Types of materials
Examples of engineering materials

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How many engineering materials can you name?

The Periodic Table of the Elements

| Group | Period | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-------|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     | 1     | H | Li | Be | B  | C  | N  | O  | F  | Ne | Na | Mg | Al | Si | P  | S  | Cl | Ar |  
| 2     | 2     | He| Ne | Ar | Kr | Xe |  
| 3     | 3     |  
| 4     | 4     |  
| 5     | 5     |  
| 6     | 6     |  
| 7     | 7     |  
| 8     | 8     |  
| 9     | 9     |  
| 10    | 10    |  
| 11    | 11    |  
| 12    | 12    |  
| 13    | 13    |  
| 14    | 14    |  
| 15    | 15    |  
| 16    | 16    |  
| 17    | 17    |  
| 18    | 18    |  

Lanthanides Actinides

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All images are in the public domain.
Categories of materials

- **Metals**
  - Systemic, regular pattern (crystal), minimize volume
  - Steel, aluminum, copper, metal alloys

- **Ceramics**
  - High viscosity at liquid-solid point prevents crystallization. These materials are usually amorphous.
  - Glass, brick, cement, clay, tiles

- **Polymers**
  - Long chains of simple structures
  - Plastics, rubbers, living things

- **Hybrids**
  - Mixture of two or more types
  - Semiconductors, concrete, steel reinforced concrete

All images are in the public domain.
1. The principles governing the behavior of materials are grounded in science and are understandable

2. The properties of a given material are determined by its structure. Processing can alter the structure in specific and predictable ways

3. Properties of all materials change over time with use and exposure to environmental conditions

4. When selecting a material for a specific application, sufficient and appropriate testing must be performed to ensure that the material will remain suitable for its intended application throughout the intended life of the product
Questions to ask when choosing a material

- **Mechanical**
  - How strong is it?
  - Will it stretch?
  - How heavy (dense) is it?
  - What tools will I need to shape it?

- **Economics**
  - How much will it cost?
  - Is enough available?

- **Durability**
  - Will it melt?
  - Will it be durable?
  - Will it chemically react with its surroundings?

- **Aesthetics / Comfort**
  - Will it feel hot?
  - Will it look good?

- **Safety**
  - Is it radioactive or unhealthy in other ways?
  - How will it show signs of failure?

- **Electrical / Magnetic**
  - Will it conduct electricity?
  - Will it be magnetic?

- **And many more…**
Tension and compression
What happens when you push or pull on a material?

Pushing on a material **moves the atoms** closer together. Pulling separates them.

In which instance are you **compressing** the material? **Extending** the material?

- A material being compressed is **in compression**.
- A material being extended is **in tension**.
Are atoms really connected by springs?

- The **springs are imaginary** and represent forces between atoms and molecules:
  - Covalent bonds
  - Ionic bonds
  - Metallic bonds
  - Hydrogen bonds
  - Van der Waal forces

- Some forces attract and others repel.

- Without external forces the atoms find an **equilibrium position**.
True or False

1. The height of your chair changes when you sit in it (as compared to when it’s empty).

2. When you push on the wall, the wall pushes back.
Equal and opposite forces

- Without external forces the atoms find an **equilibrium position**.

- With external forces the atoms find a **new** equilibrium position. The forces are balanced again.

- If you are pushing on the material with 20 pounds of force, how much is the material pushing back on you?

All images are in the public domain.
Identify components in tension and components in compression.
Stress and strain
Stress

- The strength of a structure depends on its material and shape.
- To isolate the impact of the material (ignoring the shape), we consider stress, which is a force concentration.

\[
\text{Stress} = \frac{\text{Force}}{\text{Area}} \quad \quad \sigma = \frac{F}{A}
\]

- What are the units of stress? A Pascal (Pa) is a Newton (N) per square meter.

- Below are various forces acting on small and large areas.
  - Which two apply the same force?
  - Which two apply the same stress?
Strain

- A material in tension or compression changes shape (elongates or shrinks).
- **Strain** is the *percent elongation*.

\[
\text{Strain} = \frac{\text{Change in length}}{\text{Original length}} \quad \epsilon = \frac{\Delta L}{L_0}
\]

- What are the *units* of strain?
- Match the three situations below with strain values listed to the right.

1. ![Image 1](https://via.placeholder.com/150)
   - 0.15 (15%)
   - 0.30 (30%)

2. ![Image 2](https://via.placeholder.com/150)
   - 0.50 (50%)
   - 0.75 (75%)

3. ![Image 3](https://via.placeholder.com/150)
   - 1.00 (100%)
   - 1.50 (150%)
In special circumstances we know the equation that relates stress and strain:

1. For some materials called “Hookean solids”
2. For small deformations (small strain)

**Hooke’s Law** for some materials at small strain:

\[
\text{Stress} = \text{Constant Modulus} \times \text{Strain} \quad \sigma = E\epsilon
\]

We call the constant \( E \) the **Young’s Modulus** or the **Modulus of Elasticity**. Each material has its own value for \( E \).

What are the **units** for Young’s Modulus?
A deformation is a change of shape. It can be elastic or plastic.

If a material stretches too far, it becomes permanently deformed. This is called plastic deformation.

