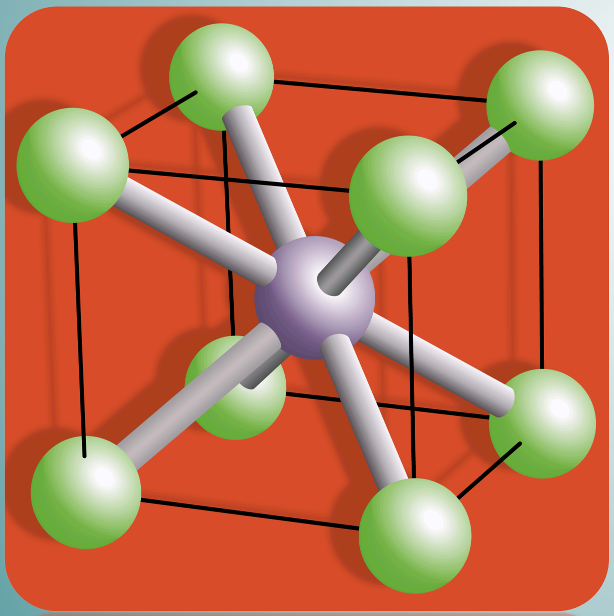
Materials

Topic 1. Introduction to Materials



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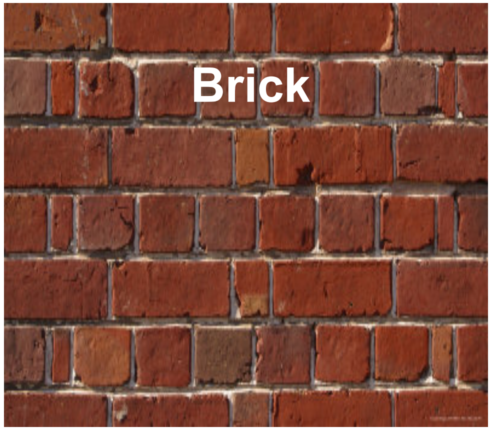
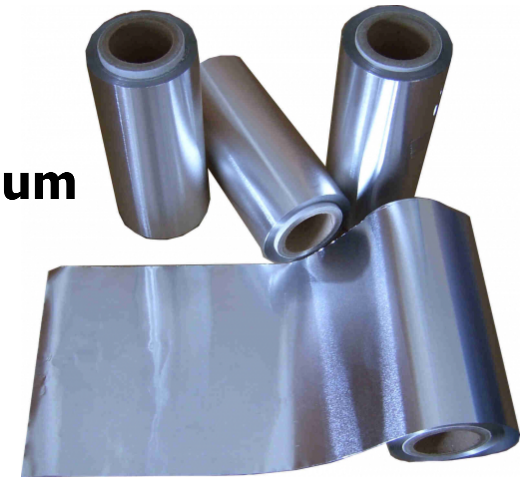
1.1. MATERIALS AND ENGINEERING

Material: constituent substance of components and structures.

