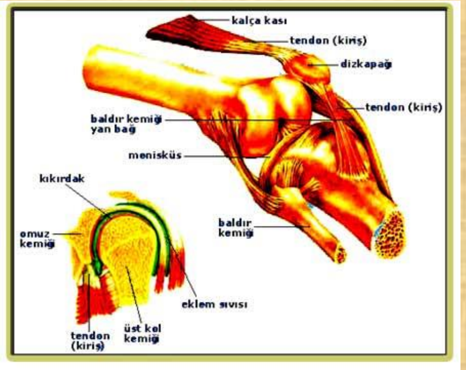
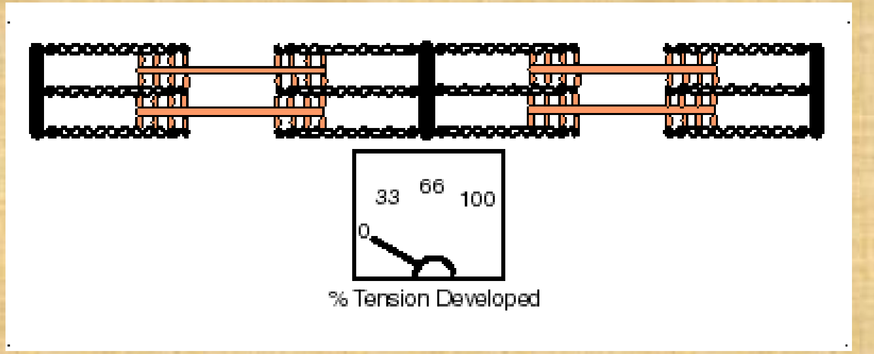
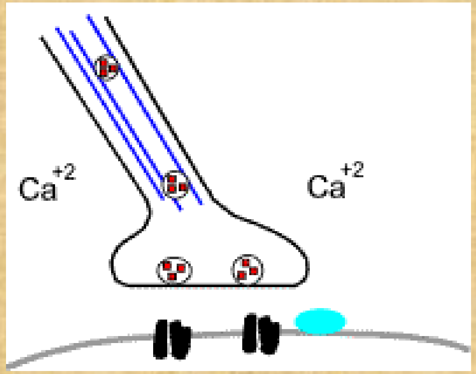




