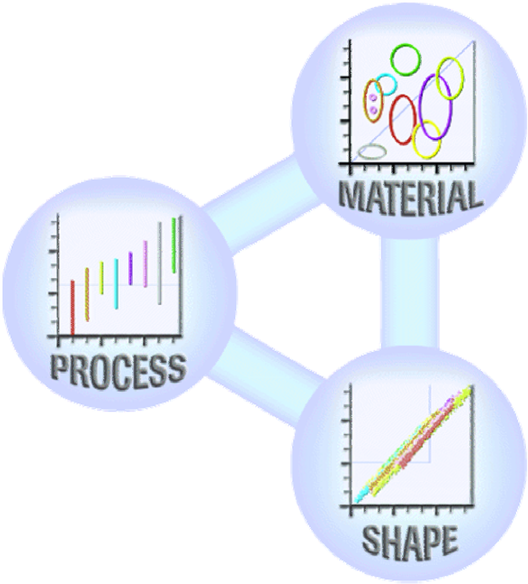
The *CES 4* EduPack

Unit 1. Mapping the World of Materials:

the first step in exploration and selection



New approaches to Materials Education

- a course authored by
Mike Ashby and Dave Cebon
Cambridge, UK

Difficulty level 1

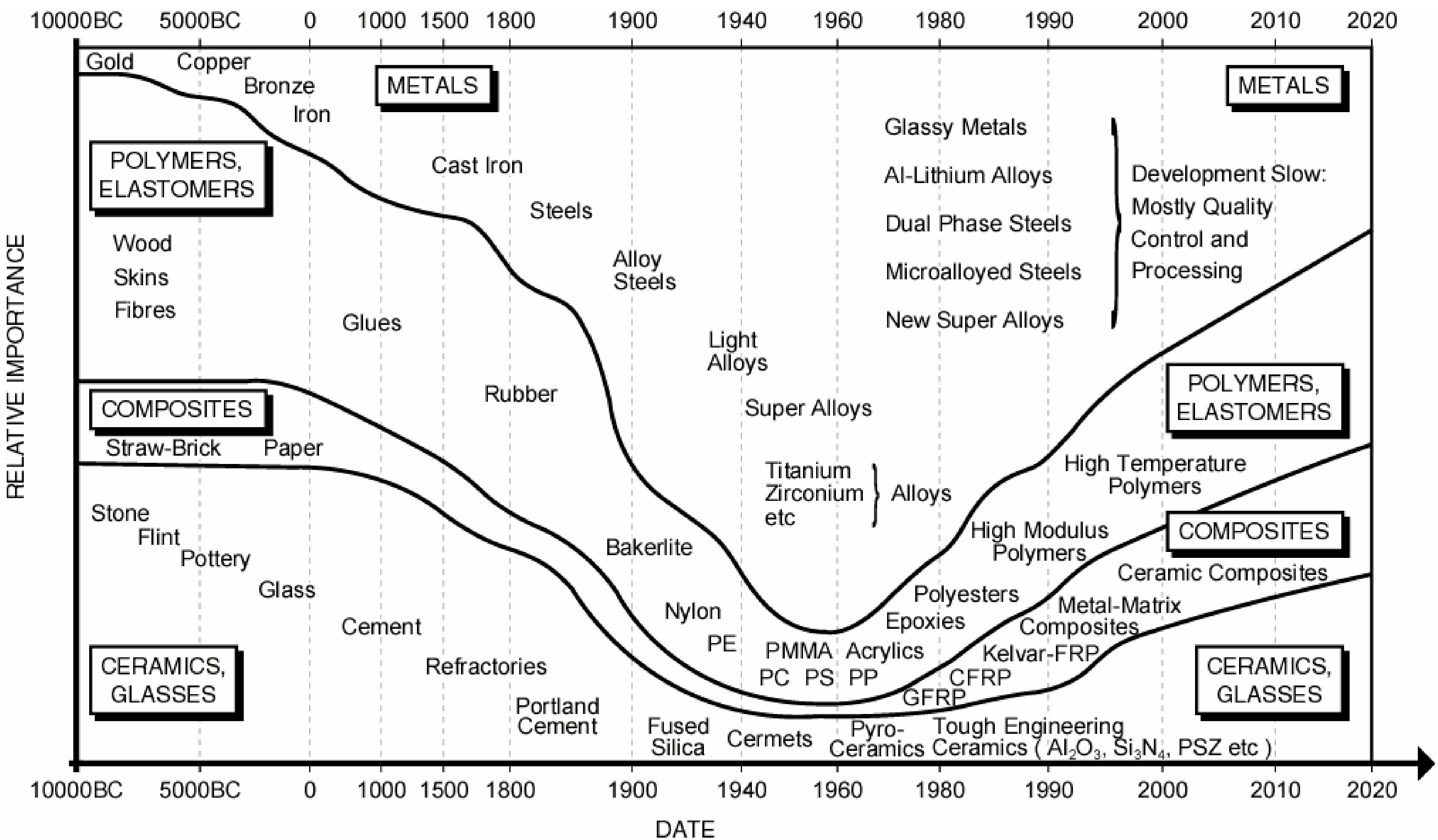
Outline

- **History -- the evolution of materials**
- **Materials and their attributes**
- **The nature of materials data**
- **Exploring relationships: Material Property Charts**
- **The design process**
- **Matching material to design: screening and ranking**

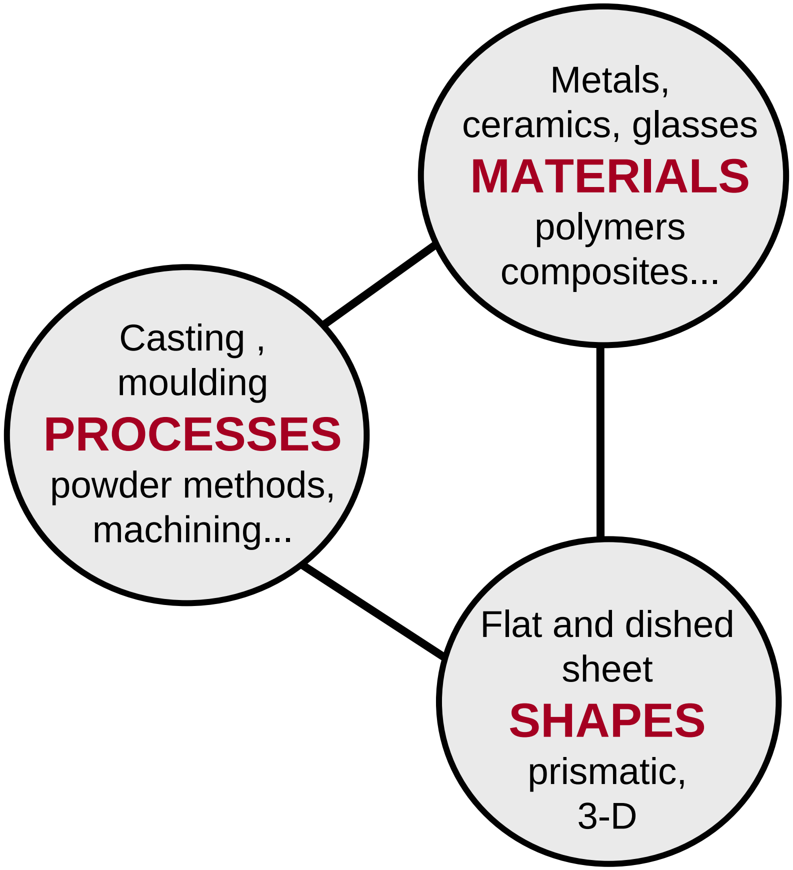
Resources:

- "Materials Selection in Mechanical Design", ("The Text") by M.F. Ashby, Butterworth Heinemann, Oxford, 1999, Chapters 1 - 4.
- The Cambridge Material Selector *(CES 4)* software -- Granta Design, Cambridge (www.grantadesign.com)

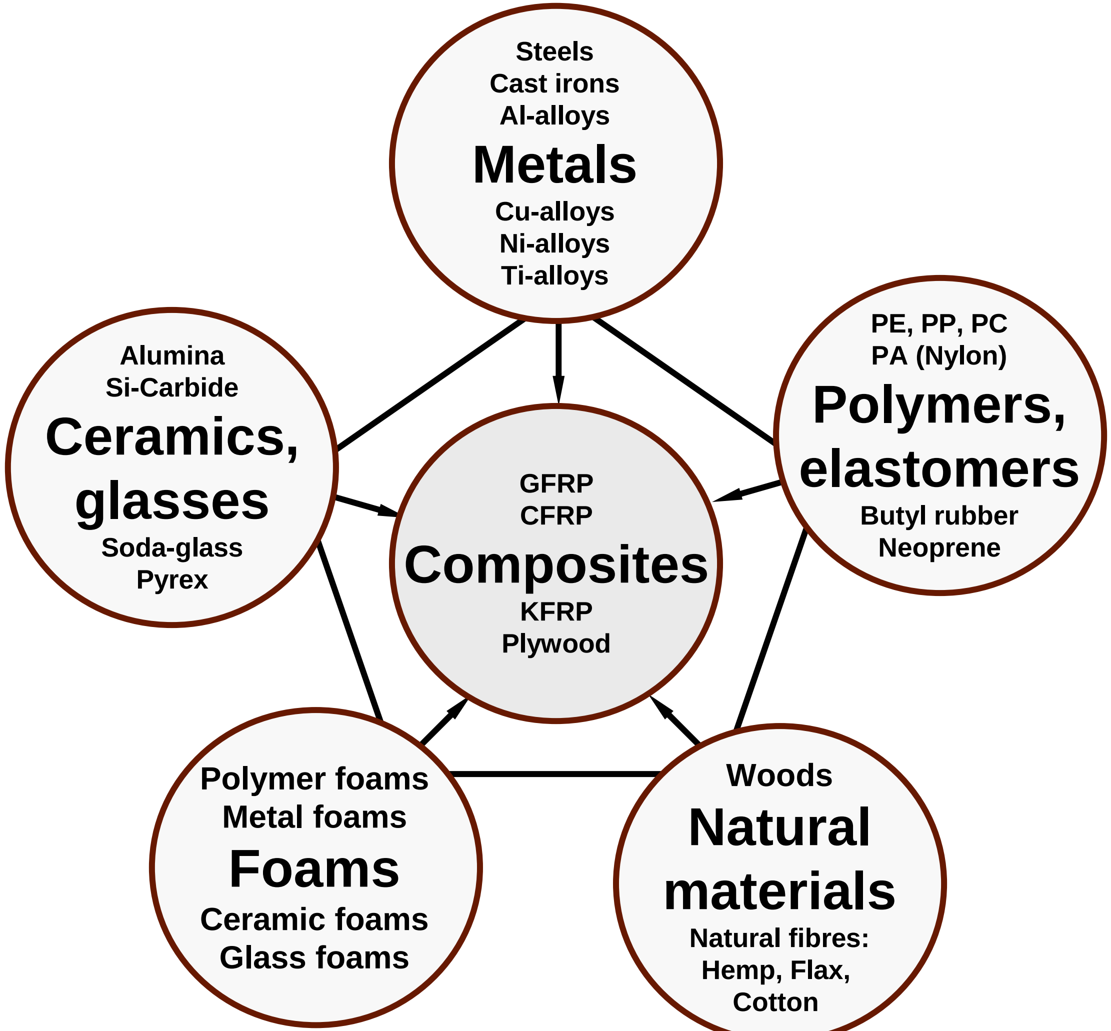
The evolution of materials



Materials, process and shape

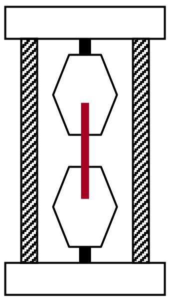


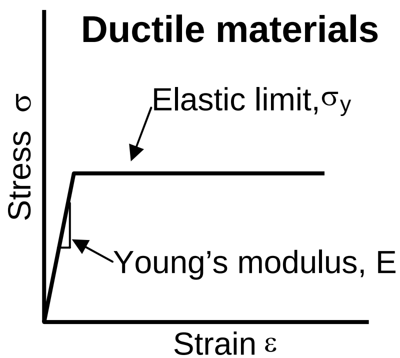
The world of materials

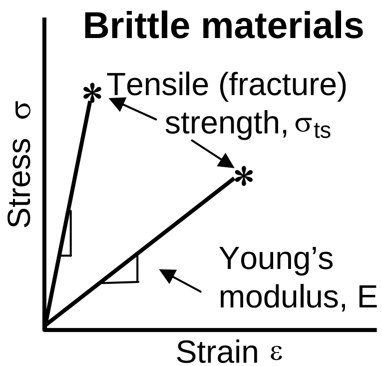


Basic material properties

Mechanical properties







General

Weight: Density ρ, Mg/m^3

Expense: Cost/kg C_m, \$/kg

Mechanical

Stiffness: Young's modulus E, GPa

Strength: Elastic limit σ_y, MPa

Fracture strength: Tensile strength σ_{ts}, MPa

Brittleness: Fracture toughness K_{ic}, $MPa.m^{1/2}$

Thermal

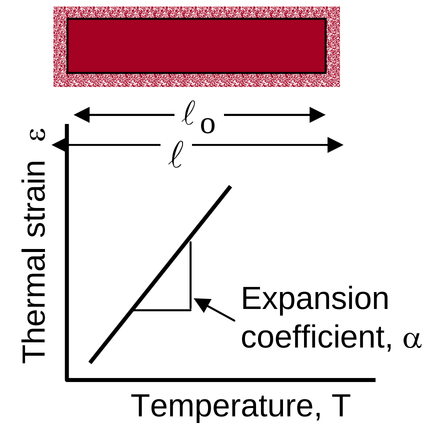
Expansion: Expansion coeff. α, 1/K

Conduction: Thermal conductivity λ, W/m.K

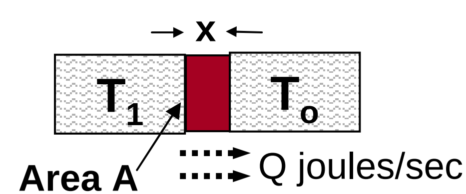
Electrical

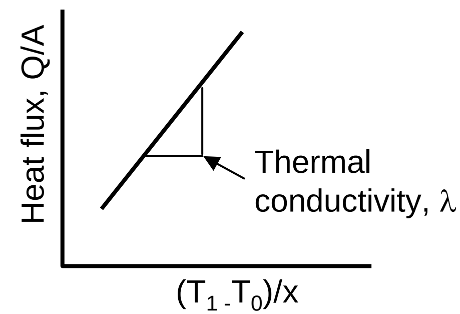
Conductor? Insulator?

