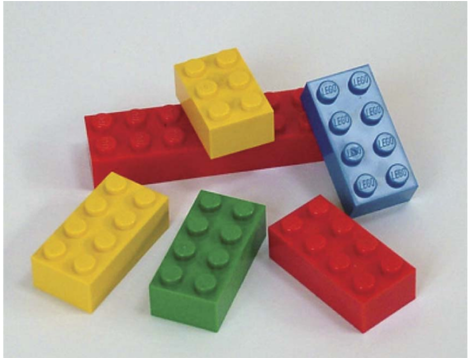
Chapter 2
Family trees: organizing materials and processes



LEGO elements are thermoplastics. They are melted at 235°C, molded (**gevormd**) under pressure, and harden as they cool in the mold. In principle, these plastics can be melted and remolded an infinite number of times - there is usually a practical limit.

2.1 Introduction and synopsis

- Families of <u>materials</u> exhibit a certain profile of properties – we select materials on this basis.
- There are also <u>process</u> families and attributes. Note that the process itself can control the properties of the material.
- We will use material property charts using properties as axes; materials families occupy regions on these charts. A tool for materials selection.
- Process attribute charts are also developed to assist in selection of the appropriate process for a particular application.

2.2 Getting materials organized: the materials tree

- Materials conventionally organized into 6 families (metals, polymers, elastomers, ceramics, glasses, hybrids). Members of a family have broadly similar properties, processing routes, and often applications.
- Chemical composition largely defines the materials family.

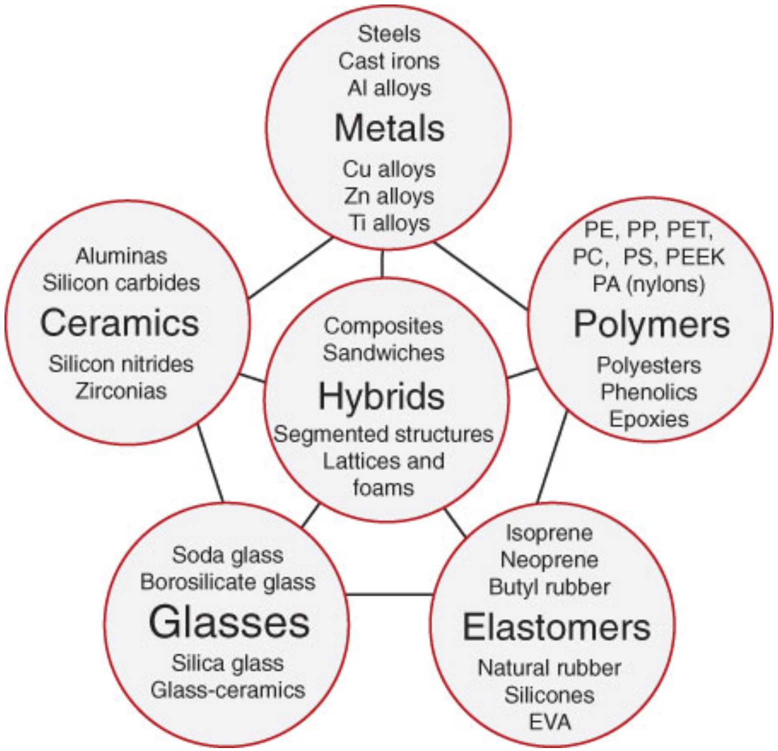


Figure 2.1 The menu of engineering materials. The basic families of metals, ceramics, glasses, polymers and elastomers can be combined in various geometries to create hybrids.