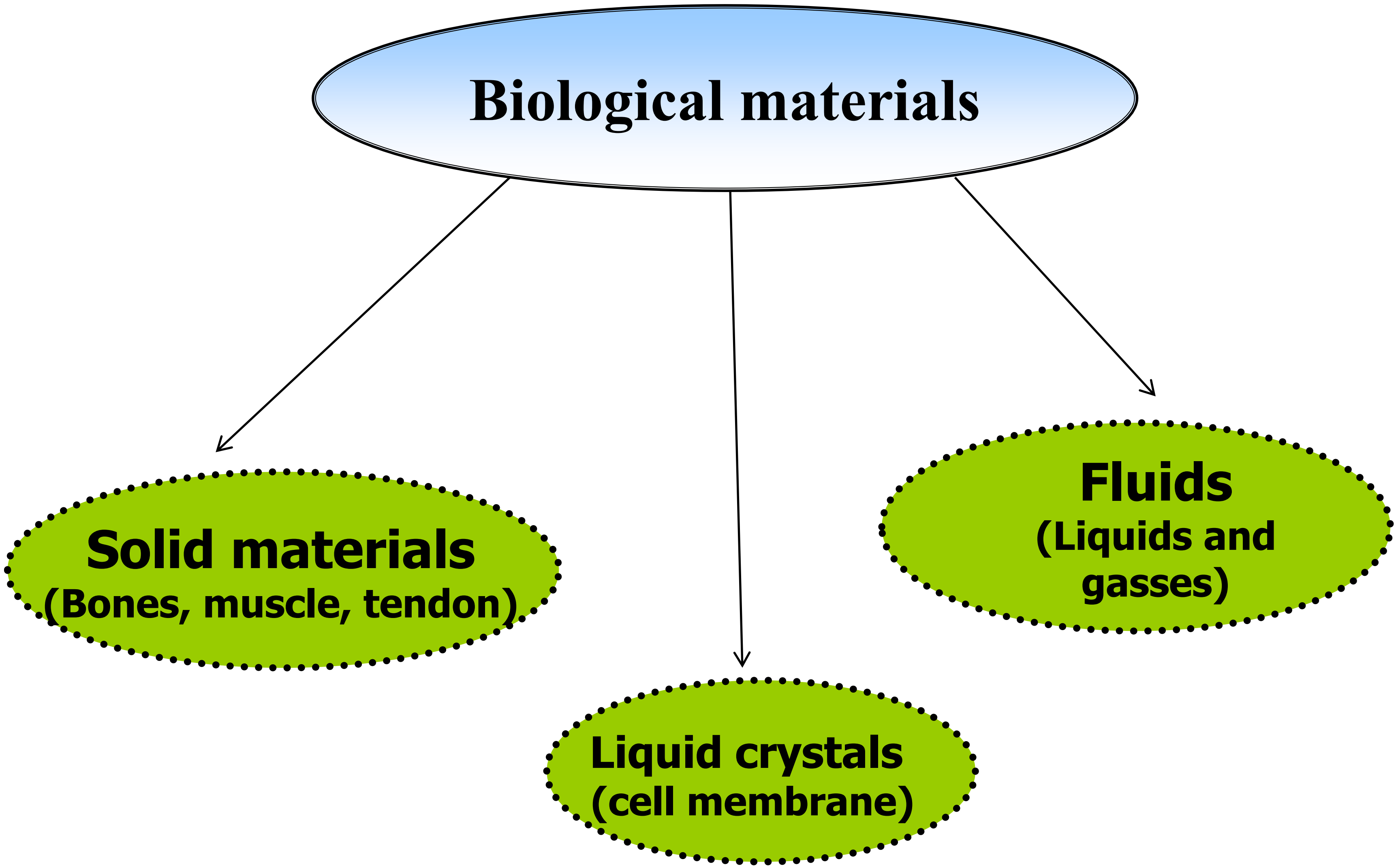


Viscoelastic and elastic properties of biological materials

Assoc. Prof. Erkan Tuncay
Department of Biophysics

Lecture outline

- Biological meterials
- Introduction to Elasticity and Viscosity
- Relationship between stress and strain
- Comparison of Elasticity and Viscoelasticity
- HOOKE'S LAW
- Mechanical Properties of the Materials


Biological materials
Solid materials
(Bones, muscle, tendon)
Liquid crystals
(cell membrane)
Fluids
(Liquids and
gasses)

BIOLOGICAL MATERIALS

Rigid materials: These are the material which does not undergo deformation (Strain) whatever the amount of stress is applied.

Elastic materials: Structures that change shape in the face of an external force but can take their former shape when the force is removed.
(solids and fluids)

Plastic (inelastic) materials : Structures that change shape in the face of an external force and never return to their former shape when the force is removed.

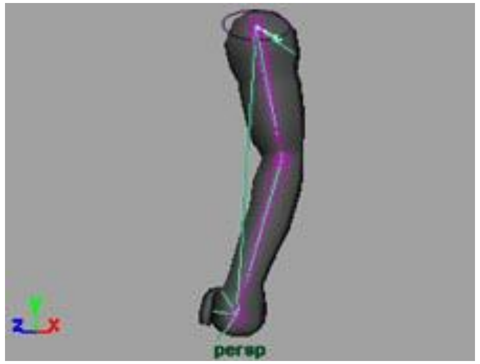
Viscoelastic materials : Such as bone, muscle, tendon, vein, nerve..

