MECHANICAL ENGINEERING SCIENCE

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STRESS – STRAIN DIAGRAM

- The design of machines and structures so that they will function properly requires that we understand the **mechanical behavior** of the materials being used.

- Ordinarily, the only way to determine how materials behave when they are subjected to loads is to perform experiments in the laboratory.

- The usual procedure is to place small specimens of the material in testing machines, apply the loads, and then measure the resulting deformations (such as changes in length and changes in diameter).

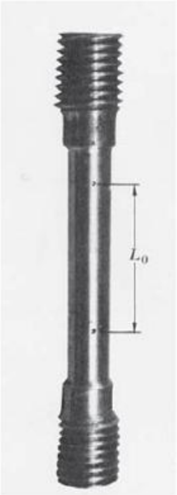
- Most materials-testing laboratories are equipped with machines capable of loading specimens in a variety of ways, including both **static and dynamic loading in tension and compression.**

STRESS – STRAIN DIAGRAM

- A typical tensile-test machine is shown in Figure. The test specimen is installed between the two large grips of the testing machine and then loaded in tension.

- Measuring devices record the deformations, and the automatic control and data-processing systems (at the left in the photo) tabulate and graph the results.

- A more detailed view of a tensile-test specimen is shown in Figure. The ends of the circular specimen are enlarged where they fit in the grips so that failure will not occur near the grips themselves.



STRESS – STRAIN DIAGRAM

- The device at the left, which is attached by two arms to the specimen, is an extensometer that measures the elongation during loading.

- In order that test results will be comparable, the dimensions of test specimens and the methods of applying loads must be standardized.

- One of the major standards organizations in the United States is the **American Society for Testing and Materials (ASTM),** a technical society that publishes specifications and standards for materials and testing.

- The ASTM standard tension specimen has a diameter of 0.505 in. and a gage length of 2.0 in. between the gage marks, which are the points where the extensometer arms are attached to the specimen.

