1 Properties of materials – tensile properties

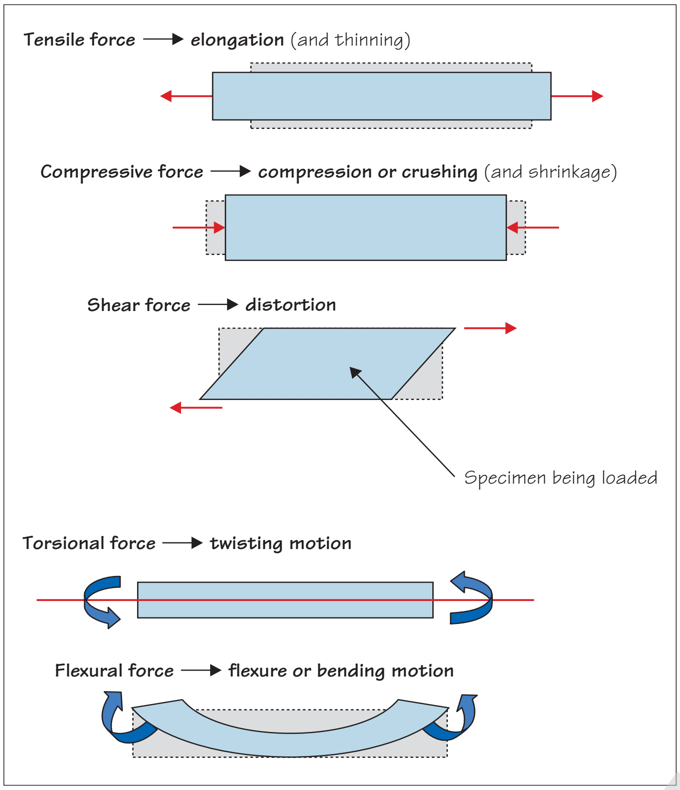

Figure 1.1 Applied forces and specimen deformations.

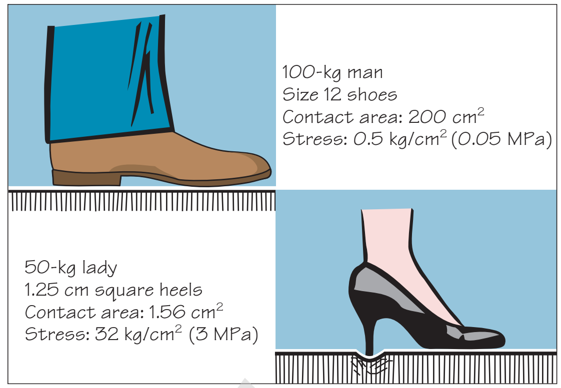

Figure 1.2 Load vs. stress for feet.

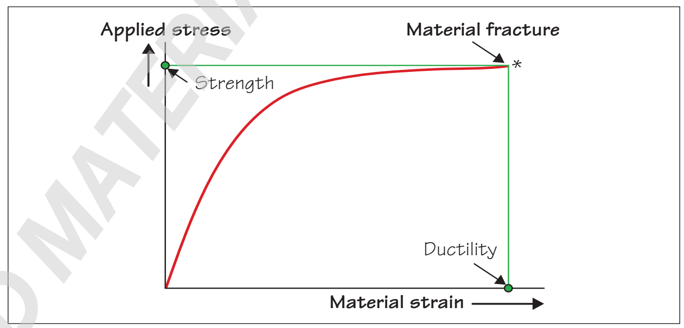

Figure 1.3 The stress–strain curve of a non-ferrous metal.

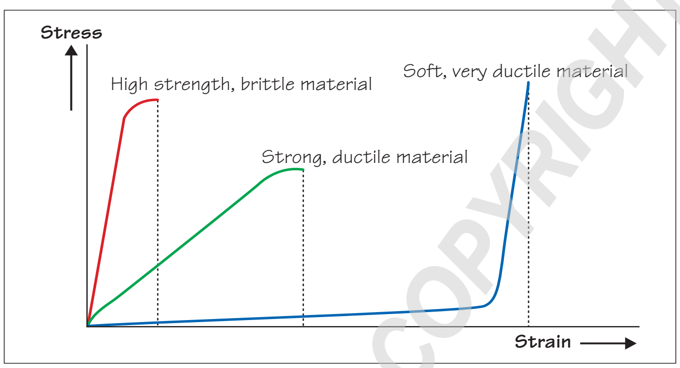

Figure 1.4 Stress–strain curves for a brittle, an elastic and a ductile material.

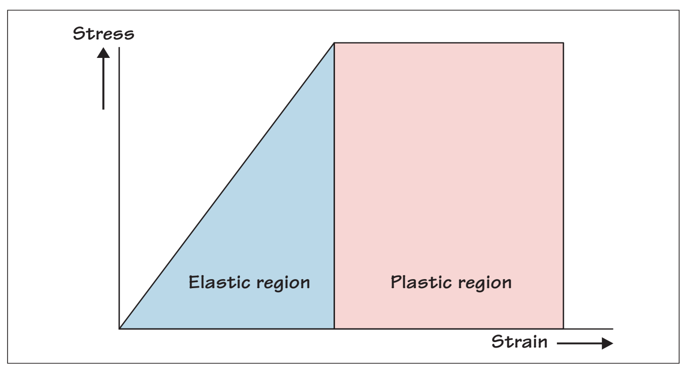

Figure 1.5 Elastic and plastic regions of a stress–strain curve.

