Beyond the elastic limit

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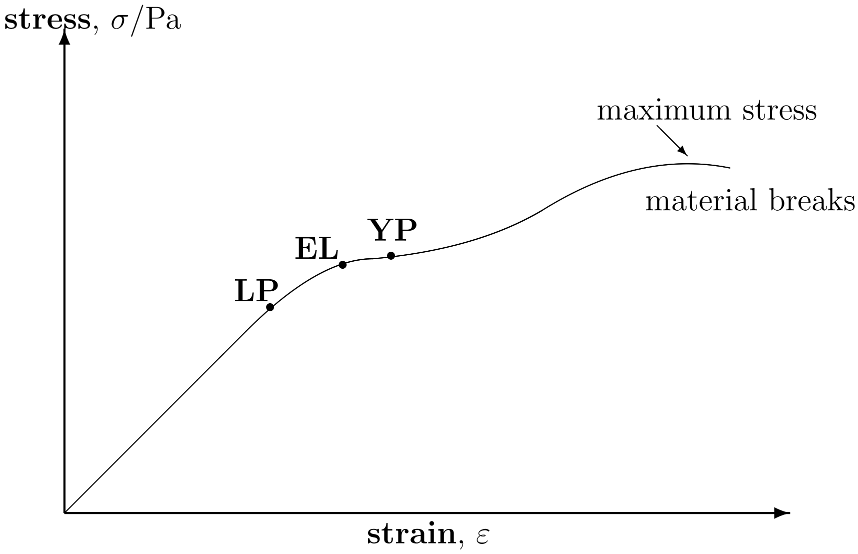
The limit of proportionality

So far, we have only looked at materials in the limit of small deformations, where Hooke's law applies (deformation is reversible and proportional to the force applied). In this limit, all materials behave in a very similar way, determined by their Young modulus. Beyond the limit of proportionality, which has widely varying values for different materials, there is a great variation between materials in what happens as more stress is applied.



The extension of a typical ductile material in tension is shown on the graph above. As the material is extended, the stress needed on the object is plotted out.

There is an elastic (Hookean) region, where the strain is directly proportional to the stress, before the *limit of proportionality* (**LP**). Beyond this limit, the the material will return to a similar shape and size when the stress is removed, but there will be some permanent extension (it will continue to return to this new form if forces are applied) – this is shown as the dashed line. Some materials cannot be permanently stretched in this way—the limit of proportionality for these materials is almost exactly the same as the elastic limit and yield point—and these materials, e.g. glass, are said to be *brittle*.

After the *elastic limit* (**EL**), just after the limit of proportionality, has been passed, the material will no longer return to its original length or shape, but it will still reduce somewhat in length if the stress is reduced.

Just after the elastic limit, there is a point called the *yield point* (**YP**), at which a stress causes a major change in a material. The material undergoes plastic deformation, meaning that in a ductile material, the bonds between molecular layers break, and the layers flow over each other. It will continue to stretch without extra stress, and even if the stress is reduced. At this point, the material has lost its strength, it has passes the maximum stress it can take—the breaking stress or ultimate tensile stress (UTS), and its strain will increase until it finally reaches the breaking point.

The work done in extending the material is equal to the energy stored in the material, and is given by the area under the curve.

Describing materials

Quite a lot of information about a material can be gleaned from the stress–strain curve, and materials scientists and engineers use a number of different terms to describe how materials behave under load:

- *Stiffness* and *flexibility* — Materials like rubber which are easily deformed are *flexible*, whearas materials which hold their shape when a force is applied, like glass, are termed *stiff*. The stiffness of different materials can be compared using the gradient of the stress–strain line, which is the Young modulus.

- *Strength* — This is determined by how much force is required to break the material. *strong* materials require much more force to break them than do weak ones. The strength of the same material can be very different depending on its shape and how it is measured, so normally we take the ultimate tensile stress (UTS) as a measure of *tensile* strength.

- *Toughness* — *Brittle* materials such as china have tiny cracks which can spread and open up, making them snap cleanly and sharply. This means that they can often fail catastrophically, with the release of lots of energy. Materials which resist the formation and spreading of cracks, such as steel, are *tough*.

- *Ductility* — *Ductile* materials are those which can be stretched, and the term is normally used of metals which can be drawn out into a thin wire.
- *Elasticity* and *plasticity* — Materials which return to their original shape after a deformation, like rubber, are known as *elastic* materials, but materials which are permanently deformed, like plasticine, are known as *plastic* materials.