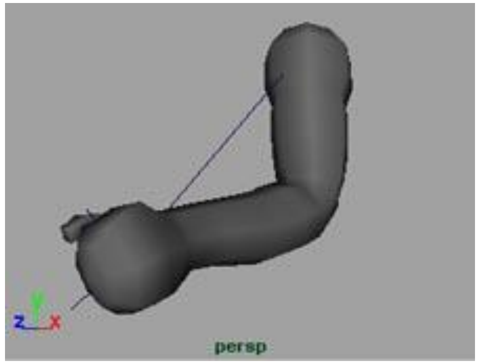
Elastomers: structures such as rubber (polimer’s behaviours; for example, the change in length can be 10-15 times)

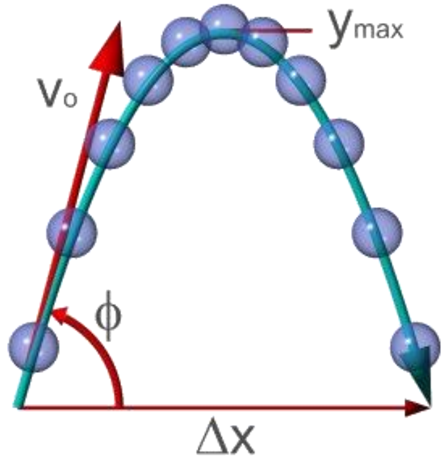
The forces applied to biological materials are examined with physics principles.

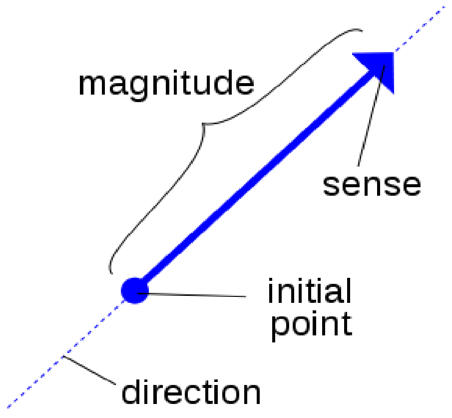
TERMINOLOGY

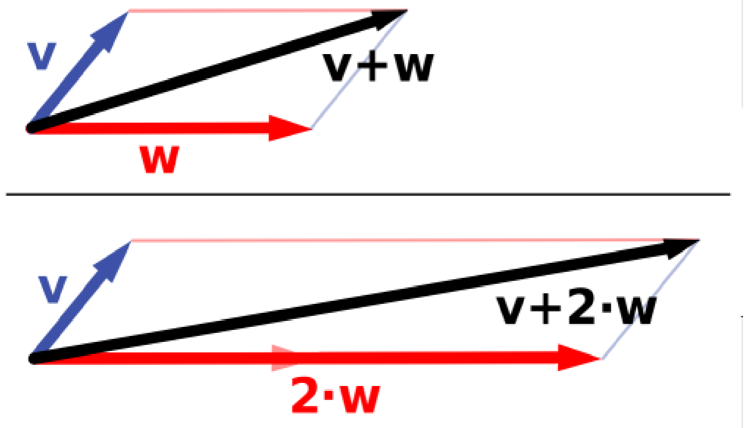
VECTORS











Scalars vs. Vectors

Scalars are physical quantities represented by a single number, and vectors are represented by both a number and a direction.

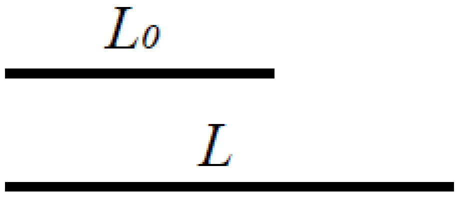
Introduction to elasticity and viscosity

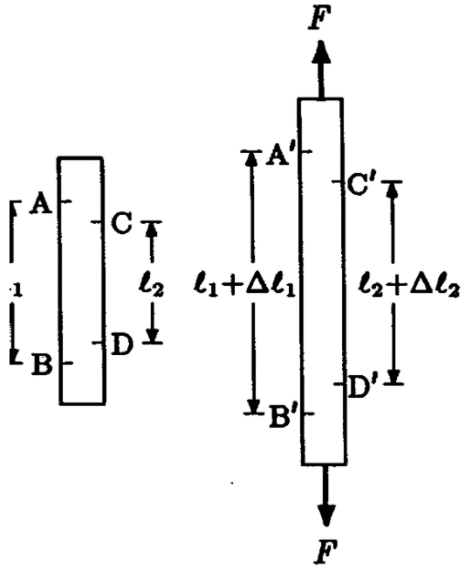
- Elasticity is a material property that generates recovering force at an application of an external force to deform the material.

