Lecture 4

Mechanical Properties of Materials (1)

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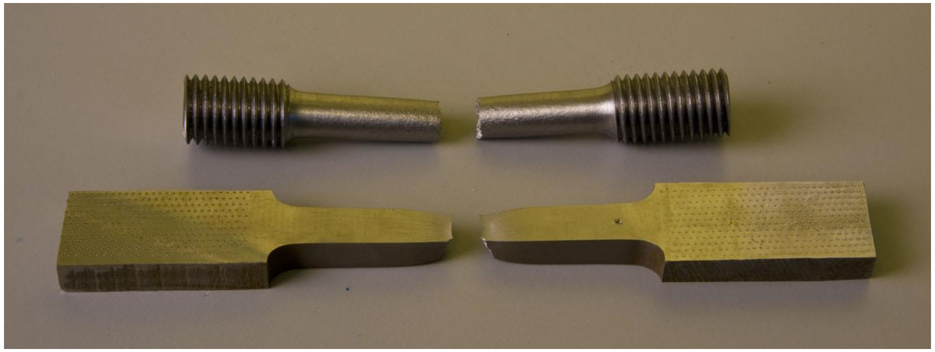
Lecture Objectives

- ✓ Show relationship of stress and strain using experimental methods to determine stress-strain diagram of a specific material
- ✓ Discuss the behavior described in the diagram for commonly used engineering materials
- ✓ Discuss the mechanical properties and other test related to the development of mechanics of materials

Lecture Outline

- ✓ Classification of Materials
- ✓ Properties of Materials
- ✓ Levels of Structure
- ✓ The Tension and Compression Test
- ✓ Stress-Strain Diagram.
- ✓ Stress-Strain Behavior of Ductile and Brittle Materials.



Classification of Materials

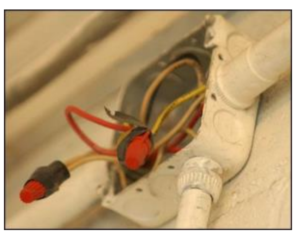
There are deferent ways of classifying materials. One way is to describe five groups:

1. metals and alloys;
2. ceramics, glasses, and glass-ceramics;
3. polymers (plastics);
4. semiconductors;
5. Biomaterials; and
6. composite materials.

Classification of Materials

Metals

•good conductors of electricity and heat
•lustrous appearance
•susceptible to corrosion
•strong, but deformable



Ceramics & Glasses

•thermally and electrically insulating
•resistant to high temperatures and harsh environments
•hard, but brittle

Polymers

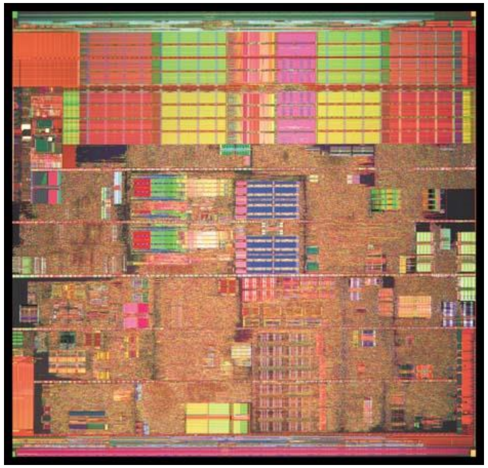
•very large molecules
•low density, low weight
•maybe extremely flexible

Classification of Materials

Biomaterials
- implanted in human body
- compatible with body tissues

hip replacement

Semiconductors
- electrical properties between conductors and insulators
- electrical properties can be precisely controlled



Intel Pentium 4

Composites
- consist of more than one material type
- designed to display a combination of properties of each component

fiberglass surfboards

Classification of Materials

Functional Classification of Materials

Properties of Materials

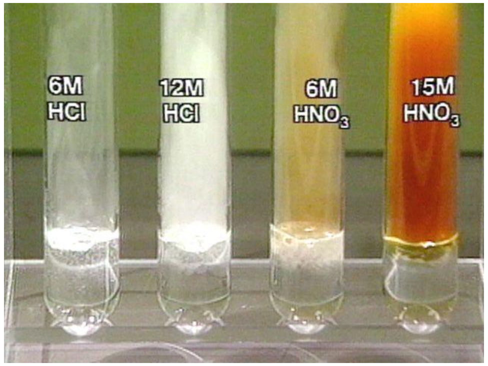
1. Chemical Properties
2. Physical Properties
3. Mechanical Properties

Chemical Properties

- ✓ how a material interacts with another material
- ✓ “social” behavior
- ✓ response to other matter (or lack of response)
- ✓ reactions

Chemical Properties

- Examples:
  - burning
  - reaction with acid
  - reaction with water
  - corrosion/rusting/oxidation
  - others????