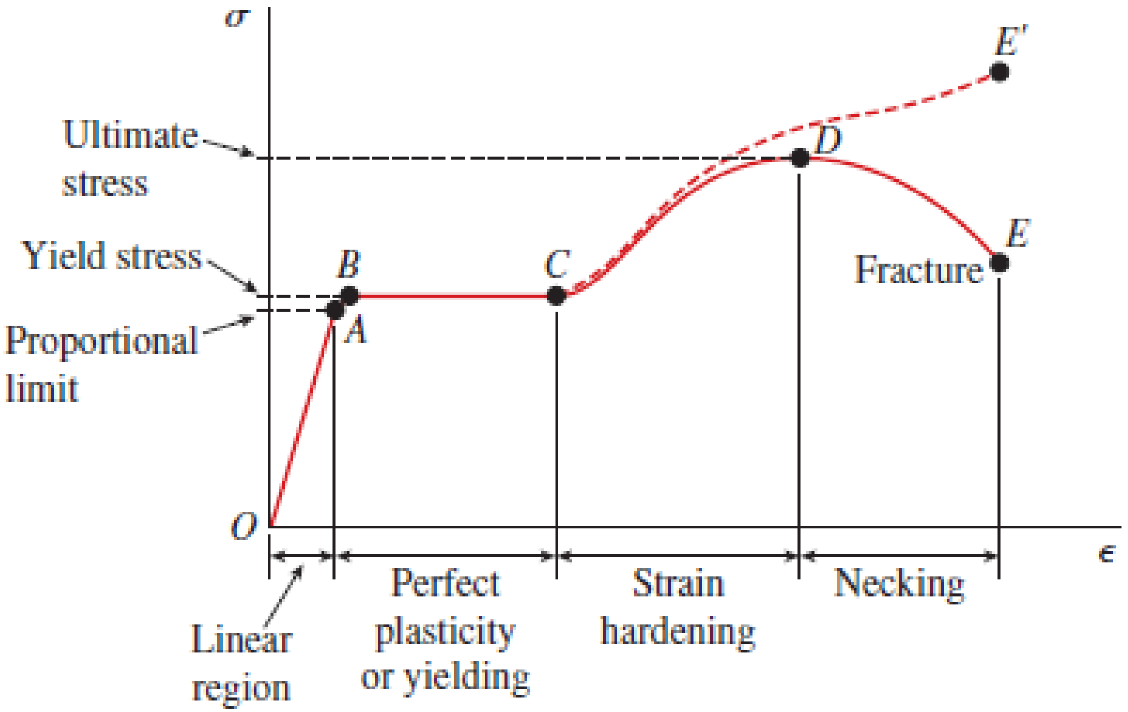
STRESS – STRAIN DIAGRAM

- As the specimen is pulled, the axial load is measured and recorded, either automatically or by reading from a dial.
- The elongation over the gage length is measured simultaneously.
- In a **static test**, the load is applied slowly and the precise *rate* of loading is not of interest because it does not affect the behavior of the specimen.
- After performing a tension or compression test and determining the stress and strain at various magnitudes of the load, we can plot a diagram of stress versus strain.
- Such a **stress-strain diagram** is a characteristic of the particular material being tested and conveys important information about the mechanical properties and type of behavior.

STRESS – STRAIN DIAGRAM OF MILD STEEL

- The first material we will discuss is structural steel, also known as **mild steel** or low-carbon steel.

- A stress-strain diagram for a typical structural steel in tension is shown in Figure.



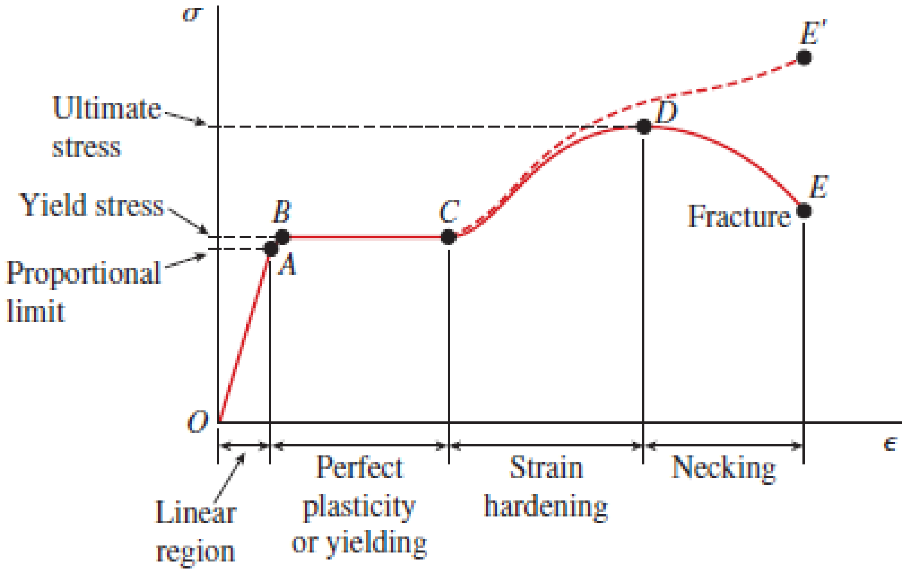
STRESS – STRAIN DIAGRAM OF MILD STEEL

- The diagram begins with a straight line from the origin O to point A, which means that the relationship between stress and strain in this initial region is not only linear but also proportional.

- Beyond point A, the proportionality between stress and strain no longer exists; hence the stress at A is called the **proportional limit**.

- For low-carbon steels, this limit is in the range (210 to 350 MPa), but high-strength steels (with higher carbon content plus other alloys) can have proportional limits of more than 550 MPa.

- The slope of the straight line from O to A is called ***the modulus of elasticity.***