Introduction to elasticity and viscosity

- The recovering force divided by the cross sectional area that the external force is working on is defined as stress, σ. Suppose the material is initially in a shape of rod of length L_0 and cross-sectional area, A_0. The force is applied to the length direction and the length after the deformation is L. The deformation is generally normalized as,

$$\varepsilon = \frac{L - L_0}{L_0}$$





where ε is called the engineering strain or the Caushy strain

Introduction to elasticity and viscosity

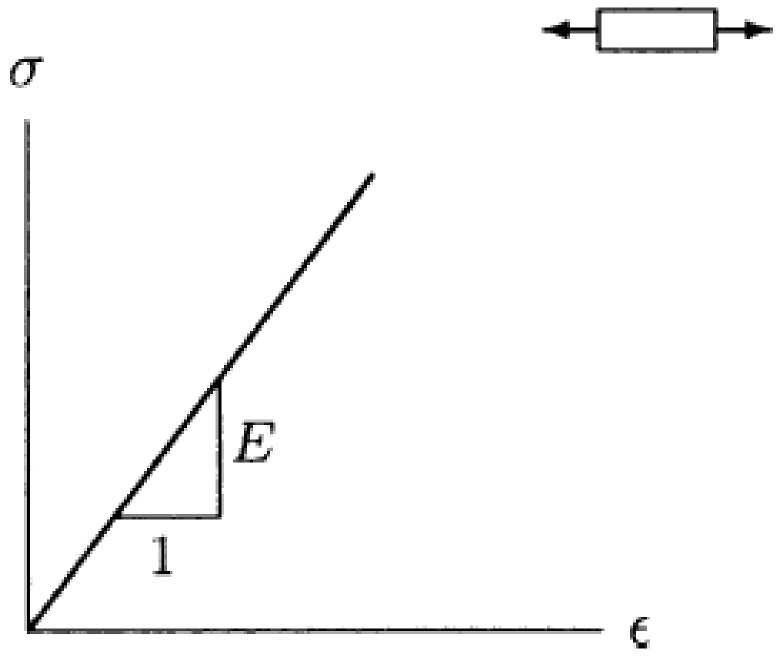
- For an elastic material, the relationship between stress and strain can be expressed in the following general form;

$$\sigma = \sigma(\varepsilon)$$

This equation states that the normal stress σ is a function of normal strain ε only.

Relationship between stress and strain

- For a linearly elastic material, stress is linearly proportional to strain, and in the case of normal stress and strain, the constant of proportionality is the **elastic modulus E** of the material;

