# 2.3 Materials and their properties

Name: _____ Class: _____ Date: _____ **Total: 30 marks**

**KEY WORDS** thermoplastic • thermosetting polymer • composite • smart material • tensile strength • stiffness • toughness • Young's modulus

## Objective

Build the skills to answer exam questions on **materials** : material groups, alloys and **composites** , smart materials, physical and mechanical properties, stress, strain and Young's modulus, and choosing a material.

**You must be able to:**

- classify materials into groups and give typical properties
- distinguish thermoplastics and thermosetting polymers
- explain how smart materials respond to their surroundings, with uses
- distinguish strength, stiffness, hardness and toughness
- calculate stress, strain, Young's modulus and strength-to-weight ratio
- justify a material choice using function, manufacture, cost, aesthetics and environment



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## 1 Key knowledge and worked examples

### Groups and properties

| group | examples | typical properties |
|---|---|---|
| ferrous metals | mild steel, stainless steel | strong, stiff; most rust unless protected |
| non-ferrous metals | aluminium, copper, brass | lighter or better conductors; resist corrosion |
| **thermoplastics** | polypropylene, ABS, acrylic | soften when heated; can be reshaped and recycled |
| **thermosetting polymers** | epoxy, melamine | set permanently; resist heat; hard to recycle |
| timbers | oak, pine, plywood, MDF | renewable; good strength for their weight |
| **composites** | CFRP, GRP, concrete | two or more materials combined for better properties |
| ceramics and glass | porcelain, glass | hard, heat resistant, brittle |

An **alloy** is a metal mixed with other elements (brass = copper + zinc). **Smart materials** change a property when their surroundings change, and change back: shape memory alloy (nitinol), thermochromic (colour with temperature), photochromic (darkens in bright light), piezoelectric (voltage when squeezed).

| property | meaning |
|---|---|
| **tensile strength** | the highest stress before breaking in tension |
| **stiffness** | resistance to bending or stretching (elastic) |
| **hardness** | resistance to scratching and wear |
| **toughness** | absorbs energy without breaking; resists cracks |
| ductility / brittleness | stretches into wire / breaks suddenly |

Strength is about when a material **breaks**; stiffness is about how much it **bends** before then.

### Calculations

$$\text{stress} = \frac{F}{A} \qquad \text{strain} = \frac{\Delta l}{l} \qquad E = \frac{\text{stress}}{\text{strain}} \qquad \text{strength-to-weight} = \frac{\text{tensile strength}}{\text{density}}$$

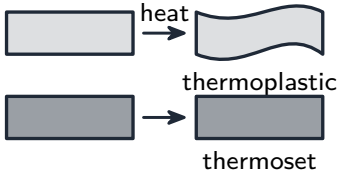
$1\ \text{N/mm}^2 = 1$ MPa. Strain has no units.

**Worked example.** A steel rod, area 50 mm$^2$, length 500 mm, carries 10,000 N and stretches 0.5 mm. Stress $= 10\,000 \div 50 = 200$ MPa; strain $= 0.5 \div 500 = 0.001$; $E = 200 \div 0.001 = 200\,000$ MPa $= 200$ GPa.

**Choosing:** function (properties) + manufacture + cost and availability + aesthetics + environment.

## 2 Practice

**2.1** Distinguish between a **thermoplastic** and a **thermosetting polymer**. [2]




**2.2** Identify a suitable smart material for:

(a) a baby spoon that warns when food is too hot; [1]

(b) glasses lenses that darken outdoors. [1]

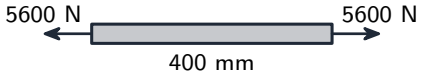




**2.3** Explain the difference between **toughness** and **hardness**, with a product example of each. [4]



**2.4** An aluminium rod has a cross-sectional area of 40 $mm^2$ and a length of 400 mm. A load of 5600 N stretches it by 0.8 mm. Calculate Young's modulus of the aluminium in GPa. [3]




**2.5** A titanium alloy has a tensile strength of 900 MPa and a density of 4.5 $g/cm^3$. A steel has a tensile strength of 400 MPa and a density of 7.85 $g/cm^3$. Calculate the strength-to-weight ratio of each and state which is better for a racing bicycle part. [2]

| | strength (MPa) | density ($g/cm^3$) |
|---|---|---|
| titanium alloy | 900 | 4.5 |
| steel | 400 | 7.85 |



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## 3 Exam-style questions

**3.1** A bicycle maker is choosing the frame material for a new model. Typical data are shown.

| | steel | aluminium alloy | CFRP |
|---|---|---|---|
| tensile strength (MPa) | 670 | 310 | 600 |
| density (g/cm$^3$) | 7.85 | 2.7 | 1.6 |
| cost per kg ($) | 2 | 4 | 40 |
| easy to recycle? | yes | yes | no |

(a) Calculate the strength-to-weight ratio of each material. [3]

(b) Explain why CFRP is described as a **composite**. [2]

(c) Explain **two** factors, other than mechanical properties, that affect the choice of frame material. [4]



(d) Discuss which material the firm should use for a low-cost city bicycle made in large numbers. [8]



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