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Applied Physics

Lecture-5 & 6

Unit II-Mechanical Properties of solids

Topics to be discussed in this lecture:

- A little more insight to Stress-Strain curve giving rise to definitions of the following:
  - Yield point
  - Limit of proportionality
  - Elastic limit
  - Yield strength
  - Ultimate tensile strength
- Brittle materials
- Malleability and Ductility

Tensile test and Stress-Strain Diagram

Stress-Strain Diagram expresses a relationship between a load applied to a material and the deformation of the material, caused by the load.

Stress-Strain Diagram is determined by **tensile test**.

Tensile tests are conducted in **tensile test machines**, providing controlled uniformly increasing tension force, applied to the specimen.

The specimen's ends are gripped and fixed in the machine and its **gauge length** L_0 (a calibrated distance between two marks on the specimen surface) is continuously measured until the rupture.

Test specimen may be round or flat in the cross-section.

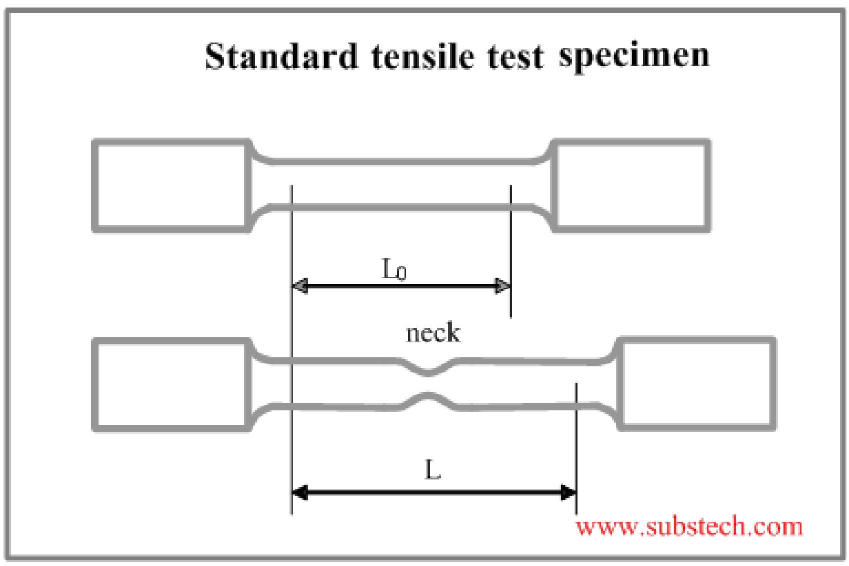
In the round specimens it is accepted, that **L_0 = 5 * diameter**.

The specimen deformation (**strain**) is the ratio of the increase of the specimen gauge length to its original gauge length:

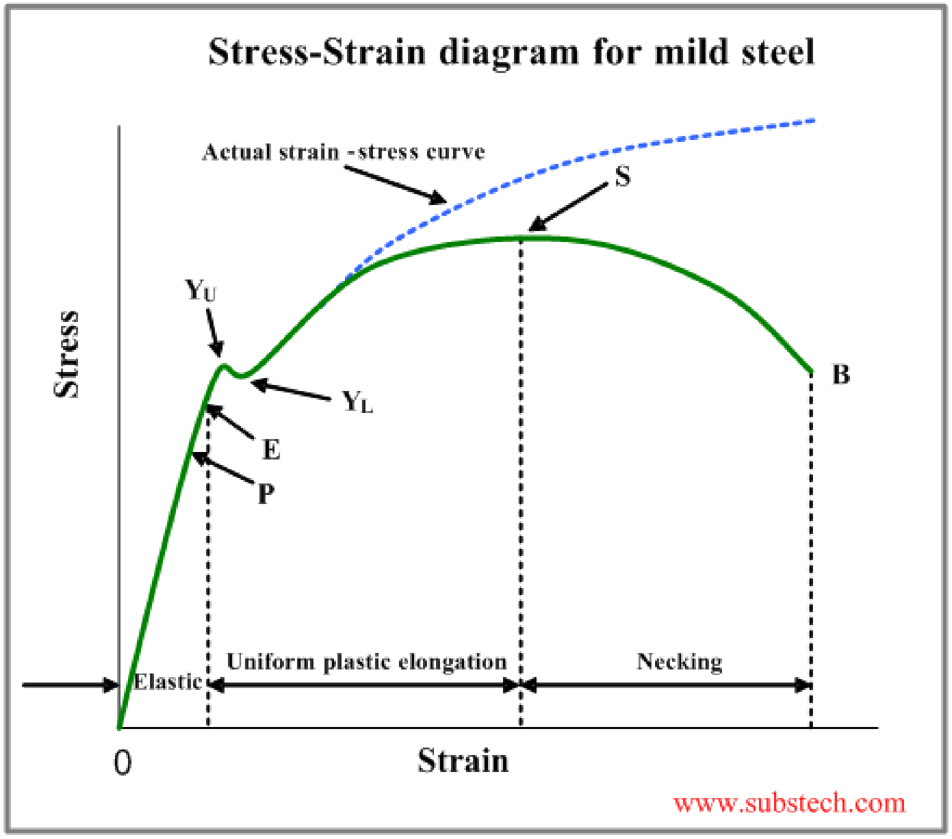
$$\delta = (L - L_0) / L_0$$

Tensile stress is the ratio of the tensile load **F** applied to the specimen to its original cross-sectional area S_0:

$$\sigma = F / S_0$$



Let's say we used mild steel as our specimen and the observed stress strain curve is shown below:



The initial straight line (**0P**) of the curve characterizes proportional relationship between the stress and the deformation (strain).

The stress value at the point **P** is called the **limit of proportionality**:

$\boldsymbol{\sigma_p = F_P / S_0}$

This behavior conforms to the **Hook's Law**:

$\boldsymbol{\sigma = E * \delta}$

where **E** is a constant, known as **Young's Modulus** or **Modulus of Elasticity**

The value of Young's Modulus is determined mainly by the nature of the material and is nearly insensitive to the heat treatment and composition.

Modulus of elasticity determines **stiffness** - resistance of a body to elastic deformation caused by an applied force.

The line **0E** in the Stress-Strain curve indicates the range of **elastic deformation** – removal of the load at any point of this part of the curve results in return of the specimen length to its original value.

The elastic behavior is characterized by the **elasticity limit** (stress value at the point **E**):

$\boldsymbol{\sigma_{el} = F_E / S_0}$

For the most materials the points **P** and **E** coincide and therefore $\boldsymbol{\sigma_{el}=\sigma_p}$.

$\boldsymbol{\sigma_y = F_Y / S_0}$

The highest stress (point $\mathbf{Y_U}$) , occurring before the sudden deformation is called **upper yield limit** .

The lower stress value, causing the sudden deformation (point $\mathbf{Y_L}$) is called **lower yield limit**.

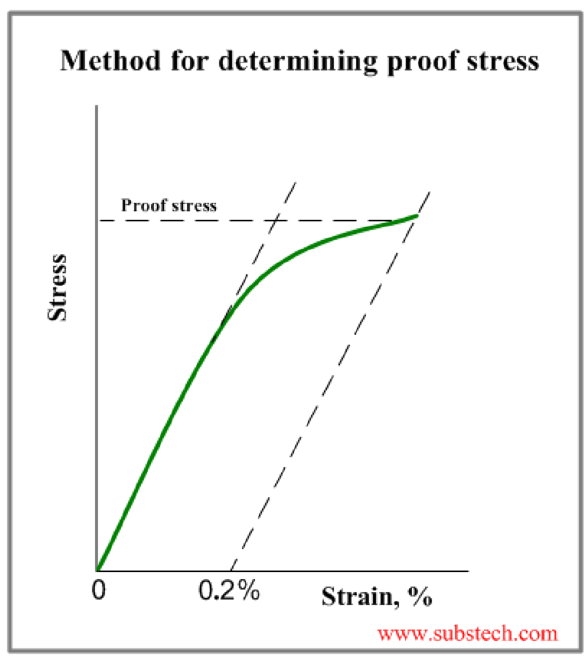
The commonly used parameter of yield limit is actually lower yield limit.

