

ENGINEERING MATERIALS AND THEIR PROPERTIES

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Introduction

- More than 50,000 materials available to the engineer in design
- Choice not easy from this vast menu which material best suits the purpose.
- Other consideration needed to facilitate choice process.

- Mistakes can cause disasters.
 - During World War II, one class of welded merchant ships suffered heavy losses, by breaking in half at sea: low **fracture toughness** of the steel welds.
 - Aircraft lost due to use of materials with lower **fatigue strength**
 - Bridges collapse due to resonance with marching soldiers.
 - Appliances made of plastic: usually fail because of low **modulus (of Elasticity)** of the polymer.


- 
- These bulk properties are listed in Table 1, along with other common classes of properties that the designer must consider when choosing a material.
 - Many properties will be unfamiliar - we will introduce them through examples

Table 1: Classes of properties of Materials

Economic:

Price, availability, Recyclability

General Physical:

Density

Mechanical:

Modulus, Yield & tensile strength, Hardness, Fracture toughness, Fatigue strength, Creep strength, Damping



Thermal:

Thermal conductivity, Specific heat, Thermal expansion coefficient

Electrical:

Conductivity, Resistivity



Magnetic:

Dielectric constant, Magnetic permeability

Environmental:

Oxidation Interaction, Corrosion, Wear

Production:

Ease of manufacture, Joining, Finishing

Aesthetic (Ergonomic):

Colour, Texture, Feel



- **Table 2 Classes of materials**

- ***Metals and alloys*** – good conductors, strong, ductile, tough
 - Iron and steels
 - Aluminium and its alloys
 - Copper and its alloys
 - Nickel and its alloys
 - Titanium and its alloys

- **Polymers** – light, non-conductors, not resistant to temperatures above 400°C
 - Polyethylene (PE)
 - Polymethylmethacrylate (Acrylic and PMMA)
 - Nylon, alias Polyamide (PA)
 - Polystyrene (PS)
 - Polypropylene (PP)



- ***Polymers*** – Cont'd

- Polyurethane (PU)
- Polyvinylchloride (PVC)
- Polyethylene tetrathalate (PET)
- Polyethyl ether Ketone (PEEK)
- Epoxies (EP)
- Elastomers, such as natural rubber (NR)

Ceramics and glasses - good insulators, brittle, good at elevated temperatures.

- ❖ Ceramics - crystalline, inorganic, non-metals.
- ❖ Glasses - non-crystalline (or *amorphous*) solids
- ❖ Most engineering glasses - non-metals, but a range of *metallic glasses* with useful properties is now available.

● ***Ceramics and glasses*** – Cont'd.

- Alumina (Al_2O_3 , emery, sapphire)
- Magnesia (MgO)
- Silica (SiO_2) glasses and silicates
- Silicon carbide (SiC)
- Silicon nitride (Si_3N_4)
- Cement and concrete

- **Composites** – combinations of two or more groups of above materials to get special properties
 - Fibreglass (GFRP)
 - Carbon-fibre reinforced polymers (CFRP)
 - Filled polymers
 - Cermets (composed of ceramic (cer) and metal (met))