Thermal expansion

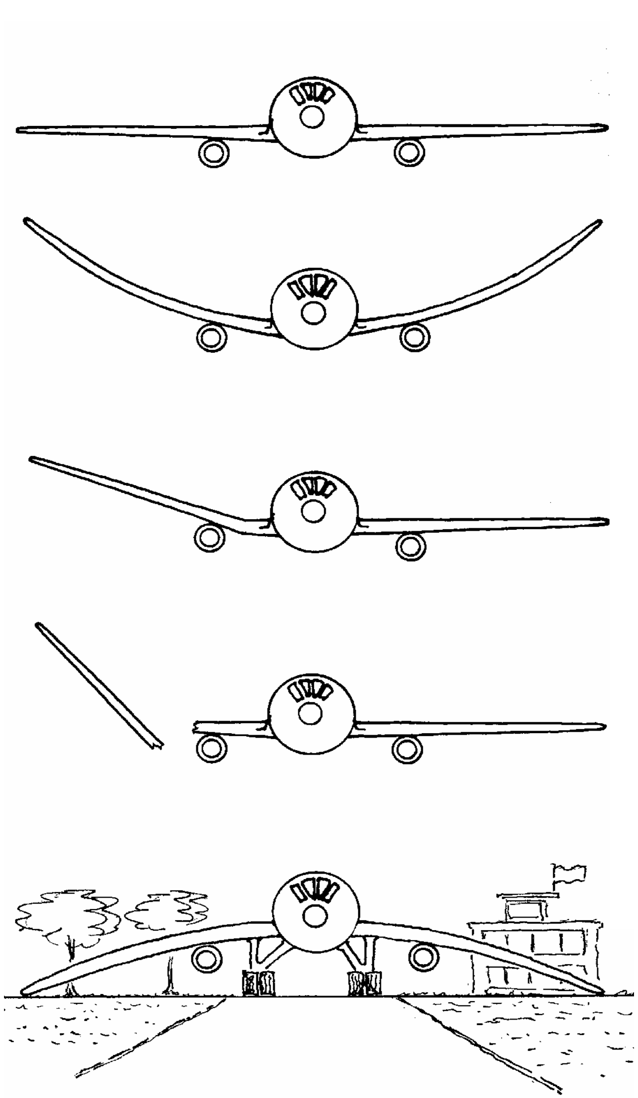


Thermal conduction





Mechanical properties illustrated



← Stiff
Strong
Tough
Light

} **All OK !**

← **Not stiff enough (need bigger E)**

← **Not strong enough (need bigger σ_y)**

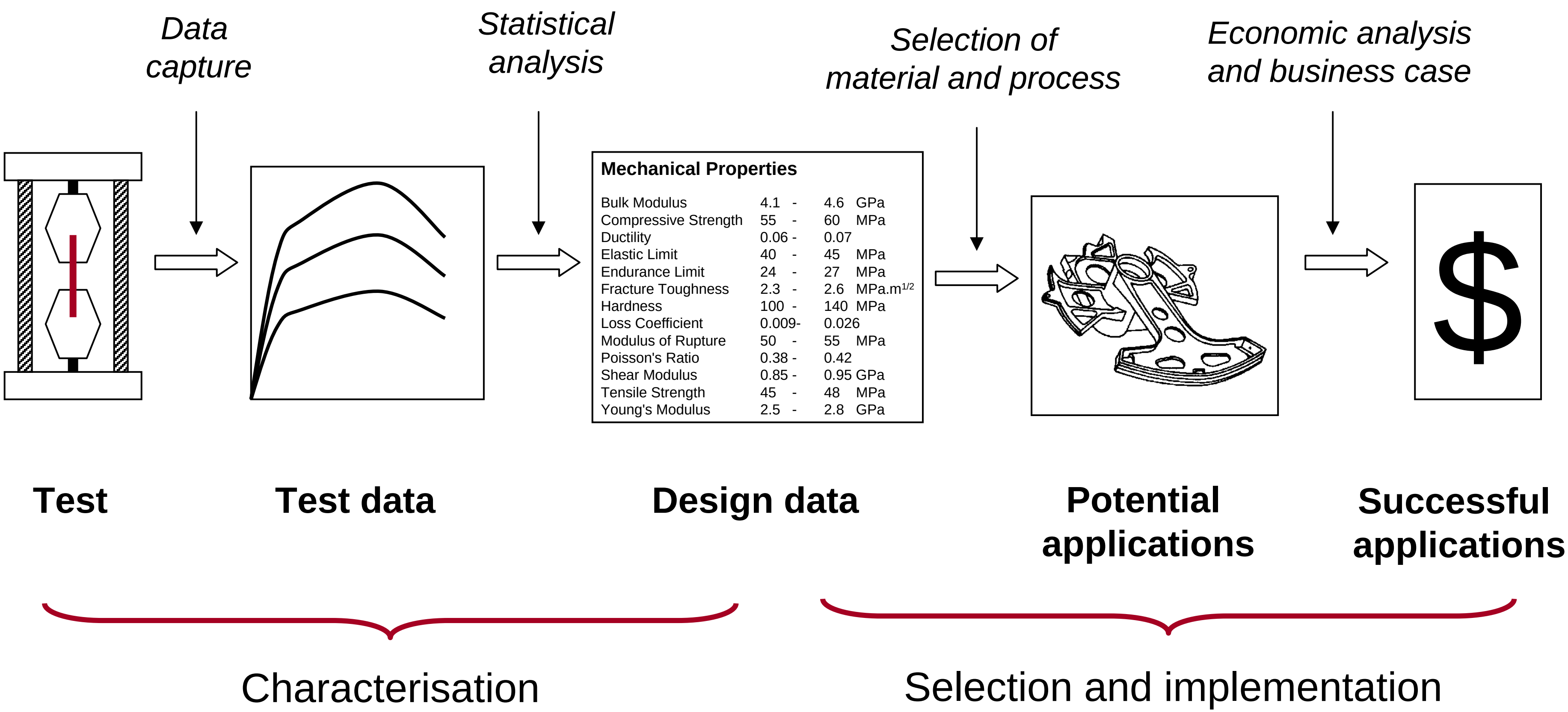
← **Not tough enough (need bigger K_{ic})**

← **Too heavy (need lower ρ)**

The goal of design:

"To create products that perform their function effectively, safely, at acceptable cost"

What do we need to know about materials to do this?   *More than just test data*.