If the load reaches the yield point the specimen undergoes plastic deformation – it does not return to its original length after removal of the load.

Hard steels and non-ferrous metals do not have defined yield limit, therefore a stress, corresponding to a definite deformation (0.1% or 0.2%) is commonly used instead of yield limit. This stress is called **proof stress** or **offset yield limit (offset yield strength):**

$\boldsymbol{\sigma_{0.2\%} = F_{0.2\%} / S_0}$

The method of obtaining the proof stress is shown in the picture (right).



As the load increase, the specimen continues to undergo plastic deformation and at a certain stress value its cross-section decreases due to "necking" (point **S** in the Stress-Strain Diagram). At this point the stress reaches the maximum value, which is called **ultimate tensile strength** (**tensile strength**):

$\boldsymbol{\sigma_t = F_S / S_0}$

Continuation of the deformation results in breaking the specimen - the point B in the diagram.

The actual Stress-Strain curve is obtained by taking into account the true specimen cross-section instead of the original value.

Other important characteristic of metals is **ductility** - ability of a material to deform under tension without rupture, which we will be discussing in the end of this lecture.

Ductile & Brittle Material

So what is a ductile material and what is a brittle material? Simply a ductile material is a material that will typically deform when a large amount of energy is absorbed into the material during short period of time, while a brittle material will instead shatter when a large amount of energy is absorbed into the material in a short amount of time.

Brittle Material

Unlike ductile material, a brittle material will have a very small plastic region in comparison. Due to this fact once a brittle material leaves the elastic region it will fail a lot quicker. The break will also be a lot cleaner since there will be less necking.

The images below show what a ductile material break would be in comparison to a brittle material. They also show what the stress strain curves would look like.