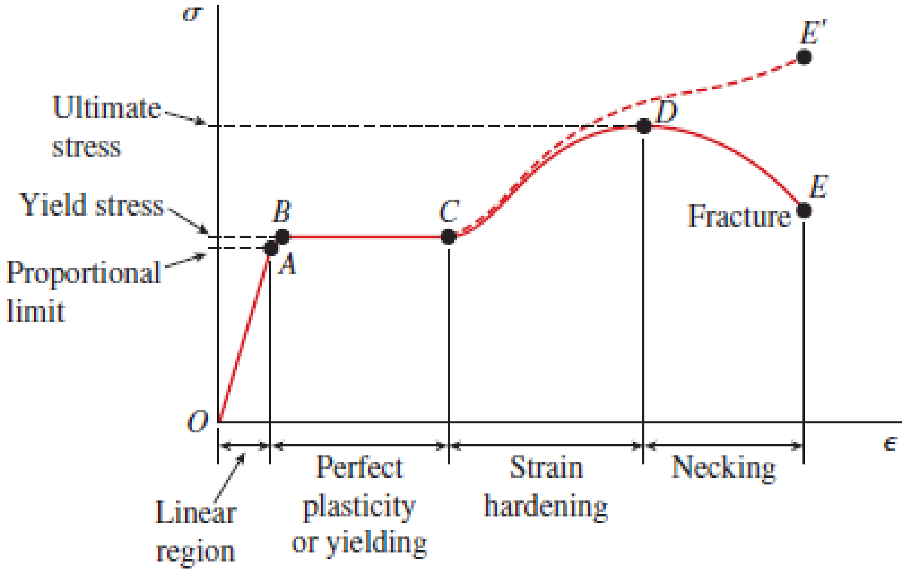
STRESS – STRAIN DIAGRAM OF MILD STEEL

- With an increase in stress beyond the proportional limit, the strain begins to increase more rapidly for each increment in stress.

- Consequently, the stress-strain curve has a smaller and smaller slope, until, at point B, the curve becomes horizontal.

- Beginning at this point, considerable elongation of the test specimen occurs with no noticeable increase in the tensile force (from B to C). This phenomenon is known as **yielding** of the material, and point B is called the **yield point**. The corresponding stress is known as the **yield stress** of the steel.

- In the region from *B* to *C* , the material becomes **perfectly plastic**, which means that it deforms without an increase in the applied load.



STRESS – STRAIN DIAGRAM OF MILD STEEL

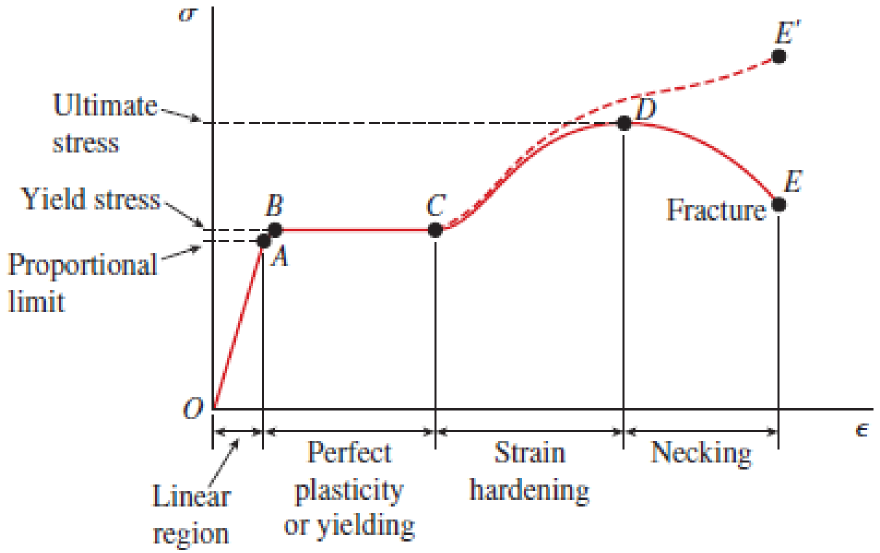
- After undergoing the large strains that occur during yielding in the region BC, the steel begins to strain harden.

- During **strain hardening**, the material undergoes changes in its crystalline structure, resulting in increased resistance of the material to further deformation.

- Elongation of the test specimen in this region requires an increase in the tensile load, and therefore the stress-strain diagram has a positive slope from C to D.