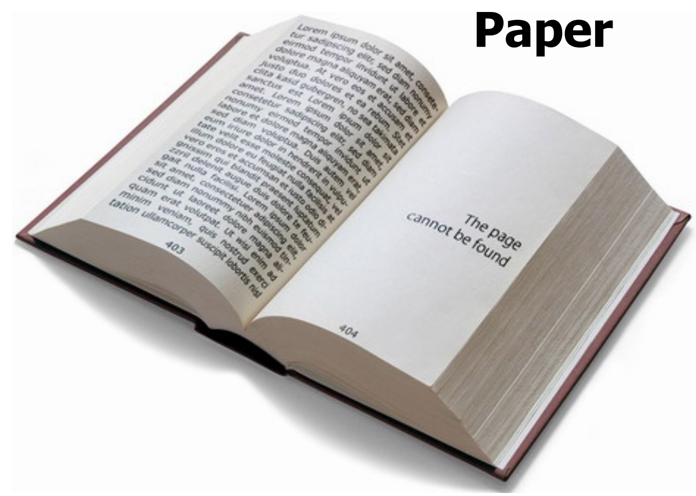
Glass

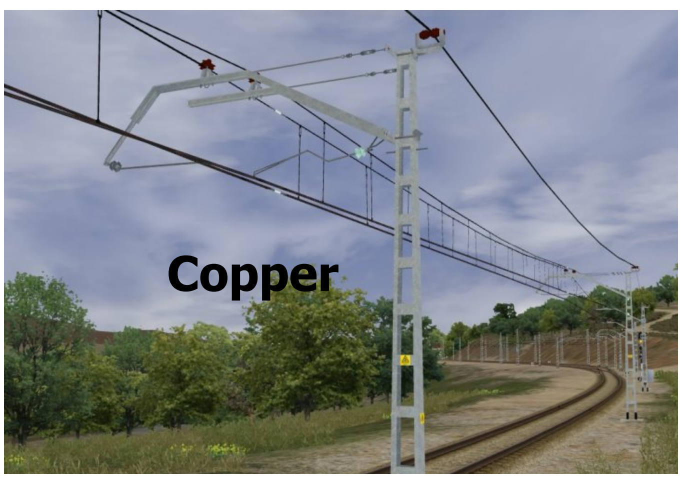


Aluminum



Plastic





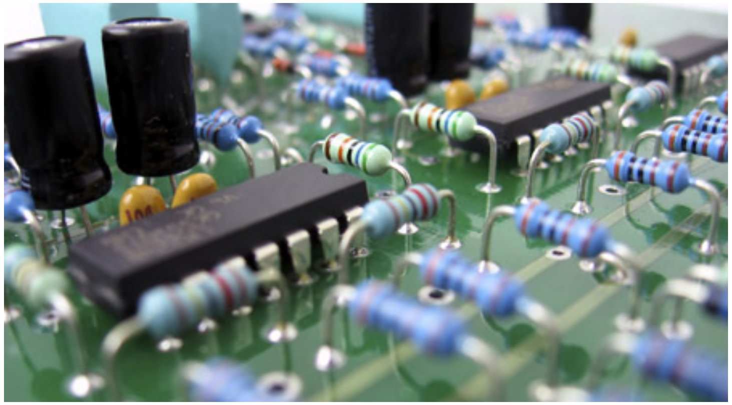
- **Its use has undergone an evolutionary process:**
  - **Selection.**
  - **Design (production and proccesing).**




- **Search for new materials:**

**Mechanical engineers:
high temperature resistance.**

**Electrical engineers:
higher operating speed.**



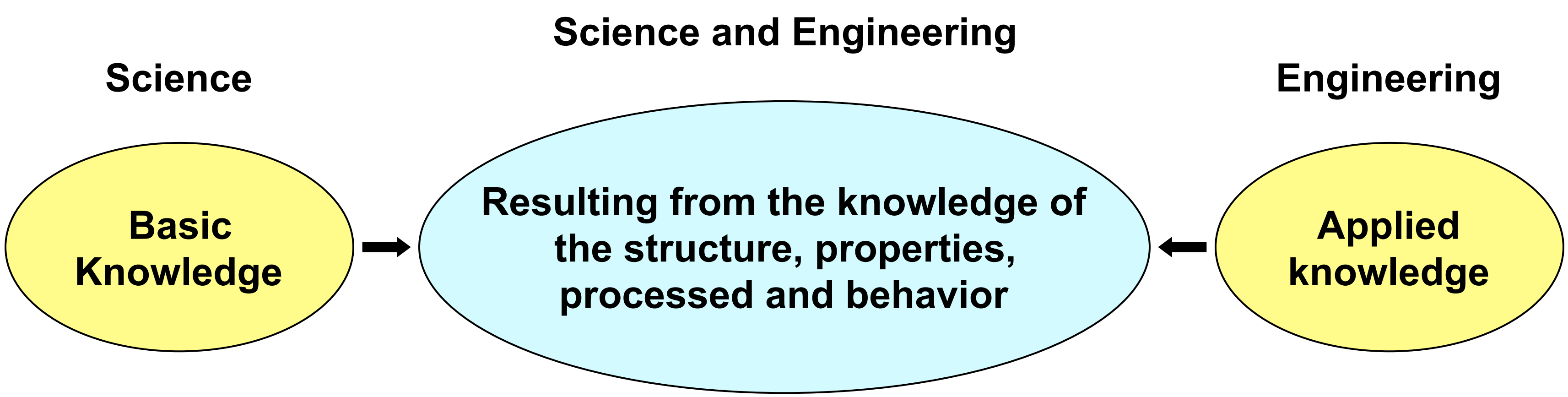
**Aeronautical engineers:
improve resistance - weight ratio.**

**Chemical engineers:
greater resistance to corrosion.**

THE ENGINEER MUST KNOW THEIR INTERNAL STRUCTURE AND PROPERTIES

1.2. SCIENCE AND ENGINEERING OF MATERIALS

- **Materials Science:**
  - **Basic knowledge about structure and properties.**
- **Materials Engineering:**
  - **Practical or applied aspect of scientific knowledge.**
- **Materials technology:**
  - **Art of producing, processing and shaping.**