Mechanical Properties		
Bulk Modulus	4.1 -	4.6 GPa
Compressive Strength	55 -	60 MPa
Ductility	0.06 -	0.07
Elastic Limit	40 -	45 MPa
Endurance Limit	24 -	27 MPa
Fracture Toughness	2.3 -	2.6 MPa.m$^{1/2}$
Hardness	100 -	140 MPa
Loss Coefficient	0.009-	0.026
Modulus of Rupture	50 -	55 MPa
Poisson's Ratio	0.38 -	0.42
Shear Modulus	0.85 -	0.95 GPa
Tensile Strength	45 -	48 MPa
Young's Modulus	2.5 -	2.8 GPa

The nature of material data

- **Numeric:** properties measured by numbers: density, modulus, cost …other properties

Can extrude?

Good or bad in sea water?

- **Non-numeric:** properties measured by yes - no (Boolean) or poor-average-good type (Rankings)

- **Supporting information, specific:** what is the experience with the material?

Design guide lines

Case studies

Failure analyses

Established applications

- **Supporting information, general:** what else do you need to know?

Supplier information

FE modules

Standards and codes (ISO 14000)

Sector-specific approval (FDA, MilSpec)

"Structured" and "Unstructured" data

Handbooks, data sheets

Reports, papers, the Web

Data organisation: materials

Kingdom	Family	Class	Member	Attributes
Materials	Ceramics	Steels	1000	Density
	Polymers	Cu-alloys	2000	Mechanical props.
	Metals	**Al-alloys**	3000	Thermal props.
	Natural	Ti-alloys	4000	Electrical props.
	Foams	Ni-alloys	5000	Optical props.
	Composites	Zn-alloys	**6000**	Corrosion props.
			7000	Supporting information
			8000	-- specific
				-- general

Structured information: Density; Mechanical, Thermal, Electrical, Optical and Corrosion props.

Unstructured information: Supporting information (-- specific, -- general)

A material record

Structured data for ABS*

Acrylonitrile-butadiene-styrene (ABS) - $(CH2\text{-}CH\text{-}C6H4)_n$

General Properties

Density	1.05	-	1.07	Mg/m^3
Price	2.1	-	2.3	US $/kg

Mechanical Properties

Young's Modulus	1.1	-	2.9	GPa
Elastic Limit	18	-	50	MPa
Tensile Strength	27	-	55	MPa
Elongation	6	-	8	%
Hardness - Vickers	6	-	15	HV
Endurance Limit	11	-	22	MPa
Fracture Toughness	1.2	-	4.2	$MPa.m^{1/2}$

Thermal Properties

Max Service Temp	350	-	370	K
Thermal Expansion	70	-	75	10^{-6}/K
Specific Heat	1500	-	1510	J/kg.K
Thermal Conductivity	0.17	-	0.24	W/m.K

Electrical Properties

Conductor or insulator?	Good insulator

Optical Properties

Transparent or opaque?	Opaque

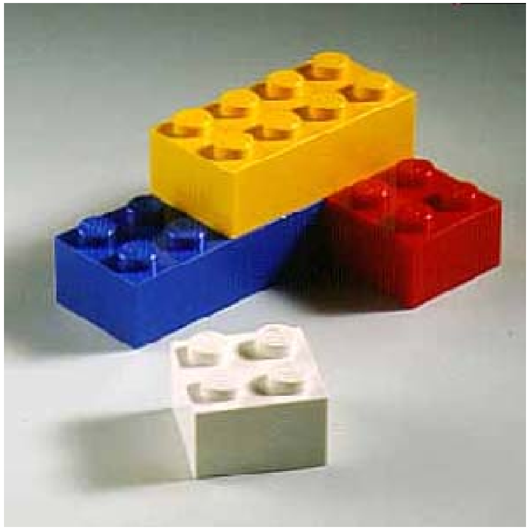
Corrosion and Wear Resistance

Flammability	Average
Fresh Water	Good
Organic Solvents	Average
Oxidation at 500C	Very Poor
Sea Water	Good
Strong Acid	Good
Strong Alkalis	Good
UV	Good
Wear	Poor
Weak Acid	Good
Weak Alkalis	Good

*Using the *CES 4* Level 2 DB

Unstructured data for ABS*

What is it? ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.



Design guidelines. ABS has the highest impact resistance of all polymers. It takes color well. Integral metallics are possible (as in GE Plastics' Magix.) ABS is UV resistant for outdoor application if stabilizers are added. It is hygroscopic (may need to be oven dried before thermoforming) and can be damaged by petroleum-based machining oils.

ABS can be extruded, compression moulded or formed to sheet that is then vacuum thermo-formed. It can be joined by ultrasonic or hot-plate welding, or bonded with polyester, epoxy, isocyanate or nitrile-phenolic adhesives.

Technical notes. ABS is a terpolymer - one made by copolymerising 3 monomers: acrylonitrile, butadiene and syrene. The acrylonitrile gives thermal and chemical resistance, rubber-like butadiene gives ductility and strength, the styrene gives a glossy surface, ease of machining and a lower cost. In ASA, the butadiene component (which gives poor UV resistance) is replaced by an acrylic ester. Without the addition of butyl, ABS becomes, SAN - a similar material with lower impact resistance or toughness. It is the stiffest of the thermoplastics and has excellent resistance to acids, alkalis, salts and many solvents.

Typical Uses. Safety helmets; camper tops; automotive instrument panels and other interior components; pipe fittings; home-security devices and housings for small appliances; communications equipment; business machines; plumbing hardware; automobile grilles; wheel covers; mirror housings; refrigerator liners; luggage shells; tote trays; mower shrouds; boat hulls; large components for recreational vehicles; weather seals; glass beading; refrigerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems.

The environment. The acrylonitrile monomer is nasty stuff, almost as poisonous as cyanide. Once polymerized with styrene it becomes harmless. ABS is FDA compliant, can be recycled, and can be incinerated to recover the energy it contains.

*Using the *CES 4* Level 2 DB

Data, perspective and comparisons

- Handbooks, compilations (see Chapter 13 of The Text)
- Suppliers' data sheets
- The Worldwide Web (e.g. www.matweb.com)

BUT: no perspective, or comparison between material classes

Example: Typical properties of wrought Al-alloys (extract)

	Tension				Hardness	Shear	Fatigue	Modulus
	Strength, ksi		Elongation, % in 2 in.					
Alloy and temper	Ultimate	Yield	1/16 in. thick specimen	1/2 in. dia. specimen	Brinnell number 500 kg load 10 mm ball	Ultimate shearing strength, ksi	Endurance[3] limit, ksi	Modulus[4] of elasticity, ksi $\times 10^3$
5652-HO	28	13	25	30	47	18	16	10.2
5652-H32	33	28	12	18	60	20	17	10.2
5652-H34	38	31	10	14	68	21	18	10.2
5652-H36	40	35	8	10	73	23	19	10.2
5652-H38	42	37	7	8	77	24	20	10.2
5657-H25	23	20	12	. .	40	12	. .	10.0
5657-H38, H28	28	24	7	. .	50	15	. .	10.0
6061-O	18	8	25	30	30	12	9	10.0
6061-T4, T451	35	21	22	25	65	24	14	10.0
6061-T6, T651	45	40	12	17	95	30	14	10.0
Alclad 6061-O	17	7	25	. .	. .	11	. .	10.0
Alclad 6061-T4, T451	33	19	22	. .	. .	22	. .	10.0
Alclad 6061-T6, T651	42	37	12	. .	. .	27	. .	10.0