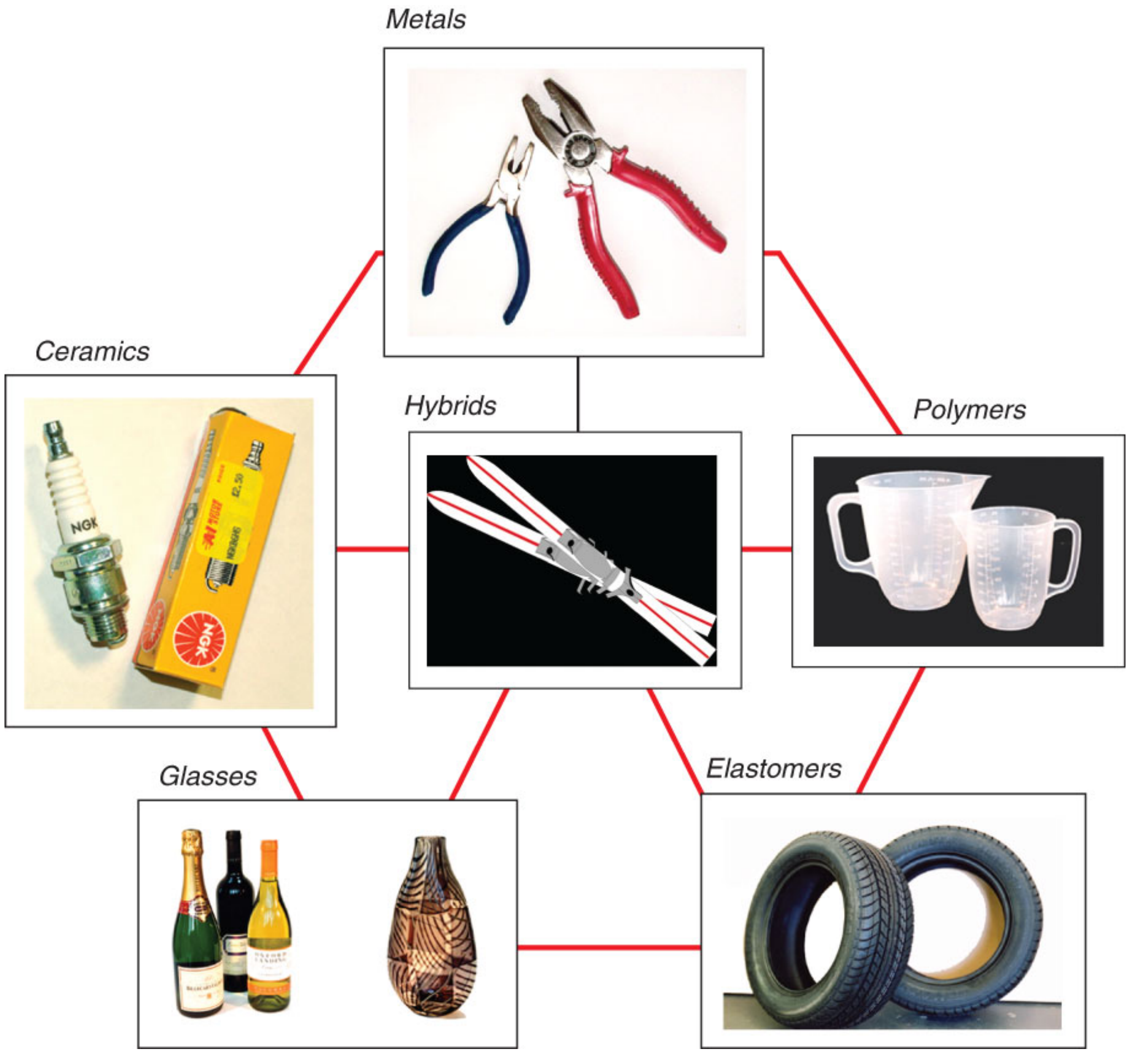


Figure 2.2 Examples of each material family. The arrangement follows the general pattern of Figure 2.1. The central hybrid here is a sandwich structure made by combining stiff, strong face sheets of aluminum with a low-density core of balsa wood.

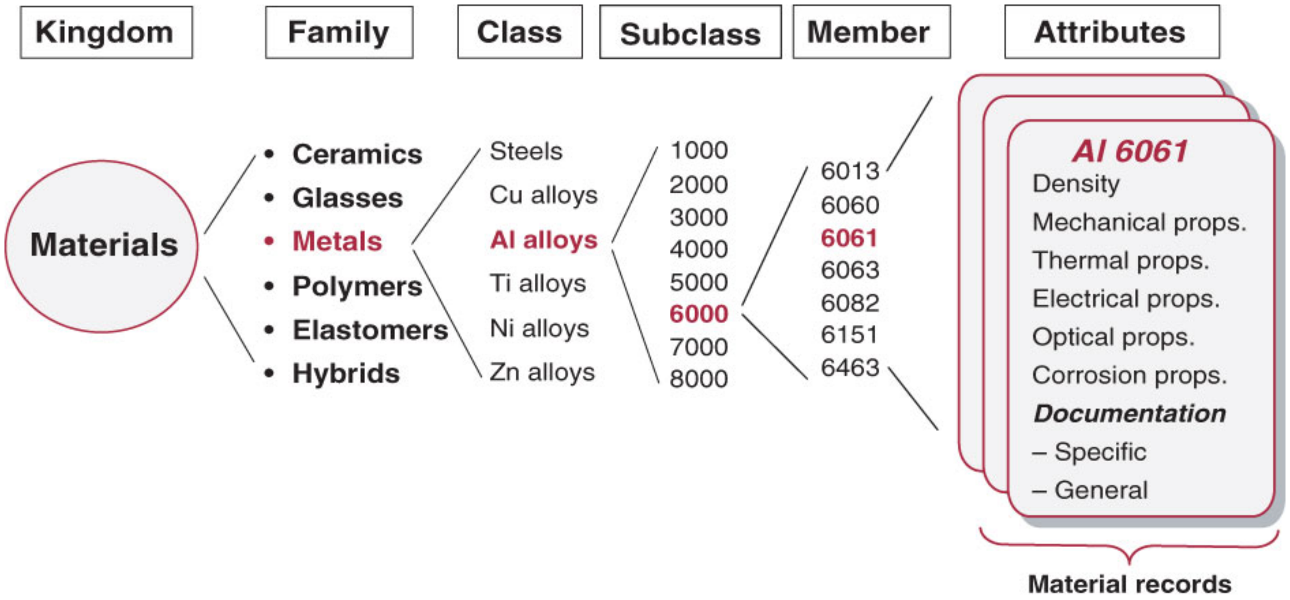


Figure 2.3 The taxonomy (**classificatie**) of the kingdom of materials and their attributes. Computer-based selection software stores data in a hierarchical structure like this.