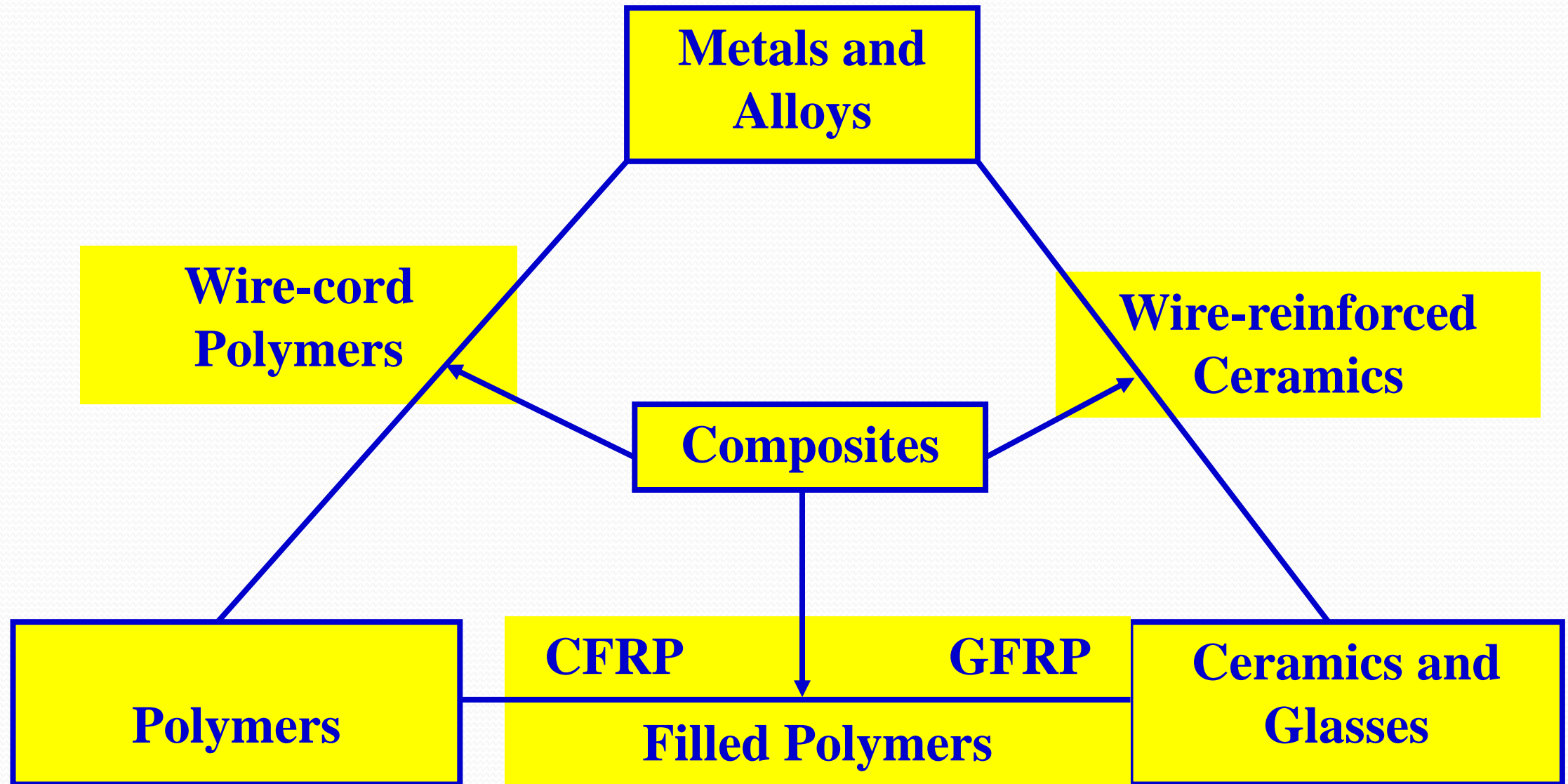


- ***Natural materials***

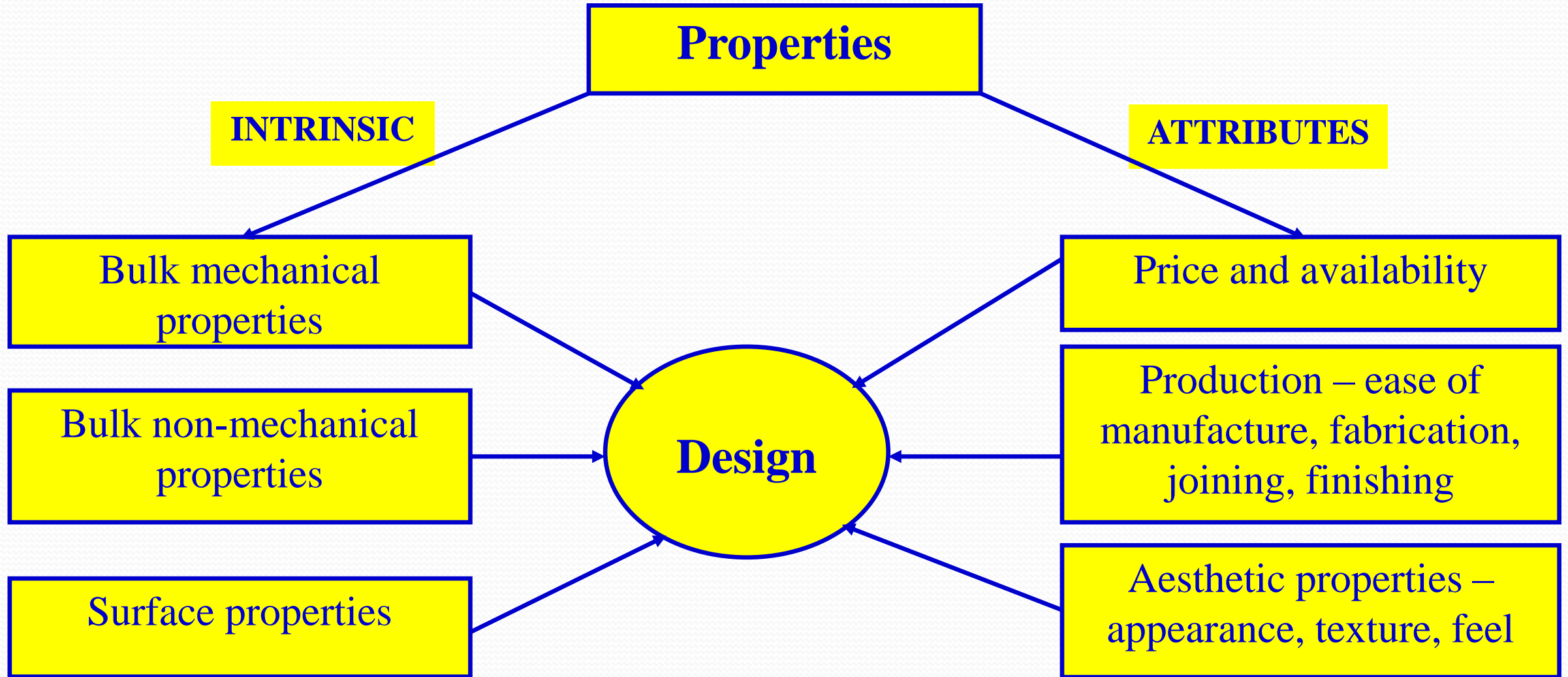
- Wood
- Leather
- Cotton/wool/silk
- Bones