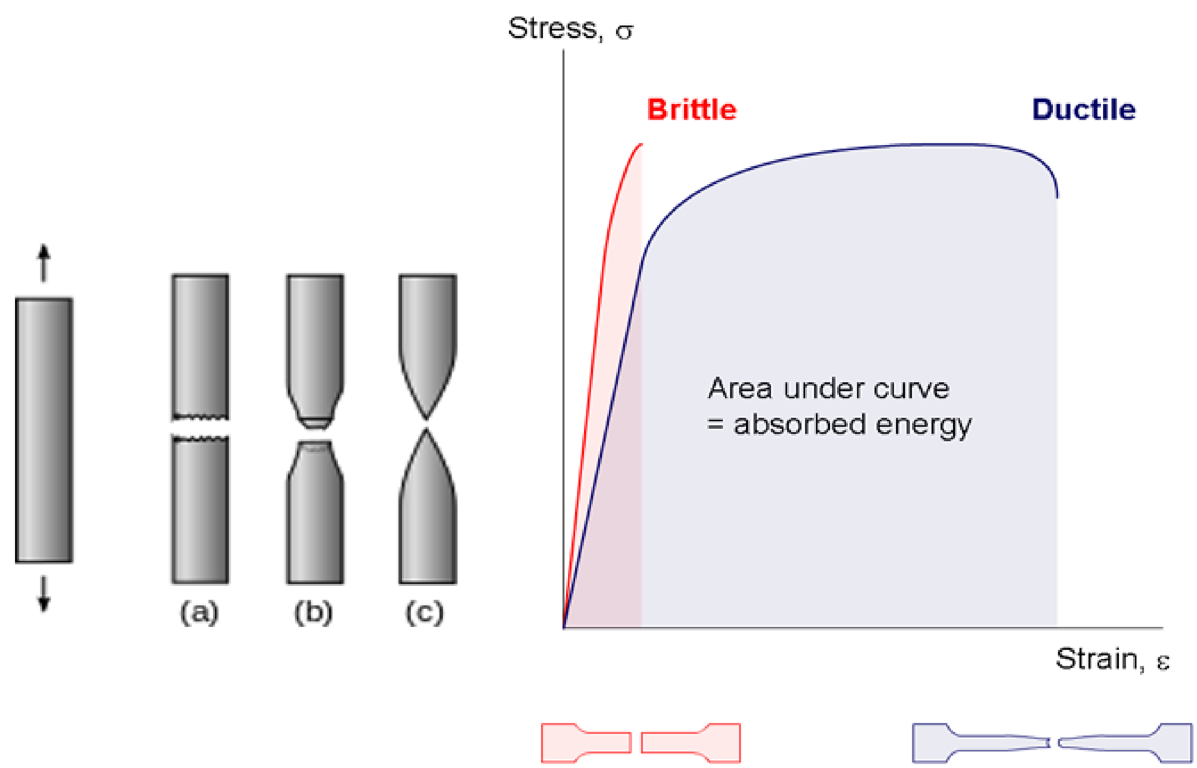


Figure 1 (a) Brittle break (b) Semi ductile break and (c) Ductile break (left), Stress-strain curve for brittle and ductile materials (right)

The material in the figure marked with (a) shows what a brittle material will look like after pulling on a cylinder of that material. Typically, there will be a large audible snap sound when the brittle material breaks. A brittle material is also known as a material having low ductility.

Looking at the stress strain curve above that is being used to compare a brittle material to a ductile material one can notice that even though the brittle material can’t absorb as much energy as the ductile material can it typically will have a higher yield point than the ductile material. This means that neither a brittle nor a ductile material is better than the other one. It really depends on what the part is being used for.

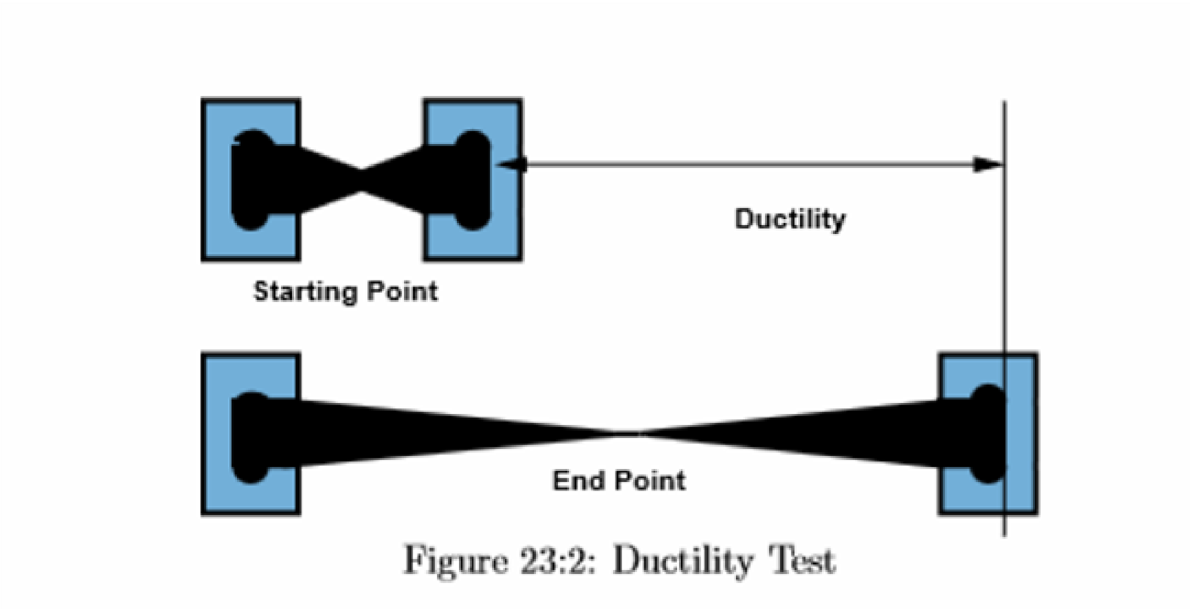
You may be asking: **why are ceramics so much more brittle than metals?** It has to do with the bonding. In metals, their metallic bonds allow the atoms to slide past each other easily. In ceramics, due to their ionic bonds, there is a resistance to the sliding. Since in ionic bonding every other atom is of opposite charge when a row of atoms attempts to slide past another row, positive atoms encounter positive atoms and negative atoms encounter negative atoms. This results in a huge electrodynamic repulsion which inhibits rows of ceramic atoms from sliding past other rows. In metals, the sliding of rows of atoms results in slip, which allows the metal to deform plastically instead of fracturing. Since in ceramics the rows cannot slide, the ceramic cannot plastically deform. Instead, it fractures, which makes it a brittle material.

