MECHANICAL PROPERTIES
General concepts about strength

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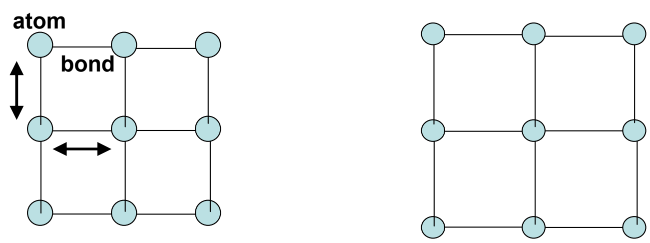
Welcome to the beginning of a series of modules that discuss the mechanical properties of materials.

INTRODUCTION

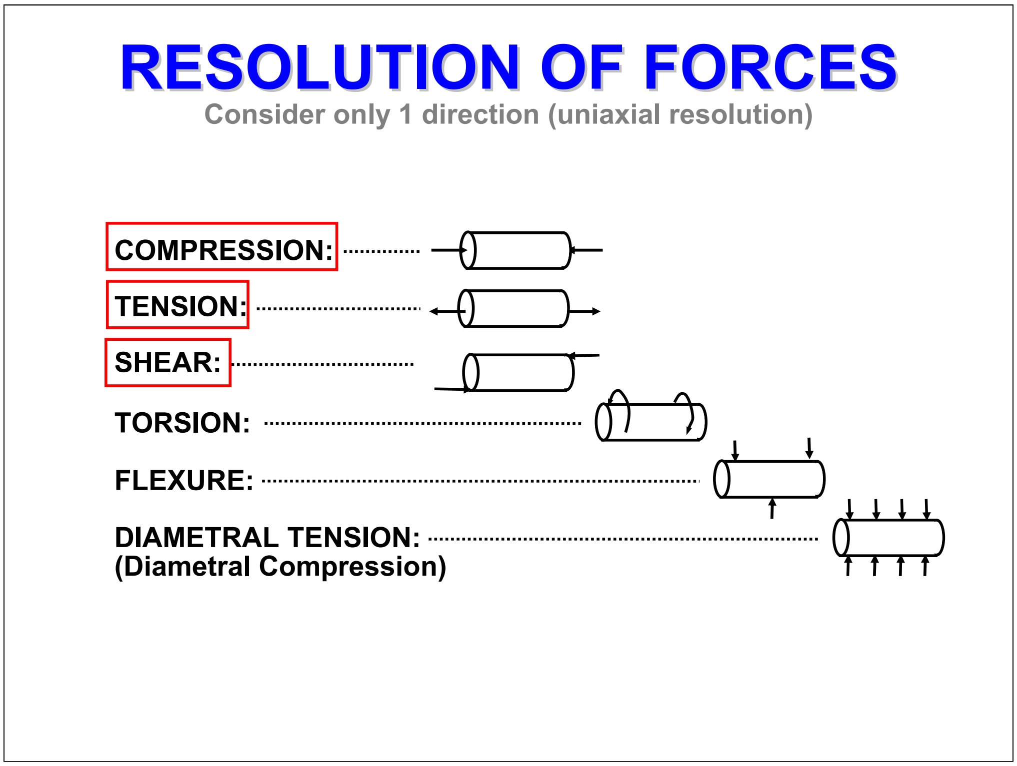
Concept of Strength or Ultimate Strength

STRENGTH (definition) =
resistance to “fracture” or “failure” when deformed.



In everyday conversation we use the term “strength” all the time – usually to mean both the ability to generate a force and the ability to resist a force. We are going to exclusively reserve the term for “a materials resistance to an external force.” If you try to bend something and it demonstrates great resistance to that force, it is very strong.

[CLICK] Now, that said, let’s probe the topic a little bit more and consider what might be happening at the atomic level. **[CLICK]** What happens to atoms when you try to exert a force on an object? **[CLICK]** The atoms are actually getting moved from their original positions when their bonds are being pulled, pushed, twisted, etc. The resistance is the resistance of the bonds. You can probably already anticipate that the strength of an object will depend on the way the bonds are stretched. There is NOT just one overall strength, but rather a value for each type of push or pull or whatever. Let’s look at what is possible.