Physical Properties

- ✓ characteristics it possesses by itself (in and of itself)
- ✓ "personal" traits
- ✓ response to energy

Physical Properties

- ✓ color
- ✓ size
- ✓ melting point
- ✓ boiling point
- ✓ Solubility
- ✓ Electrical Conductivity
- ✓ Thermal Conductivity
- ✓ Response to light
- ✓ luster
- ✓ density
- ✓ magnetism
- ✓ odor
- ✓ viscosity

Mechanical Properties

Response to force or stress

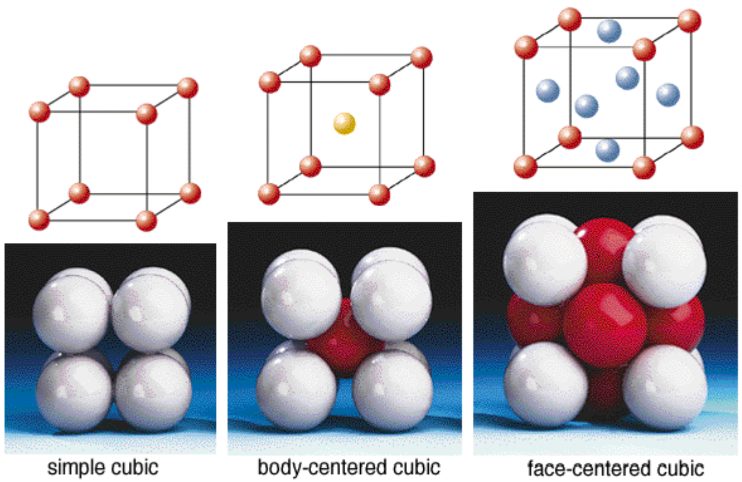
Levels of Structure

STRUCTURE (length scale) →

Sub-atomic	Atomic	Microscopic	Macroscopic
< 0.2 nm	0.2-10 nm	1-1000 μm	mm
Electronic structure of individual atoms that defines interaction among atoms	Arrangement of atoms in materials (for the same atoms can have different properties)	Arrangement of small grains of material	Structural elements that may be viewed with the naked eye

Unit cell

Atoms are arranged in a 3D, making "unit cell"



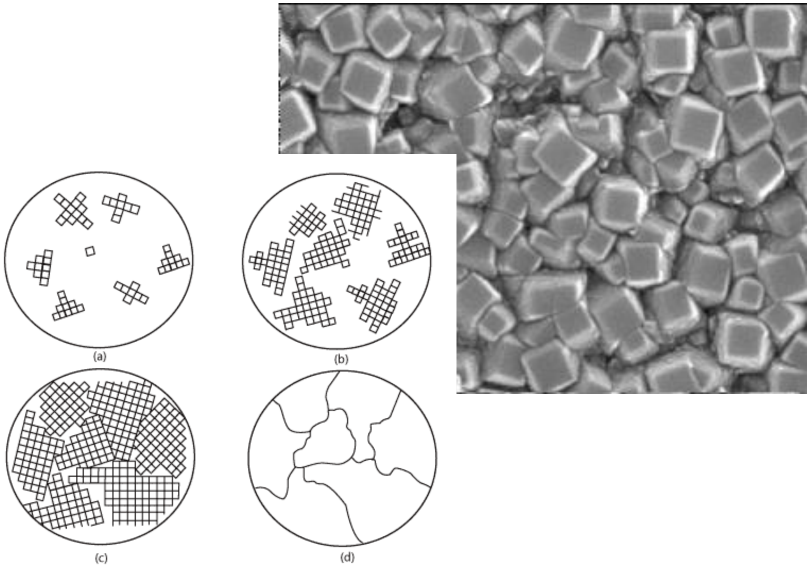
Microstructure

Monocrystalline

- the periodic arrangement of atoms (unit cells) extends throughout the entire sample
- difficult to grow, environment must be tightly controlled
- anisotropic materials

Polycrystalline

- many small crystals or grains
- small crystals misoriented with respect to on another
- several crystals are initiated and grow towards each other
- anisotropic or isotropic materials