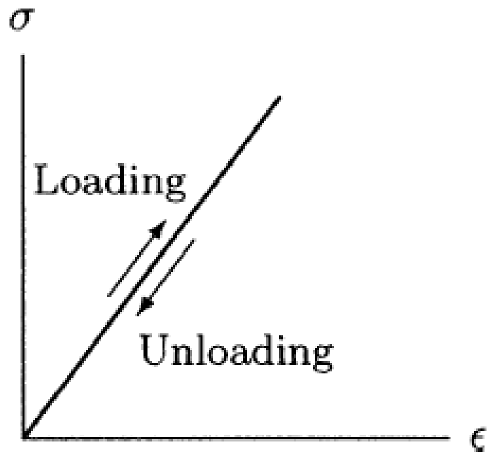


Linearly elastic material behavior

$$\sigma = E\varepsilon.$$

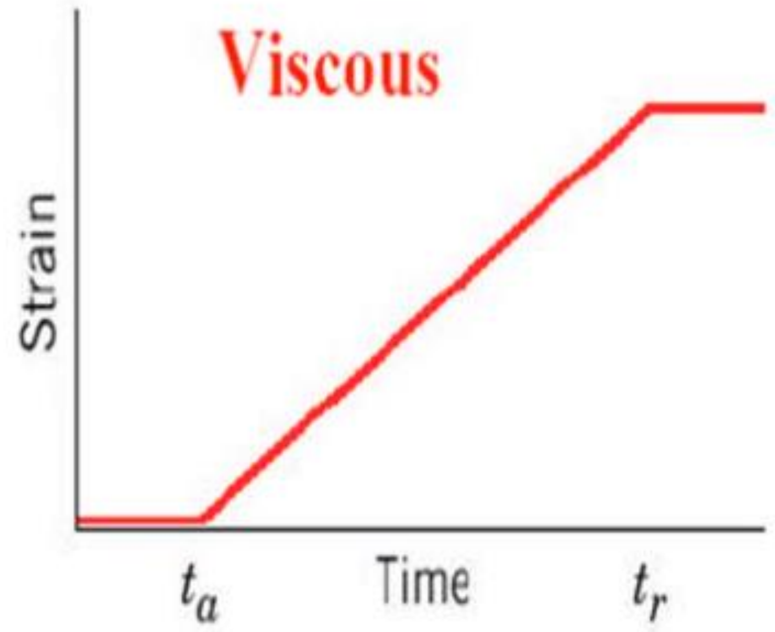
Elastic behavior

- Instant deformation under load
- Deformation is recovered
- Elastic materials show time-independent material behavior



Vicous behavior

- Not instantaneous deformation
- Deformation cant be recovered
- Totally dependent with time
- Stress independent strain

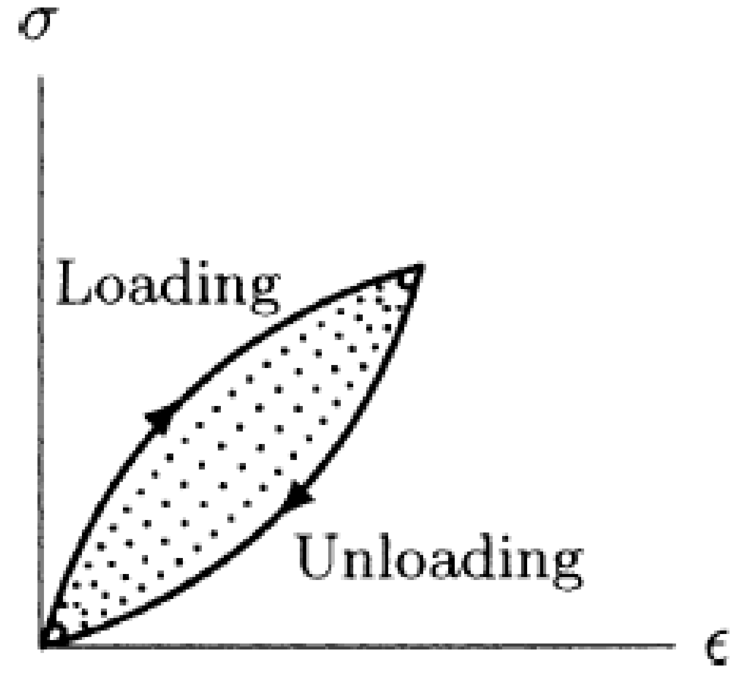


Vicoelastic behavior

- Viscoelastic= viscous +elastic behavior
  - Instantaneous and delayed deformation
  - Some deformation is recovered , some is not
  - Hysterisis loop
  - Time dependent behavior

Vicoelastic behavior

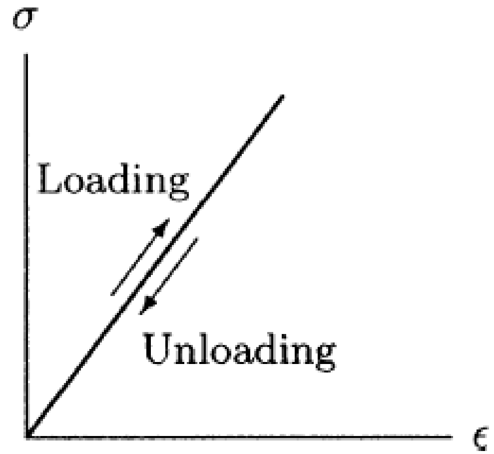
- The area enclosed by the loading and unloading paths is called the hysteresis loop, which represents the energy dissipated as heat during the deformation and recovery phases.

