeycombs*
- *Triangulated lattices*



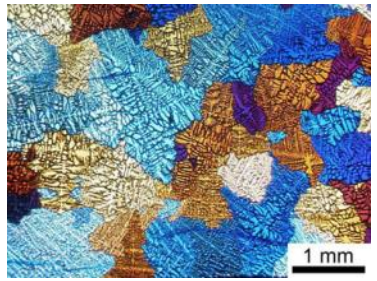
Sandwich structures

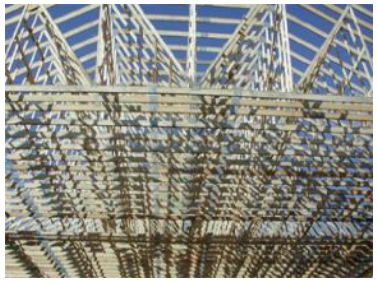
- *Symmetric sandwiches*



Many more

Designing hybrid materials





Combine:

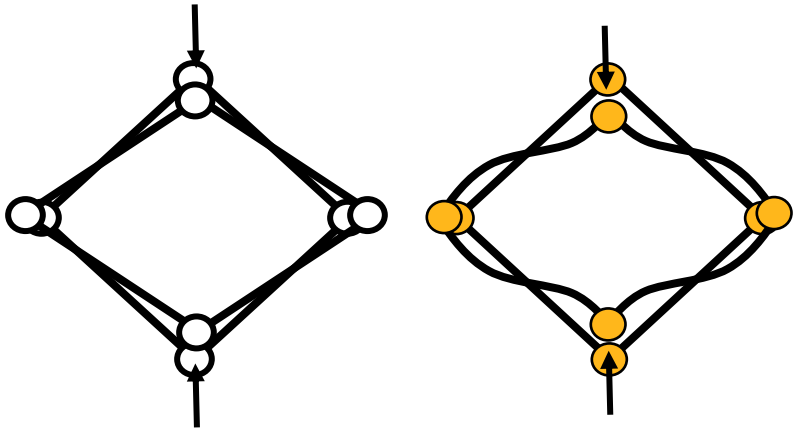
- **Materials –** relate properties to microstructure: controlled nature, scale through alloy design and processing.

- **Mechanics –** accept properties as “given”, optimise the geometry

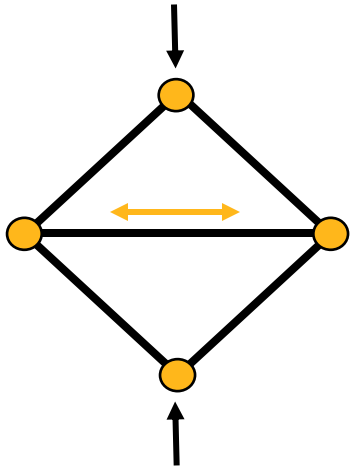
- **Textile technology –** exploit unique strength and blending properties of fibers