The Tension and Compression Test

Strength of a Material

ability to sustain a load without undue deformation or failure

Experiment

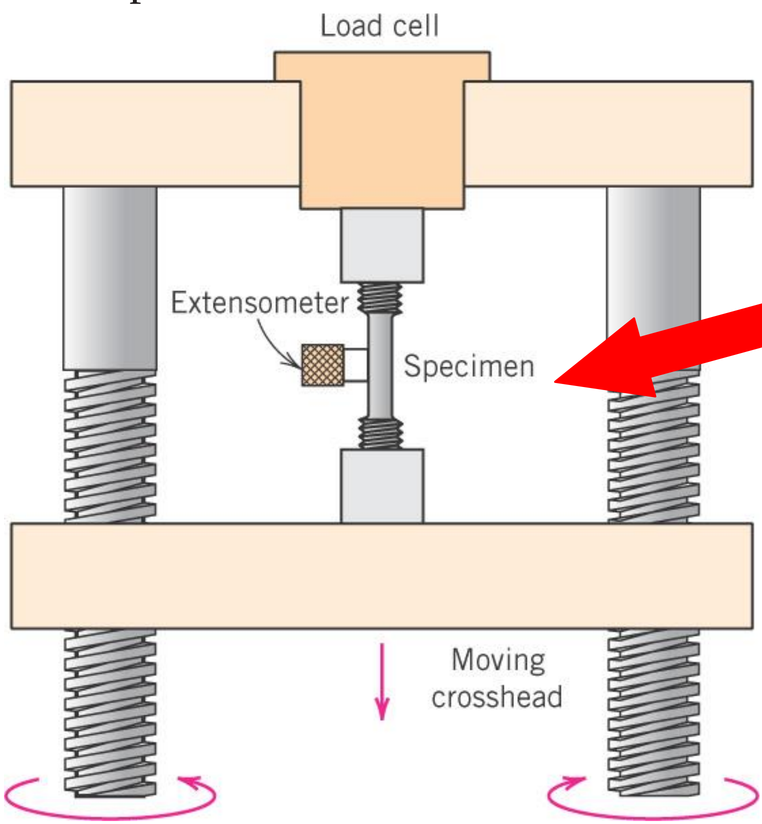
1- Tension and Compression Test
2- .....
3- ....

mechanical properties of a material

The Tension and Compression Test

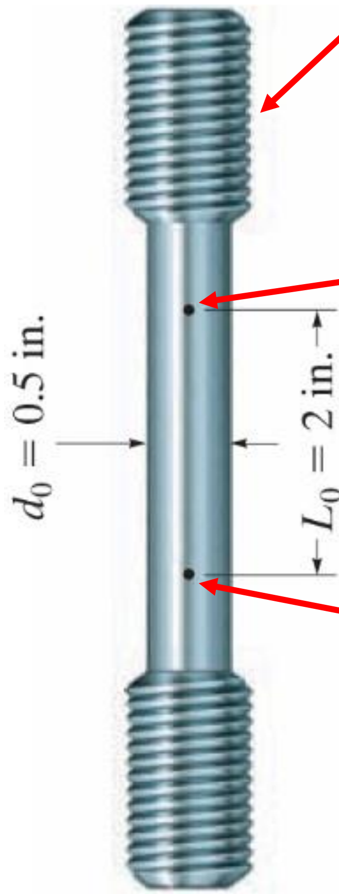
Specimen:

Test specimen of the material is made into a "standard" shape and size



Enlarged Ends

failure will not occur at the grips



two small punch marks are placed along the specimen's uniform length.

The Stress–Strain Diagram

A curve shows the variation of the strain in function of the stress where the vertical axis represent the stress and the horizontal axis represent the strain

1. Conventional Stress–Strain Diagram.
2. True Stress–Strain Diagram

Two stress–strain diagrams for a particular material will be quite similar, but will never be exactly the same. This is because the results actually depend on variables such as:

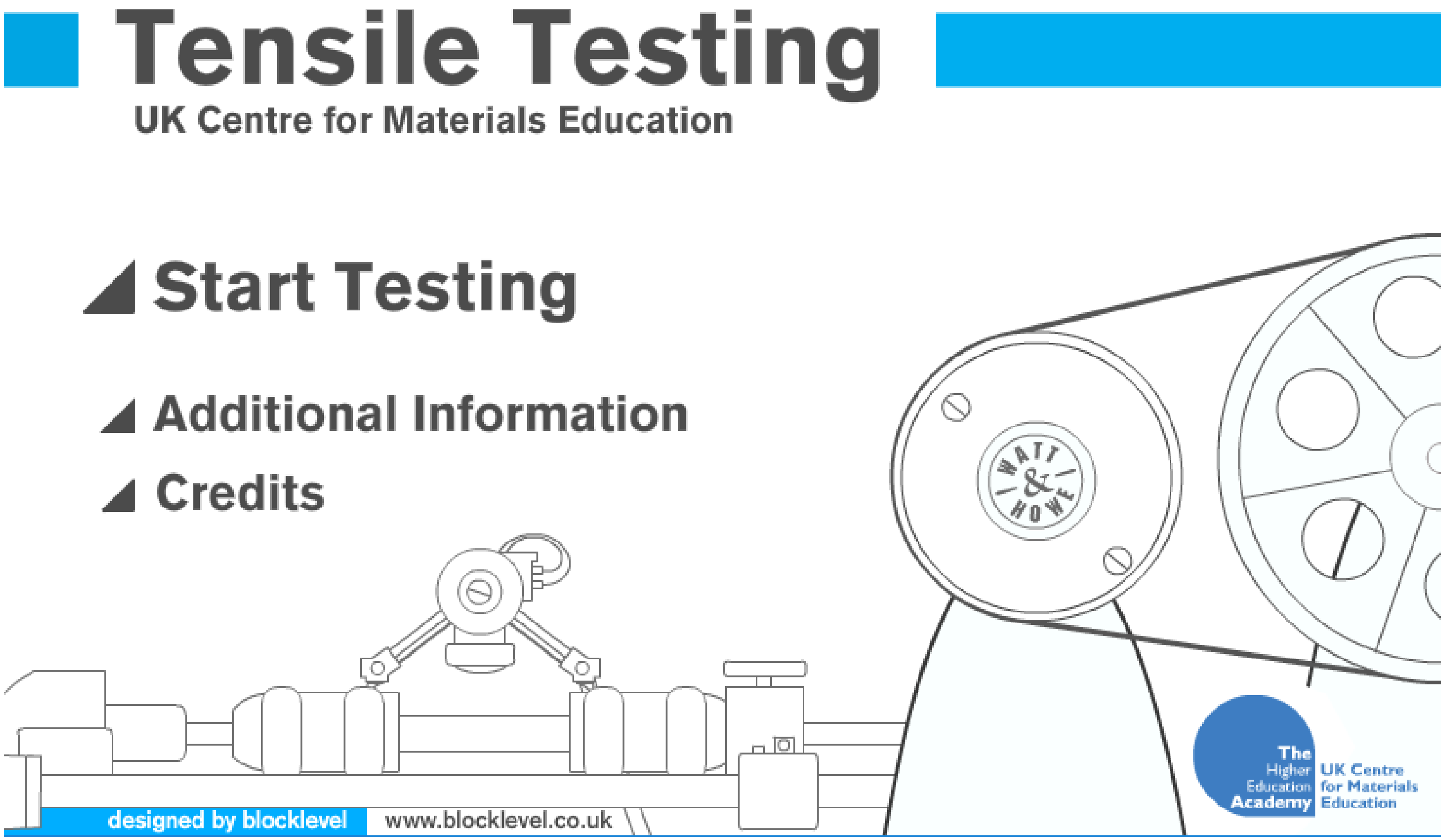
- ✓ The material’s composition.
- ✓ Microscopic imperfections,
- ✓ The way it is manufactured,
- ✓ The rate of loading,
- ✓ The temperature during the test
- ✓ The time of the test.

Conventional Stress–Strain Diagram

Nominal or **Engineering Stress:** Applied load dividing by the specimen's original cross-sectional area.
Here the stress is assumed to be constant over the cross section and throughout the gauge length.