1.3. TYPES AND PROPERTIES

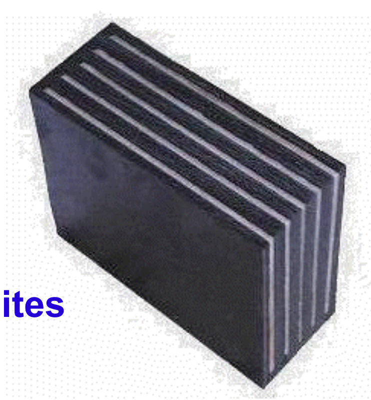
- **Types of materials:**

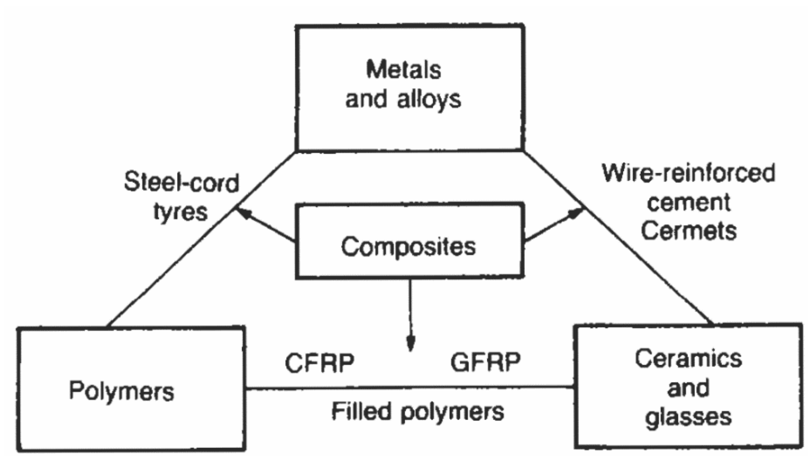
Metals

Ceramics and glasses

Polymers

Composites



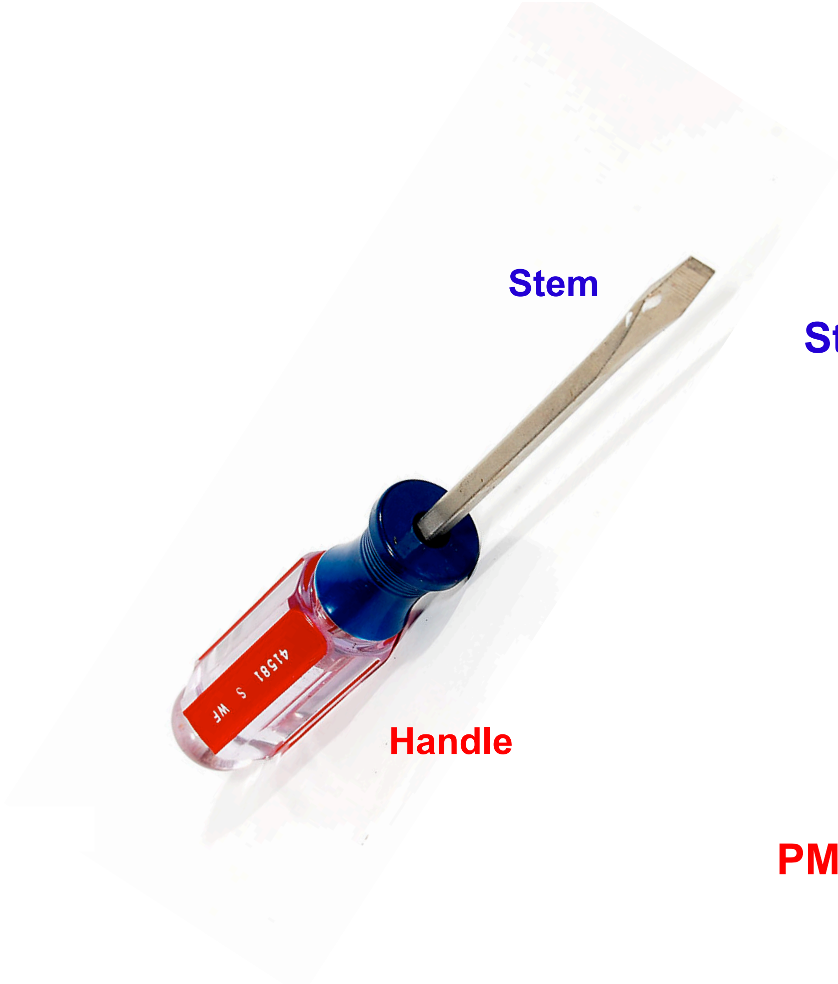


- **Properties of materials:**

Classes of properties

Economic	Price and availability Recyclability
General Physical	Density
Mechanical	Modulus Yield and tensile strength Hardness Fracture toughness Fatigue strength Creep strength Damping
Thermal	Thermal conductivity Specific heat Thermal expansion coefficient
Electrical and Magnetic	Resistivity Dielectric constant Magnetic permeability
Environmental Interaction	Oxidation Corrosion Wear
Production	Ease of manufacture Joining Finishing
Aesthetic	Colour Texture Feel

- **Example: design of a screwdriver with plastic handle:**



Steel
- Elasticity modulus.
- Elastic limit.
- Hardness.
- Fracture toughness.