Using CES 4 to find data

- Three levels of database (levels 1,2 and 3)

Finding data ("browsing"):

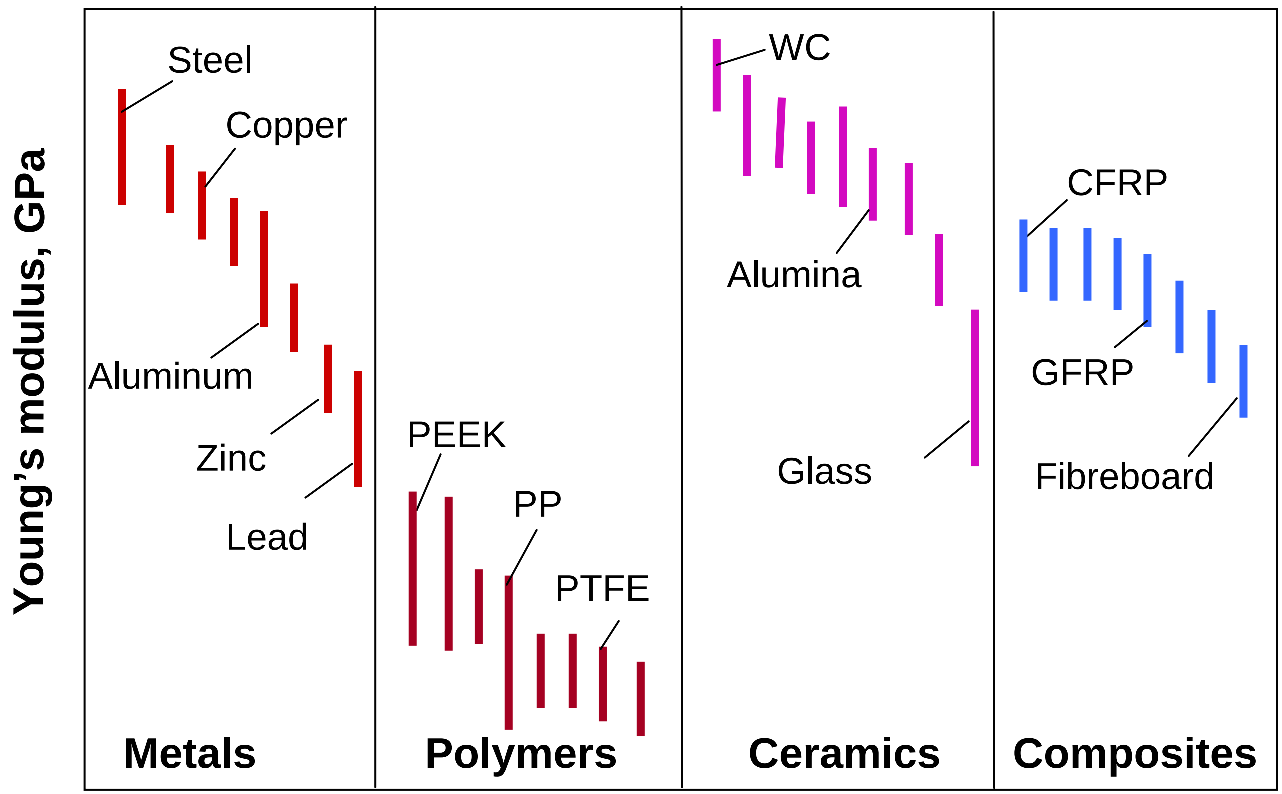
- Locate candidate on MATERIALS tree and double click, or
- Use the SEARCH facility to find all records contain candidate name, or trade-name, or application