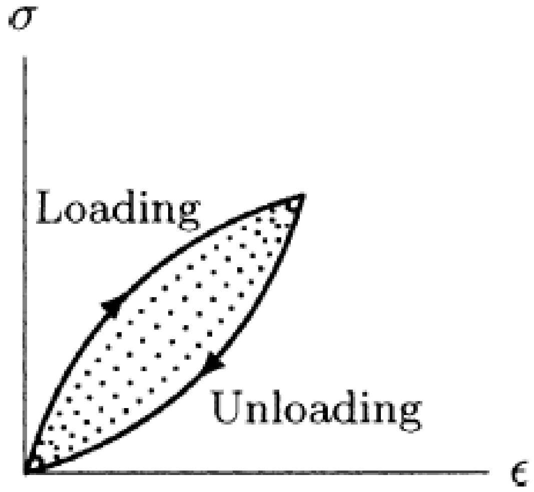


Hysteresis loop

Comparison of Elasticity and Viscoelasticity

- An elastic material has a unique stress–strain relationship that is independent of the time or strain rate
- Viscoelastic materials exhibit time-dependent material behavior. The response of a viscoelastic material to an applied stress not only depends upon the magnitude of the stress but also on how fast the stress is applied to or removed from the material.

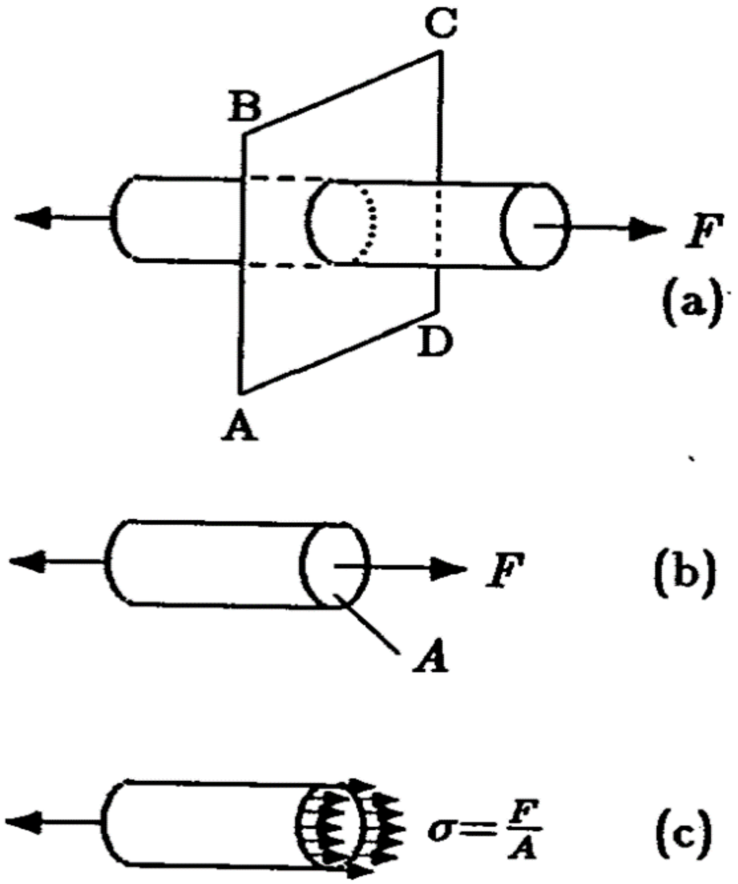




Stress (σ)

$\sigma = F/A$ (N/m^2 or Pa)

- **Normalized load**
- **Force applied per unit area** measured from the surface perpendicular to the force vector.



gure 14.10 *Normal (axial)* 'ess.

