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

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

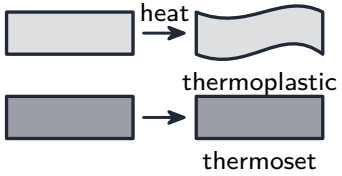
$1\ \text{N/mm}^2 = 1$ MPa. Strain has no units.

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]

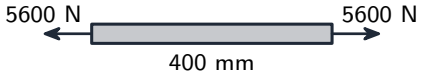
(b) glasses lenses that darken outdoors. [1]



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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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

Each answer shows the steps, then the **result**.

2.1

a thermoplastic softens when heated, so it can be reshaped and recycled; a thermosetting polymer sets permanently when cured and does not soften again

2.2

(a) thermochromic pigment / polymer

(b) photochromic material

2.3

toughness: absorbs energy / impact without breaking; e.g. polycarbonate safety glasses; hardness: resists scratching and wear; e.g. ceramic floor tiles / tool steel

2.4

stress $= 5600 \div 40 = 140$ MPa and strain $= 0.8 \div 400 = 0.002$; $E = 140 \div 0.002 = 70\,000$ MPa $=$ **70** GPa

2.5

titanium $900 \div 4.5 = 200$; steel $400 \div 7.85 \approx 51$; titanium, as it carries about four times the load for the same mass

3.1

(a) steel $670 \div 7.85 \approx$ **85**; aluminium $310 \div 2.7 \approx$ **115**; CFRP $600 \div 1.6 =$ **375**

(b) it combines two materials: strong, stiff carbon fibres in a polymer matrix; together they give properties neither has alone, e.g. high strength with low density

(c) any two, explained: cost: material and process cost per frame must fit the selling price; manufacture: steel and aluminium tubes can be cut and welded; CFRP needs moulds and hand lay-up; environment: steel and aluminium are easy to recycle; CFRP is hard to recycle; aesthetics or availability

(d) award up to [8]: CFRP has the best strength-to-weight (375) but costs about $40 per kg and is hard to recycle; it suits racing bikes, not low-cost city bikes; steel is the cheapest and easy to weld and repair; but it is heavy (low ratio, 85) and can rust unless protected; aluminium is lighter than steel (ratio 115) at moderate cost; it resists corrosion, useful for bikes left outside; both metals are recyclable, unlike CFRP; judgement: aluminium or steel, e.g. steel if cost matters most, aluminium if lower mass is needed

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