Demo: finding data for materials

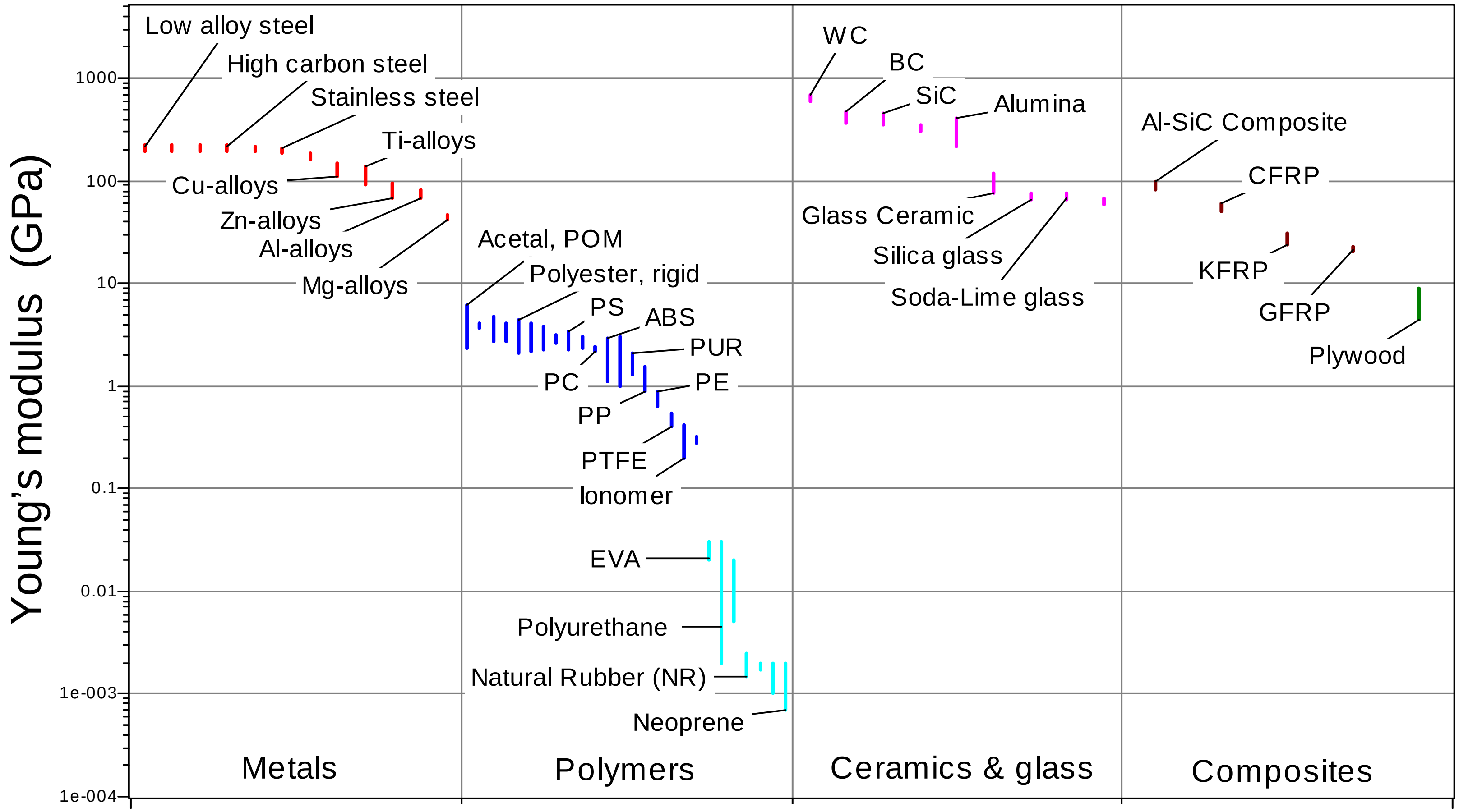
Relationships and comparisons

- Material bar-charts
- Material property charts

Relationships: property bar-charts

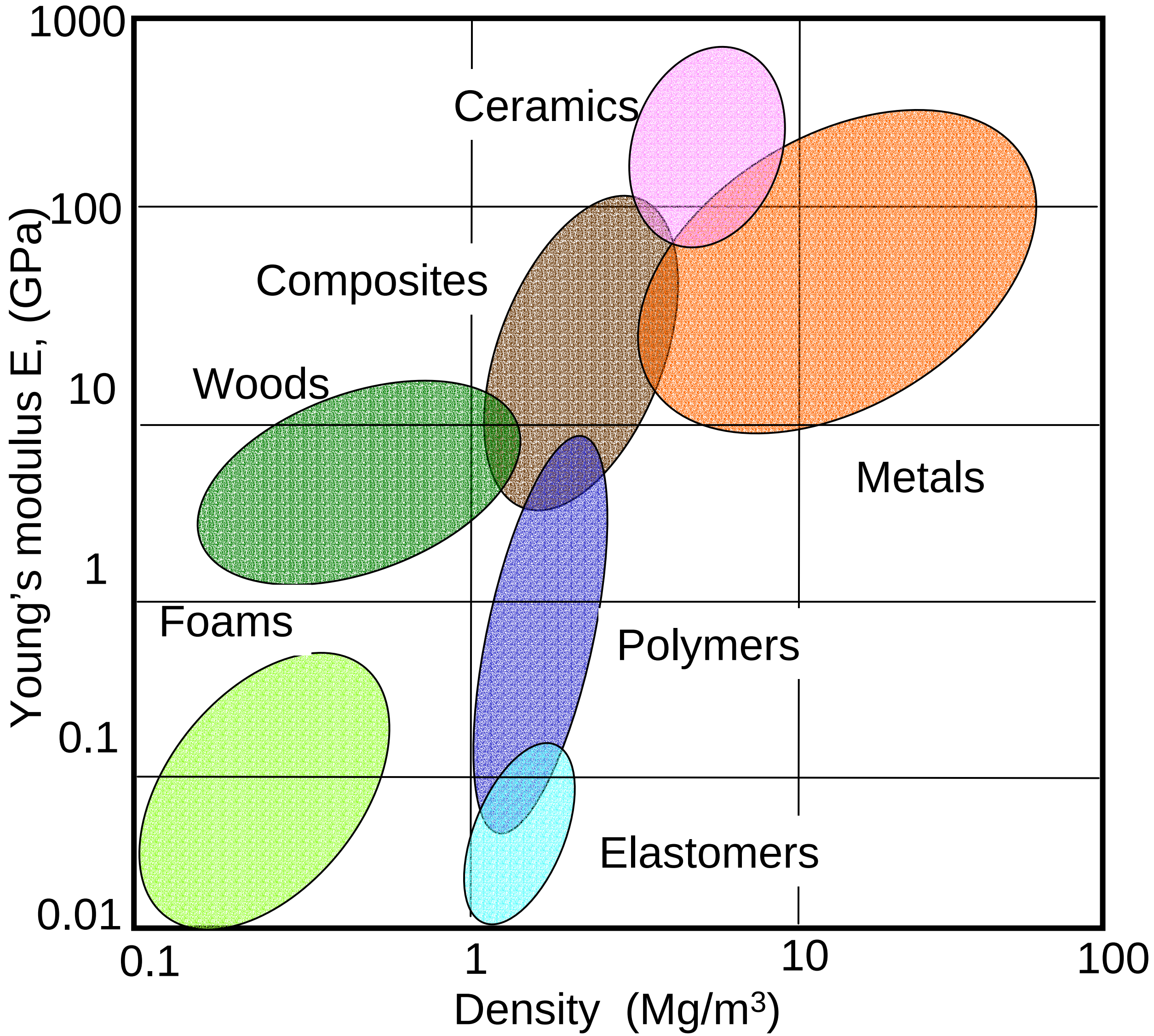


Bar- chart created with ***CES 4*** (Edu1)