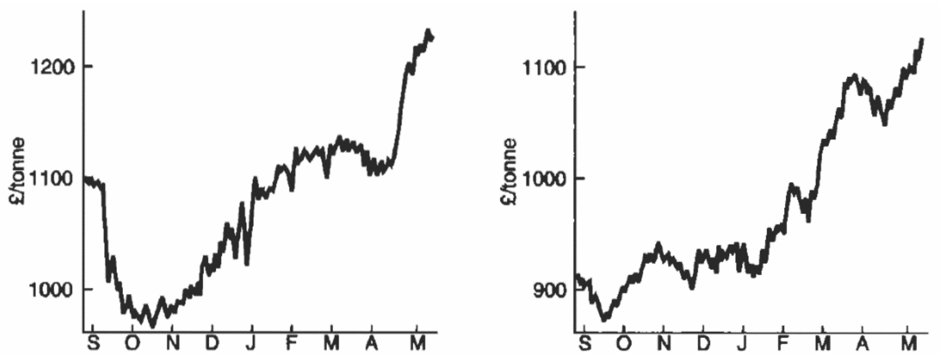
PMMA
- Manufacturing easiness.
- Density.
- Esthetic.
- Price.

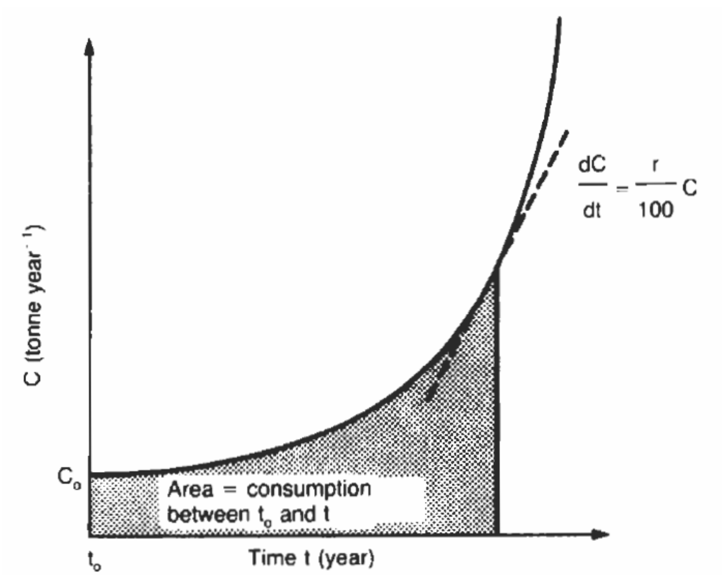
1.4. PRICE AND AVAILABILITY

- **The price and availability are important factors and, sometimes, determinants to select materials in specific cases of application.**
  - **Price.**

Class of use	Material	Price per tonne		€ / ton
Basic construction	Wood, concrete, structural steel	UK£50–500	US$75–750	60 – 600
Medium and light engineering	Metals, alloys and polymers for aircraft, automobiles, appliances, etc.	UK£500–5,000	US$750–7,500	600 – 6,000
Special materials	Turbine-blade alloys, advanced composites (CFRP, BRFP), etc.	UK£5,000–50,000	US$7,500–75,000	6,000 – 60,000
Precious metals, etc.	Sapphire bearings, silver contacts, gold microcircuits	UK£50,000–10m	US$75,000–15m	60,000 – 12,000,000
Industrial diamond	Cutting and polishing tools	>UK£10m	>US$15m	> 120,000,000

Subject to the law of supply and demand and political factors





The exponentially rising consumption of materials.