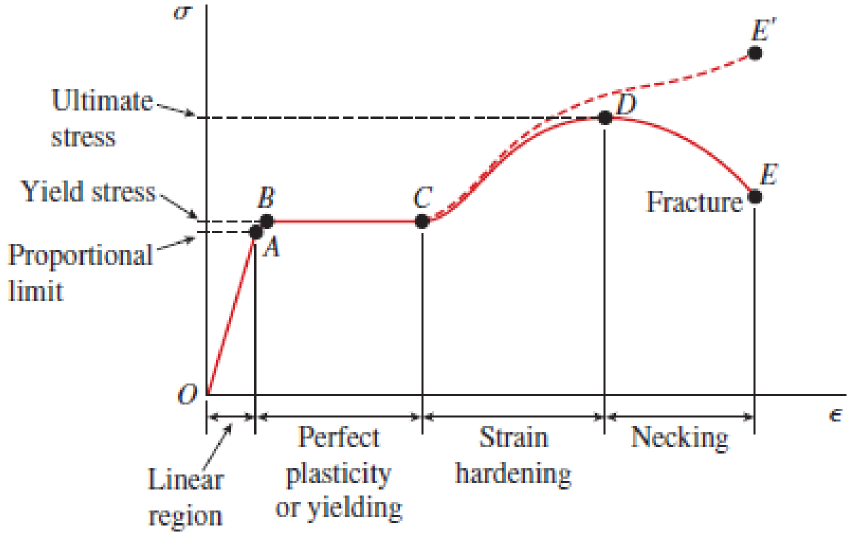
- The load eventually reaches its maximum value, and the corresponding stress (at point D) is called the **ultimate stress**.

- Further stretching of the bar is actually accompanied by a reduction in the load, and fracture finally occurs at a point such as E.



STRESS – STRAIN DIAGRAM OF MILD STEEL

- When a test specimen is stretched, lateral contraction occurs, as previously mentioned.
- The resulting decrease in cross-sectional area is too small to have a noticeable effect on the calculated values of the stresses up to about point C.
- In the vicinity of the ultimate stress, the reduction in area of the bar becomes clearly visible and a pronounced **necking** of the bar occurs.
- Fracture finally occurs at a point such as E.



STRESS – STRAIN DIAGRAM OF MILD STEEL

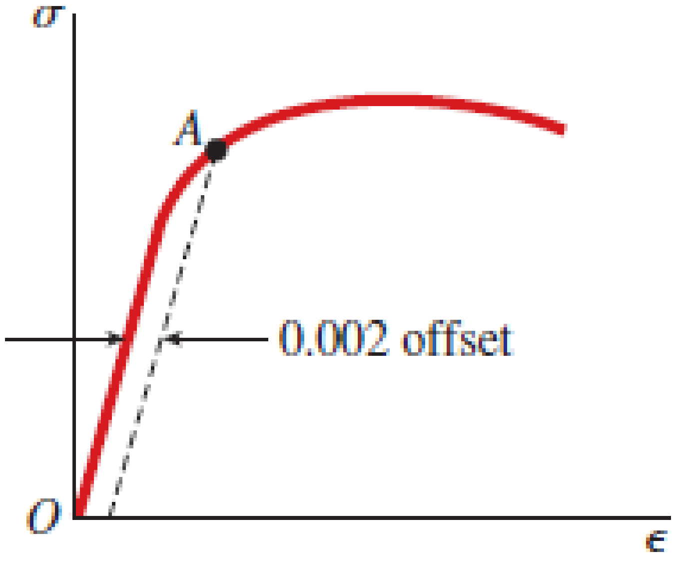
- The axial stress σ in a test specimen is calculated by dividing the axial load P by the cross-sectional area A.
- When the initial area of the specimen is used in the calculation, the stress is called the **nominal stress** (other names are conventional stress and engineering stress).
- A more exact value of the axial stress, called the **true stress**, can be calculated by using the actual area of the bar at the cross section where failure occurs. Since the actual area in a tension test is always less than the initial area, the true stress is larger than the nominal stress.
- The average axial strain ε in the test specimen is found by dividing the measured elongation δ between the gage marks by the gage length L.
- If the initial gage length is used in the calculation then the **nominal strain** is obtained. Since the distance between the gage marks increases as the tensile load is applied, we can calculate the **true strain** (or natural strain) at any value of the load by using the actual distance between the gage marks. In tension, true strain is always smaller than nominal strain.

STRESS – STRAIN DIAGRAM OF OTHER MATERIALS

- The presence of a clearly defined yield point followed by large plastic strains is an important characteristic of structural steel that is sometimes utilized in practical design.

- Metals such as structural steel that undergo large permanent strains before failure are classified as **ductile**. Other materials that behave in a ductile manner (under certain conditions) include aluminum, copper, magnesium, lead, molybdenum, nickel, brass, bronze, monel metal, nylon, and teflon.