A complete ‘property profile’ includes not just properties but processing characteristics, environmental consequences, etc.

Al 6061

Composition

Element	Weight %
Al	97.9
Si	0.60
Cu	0.28
Mg	1.0
Cr	0.20

Mechanical Properties

Properties	
Density ($\times$1000 kg/m^3)	2.7
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70-80
Tensile Strength (Mpa)	115
Yield Strength (Mpa)	48
Elongation (%)	25
Reduction in Area (%)	
Hardness (HB500)	30
Shear Strength (MPa)	83
Fatigue Strength (MPa)	62

Thermal Properties

Properties	
Thermal Expansion (10^{-6}/ºC)	23.4
Thermal Conductivity (W/m-K)	180

Electric Properties

Properties	
Electric Resistivity (10^{-9}W-m)	37

2.2 Getting materials organized: the materials tree

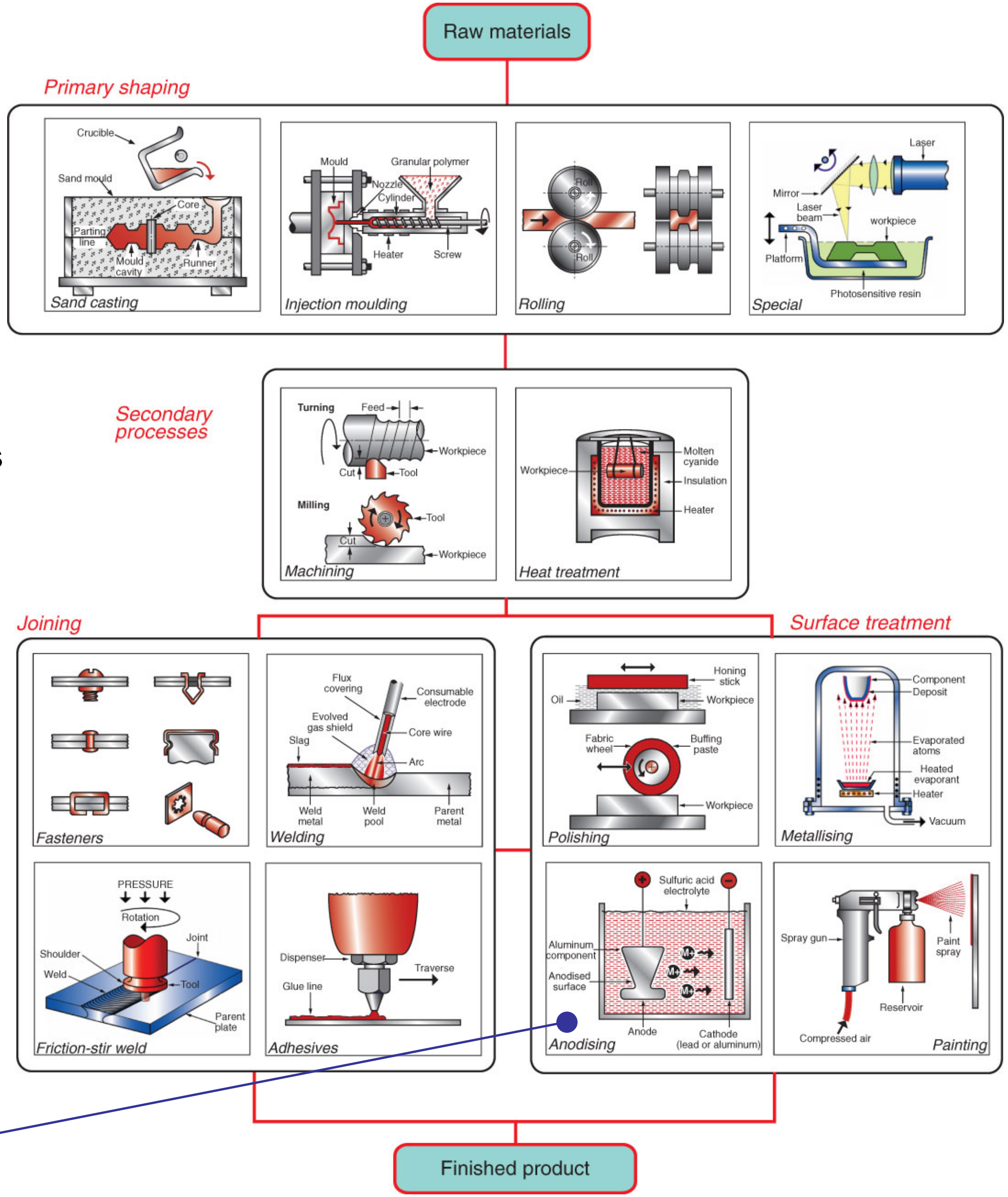
- *Metals*: Relatively high stiffness, soft when pure but hardenable by alloying, working, and heat treatment, tough, good conductors, often reactive.
- *Ceramics*: Inorganic solids, stiff, hard, abrasion resistant, good high T behavior, corrosion resistant, insulating, brittle.
- *Glasses*: Amorphous solids, hard, corrosion resistant, brittle, insulators, transparent.
- *Polymers*: Organic solids based on carbon chains, light, low modulus, strength to weight can be comparable to metals, low T only, easy to shape/snap together, near net shape, easily colored.
- *Elastomers*: Polymers with very low stiffness, very large recoverable shape change, can be strong and tough (tires).
- *Hybrids*: Combination of two or more of the other materials classes to get properties unattainable in a single material. Often difficult to process and join. CFRP, laminates, wood, bone (=polymer/ceramic) Modern, high-performance materials.