Material	US$ / tonne
Diamonds, industrial	$6–9 \times 10^8$
Platinum	$1.8–2.25 \times 10^7$
Gold	$7.5–8.4 \times 10^6$
Silver	$4.5–6.75 \times 10^5$
CFRP (mats. 70% of cost; fabr. 30% of cost)	$5.25–12 \times 10^4$
Cobalt/tungsten carbide cermets	$5.55–7.5 \times 10^4$
Tungsten	$1.95–2.25 \times 10^4$
Cobalt alloys	$2.4–3.6 \times 10^4$
Titanium alloys	$4.8–6.0 \times 10^4$
Nickel alloys	$7.6–9.0 \times 10^4$
Polyimides	$3.3–3.75 \times 10^4$
Silicon carbide (fine ceramic)	$2.25–3.75 \times 10^4$
Magnesium alloys	3300–4950
Nylon 66	3750–8100
Polycarbonate	4125–4800
PMMA	2700–3750
Magnesia, MgO (fine ceramic)	7500–22500
Alumina, Al_2O_3 (fine ceramic)	12000–18000
Tool steel	1800–3000
GFRP (mats. 60% of cost; fabr. 40% of cost)	1950–4500
Stainless steels	2700–3450
Copper, worked (sheets, tubes, bars)	1800–1875
Copper, ingots	1725–1800
Aluminium alloys, worked (sheet, bars)	1365–1800
Aluminium ingots	1365–1395
Brass, worked (sheet, tubes, bars)	1800–2100
Brass, ingots	1650–2100
Epoxy	3750–4800
Polyester	1800–2700
Glass	1020–1800
Foamed polymers	1650–4500
Zinc, worked (sheet, tubes, bars)	1500–1950
Zinc, ingots	1500–1650
Lead, worked (bars, sheet, tube)	825–1200
Lead, ingots	750–825
Natural rubber	675–2250
Polypropylene	750–1050
Polyethylene, high density	825–900
Polystyrene	900–1200
Hard woods	600–1500
Polyethylene, low density	900–975
Polyvinyl chloride	675–1800
Plywood	450–1500
Low-alloy steels	480–675
Mild steel, worked (angles, sheet, bars)	375–525
Cast iron	300–525
Iron, ingots	270–300
Soft woods	150–450
Concrete, reinforced (beams, columns, slabs)	192–270
Fuel oil	150–210
Cement	75–90
Coal	75–87

- **Search for new materials:**

Fig. 1.2. The wooden bridge at Queens' College, a 1902 reconstruction of the original 'mathematical' bridge built in 1749 to William Etheridge's design.

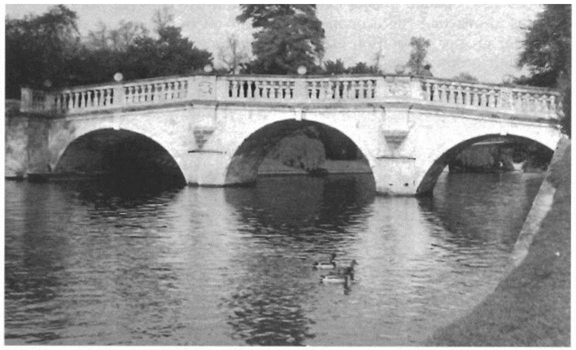
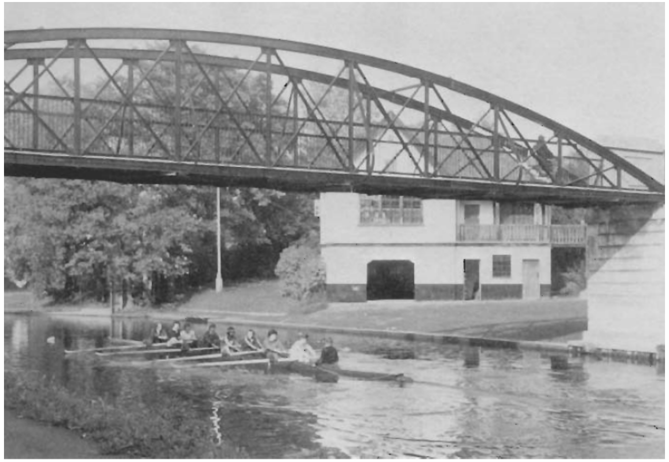


Fig. 1.3. Clare Bridge, built in 1640, is Cambridge's oldest surviving bridge; it is reputed to have been an escape-route from the college in times of plague.

Fig. 1.4. Magdalene Bridge built in 1823 on the site of the ancient Saxon bridge over the Cam. The present cast-iron arches carried, until recently, loads far in excess of those envisaged by the designers. Fortunately, the bridge has now undergone a well-earned restoration.

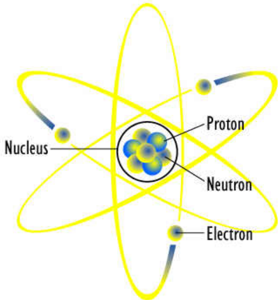


. A typical twentieth-century mild-steel bridge; a convenient crossing to the Fort St George inn!

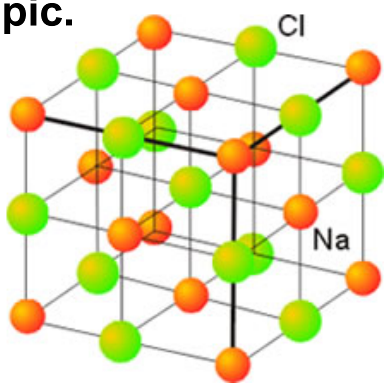
Fig. 1.6. The reinforced concrete footbridge in Garret Hostel Lane. An inscription carved nearby reads: 'This bridge was given in 1960 by the Trusted family members of Trinity Hall. It was designed by Timothy Guy MORGAN an undergraduate of Jesus College who died in that year.'

