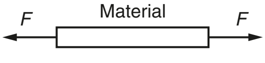
6

Engineering Materials

6.1 Mechanical properties

6.1.1 Tensile strength

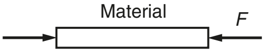
This is the ability of a material to withstand tensile (stretching) loads without rupture occurring. The material is in tension.



F = Applied load

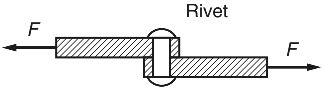
6.1.2 Compressive strength

This is the ability of a material to withstand compressive (squeezing) loads without being crushed or broken. The material is in compression.

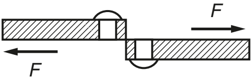


6.1.3 Shear strength

This is the ability of a material to withstand offset or transverse loads without rupture occurring. The rivet connecting the two bars shown is in *shear* whilst the bars themselves are in *tension*. Note that the rivet would still be in *shear* if the bars were in *compression*.



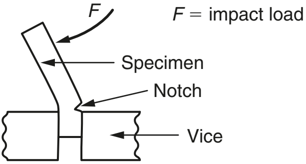
Rivet connecting the two bars is in resisting shear



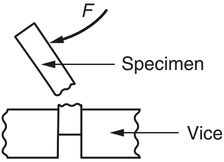
Rivet connecting the two bars has failed in shear

6.1.4 Toughness: impact resistance

This is the ability of a material to resist shatter. If a material shatters it is brittle (e.g. glass). If it fails to shatter when subjected to an impact load it is tough (e.g. rubber). Toughness should not be confused with strength. Any material in which the spread of surface cracks does not occur or only occurs to a limited extent is said to be tough.



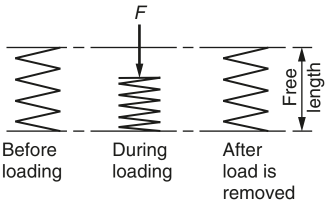
Tough: bends
when hit



Brittle: breaks
(shatters) when hit

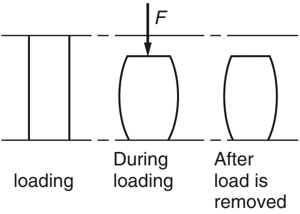
6.1.5 Elasticity

This is the ability of a material to deform under load and return to its original size and shape when the load is removed. Such a material would be required to make the spring as shown.



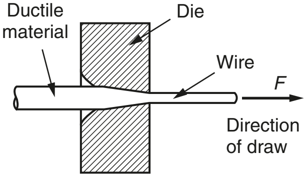
6.1.6 Plasticity

This property is the exact opposite of elasticity. It is the state of a material which has been loaded beyond its elastic state. Under a load beyond that required to cause elastic deformation (the elastic limit) a material possessing the property of plasticity deforms permanently. It takes a *permanent set* and will not recover when the load is removed.



6.1.7 Ductility

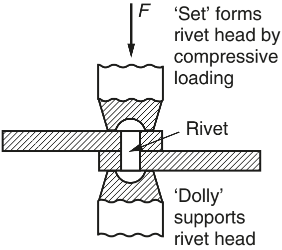
This is the term used when plastic deformation occurs as the result of applying a *tensile load*. A *ductile* material combines the properties of plasticity and tenacity (tensile strength) so that it can be stretched or drawn to shape and will retain that shape when the deforming force is removed. For example, in wire drawing the wire is reduced in diameter by drawing it through a die.



$F =$ Applied load (tensile)

6.1.8 Malleability

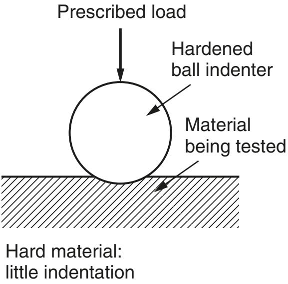
This is the term used when plastic deformation occurs as the result of applying a *compressive load.* A *malleable* material combines the properties of plasticity and compressibility, so that it can be squeezed to shape by such processes as forging, rolling and rivet heading.



$F =$ Applied load (compressive)

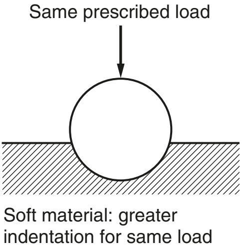
6.1.9 Hardness

This is the ability of a material to withstand scratching (abrasion) or indentation by another hard body. It is an indication of the wear resistance of a material.



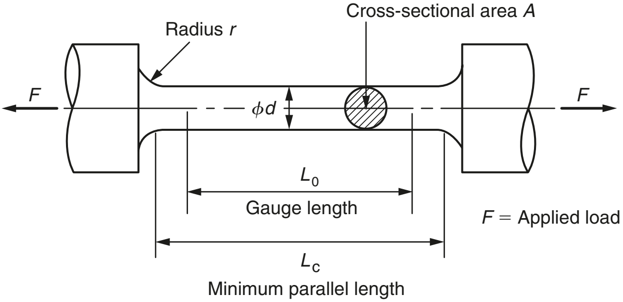
Processes which increase the hardness of materials also increase their tensile strength. At the same time the toughness of the material is reduced as it becomes more brittle.