- More engineering components made of ***metals and alloys***
- ***Polymers*** - increasingly replacing metals - they offer a combination of properties (good weight-to-strength ratio)
- ***Ceramics*** - emerging class of engineering material
 - may permit more efficient heat engines, sharper knives, and bearings with lower friction.
- ***Composites*** (e.g. fibreglass) - Combination of materials
 - Offer attractive packages of engineered properties
- ***Natural materials*** (e.g. wood and leather) still offer unbeatable properties.

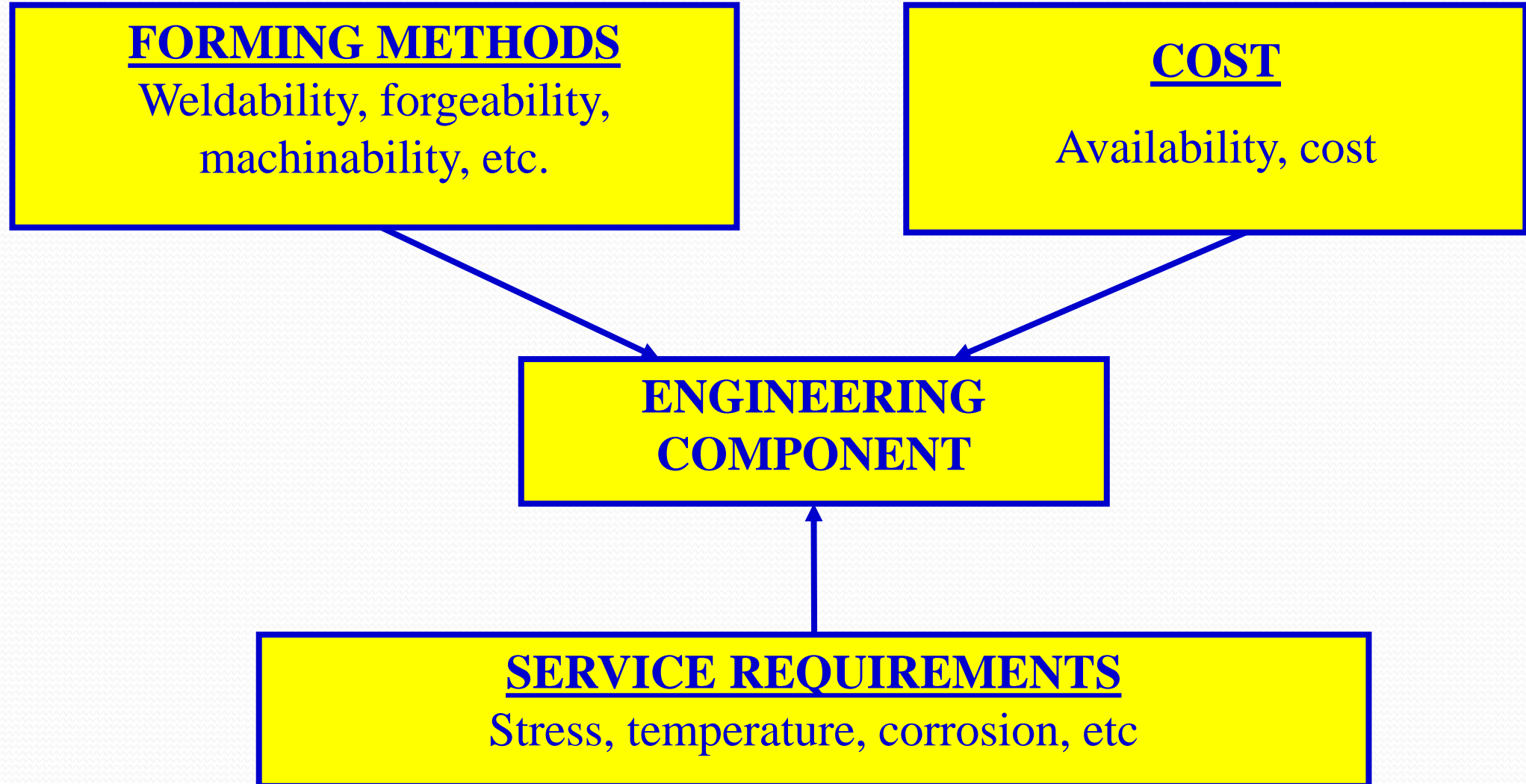
Some Engineered Classes of Engineering Materials