Table 1.1 Desirable properties of dental materials.

Biocompatibility
Absence of toxicity
Esthetic appearance
Strength and durability
Low solubility
Ease of manipulation
Long shelf life
Simple laboratory processing
Long working time
Rapid/snap set

Table 1.2 Typical mechanical properties of dental biomaterials.

Material	Tensile strength (MPa)	Compressive strength (MPa)	Shear strength (MPa)	Elastic modulus (GPa)	Hardness (KHN)
Gold alloy	448	–	–	77	22
Dental amalgam	54.7	318	188	34	110
Dentin	51.7	297	138	1.4	68
Enamel	10.3	384	90	4.6	343
Porcelain	24.8	149	111	140	460
Composite	45.5	237	–	14	–
Zn phosphate cement	8.1	117	13	13.7	40
Die stone	7.7	48	–	–	–
$Ca(OH)_2$	1.0	10.3	–	–	–
Glass ionomer	18	150	–	20	–

KHN, Knoop hardness number.

Dental biomaterials are used in laboratory procedures and for the restoration and replacement of teeth and bone. Material selection must consider function, properties and associated risks, and all dental biomaterials must satisfy certain criteria (Table 1.1).

Mechanical properties

Mechanical properties are important since teeth and restorations must resist biting and chewing (masticatory) forces. Typical properties are given in Table 1.2.

Biting forces

Biting forces vary with patient age and dentition, decreasing for restored teeth and when a bridge, removable partial denture (RPD) or complete denture is present. Effects vary with the type of applied force and its magnitude. Types of applied force, and the resulting deformations, are shown in Figure 1.1.

Stress

Stress, σ: force per unit cross-sectional area. **Strength** is the stress that causes failure. **Ultimate strength** is the maximum stress sustained before failure.

Stress, the applied force and the area over which it operates, determines the effect of the applied load. For example, a chewing force of 72 kg (10 N) spread over a quadrant 4 cm^2 in area exerts a stress of 18 kg/cm^2 (1.76 MPa). However, the same force on a restoration high spot or a 1-mm^2 hard food fragment produces a stress of 7200 kg/cm^2 (706 MPa), a 400-fold increase in loading. This stress effect is one reason that occlusal balancing is essential in restorative dentistry. A more graphic example of the difference between applied force and stress is shown in Figure 1.2. This example also clearly indicates why it is more painful when a woman wearing high heels steps on you than when a man does!

Proportional limit

Proportional limit is the maximum stress that the material can sustain without deviation from a linear stress–strain proportionality.

Elastic limit is the maximum stress that can be applied without permanent deformation.

Yield strength, σ_y is the stress at which there is a specified deviation from proportionality of stress to strain. It is usually 0.1, 0.2 or 0.5% of the permanent strain.

Strain

Strain, ε: ratio of deformation to original length $\Delta L/L$. Strain measures deformation at failure.

Ductility: percentage elongation, i.e. $\Delta L/L \times 100\%$.

Ductile materials exhibit greater percentage elongations than brittle materials and can withstand greater deformation before fracture.

Burnishing index: ability of a material to be worked in the mouth or burnished, expressed as the ratio of percentage elongation to yield strength.

Poisson's ratio

Poisson's ratio, ν: ratio of lateral to axial strain under tensile loading. It denotes reduction in cross-section during elongation.

Brittle materials have low ν values, i.e. little change in cross-section with elongation, while ductile materials show a greater reduction in cross-section, known as specimen necking.

Elastic modulus

Elastic modulus, E is the ratio of stress to strain. It is also known as **modulus of elasticity** or **Young's modulus** and denotes material stiffness. It is determined as the slope of the elastic (linear) portion of the stress–strain curve.

Stress–strain curves

Stress–strain curves are generated by applying a progressively increasing tensile force while measuring applied stress and material strain until fracture occurs. The shape of the curve indicates the properties of the material (Figures 1.3 and 1.4). Non-ferrous metals (e.g. gold and copper) show a continuous curve to failure while ferrous materials exhibit a 'kink' in the curve, known as the **yield point**.

The intersection of a line parallel to the abscissa (strain) axis from the failure point to the ordinate (stress) axis is **specimen strength** while the vertical line from the failure point to the strain axis is the **ductility**.

High strength, brittle materials show steep stress–strain curves with little strain at failure, e.g. ceramics.

Strong ductile materials (e.g. metals) show moderate slopes in the stress–strain curve but good extension until failure.

Soft ductile materials (e.g. elastomers) show long, shallow linear stress–strain behavior followed by a sharp rise in the curve when, with increasing applied force, the elastomer no longer extends linearly (or elastically) and failure occurs.

Resilience

Resilience: resistance to permanent deformation (i.e. energy required for deformation to the proportional limit). It is given by the area under the elastic portion of the stress–strain curve (Figure 1.5).

Toughness

Toughness: resistance to fracture (i.e. energy required to cause fracture). It is given by the total area (i.e. both the elastic and plastic regions) under the stress–strain curve (Figure 1.5).