2.3 Organizing processes: the process tree

Process: a shaping, joining, or finishing method.

- Process choice is critical to performance and cost. A function of material, shape, dimensions, tolerances, quantity required.
- Material choice limits process options. Polymers can be molded, ductile materials can be forged (**gesmeed**), rolled, and drawn, brittle materials must be shaped in other ways.
- *Shaping:* Primary processes create shapes. Casting, molding, etc. Secondary processes modify shapes or properties. Machining, heat treatment.
- Followed by *joining* and *surface treatment.*
- The three process families can be expanded to show classes, members and attributes.

Figure 2.5 Examples of the families and classes of manufacturing processes. The arrangement follows the general pattern of Figure 2.4.



iPod shuffle (2010)

Anodising = fabricating a protective oxide layer on a surface

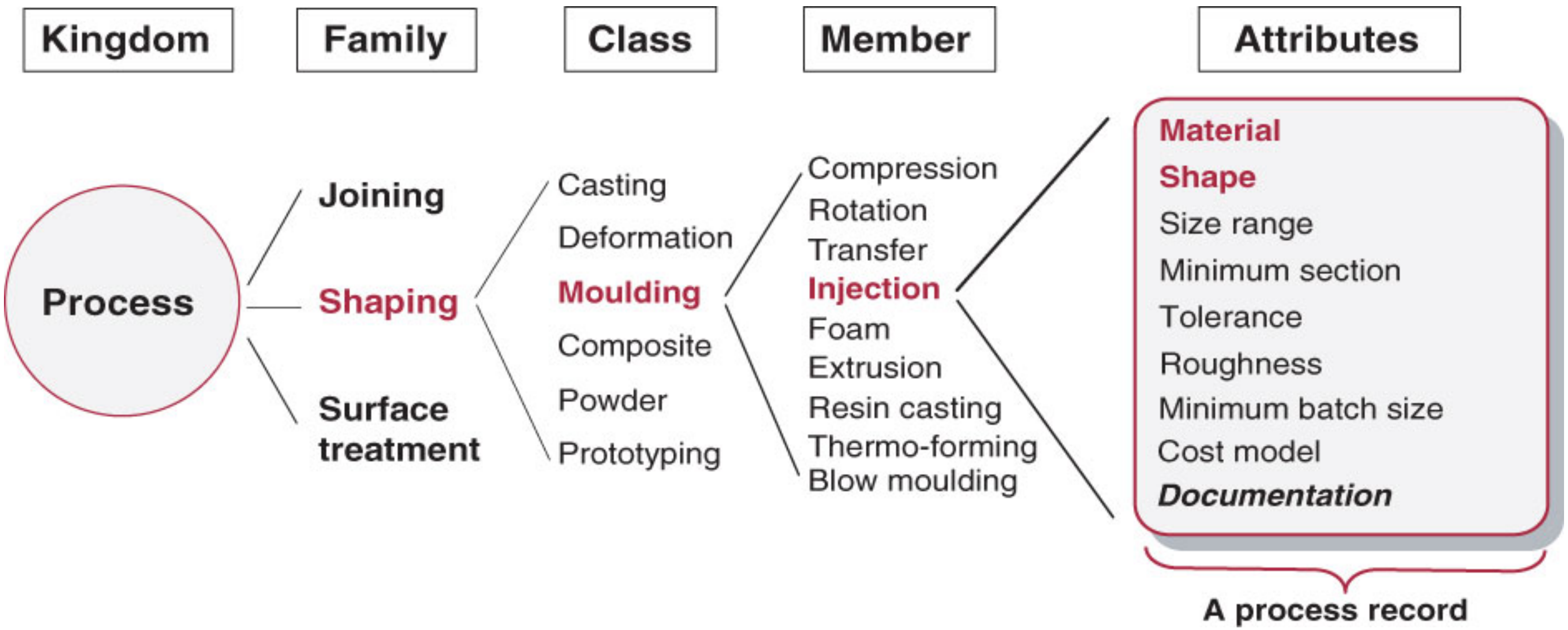


Figure 2.6 The taxonomy of the kingdom of process with part of the shaping family expanded. Each member is characterized by a set of attributes. Process selection involves matching these to the requirements of the design.