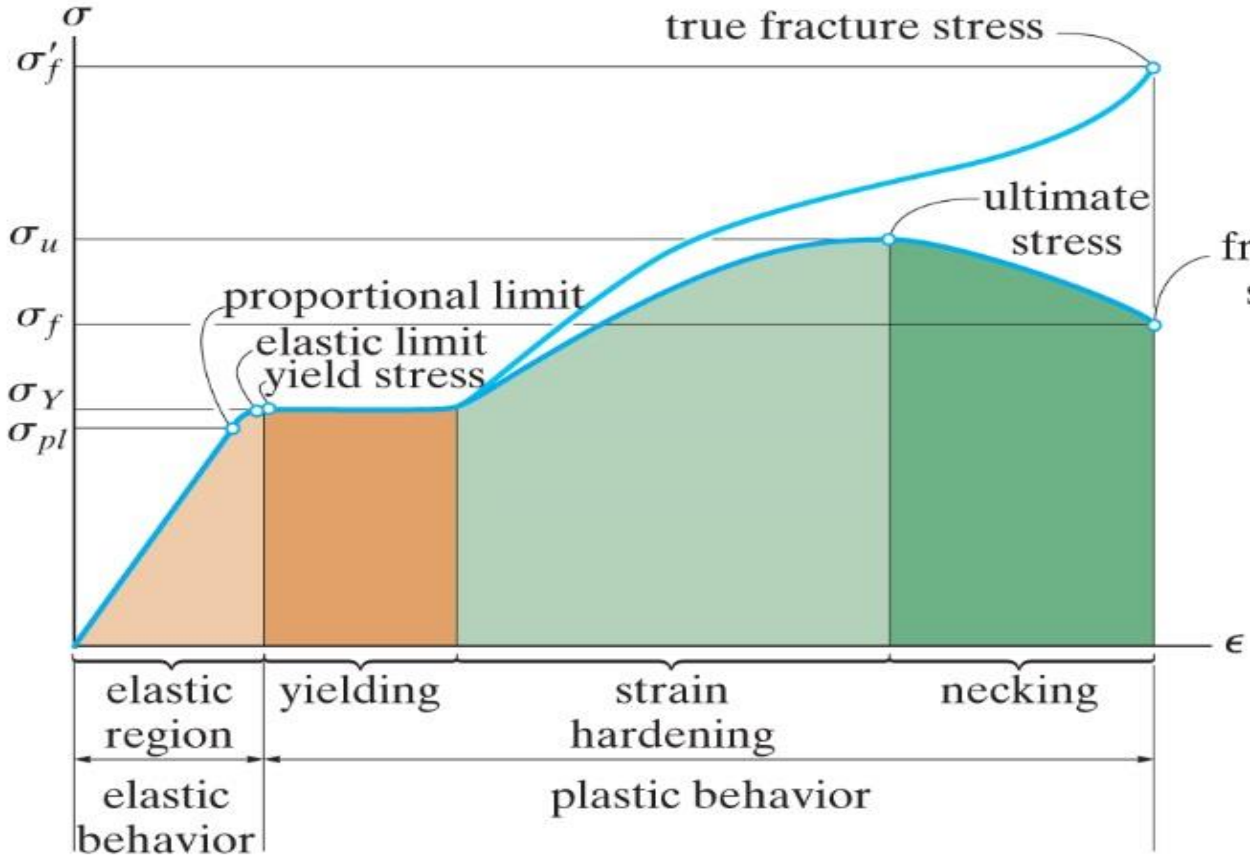
Nominal or **Engineering Strain:** Strain gauge reading, or The change in the specimen's gauge length dividing by the specimen's original gauge length.
Here the strain is assumed to be constant throughout the region between the gauge points.

Conventional Stress–Strain Diagram



http://classroom.materials.ac.uk/flash/tensile.swf

Conventional Stress–Strain Diagram



Conventional and true stress-strain diagrams for ductile material (steel) (not to scale)

From this curve we can identify four different ways in which the material behaves, depending on the amount of strain induced in the material.

Conventional Stress–Strain Diagram

Elastic Behavior:

Light orange region

The curve is actually a straight line throughout most of this region, so that the stress is proportional to the strain. The material in this region is said to be linear elastic. The upper stress limit to this linear relationship is called the **proportional limit**, If the stress slightly exceeds the proportional limit, the curve tends to bend and flatten out. This continues until the stress reaches the **elastic limit**. Upon reaching this point, if the load is removed the specimen will still return back to its original shape.

Normally for steel, however, the elastic limit is seldom determined, since it is very close to the proportional limit and therefore rather difficult to detect.

Conventional Stress–Strain Diagram

Yielding:

Dark orange region

A slight increase in stress above the elastic limit will result in a breakdown of the material and cause it to deform permanently.

This behavior is called **yielding**. The stress that causes yielding is called the **yield stress** or **yield point**, and the deformation that occurs is called **plastic deformation**.

For low carbon steels or those that are hot rolled, the yield point is often distinguished by two values. The **upper yield point** occurs first, followed by a sudden decrease in load-carrying capacity to a **lower yield point**. Notice that once the yield point is reached, then as shown, the specimen will continue to elongate (strain) without any increase in load. When the material is in this state, it is often referred to as being **perfectly plastic**.

Conventional Stress–Strain Diagram

Strain Hardening: Light green region

An increase in load can be supported by the specimen, resulting in a curve that rises continuously but becomes flatter until it reaches a maximum stress referred to as the **ultimate stress**.