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<th>Example</th>
<th>Elastic Deformation</th>
<th>Plastic Deformation</th>
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<tr>
<td>Behavior when force is removed</td>
<td>Returns to original shape</td>
<td>Remains stretched</td>
</tr>
<tr>
<td>Equation relating $\sigma$ and $\varepsilon$</td>
<td>$\sigma = E\varepsilon$</td>
<td>Unknown</td>
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Quiz

► These are previous quiz questions:

1) One set of possible units for stress are:
   a. \( \frac{N}{m^2} \)  b. \( \frac{m^2}{N} \)  c. \( \frac{kg}{m^2} \)  d. \( \frac{1}{Pa} \)  e. Unitless

2) One set of possible units for strain are:
   a. \( \frac{N}{m^2} \)  b. \( \frac{m^2}{N} \)  c. \( \frac{kg}{m^2} \)  d. \( \frac{1}{Pa} \)  e. Unitless

3) One set of possible units for Young’s Modulus is:
   a. \( \frac{N}{m^2} \)  b. \( \frac{m^2}{N} \)  c. \( \frac{kg}{m^2} \)  d. \( \frac{1}{Pa} \)  e. Unitless

All images are in the public domain.
If the Young’s Modulus for human tendon is 500 MPa, how much force do you need to apply on a 400 μm diameter tendon to stretch it by 20%?

**What we know:**
- \( E = 500 \text{ MPa} = 500 \times 10^6 \text{ Pa} \)
- \( d = 400 \mu \text{m} = 400 \times 10^{-6} \text{ m} \)
- \( \varepsilon = 20\% = 0.20 \)

**Calculations:**
- \( \sigma = E \varepsilon = (500 \times 10^6 \text{ Pa})(0.20) = 100 \times 10^6 \text{ Pa} \)
- \( A = \frac{\pi}{4} d^2 = \frac{\pi}{4} (400 \times 10^{-6} \text{ m})^2 = 1.26 \times 10^{-7} \text{ m}^2 \)
- \( F = \sigma A = (100 \times 10^6 \text{ Pa})(1.26 \times 10^{-7} \text{ m}^2) = 0.016 \text{ N} \)
Stress-strain curves
Stress-strain curves

- When choosing a material, it’s helpful to know how much it stretches (the **strain**) when it is pulled (the **stress**).

- This is determined using experiments. The result is a **stress-strain curve**.

All images are in the public domain.
Activity: make a stress-strain curve for rubber

Use the materials and setup shown below to experimentally determine the stress-strain curve for rubber.

- Stress
- Strain
- Scale
- Digital calipers
- Ruler

All images are in the public domain.
Stress-strain curves for four materials

The stress-strain curve below contains curves for:
- aluminum
- carbon steel
- glass
- rubber

Match the material with its stress-strain curve.

Which material is…
- Stiffest?
- Strongest?
- Most flexible?

Stress-strain curve: https://www.ecourses.ou.edu/cgi-bin/eBook.cgi?doc=&topic=me&chap_sec=01.3&page=theory; Accessed 6/23/17
Quiz: Young’s Modulus for four materials

Order the Young’s Moduli values from smallest to largest:
- aluminum
- carbon steel
- glass
- rubber

Stress-strain curve: https://www.ecourses.ou.edu/cgi-bin/eBook.cgi?doc=&topic=me&chap_sec=01.3&page=theory; Accessed 6/23/17
Quiz: Young’s Modulus for additional materials

Match each material below with its Young’s Modulus:

- 10,000 psi
- 400,000 psi
- 1,000,000 psi
- 30,000,000 psi
- 200,000,000 psi

Young’s Modulus values from https://www.engineeringtoolbox.com/young-modulus-d_417.html; Accessed 4/6/17
Experiments to determine stress-strain curves

- Apply a tensile force until the sample **fractures** (breaks). Measure force & length.
- **Tensile test video** for carbon steel and an aluminum alloy: https://youtu.be/D8U4G5kcpcM?t=17s

Sample
10 mm dia.
100 mm long

Results of the tensile test

![Force-elongation curves](https://youtu.be/D8U4G5kcpcM?t=17s); Accessed 6/23/17

Diagrams from [https://commons.wikimedia.org/wiki/File:Ductility.svg](https://commons.wikimedia.org/wiki/File:Ductility.svg); Accessed 4/6/18

**Sample 1**

**Carbon steel**

29% elongation before fracture

**Sample 2**

**Aluminum alloy**

11% elongation before fracture

Both samples: Uniform elongation until necking began
Necking

- Some material samples form a **neck** – a location where the sample narrows. This behavior is called **necking**.

- Examples:
  - (a) No necking
  - (b) Moderate necking
  - (c) Extreme necking
Additional material properties
A **ductile** material experiences significant degree of plastic deformation before failure.

A **brittle** material experiences little or no plastic deformation.
**Toughness**

- **Toughness** indicates how much energy a material can absorb before fracturing.

- It is proportional to the area under the $\sigma$-$\varepsilon$ curve.

**Order from most to least tough:**

- Glass
- Carbon steel
- Aluminum
- Rubber
Yielding is the transition from elastic to plastic deformation. Steel and similar materials: look for peak before the sharp drop.

This is the yield point where the deformation changes from elastic to plastic.

Yielding without a sharp transition

- How do you define the yield point when there isn’t a sharp transition?

- **Aluminum and similar materials:** use the 0.2% offset rule

Draw a line that begins at 0.2% strain (\(\varepsilon = 0.002\)) and is parallel to the linear elastic portion. The yield point is the intersection of the two curves. The stress here is the yield stress.

Another important property of a material is the **ultimate tensile strength**, which is the maximum stress a material can withstand before fracture.
Quiz: identify important points on a stress-strain curve

- Maximum stress
- When necking begins
- When yielding occurs
- Maximum strain
- When fracture occurs
- Transition from elastic to plastic deformation

Graph from the video [https://youtu.be/D8U4G5kcpcM?t=17s](https://youtu.be/D8U4G5kcpcM?t=17s); Accessed 6/23/17
Up next: ways to break spaghetti