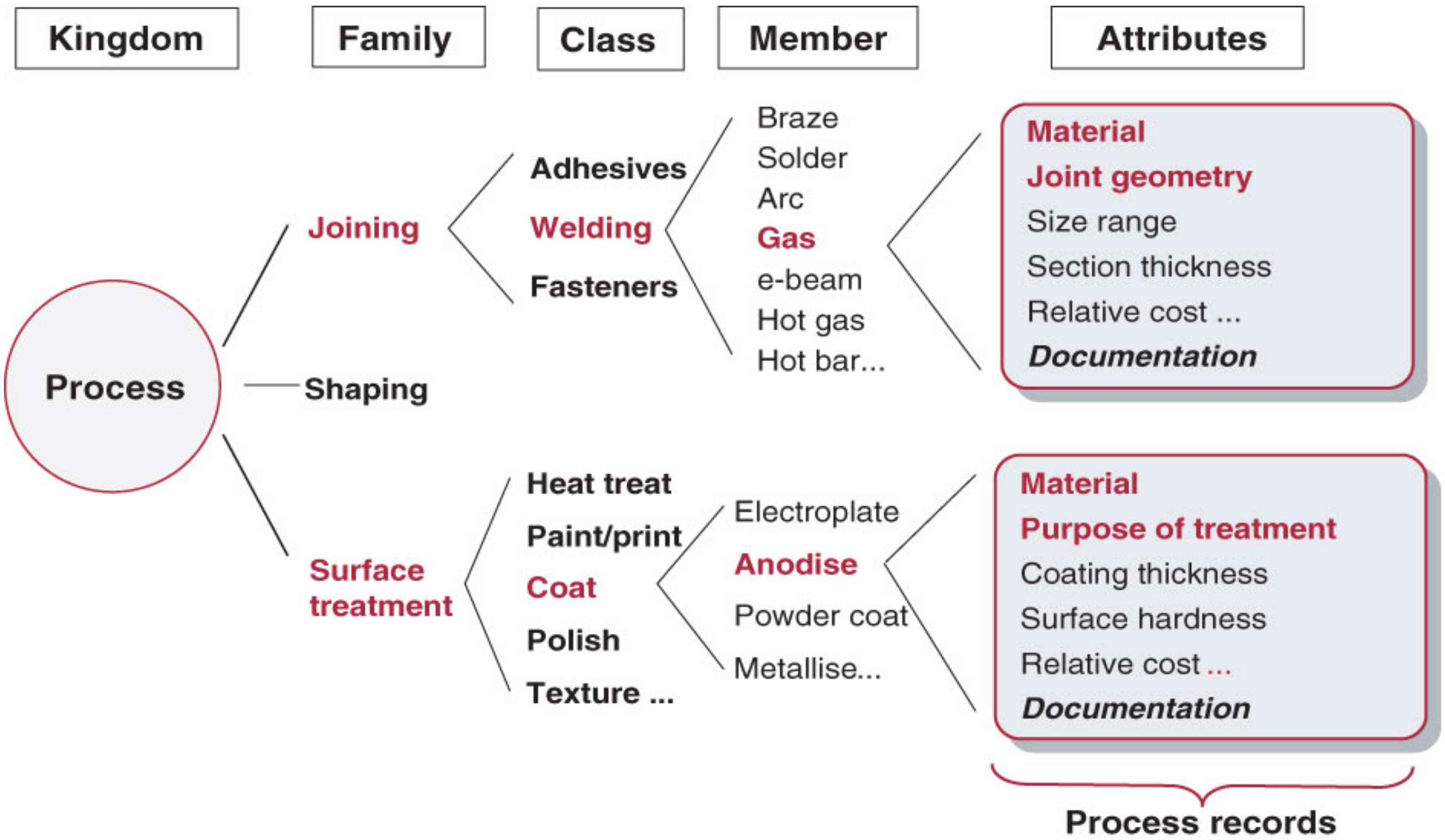


Figure 2.7 The taxonomy of the process kingdom again, with the families of joining and finishing partly expanded.

2.4 Process – property interaction

- *Processing influences properties.* Shaping, joining, and surface treatment can all modify material properties. See book (p. 20/21).

2.5 Material property charts

- *Bar charts* plot one property for all the materials families. Properties often vary over many orders of magnitude so logarithmic scales are used. The bar height shows the range of values.
- More information is included in a *bubble chart* with two properties plotted against one another – families tend to segregate into regions (bubbles).
- Bubble charts are a key element of this course. They provide a compact overview, reveal aspects of the physical origin or properties, and can be a tool for optimizing materials selection to meet design requirements.