Conventional Stress–Strain Diagram

Necking: Dark green region

Up to the ultimate stress, as the specimen elongates, its cross-sectional area will decrease. This decrease is fairly uniform over the specimen's entire gauge length; however, just after, at the ultimate stress, the cross-sectional area will begin to decrease in a localized region of the specimen. As a result, a constriction or "neck" tends to form in this region as the specimen elongates further, Here the stress–strain diagram tends to curve downward until the specimen breaks at the **fracture stress**.

True Stress–Strain Diagram.

Instead of always using the original cross-sectional area and specimen length to calculate the (engineering) stress and strain, we could have used the actual cross-sectional area and specimen length at the instant the load is measured. The values of stress and strain found from these measurements are called true stress and true strain, and a plot of their values is called the **true stress–strain diagram**.

The conventional and true diagrams are practically coincident when the strain is small. The differences between the diagrams begin to appear in the strain-hardening range, where the magnitude of strain becomes more significant. In particular, there is a large divergence within the necking region

True & conventional Stress–Strain Diagram

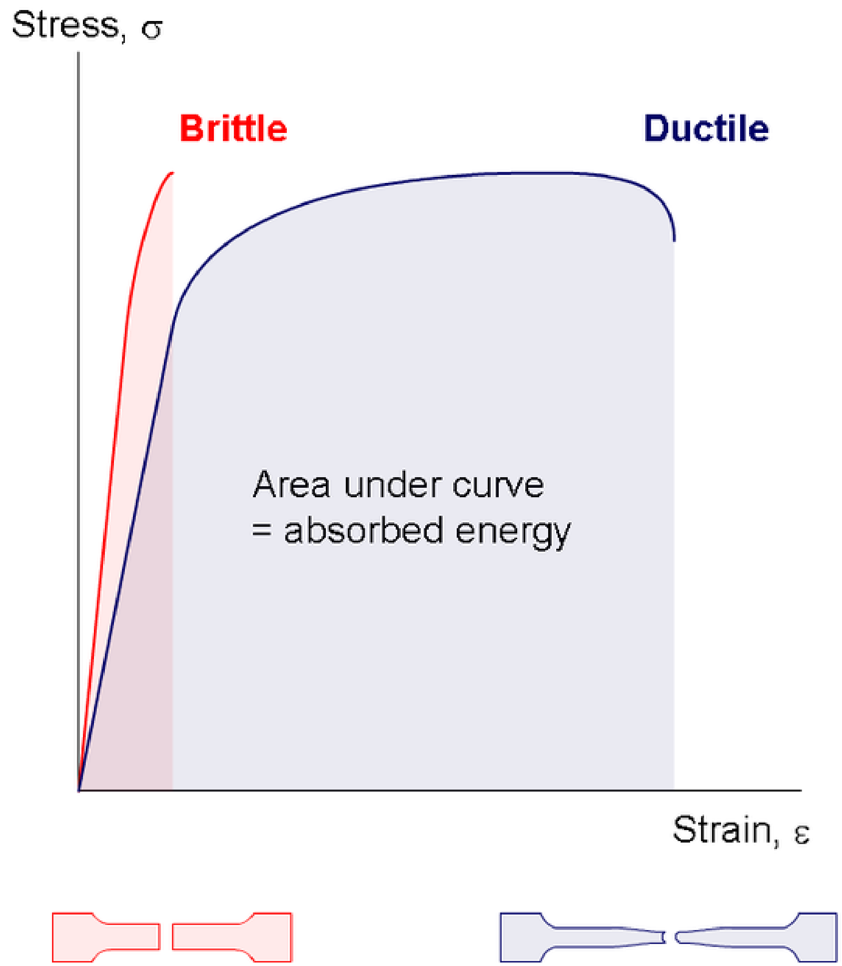
Most engineering design is done so that the material supports a stress within the elastic range. This is because the deformation of the material is generally not severe and the material will restore itself when the load is removed. The true strain up to the elastic limit will remain small enough so that the error in using the engineering values of the stress and the strain is very small (about 0.1%) compared with their true values,

This is one of the primary reasons for using conventional stress–strain diagrams.

Stress–Strain Behavior of Ductile and Brittle Materials

Materials can be classified as either being ductile or brittle, depending on their stress–strain characteristics.

Materials
- Ductile
- Brittle



Stress–Strain Behavior of Ductile and Brittle Materials

Ductile Materials:

Any material that can be subjected to large strains before it fractures is called a ductile material. (typical example : mild steel) (also as brass, molybdenum, and zinc), Engineers often choose ductile materials for design because these materials are capable of absorbing shock or energy, and if they become overloaded, they will usually exhibit large deformation before failing.