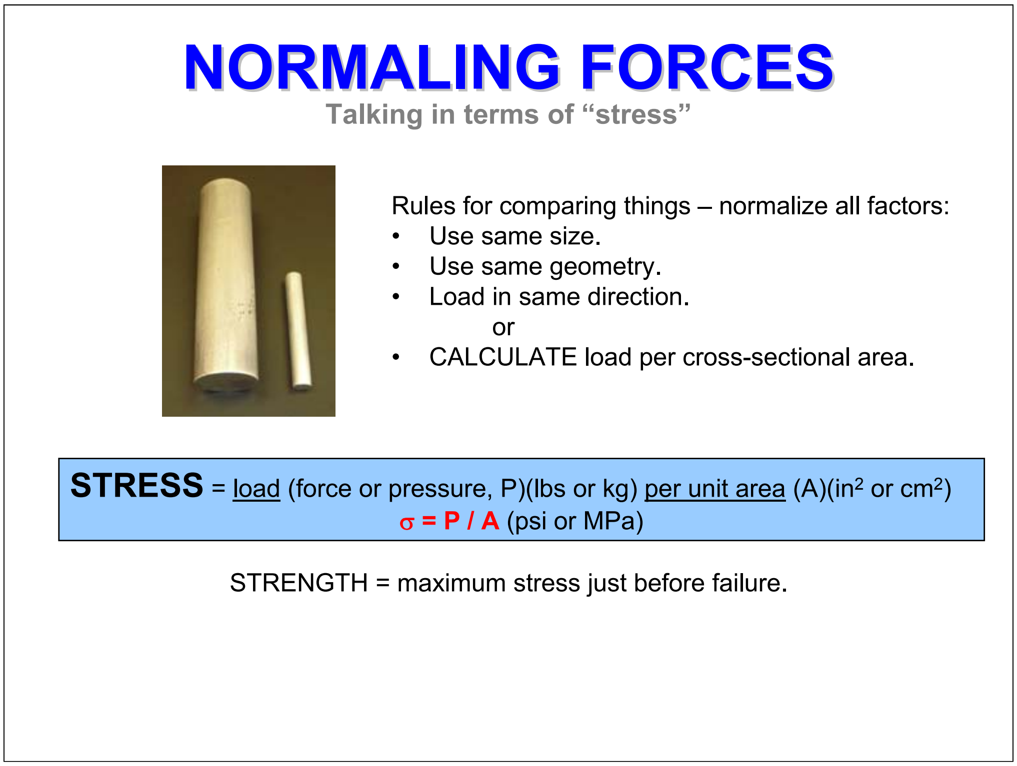


All real situations involve resolution of forces in 3 dimensions, but let's simplify the situation and only look at one. This approach is called uniaxial resolution. If you think of 2 teeth coming together perfectly into inter-cuspal relation, you can initially imagine the force of clenching as along the long axis of both teeth. We will see later than it is important to consider the other 2 dimensions (or directions) but let's start from a simple point of view.

[CLICK] If you push on things, we will call this compression (or uniaxial compression or one dimensional compression). **[CLICK]** If you pull on things, we will call this tension. **[CLICK]** If you push and slide things, we will call this shear. These are the three major resolutions of forces we will normally consider.

There are also more complicated resolutions that really involve are pseduo-1D but may be 2D or 3D as well. **[CLICK]** If you twist something, you will create "torsion." **[CLICK]** If you bend or flex something, you will create "flexure" or "flexion." **[CLICK]** If you push in one direction, you may create tension in a different direction. The last case is called "diametral compression" or "diametral tension."

In most cases, mechanics in dentistry is discussed in terms of one of these 6 situations.



Consider comparing the strength of the two cylinder shown in the figure. Assume they are both made from pure aluminum. Which one is stronger? ------ The larger one will fail at a higher load, but is that really fair to compare these two things that way? They both are the same material, have the same types of bonds, and should respond to loading the same way.

[CLICK] When 2 things are being compared in terms of strength, the only fair approach is to make them the same size, make them the same geometry, and load them in the same manner. The one that survives the longest is the strongest.

However, that requires a huge number of comparisons. An alternative approach is to determine the failure load or simply load per unit of cross-sectional area. **[CLICK]** The STRESS is load per unit area. **[CLICK]** The STRENGTH is the maximum stress at failure.