Bending and stretch dominated structures

Bending-dominated structures

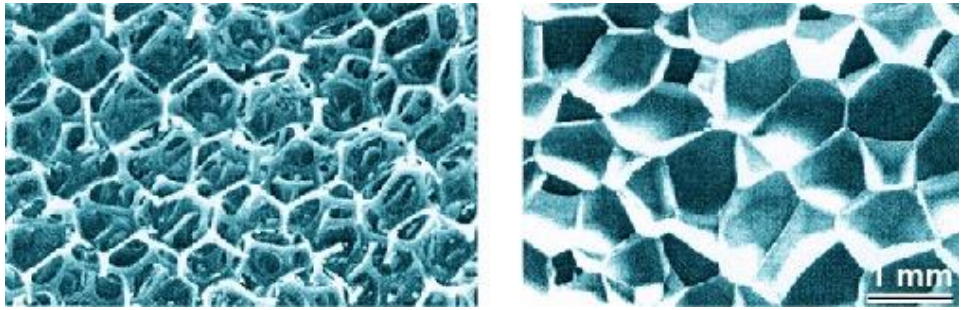


Stretch-dominated structures

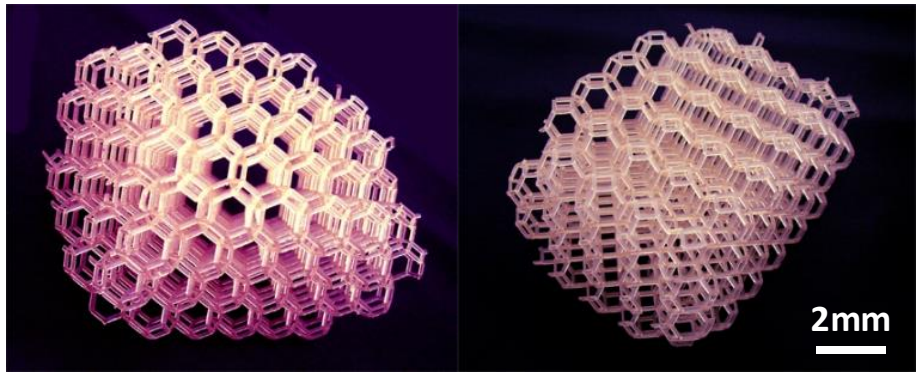


- Lock joints in a ***mechanism*** prevents rotation, deformation by **bending**

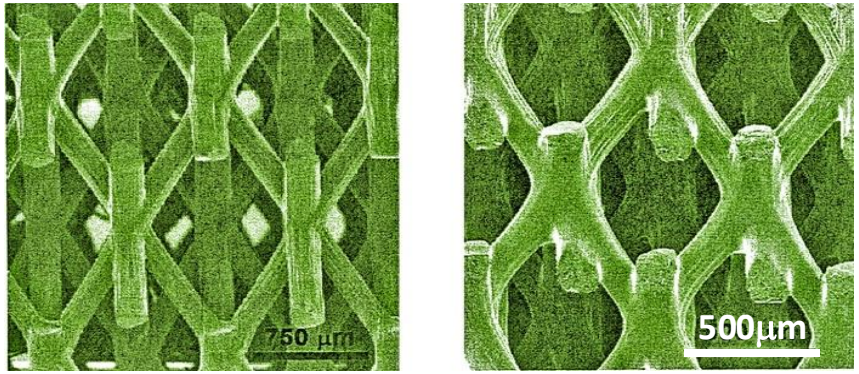
Foams and micro-lattices



Polymer foams

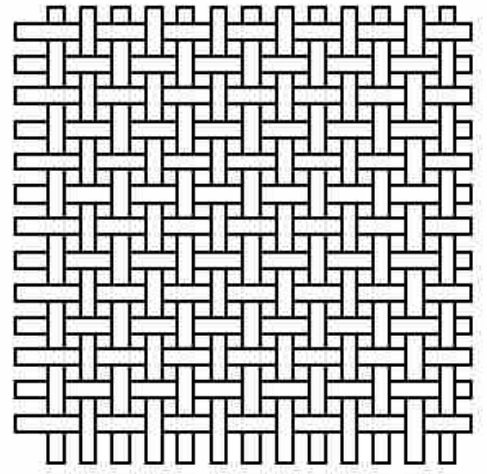