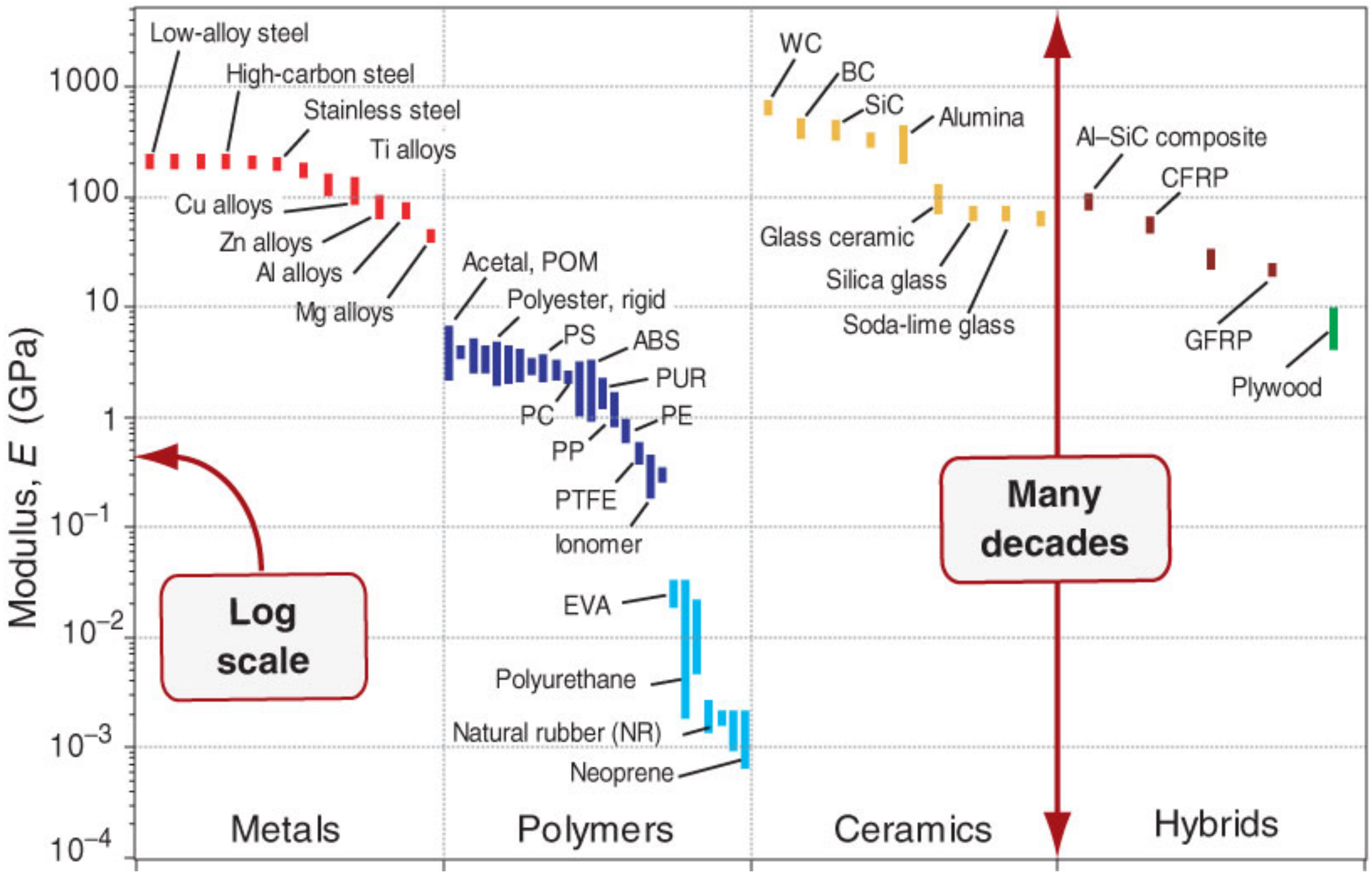


Figure 2.8 A bar chart of modulus. It reveals the difference in stiffness between the families.