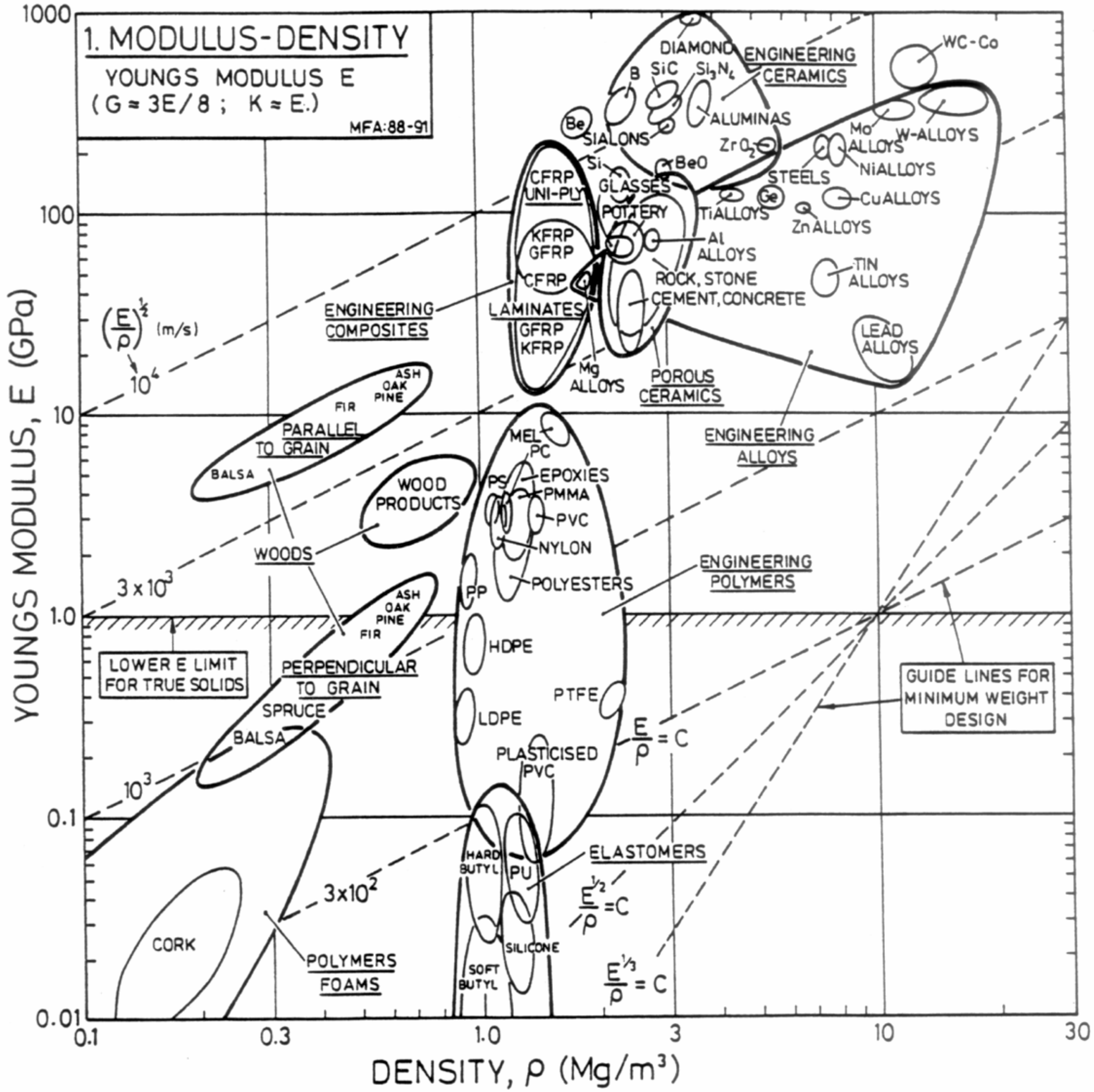


- Explore relationships
- Elementary selection ("Find materials with large elastic limit")