Bending-dominated micro-lattices

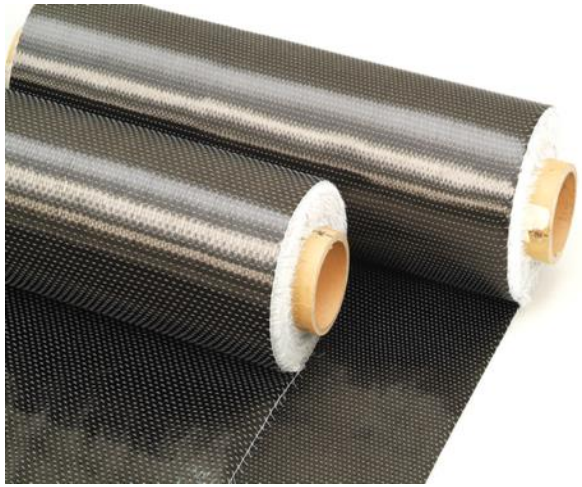


Stretch-dominated micro-lattices

Combining textile technology, mechanics and material

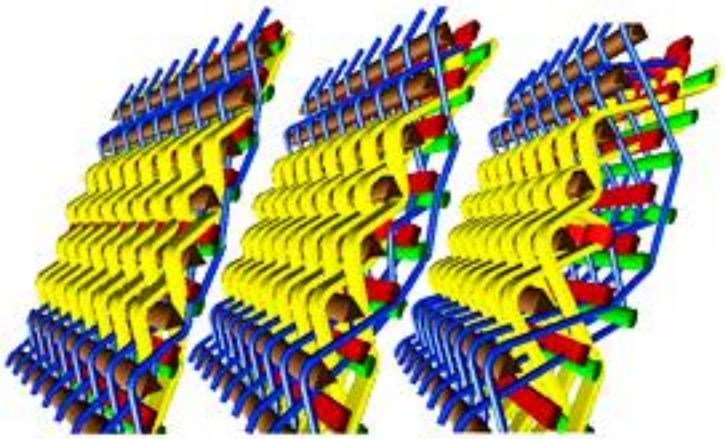


(a) Simple weave

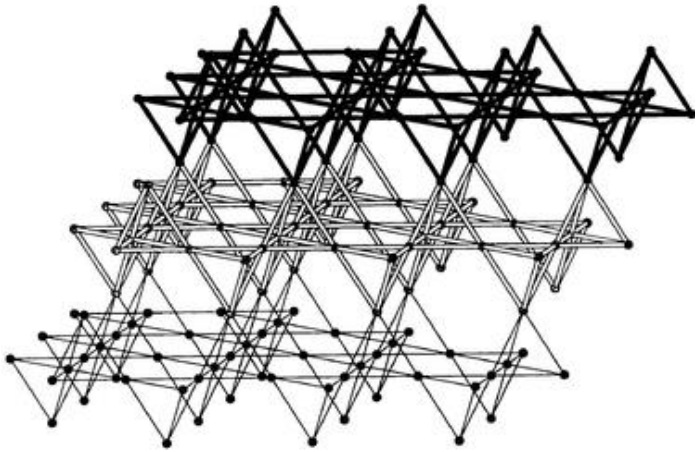


Woven carbon fiber

CFRP product

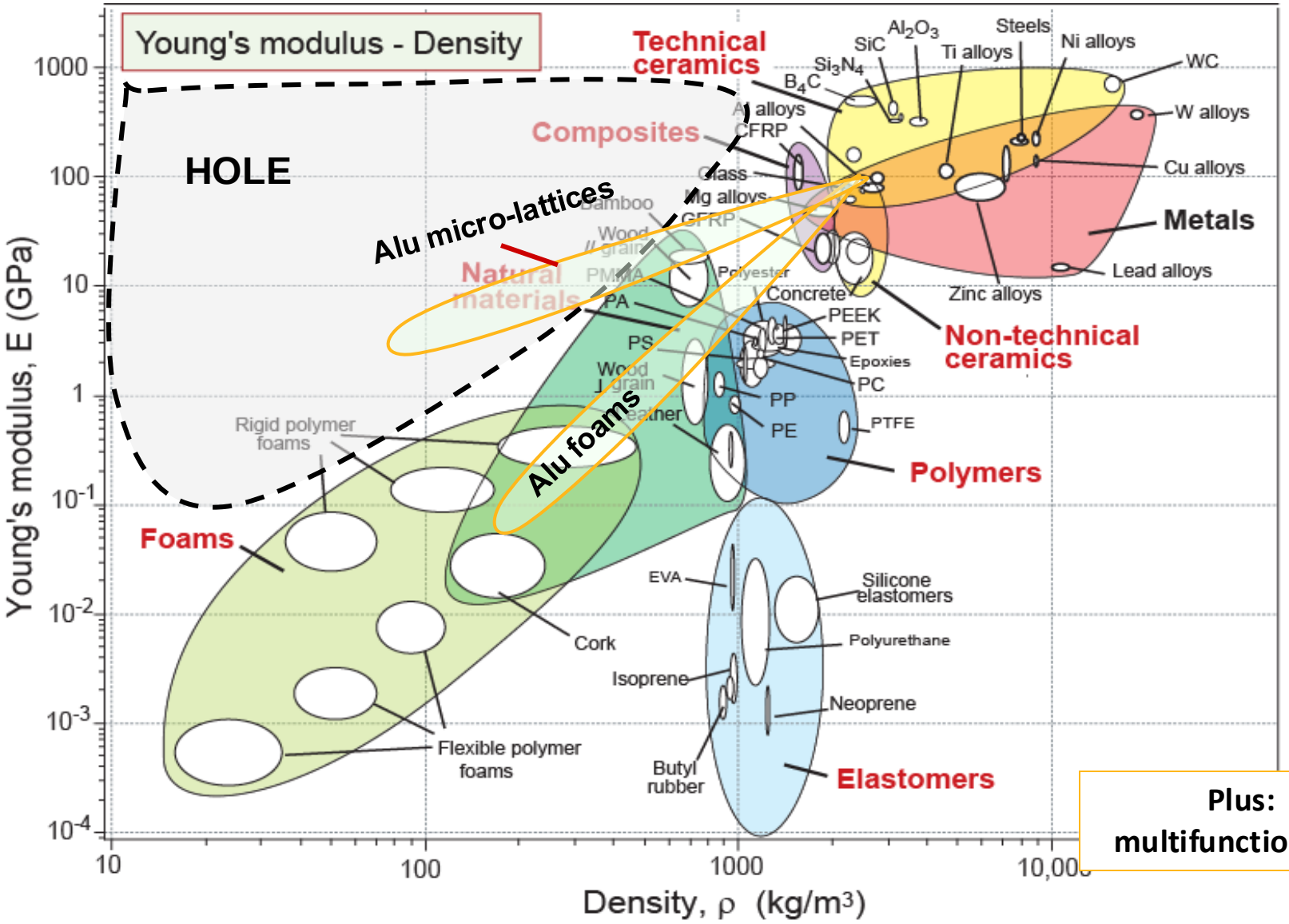


(b) 3-dimensional weaving