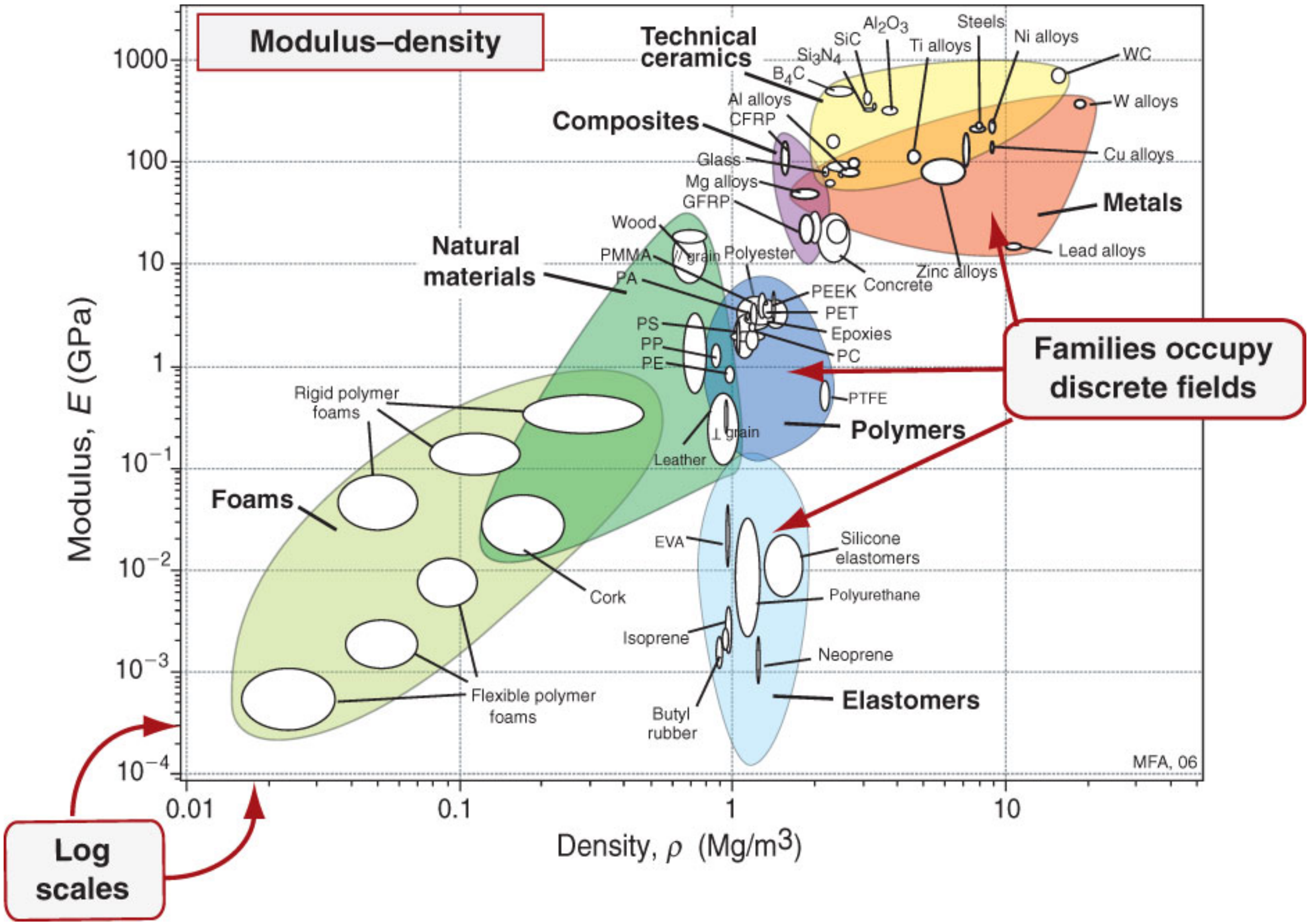
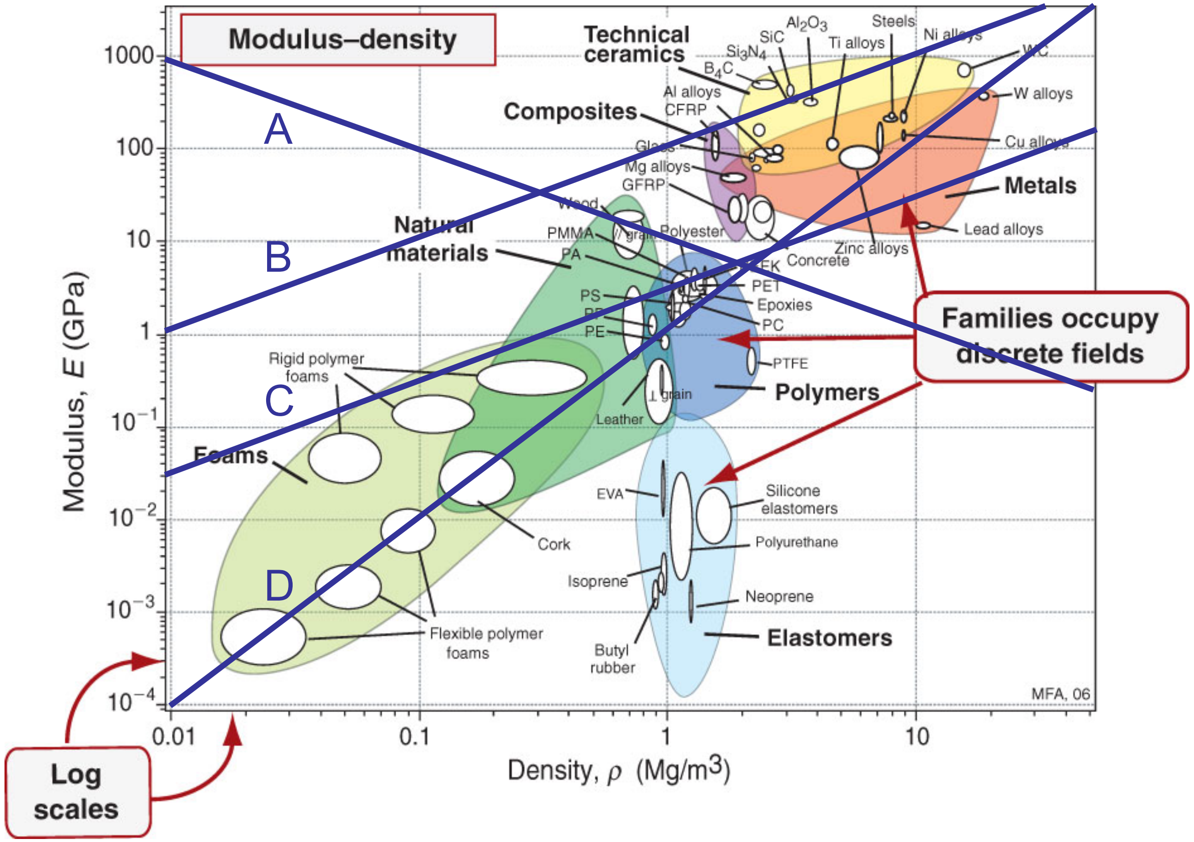