Material property- charts: Modulus - Density

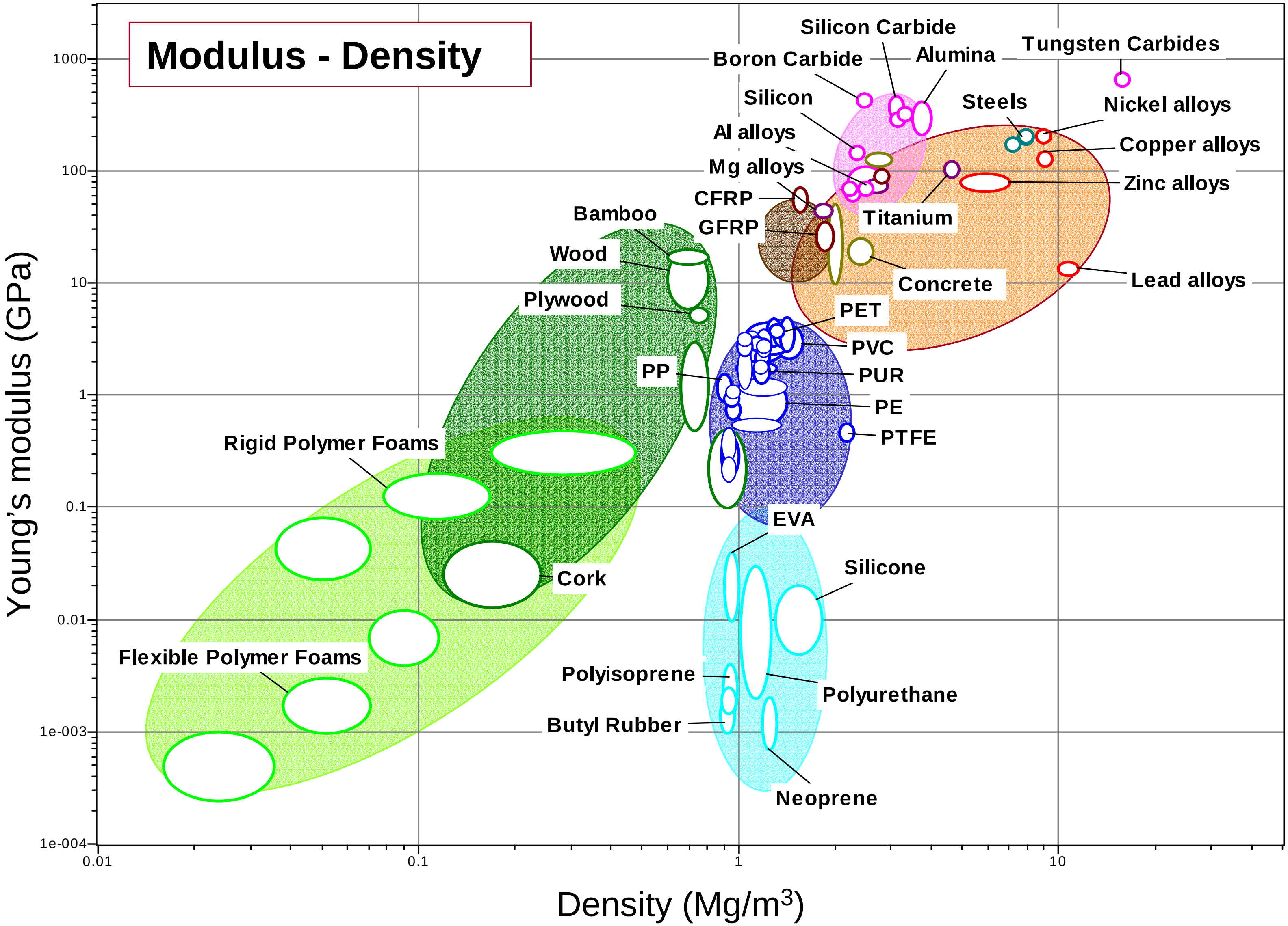


Hard-copy charts: Modulus - Density

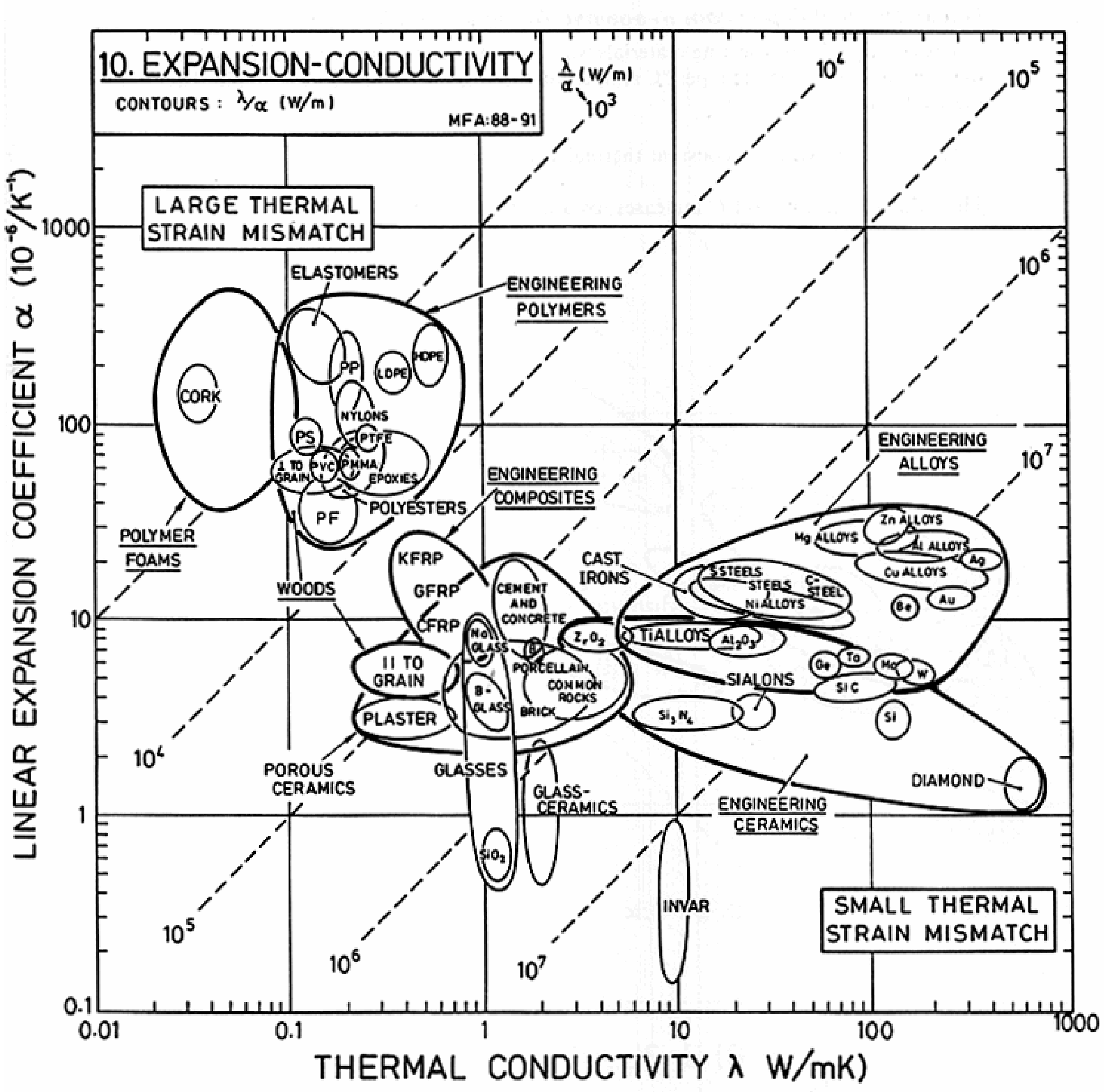


Hard-copy charts can be copied from MSMD, or downloaded from www.grantadesign.com

Property chart created with *CES 4, Level 1*

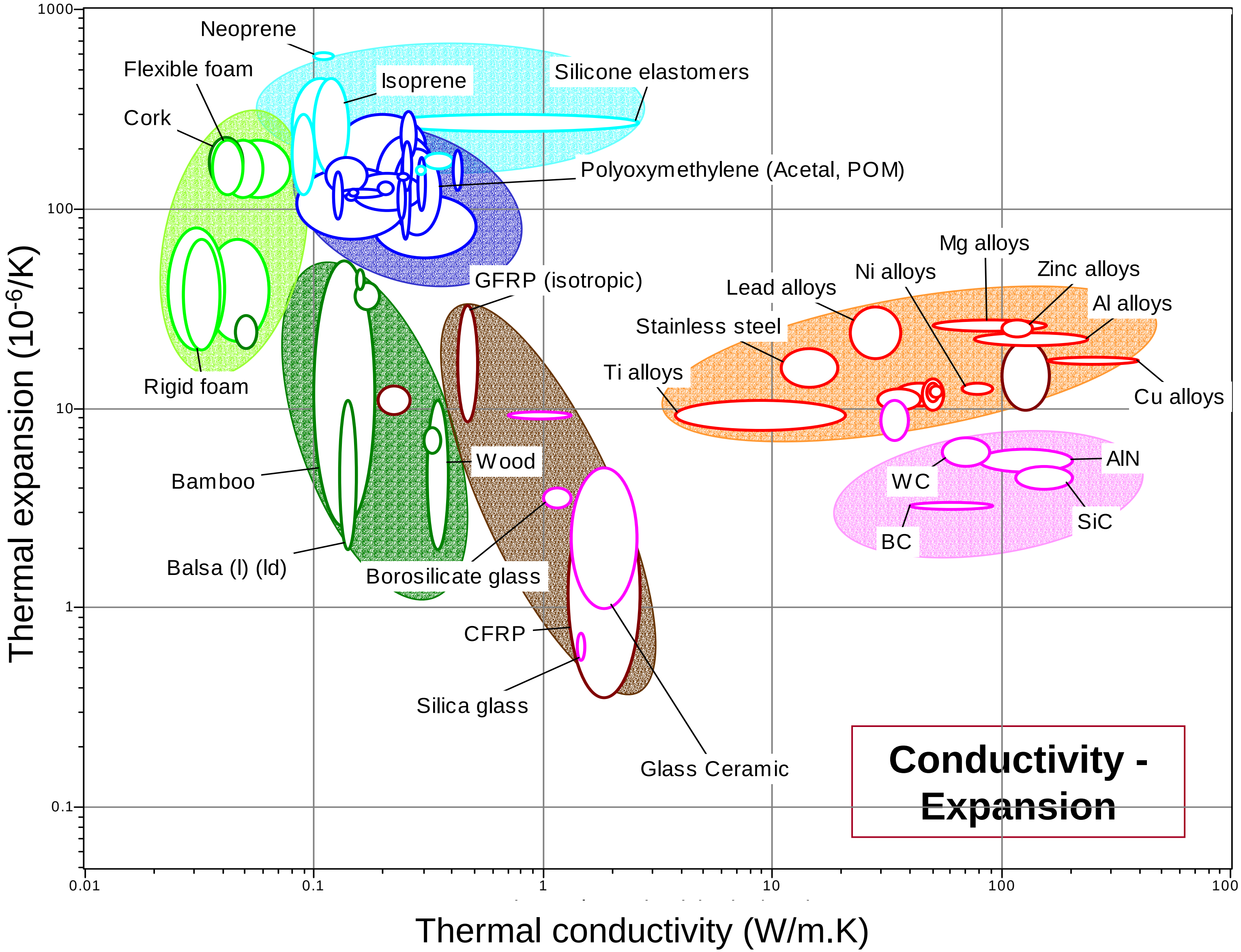


Hard-copy charts: T-expansion - T-conduction



Hard-copy charts can be copied from MSMD, or downloaded from www.grantadesign.com

Property chart created with *CES 4*, *Level 1*



The main points

- A classification system for materials allows data for them to be organised
- The data takes several forms:

  (a) numeric, non-numeric data that can be structured in a uniform way for all materials

  (b) supporting information specific to a single material, best stored as text and images
- The organization allows information to be retrieved accurately and efficiently
- Visual presentation of data as bar-charts and property (bubble) charts reveals relationships and allows comparisons

Demo: creating bar and bubble charts with CES 4