Effect of Material Properties on Design



Material Selection Criteria



Examples of how the designer selects materials.

1. Plastic-handheld screwdriver

2. The turbofan blades

3. The spark plug of an internal combustion engine

1. Plastic-handheld screwdriver



Shaft and blade - *high-carbon steel* - a metal.

- *modulus* is high.
- *modulus = resistance to elastic deflection or bending.*
- Shaft needs high *yield strength* to resist bending & twisting
- Blade needs high *hardness*, to resist damage
- The material of the shaft and blade must have high *fracture toughness* so that it does not break easily.

The handle of the screwdriver - polymer or plastic,
(polymethylmethacrylate (PMMA), plexiglass or perspex).

- Larger section than shaft – so twisting \Rightarrow less important.
- For soft **rubber** (another polymer) - modulus is very low, but a thin skin of rubber might be useful because its **friction coefficient** is high, for easy grip.
- **Wood** – still important but being replaced by PMMA for **ease of fabrication**.
- Aesthetic reasons: **appearance** and **feel** or **texture**, are right; **density** low, so screwdriver can be light.
- **PMMA** = cheap thus product can be of reasonable **price**.

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2. The turbofan blades



- Air is propelled past (and into) the engine to provide aerodynamic thrust.
- The air is further compressed by the compressor blades, and is then mixed with fuel and burnt in the combustion chamber.
- Expanding gases drive the turbine blades, to provide power to the turbofan and the compressor blades, and
- Finally pass out of the rear of engine, adding to the thrust.

Made from a ***titanium alloy***, a metal.

- Good ***modulus***, ***yield strength***, ***fracture toughness*** and ***light***.
- Resists ***fatigue*** (failure due rapidly fluctuating or reversing loads), ***surface wear*** (striking everything from water droplets to large birds) and ***corrosion*** (important at seaside takeoffs).
- ***Density*** \Rightarrow very important - the heavier the engine, the less the payload.

- To reduce weight further, **composite blades** (made of **carbon-fibre reinforced polymers – CFRP**) used. $\rho_{\text{CFRP}} < 0.5\rho_{\text{Titanium}}$
- $\rho_{\text{Titanium}} = 4.5 \text{ kg/m}^3$
- **Cladding** with metallic leading edges used to improve **toughness**.

- **The turbine blades** (in the hottest part of the engine, e.g. the first row of blades, the 'HP1' blades) run at metal temperatures of about 950°C,
- They require high resistance to ***creep***.
- They also require high resistance to ***oxidation***.
- Nickel-based alloys used for this application.

3. The spark plug of an internal combustion engine



Spark electrodes must resist **thermal fatigue** (rapidly fluctuating temps), **wear** (spark erosion) and **oxidation and corrosion** from hot upper-cylinder gases containing compounds of S, and Pb (from anti-knock additives)

- **Tungsten alloys** used for the electrodes

Insulation around the central electrode is non-metallic

- **Alumina** (a ceramic) is used.
- It has high **electrical insulation**, **good thermal fatigue resistance** and **resistance to corrosion and oxidation** (it is an oxide already).



The End

But Wait!!!

Assignment 1

**Due: 20/02/2020
at 17:00 hours.**

- a) Examine a typical pen. Sketch it and list six important parts excluding ink.
- b) What materials do you think each of these parts are made of and why?





The End

Now for Real!!!