1.5. RELATIONSHIP BETWEEN STRUCTURE, PROPERTIES AND PROCESSING

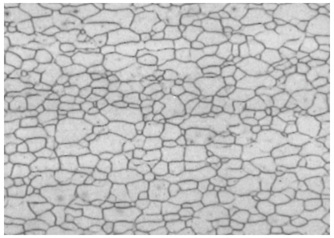
- **The structure of a material can be considered at different levels.**
  - **Atomic (electric, magnetic, thermal, optical).**



  - **Microscopic.**

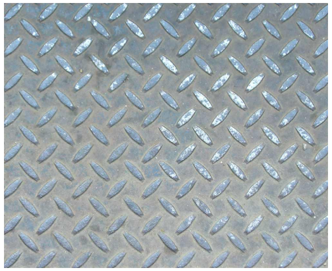


Crystalline (X ray Diffraction).



Granular or micrographic (OM and SEM).

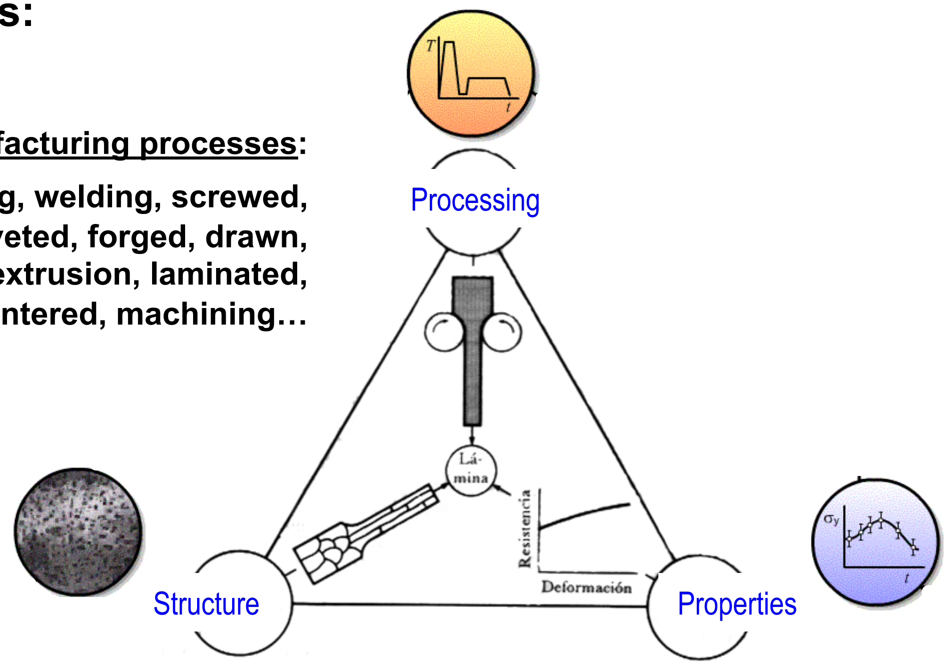
  - **Macroscopic (naked eye).**



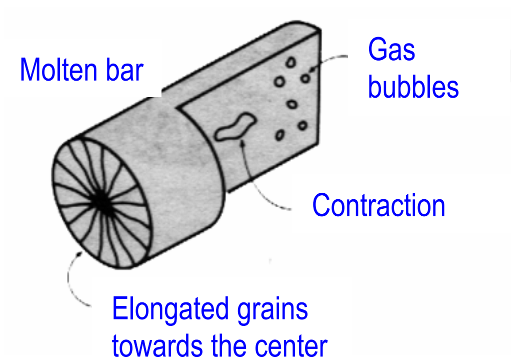
- **Ternary relationship among internal structure of the material, processes and final properties:**

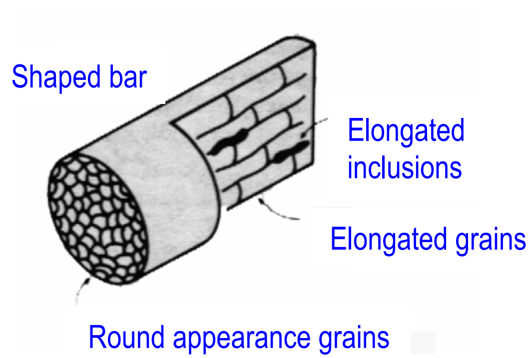
Manufacturing processes:

molding, welding, screwed, riveted, forged, drawn, extrusion, laminated, sintered, machining…