- Although they may have considerable ductility, **aluminum alloys** typically do not have a clearly definable yield point, as shown by the stress-strain diagram of Figure.

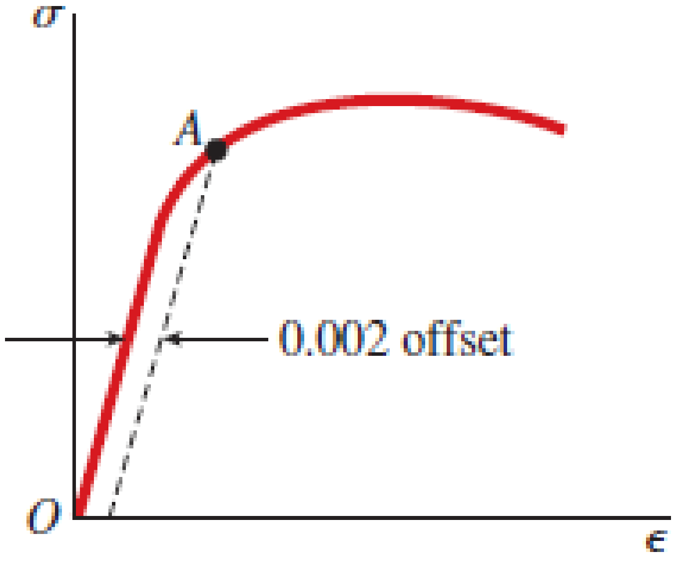


STRESS – STRAIN DIAGRAM OF OTHER MATERIALS

- When a material such as aluminum does not have an obvious yield point and yet undergoes large strains after the proportional limit is exceeded, an arbitrary yield stress may be determined by the offset method.

- A straight line is drawn on the stress-strain diagram parallel to the initial linear part of the curve but offset by some standard strain, such as 0.002 (or 0.2%). The intersection of the offset line and the stress-strain curve (point A in the figure) defines the yield stress.

- Because this stress is determined by an arbitrary rule and is not an inherent physical property of the material, it should be distinguished from a true yield stress by referring to it as the **offset yield stress**.



MEASURES OF DUCTILITY

- The ductility of a material in tension can be characterized by its elongation and by the reduction in area at the cross section where fracture occurs.

- The **percent elongation** is defined as follows:

$$\text{Percent elongation} = \frac{L_1 - L_0}{L_0}(100)$$

in which L_0 is the original gage length and L_1 is the distance between the gage marks at fracture.

- Because the elongation is not uniform over the length of the specimen but is concentrated in the region of necking, the percent elongation depends upon the gage length. Therefore, when stating the percent elongation, the gage length should always be given. For a 2 in. gage length, steel may have an elongation in the range from 3% to 40%, depending upon composition.

MEASURES OF DUCTILITY

- The **percent reduction in area** measures the amount of necking that occurs and is defined as follows

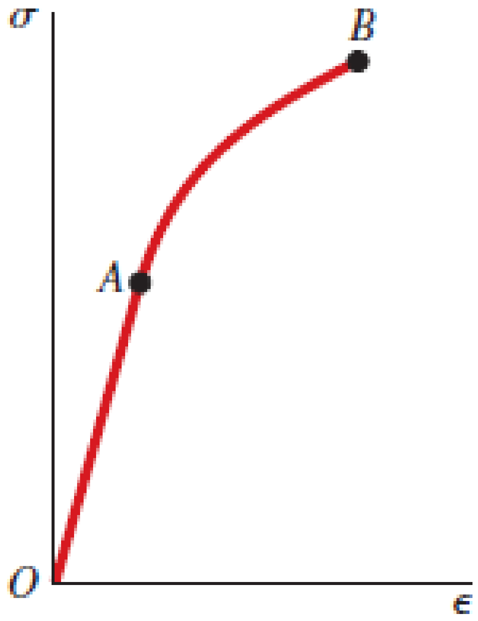
$$\text{Percent reduction in area} = \frac{A_0 - A_1}{A_0}(100)$$

- in which A_0 is the original cross-sectional area and A_1 is the final area at the fracture section. For ductile steels, the reduction is about 50%.

STRESS- STRAIN DIAGRAM OF A BRITTLE MATERIAL

- Materials that fail in tension at relatively low values of strain are classified as **brittle**. Examples are concrete, stone, cast iron, glass, ceramics, and a variety of metallic alloys.