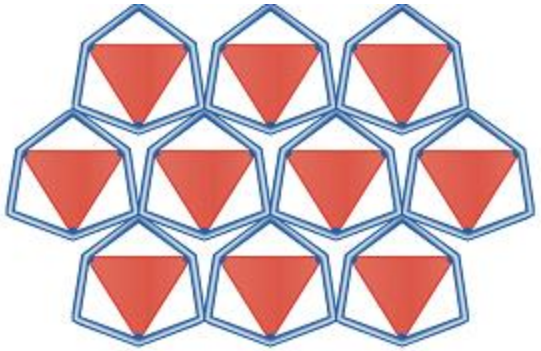
(c) The kagome weave

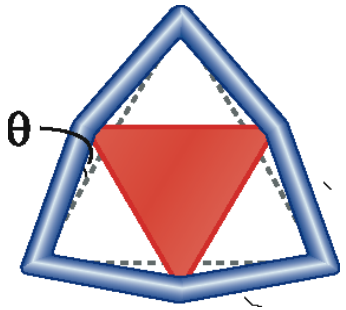
Foams and lattice structures

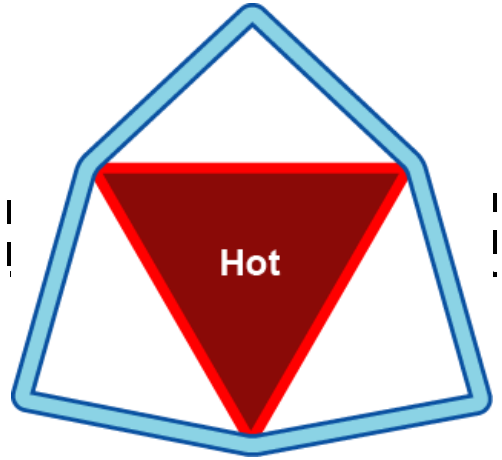


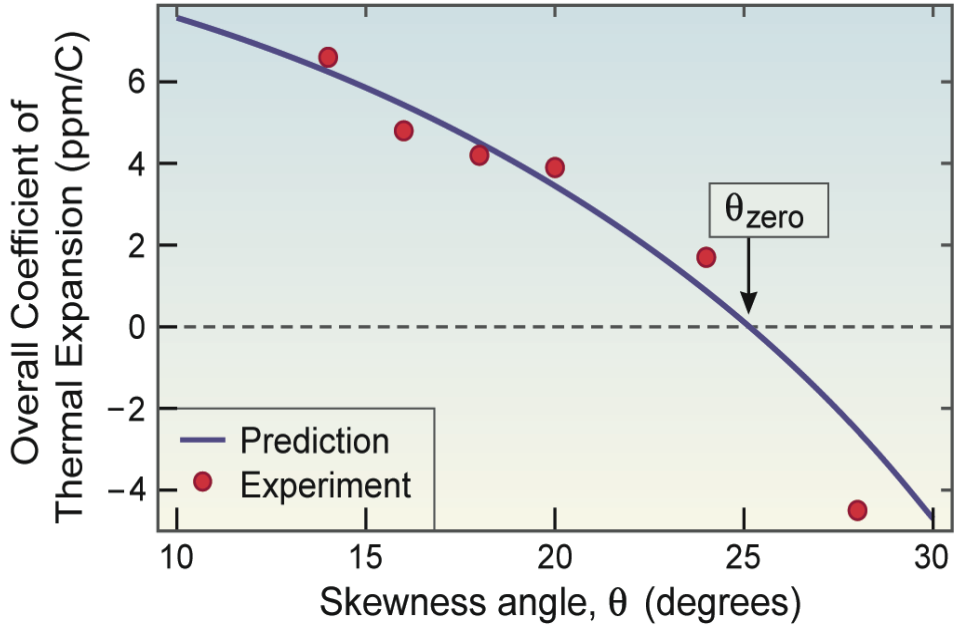
Plus: multifunctionality

Configuration: controlling expansion

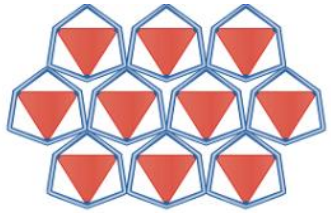


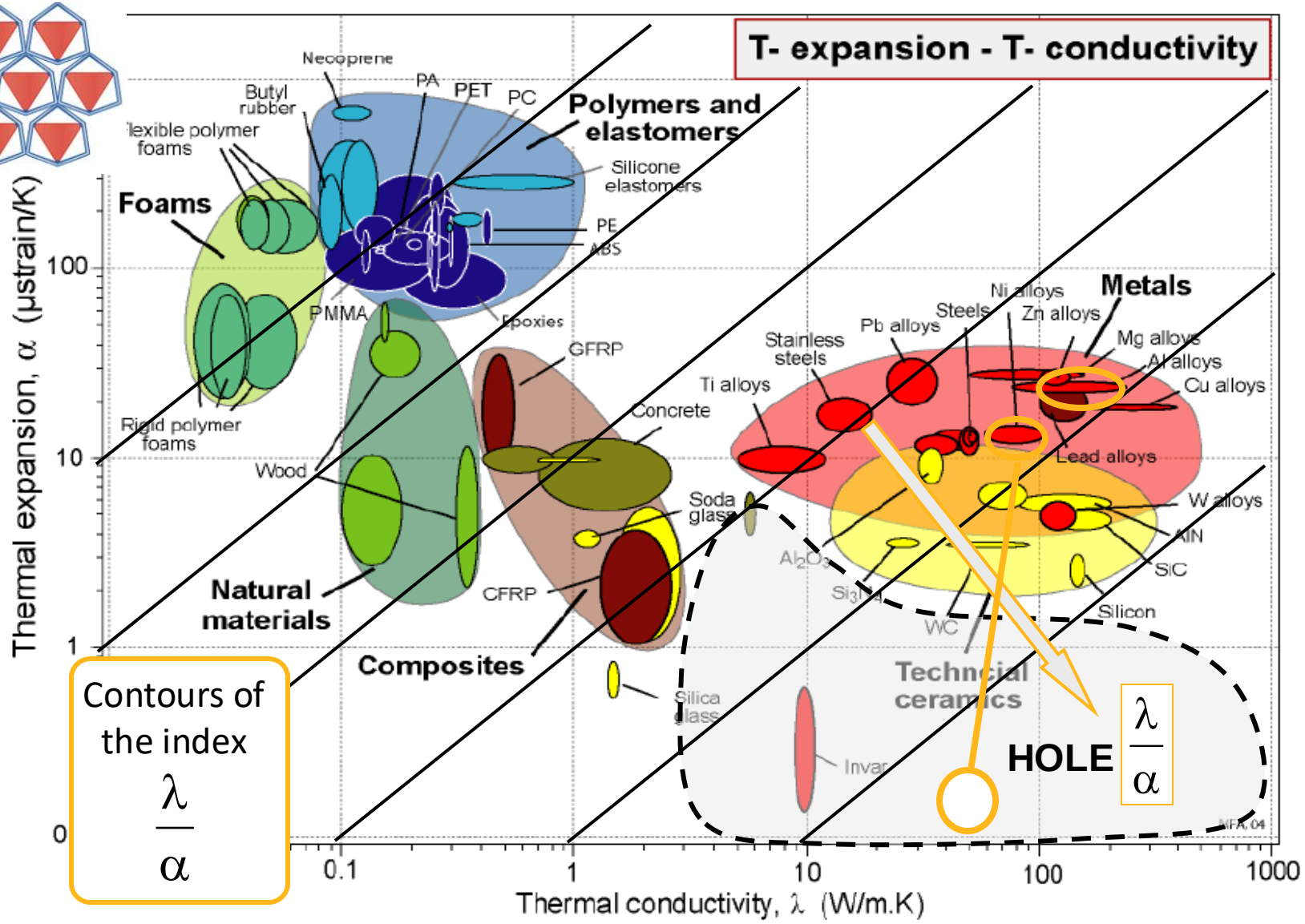






Material-property space: α and λ





Summary

- **Multi-dimensional material-property space**
  - **Only part-filled** by monolithic materials
  - True of **mechanical, thermal, electrical, magnetic** and **optical** properties

- **Material development strategies**
  - **Classical** (classical alloy development, polymer chemistry….)
  - **“Nano” (sub-micron) scale** (exploiting scale-dependence of properties)
  - **Hybridization** (exploiting materials, configuration and connectivity)

- **The strategy:**
  - Map out the filled areas
  - Explore the ultimate boundaries
  - Explore ways of filling the empty space.
  - Hybrids, exploiting potential of novel configurations, have potential for this

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