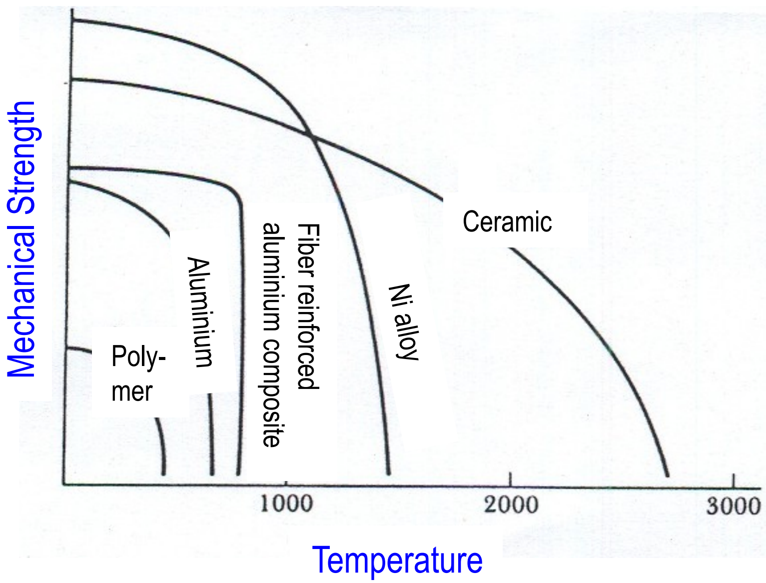
- **When the engineer changes one of the three aspects, any of the others will also be altered:**



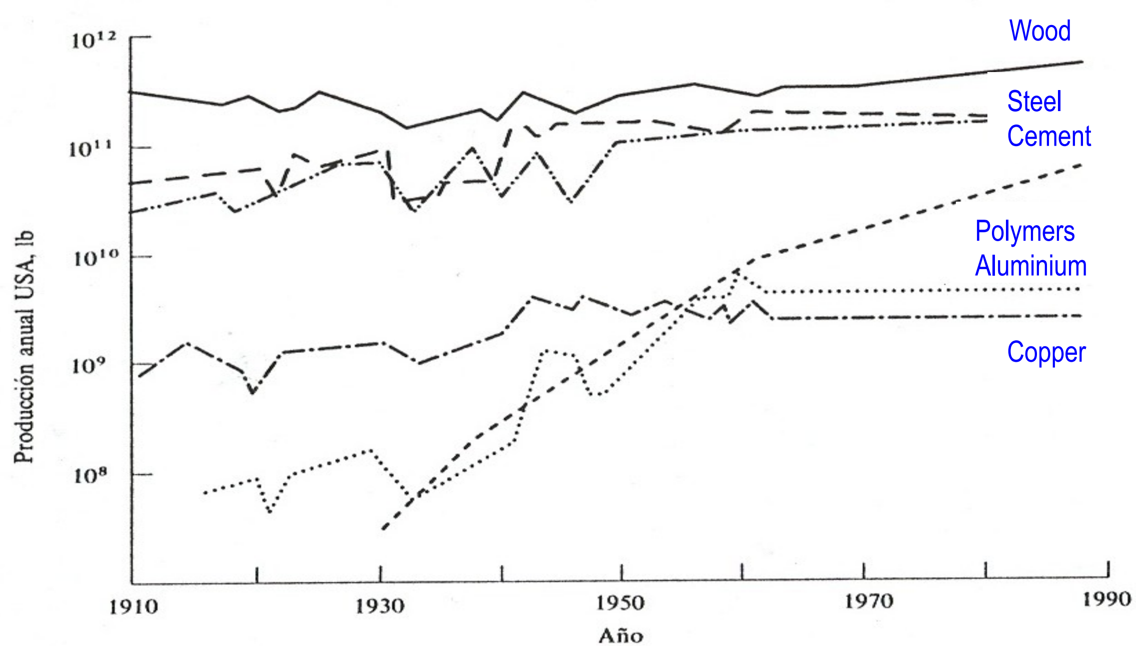


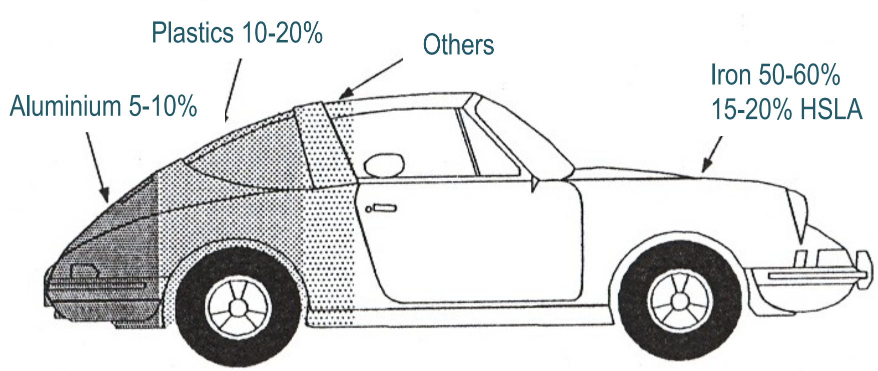
1.6. ENVIRONMENTAL EFFECTS ON THE BEHAVIOR