Stress–Strain Behavior of Ductile and Brittle Materials

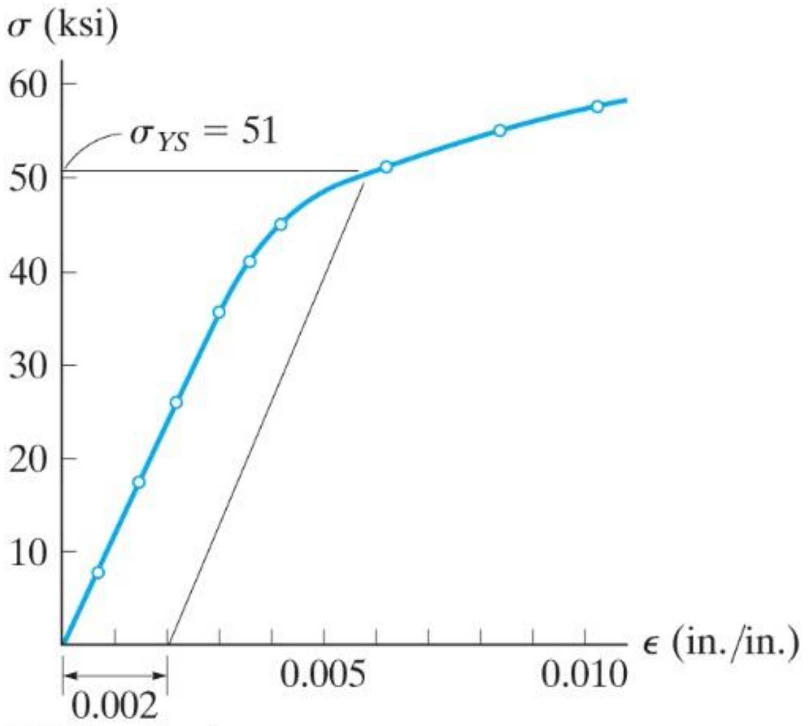
Ductile Materials:

One way to specify the ductility of a material is to report its percent elongation or percent reduction in area at the time of fracture:

- ***Percent elongation:*** is the specimen's fracture strain expressed as a percent. (for mild steel ≈38%)
- ***Percent reduction in area:*** is the ratio of reduction in cross-sectional area (the subtraction of the area of the neck at fracture from original cross-sectional area) on the specimen's original cross-sectional area. (for mild steel ≈60%).

Stress–Strain Behavior of Ductile and Brittle Materials

In most metals, however, constant yielding will not occur beyond the elastic range (for example aluminum). Actually, this metal often does not have a well-defined yield point, and consequently it is standard practice to define a **yield strength** using a graphical procedure called the **offset method**. Normally at 0.2% strain so we get for the aluminum the yield strength is (352 MPa).



Yield strength for an aluminum alloy

Stress–Strain Behavior of Ductile and Brittle Materials

Brittle Materials.

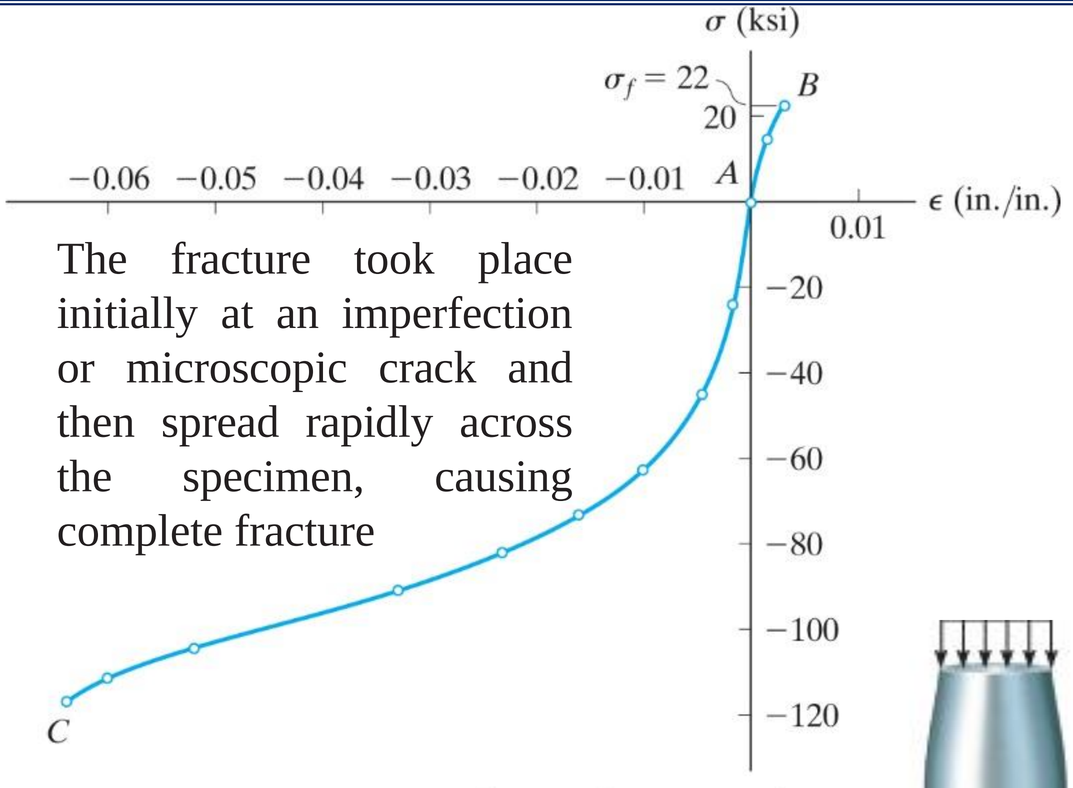
Materials that exhibit little or no yielding before failure are referred to as **brittle materials**. (typical example : Gray cast iron)