Figure 2.9 A bubble chart of modulus and density. Families occupy discrete areas of the chart.

PI question

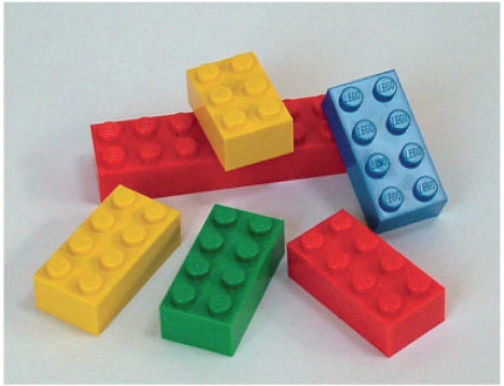
Which line in the Modulus-density chart expresses the relation E/ρ = constant?

1. A
2. B
3. C
4. Both B and C
5. D
6. Both A and D



- The CES software organizes the material and process records needed for design. Each record has both structured and unstructured data. Here is part of a record for a **material**

Acrylonitrile–butadiene–styrene (ABS)



The Material

ABS (acrylonitrile–butadiene–styrene) is tough, resilient and easily moulded. 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.

General properties

Density	1e3	–	1.2e3	kg/m^3
Price	2	–	2.7	USD/kg

Mechanical properties

Young's modulus	1.1	–	2.9	GPa
Hardness—Vickers	5.6	–	15	HV
Elastic limit	19	–	51	MPa
Tensile strength	28	–	55	MPa
Compressive strength	31	–	86	MPa
Elongation	1.5	–	1e2	%
Endurance limit	11	–	22	MPa
Fracture toughness	1.2	–	4.3	$MPa.m^{1/2}$

Thermal properties

Thermal conductivity	0.19	–	0.34	W/m.k
Thermal expansion	85	–	230	μ strain/°C
Specific heat	1400	–	1900	J/kg.K
Glass temperature	88	–	130	°C
Max service temp.	62	–	90	°C

Electrical properties

Resistivity	2.3e21	–	3e22	μohm.cm
Dielectric constant	2.8	–	2.2	

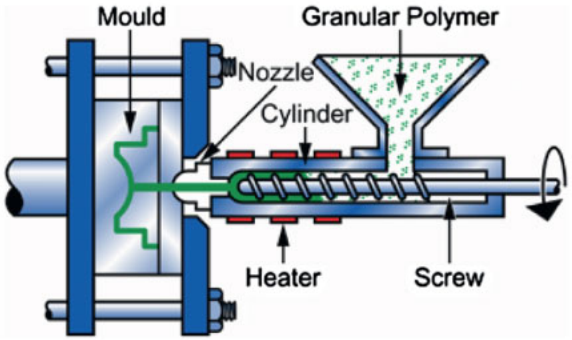
Typical uses

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.

2.6 Computer – aided information management for materials and processes

- The CES software organizes the material and process records needed for design. Each record has both structured and unstructured data. Here is part of a record for a **process**

Injection moulding



The process

No other process has changed product design more than injection moulding. Injection moulded products appear in every sector of product design: consumer products, business, industrial, computers, communication, medical and research products, toys, cosmetic packaging and sports equipment. The most common equipment for moulding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('*sprues*') into the die. The polymer solidifies under pressure and the component is then ejected.

Physical attributes

Mass range	1e3	–	25	kg
Range of section thickness	0.4	–	6.3	mm
Surface roughness (A 5 v. smooth)	A			

Economic attributes

Economic batch size (units)	1e4	–	1e6
Relative tooling cost	Very high		
Relative equipment cost	High		
Labour intensity	Low		

Shape

Circular prismatic	True
Noncircular prismatic	True
Solid 3-D	True
Hollow 3-D	True
Noncircular prismatic	True

Typical uses

Extremely varied. Housings, containers, covers, knobs, tool handles, plumbing fittings, lenses, etc.

Exercise

E 2.5. How many different surface treatment processes can you think of, based on your own experience? List them and annotate the list with the materials to which they are typically applied.

Exercise

E2.6. How many ways can you think of for joining two sheets of a plastic like polyethylene ("plastic bag")?