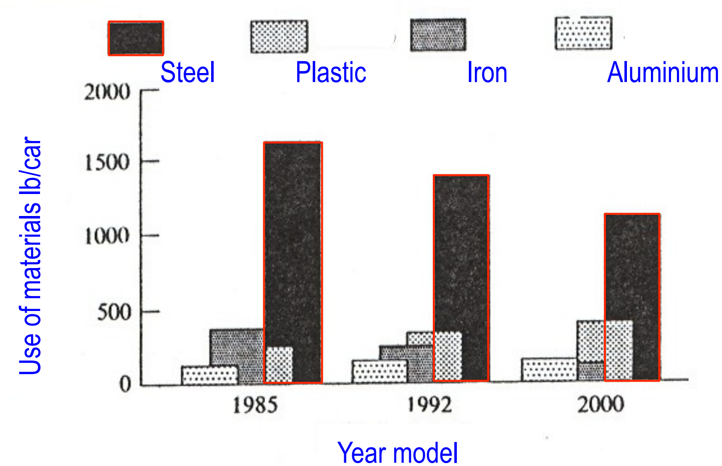
- **Force:**
  - Static, dynamic...
- **Temperature:**
  - Resistance.
- **Environment:**
  - Oxidation, corrosion...
- **Ultraviolet radiation:**
  - Polymers.
- **Neutron radiation:**
  - Vessel steels.



1.7. FUTURE TRENDS IN THE USE OF MATERIALS





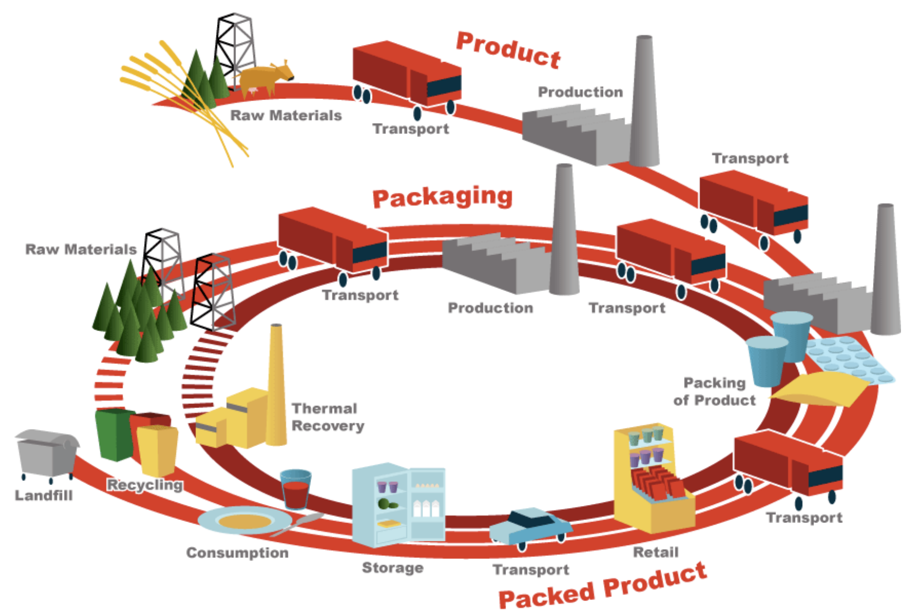


- **In the future we will have to face the shortage of engineering materials.**

EFFICIENT DESIGN	REPLACEMENT	RECYCLING

Abundance of elements / weight percent

Crust		Oceans	
Oxygen	47	Oxygen	85
Silicon	27	Hydrogen	10
Aluminium	8	Chlorine	2
Iron	5	Sodium	1
Calcium	4	Magnesium	0.1
Sodium	3	Sulphur	0.1
Potassium	3	Calcium	0.04
Magnesium	2	Potassium	0.04
Titanium	0.4	Bromine	0.007
Hydrogen	0.1	Carbon	0.002
Phosphorus	0.1	**Atmosphere**	
Manganese	0.1		
Fluorine	0.06		
Barium	0.04	Nitrogen	79
Strontium	0.04	Oxygen	19
Sulphur	0.03	Argon	2
Carbon	0.02	Carbon dioxide	0.04



The total mass of the crust to a depth of 1 km is 3×10^{21} kg.
the mass of the ocean is 10^{20} kg.
the mass of the atmosphere is 5×10^{18} kg.