Since the appearance of initial cracks in a specimen is quite random, brittle materials do not have a well-defined tensile fracture stress. Instead the average fracture stress from a set of observed tests is generally reported.

Stress–Strain Behavior of Ductile and Brittle Materials

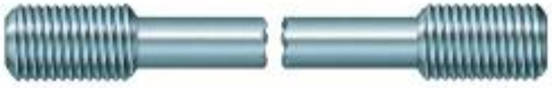
Brittle Materials.

Brittle materials, such as gray cast iron, exhibit a much higher resistance to axial compression, For this case any cracks or imperfections in the specimen tend to close up, and as the load increases the material will generally bulge or become barrel shaped as the strains become larger.



The fracture took place initially at an imperfection or microscopic crack and then spread rapidly across the specimen, causing complete fracture

σ–ϵ diagram for gray cast iron



Tension failure of a brittle material

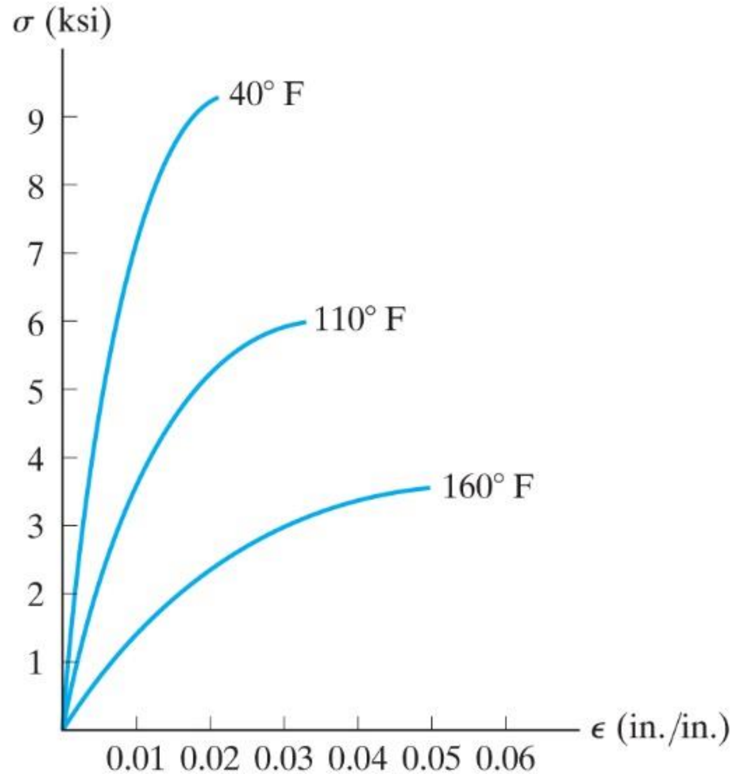
Compression causes material to bulge out

Stress–Strain Behavior of Ductile and Brittle Materials

Most materials exhibit both ductile and brittle behavior.

For example, steel has brittle behavior when it contains a high carbon content, and it is ductile when the carbon content is reduced.

Also, at low temperatures materials become harder and more brittle, whereas when the temperature rises they become softer and more ductile.



$\sigma - \epsilon$ diagrams for a methacrylate plastic