Hardenability must not be confused with hardness. Hardenability is the ability of a metal to respond to the heat treatment process of quench hardening. To harden it, the hot metal must be chilled at a rate in excess of its *critical cooling rate*. Since any material cools more quickly at the surface than at the centre there is a limit to the size of bar which can cool quickly enough at its centre to achieve uniform hardness throughout. This is the *ruling section* for the material. The greater its hardenability the greater will be its ruling section.



6.1.10 Tensile test

The tensile test is widely used for determining the strength and ductility of a material. The test involves loading a standard specimen axially as shown. The load is increased at a constant rate mechanically or hydraulically. The specimen increases in length until it finally fractures. During the test the specimen is gripped at each end to ensure simple uniaxial loading and freedom of bending. The extension is measured from the *gauge length.* The mid-portion of the specimen is reduced in diameter as shown to ensure fracture occurs within the gauge length.



Typical cylindrical tensile test specimen (BS EN 10002-1)

The results of the test are plotted as shown in Section 6.1.11; it is usual to plot the applied load vertically and the resulting extension horizontally. Alternatively, stress and strain may be plotted with the stress vertical and the resulting strain horizontal. For a given specimen similar curves would be produced. The stress and strain relations are:

$$\text{Stress} = \frac{\text{load}}{\text{original cross-sectional area}}$$

$$\text{Strain} = \frac{\text{increase in length under load}}{\text{original length}}$$

Proportional specimens (BS EN 10002-1) are given by the relationship $L_0 = 5.65\sqrt{A}$. Since $A = \pi d^2/4$, then $\sqrt{A} = d\sqrt{(\pi)}/2 = 0.886d$. Thus $L_0 = 5.65 \times 0.886 \approx 5d$. Hence a specimen of 10-mm diameter will have a gauge length of 50 mm.

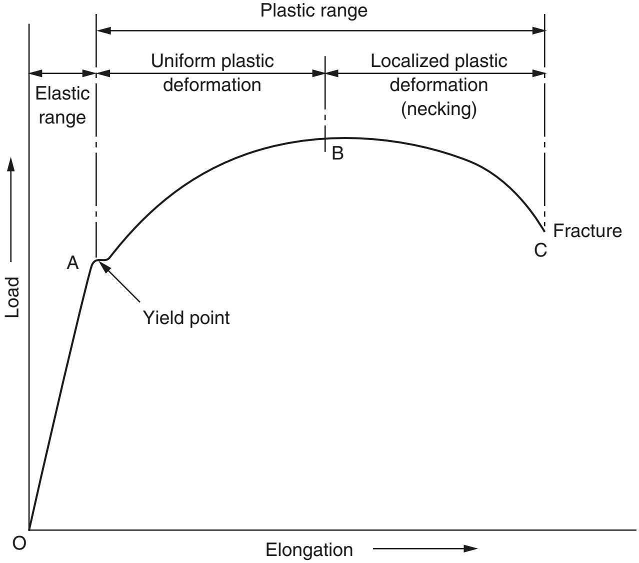
6.1.11 Interpretation of a tensile test: material showing a yield point

The curve shown is typical for a ductile material with a pronounced yield point (e.g. annealed low carbon steel).

The initial part of the plot from O to A is linear since the material is behaving in an elastic manner (Hooke's law). If the load is released at any point between O and A the specimen will return to its original length. The steeper the slope of OA the more rigid (stiffer) will be the material. The point A is called the *limit of proportionality.*

At the point A some materials may undergo a sudden extension without a corresponding increase in load. This is called the *yield point*, and the yield stress at this point is calculated by dividing the load at yield by the original cross-sectional area.

Beyond the yield point A the plot ceases to be linear since the material is now behaving in a plastic manner. If the load is released at any point in the plastic range, the elastic strain is recovered but the plastic element of the deformation is maintained and the material will have undergone permanent extension. That is, it has taken a *permanent set.*



Beyond the point B the material extends with a reducing load. However, since there is a local reduction in cross-sectional area (necking) the stress (load/area) is actually increasing up to the breaking point. The stress calculated at the point B is called the *maximum tensile stress* (or just *tensile strength*) of the material.

The *ductility* of the material is calculated by reassembling the broken specimen and measuring the increase in gauge length.

Then:

$$\text{Elongation (\%)} = \frac{\text{increase in length}}{\text{original length}} \times 100$$

Under service conditions the material is loaded to a value within the OA zone. Usually not more than 50% of the value at A to allow a *factor of safety.*

6.1.12 Interpretation of a tensile test: proof stress

Many materials do not show a marked yield point, and an offset yield stress or *proof stress* is specified instead. This is the stress required to produce a specified amount of plastic deformation.

A line BC is drawn parallel to the elastic part of the plot OA so as to cut the load/elongation curve at C. The offset is specified (usually 0.1% or 0.2% of the gauge length).