- Brittle materials fail with only little elongation after the proportional limit is exceeded. Furthermore, the reduction in area is insignificant, and so the nominal fracture stress (point B) is the same as the true ultimate stress.



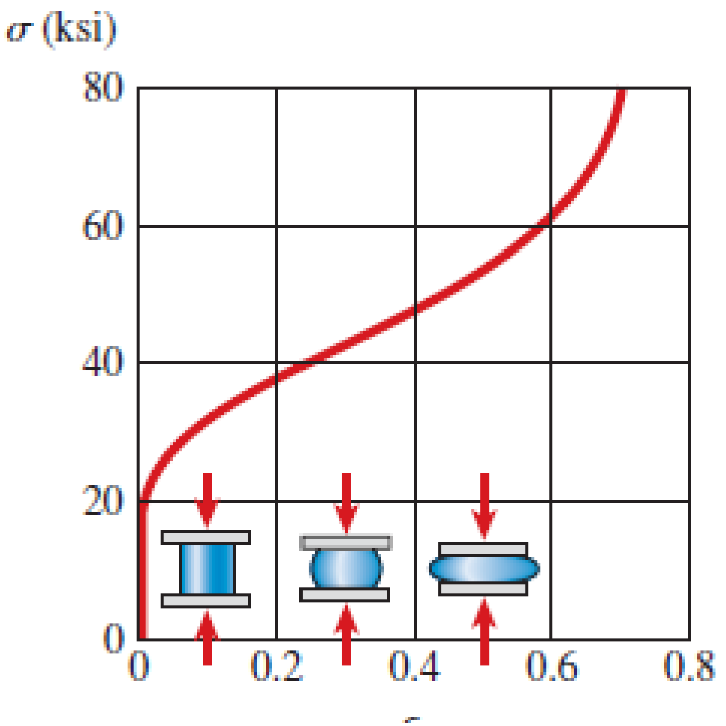
STRESS- STRAIN DIAGRAM IN COMPRESSION

- Stress-strain curves for materials in compression differ from those in tension.

- Ductile metals such as steel, aluminum, and copper have proportional limits in compression very close to those in tension, and the initial regions of their compressive and tensile stress-strain diagrams are about the same.

- However, after yielding begins, the behavior is quite different.

- In a tension test, the specimen is stretched, necking may occur, and fracture ultimately takes place. When the material is compressed, it bulges outward on the sides and becomes barrel shaped, because friction between the specimen and the end plates prevents lateral expansion.



STRESS- STRAIN DIAGRAM IN COMPRESSION

- With increasing load, the specimen is flattened out and offers greatly increased resistance to further shortening (which means that the stress-strain curve becomes very steep.

- Brittle materials loaded in compression typically have an initial linear region followed by a region in which the shortening increases at a slightly higher rate than does the load.

- The stress-strain curves for compression and tension often have similar shapes, but the ultimate stresses in compression are much higher than those in tension.

- Also, unlike ductile materials, which flatten out when compressed, brittle materials actually break at the maximum load.

LINEAR ELASTICITY AND HOOKE'S LAW

- Many structural materials, including most metals, wood, plastics, and ceramics, behave both elastically and linearly when first loaded. Consequently, their stress-strain curves begin with a straight line passing through the origin.

- When a material behaves elastically and also exhibits a linear relationship between stress and strain, it is said to be ***linearly elastic.***

- The linear relationship between stress and strain for a bar in simple tension or compression is expressed by the equation

$$\sigma = E\epsilon$$

in which σ is the axial stress, ε is the axial strain, and E is a constant of proportionality known as the **modulus of elasticity** for the material.

LINEAR ELASTICITY AND HOOKE'S LAW

- The equation $\sigma = E\varepsilon$ is commonly known as **Hooke's law**, named for the famous English scientist Robert Hooke (1635–1703).

- The modulus of elasticity has relatively large values for materials that are very stiff, such as structural metals.

- Steel has a modulus of approximately 210 GPa; for aluminum, values around 73 GPa) are typical.

- More flexible materials have a lower modulus—values for plastics range from 0.7 to 14 GPa.

- For most materials, the value of E in compression is nearly the same as in tension.

THANK YOU

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