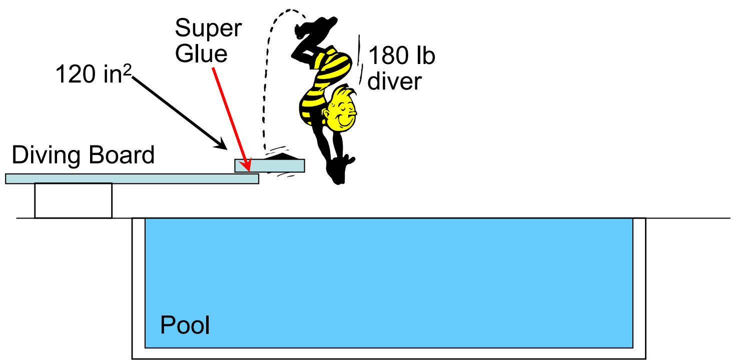
Any number being reported must have associated units. Stress is generally be reported in terms of psi or MPa. What is the air pressure inside of a car tire? It should be in the range of 28-32 psi. What is compressive strength of human enamel? It is about 60,000 psi or 400 MPa. An MPa or megapascal is equal to 145.8 psi.

EXAMPLES

Solving practical problems using the concept of "stress"

Calculations of stress:

- 200 pound man sitting (200 in^2) on a bench = 1 psi
- 100 pound woman leaning on a single high heel (1/4x1/4=1/16 in^2) = 1600 psi



Now let's look at some situations in which it is useful to calculate stress. **[CLICK]** What is the stress for a 200 pound man sitting on a bench? **[CLICK]** Divide the load by the cross-sectional area. He generates an average of 1 psi. **[CLICK]** What is the stress for a woman leaning on one of her high heels? She distributes 100 pounds onto 1/16th of a square inch, creating 1600 psi.

To control a situation in which the STRESS is high and perhaps approaching the failure for the material, either lower the load or increase the cross-sectional area. If you cannot do this, then use a stronger material.

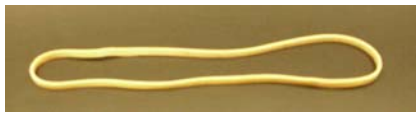
[CLICK] There is a cute example of these principles in action. The tensile strength of superglue is about 1200 psi. **[CLICK]** Imagine that you are going to glue a board to the end of a swimming pool's diving board to make the diving board longer. **[CLICK]** You overlap the new board and diving board by 10x12 inches (120 in^2). **[CLICK]** Then you (who are 180 pounds), go dive off of the new board. What is the stress on the superglue? You should divide 180 pounds by 120 in^2 and get 1.5 psi. Will the superglue hold? Absolutely. This is a very low stress and far below its ultimate tensile strength of 1200 psi for super glue.

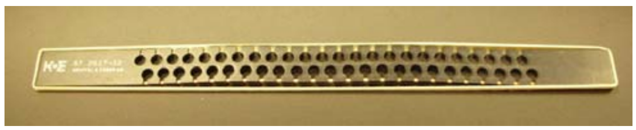
NORMALIZING DEFORMATION

Talking in terms of "strain"

STRAIN = deformation per unit length (dimensionless, %).