Malleability and Ductility

Malleability and ductility are related. A malleable material is one in which a thin sheet can be easily formed by hammering or rolling. In other words, the material has the ability to deform under compressive stress.

A malleable material is one in which a thin sheet can be easily formed by hammering. Gold is the most malleable metal.

In contrast, ductility is the ability of a solid material to deform under tensile stress. Practically, a ductile material is a material that can easily be stretched into a wire when pulled as shown in the figure below. Recall pulling is applying tensile stress.



Ductility test.

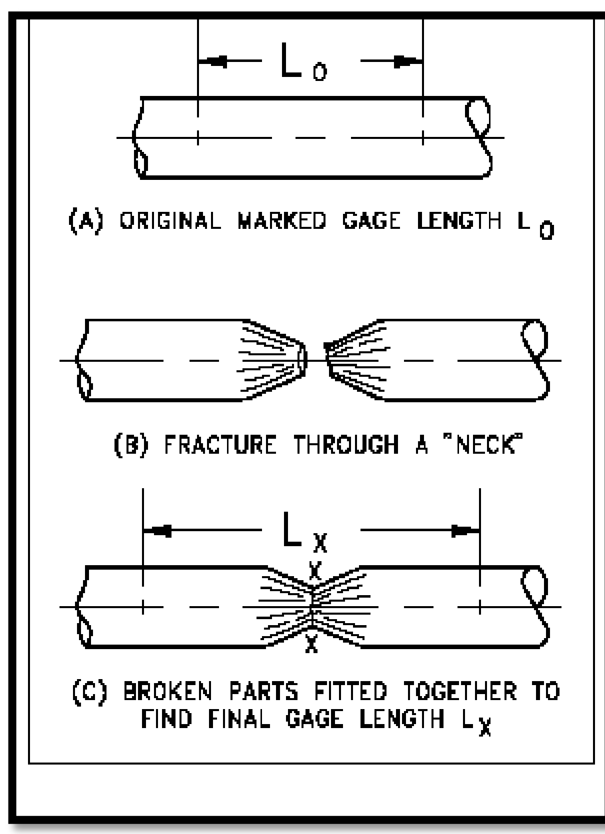
So what makes a material ductile? A material that is ductile has the ability to deform and essentially absorb quite a bit of energy before it will break. If you were to look at the stress strain plot (figure 1) of a ductile material it would have a very large plastic area that allows quite a bit of strain before the material reaches its fracture stress. There will also be large amount of necking before the material fails as shown in figure 1 (a) and (b).

Let's come back to the **TENSILE TEST** which we have talked about in the beginning of the lecture.

Ductility is the percentage elongation reported in a tensile test is defined as the maximum elongation of the gage length divided by the original gage length. The measurement is determined as shown in figure below:

$$\text{Percent elongation} = \frac{\text{final gage length} - \text{initial gage length}}{\text{initial gage length}}$$

$$= \frac{L_x - L_o}{L_o} = \text{inches per inch x } 100$$



Reduction of area is the proportional reduction of the cross-sectional area of a tensile test piece at the plane of fracture measured after fracture.

Percent reduction of area (RA) =

$$\frac{\text{area of original cross section} - \text{minimum final area}}{\text{area of original cross section}}$$

$$= \frac{A_o - A_{min}}{A_o} = \frac{\text{decrease in area}}{\text{original area}} = \frac{\text{square inches}}{\text{square inches}} \times 100$$

The reduction of area is reported as additional information (to the percent elongation) on the deformational characteristics of the material. The two are used as the indicators of ductility, the ability of the material to be elongated in tension. Because the elongation is not uniform over the entire gage length and is greatest at the center of the neck, the percent elongation is not an absolute measure of ductility (Because of this the gage length must always be stated when the percent elongation is reported). The reduction of area, being measured at the minimum diameter of the neck, is a better indicator of ductility.