Part I

Fundamentals

Tensile force ⟶ elongation (and thinning)

Compressive force ⟶ compression or crushing (and shrinkage)

Shear force ⟶ distortion

Specimen being loaded

Torsional force ⟶ twisting motion

Flexural force ⟶ flexure or bending motion

Figure 1.1 Applied forces and specimen deformations.

100-kg man
Size 12 shoes
Contact area: 200 cm^2
Stress: 0.5 kg/cm^2 (0.05 MPa)

50-kg lady
1.25 cm square heels
Contact area: 1.56 cm^2
Stress: 32 kg/cm^2 (3 MPa)
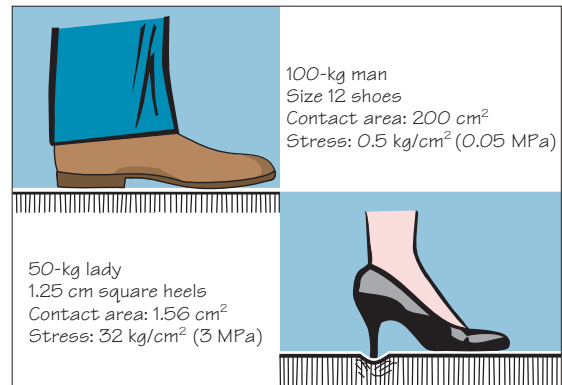
Figure 1.2 Load versus stress for feet.

Applied stress   Material fracture
Strength
Ductility
Material strain ⟶
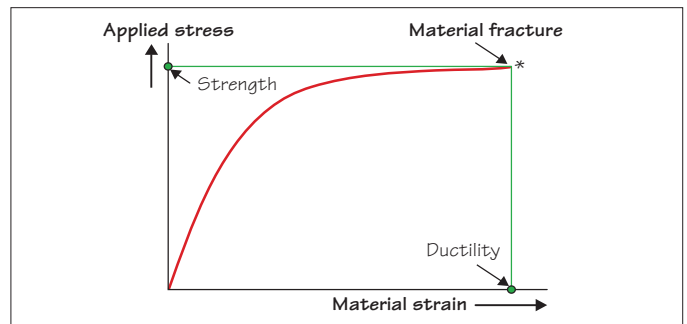
Figure 1.3 The stress–strain curve of a nonferrous metal.

Stress
High strength, brittle material
Soft, very ductile material
Strong, ductile material
Strain ⟶
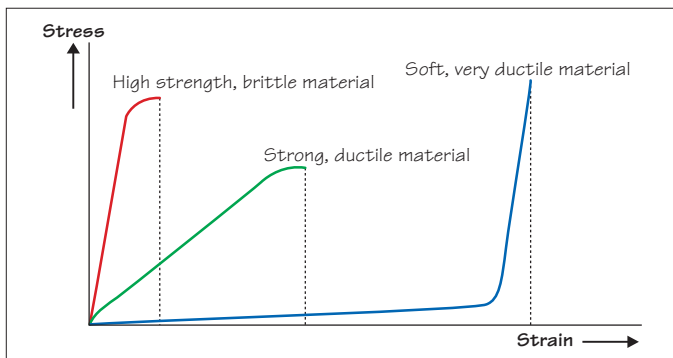
Figure 1.4 Stress–strain curves for brittle, elastic, and ductile materials.

Stress
Elastic region   Plastic region
Strain ⟶
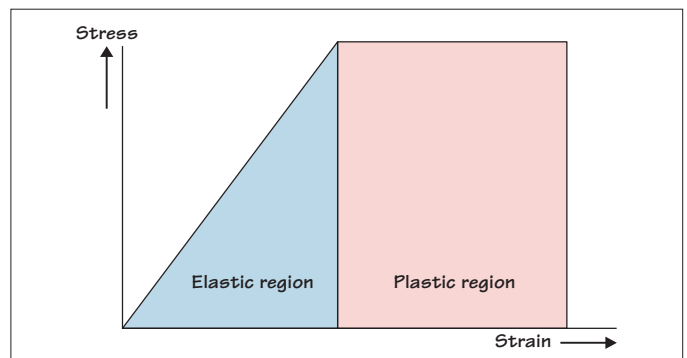
Figure 1.5 Elastic and plastic regions of a stress–strain curve.

Table 1.1 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	

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 (Box 1.1).

Mechanical properties are important since teeth and restorations must resist biting and chewing (masticatory) forces. Typical material properties are given in Table 1.1.

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.

1 **Stress:** σ, force per unit cross-sectional area
  • 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!

2 **Strength:** The stress that causes failure

3 **Ultimate strength:** The maximum stress sustained before failure

4 **Proportional limit:** The maximum stress that the material can sustain without deviation from linear stress–strain proportionality

5 **Elastic limit:** Maximum stress that can be applied without permanent deformation

6 **Yield strength:** σ_Y, stress at which there is a specified deviation from stress-to-strain proportionality, usually 0.1%, 0.2%, or 0.5% of the permanent strain

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

8 **Ductility:** Percentage elongation, i.e. $\Delta L/L \times 100\%$
  • **Ductile** materials exhibit greater percentage elongation than brittle materials and can withstand greater deformation before fracture.

9 **Burnishing index:** Ability of a material to be worked in the mouth or burnished, expressed as the ratio of % elongation to yield strength

10 **Poisson's ratio:** v, ratio of lateral to axial strain under tensile loading; denotes reduction in cross-section during elongation
  • **Brittle** materials have low v values, i.e. little change in cross-section with elongation, whereas ductile materials show greater reduction in cross-section, known as specimen necking.

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

12 **Stress–strain curves:** Generated by applying a progressively increasing tensile force while measuring applied stress and material strain until fracture occurs

The shape of the stress–strain curve indicates the properties of the material (Figure 1.3 and Figure 1.4):
• Nonferrous metals (e.g., gold and copper) show a continuous curve to failure whereas 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** whereas 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.

13 **Resilience:** Resistance to permanent deformation (i.e., energy required for deformation to the proportional limit); given by the area under the elastic portion of the stress–strain curve (Figure 1.5)

14 **Toughness:** Resistance to fracture (i.e., energy required to cause fracture); given by the total area (i.e., both the elastic and plastic regions) under the stress–strain curve (Figure 1.5)

15 **Hardness:** Resistance to penetration; a measure of scratch resistance
  • Hardness is measured by several techniques, including the **Barcol**, **Bierbaum, Brinell**, **Knoop**, **Rockwell**, **Shore**, and **Vickers tests**.