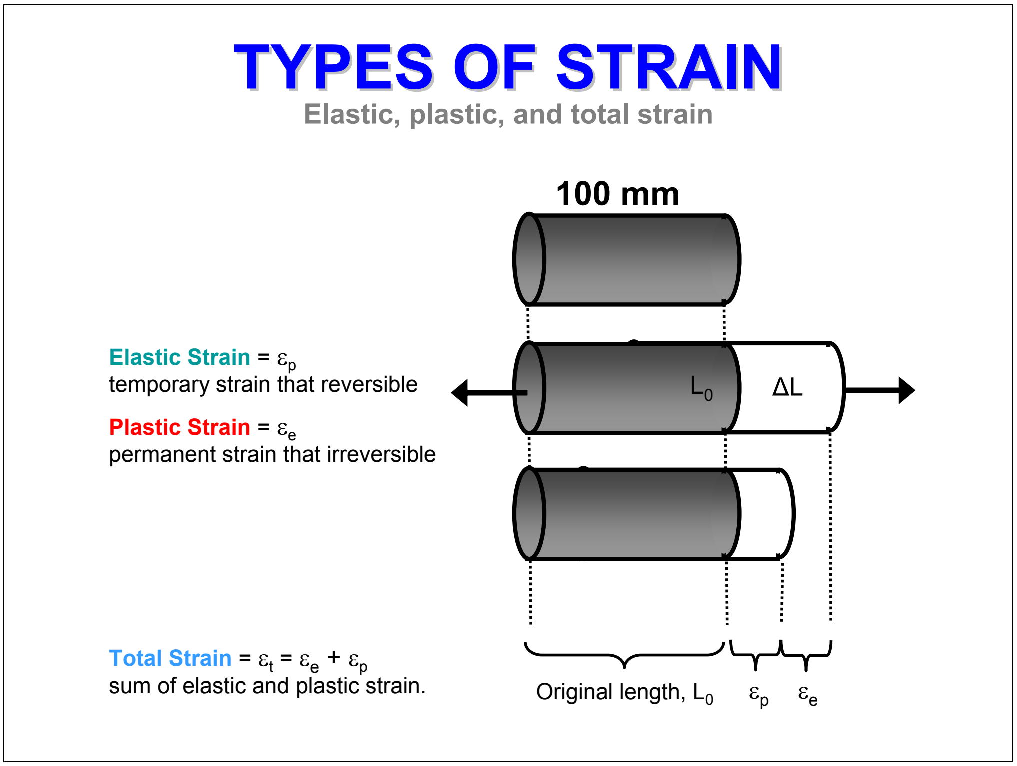
$\varepsilon = \Delta L / L$





When you apply the load, there will be deformation. **[CLICK]** The deformation per unit of length is called STRAIN. We will look at this two things together in the next module. As you stress an object, and it undergoes strain.

[CLICK] What is the strain in a rubber band that is stretched to be 50% longer? **[CLICK]** Its change in length (0.50) divided by its original length (1.00), is 0.50 – and so its strain is 0.50 or +50%.



During early phases of deformation, strain is elastic and reversible. If you remove the load, the material goes back to its original dimensions. After a certain limit, the elastic limit, further new strain is includes both elastic and plastic components, with increasing amounts of the latter as you go along. Plastic strain is permanent. It is not reversible. Ultimately all new strain is plastic and the material fails.

Consider a cylinder that is 100 mm long that is noew stretched in tension. **[CLICK]** It is the sum of both the elastic **[CLICK]** and plastic **[CLICK]** components. If you remove the load at any time, **[CLICK]** the elastic strain is recovered and only the plastic strain remains.

For our cylinder, imagine that the total strain **[CLICK]** was 0.40 meaning that the cylinder was stretched to be 40% longer. When you release the load, elastic strain recovers. **[CLICK]** In this case it was 0.25 or 25%. Since you know the remaining plastic strain, you can subtract if from the total strain to determine the elastic strain that was recovered. In this case it was 15%.

Materials with very little (<~10%) total strain at failure are called BRITTLE. Materials with lots of total strain prior to failure (>~10%) are called DUCTILE. The material just considered would be classified as ductile.

QUICK REVIEW

Review of uniaxial analysis, normalization, and stress-strain.

- **What are the 3 major uniaxial resolutions of force?**
  COMPRESSION, TENSION, SHEAR
- **How is stress defined (or normalized)?**
  STRESS = LOAD / AREA = P / A
- **How is strain defined (or normalized)?**
  STRAIN = DEFORMATION / ORIGINAL LENGTH = $\Delta L / L_0$
- **What are the components of STRAIN?**
  TOTAL STRAIN = ELASTIC STRAIN + PLASTIC STRAIN
- **What are the UNITS for STRESS and for STRAIN?**
  Stress = psi or MPa.
  Strain is dimensionless and reported as a fraction or in percent.

Here is a quick review of the concepts from this module.

[CLICK] (1) What are the 3 major uniaxial resolutions of force?
[CLICK]

[CLICK] (2) How is stress defined (or normalized)?
[CLICK]

[CLICK] (3) How is strain defined (or normalized)?
[CLICK]

[CLICK] (4) What are the components of STRAIN?
[CLICK]

[CLICK] (5) What are the UNITS for STRESS and for STRAIN?
[CLICK]
[CLICK]

THANK YOU

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