Strain (ε)

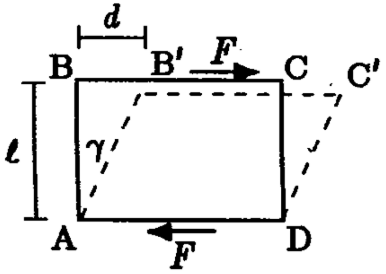


Figure 14.13 *Shear strain.*

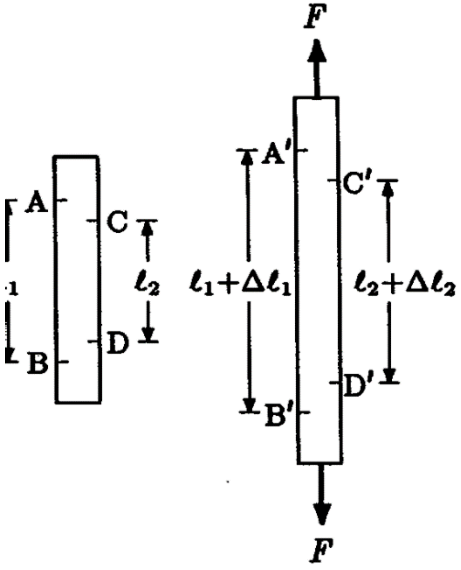
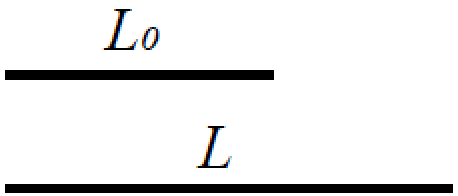


Figure 14.12 *Normal strain.*

- **Normalized deformation**
- The shape changes of a material according to its initial state.



$$\varepsilon_I = \frac{L - L_0}{L_0}$$

Terminology

- **Load** – the sum of all forces or moments acting on an object or system
- **Deformation** – local shape changes in the object

Load-deformation relationship

- The shape changes (deformation) when the tissue or structure is subjected to various loads.

The degree of deformation depends on:

- Size and shape (geometry)
- Materiel
  - Structure
  - Environmental factors (temperature, humidity)
- Depends on loading type
  - the magnitude, direction and duration of the applied load
  - Application point (location)
  - Speed of applied force
  - The frequency of the applied force
  - Variation of the size of the force

Loading types:

Uniaxial Loading

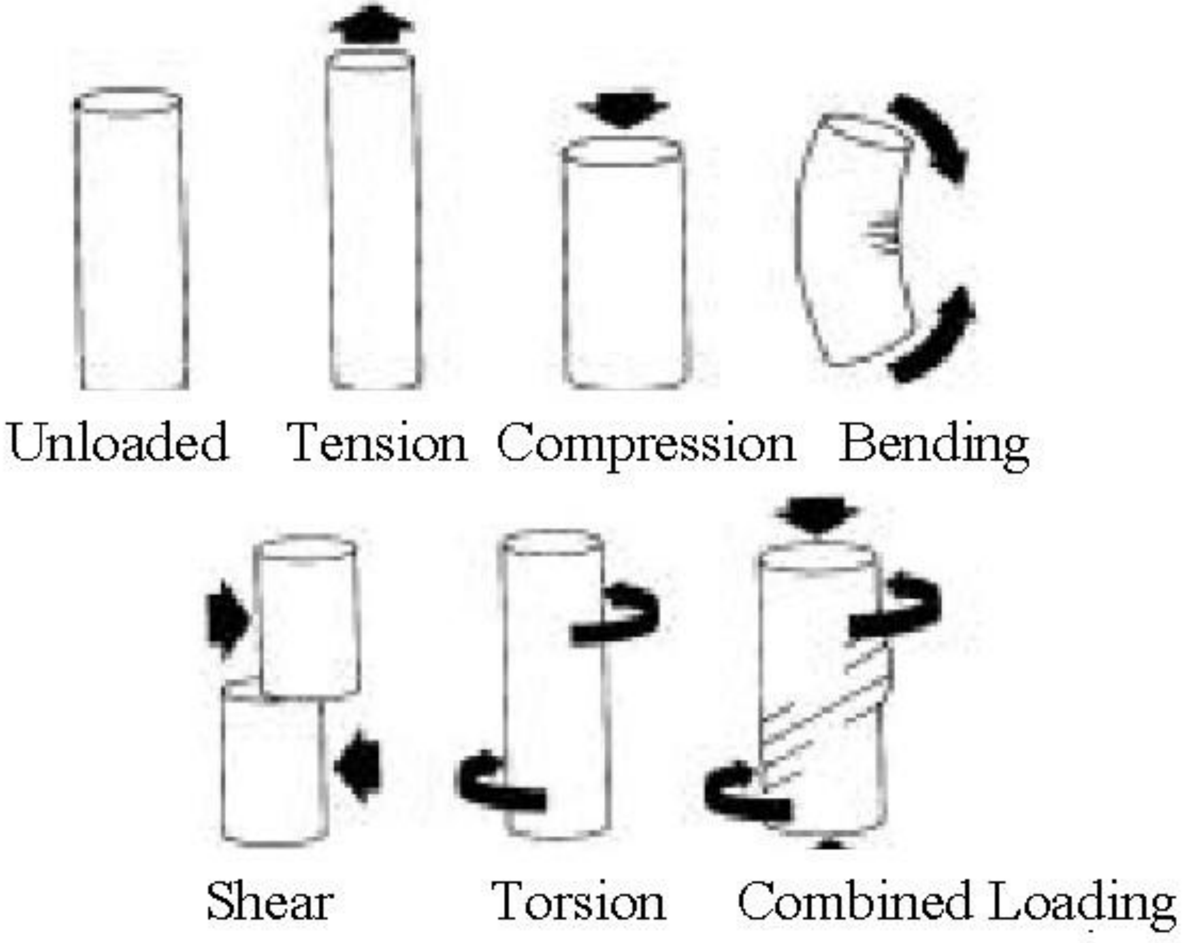
- Axial
  - Compression
  - Tension
- shear

Multiaxial Loading

- Biaxial load
- Triaxial load
- Bending
- Torsion

GENERAL MECHANICAL CONCEPTS

Mechanical properties of a material are generally determined by applying mechanical tests:

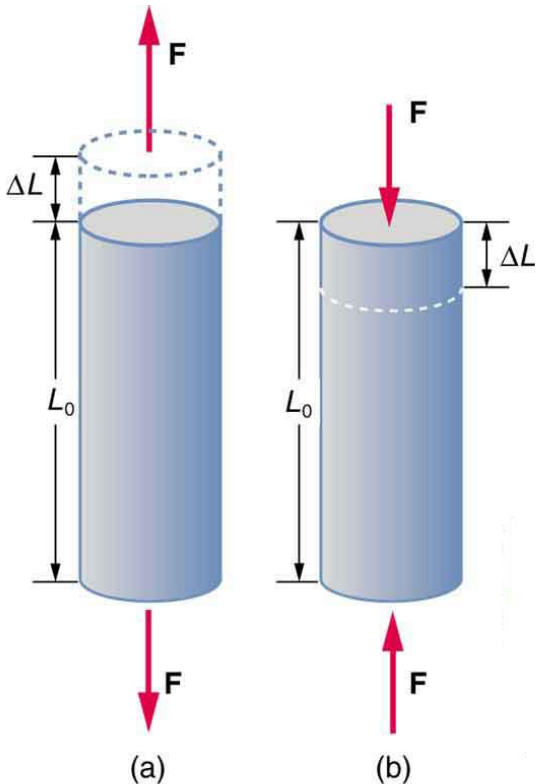


Elastic deformation has three basic changes such as elongation, change in volume and shear. The force applied to a rod-shaped flexible body in the direction of the rod is directly proportional to the elongation it creates and;

$$F \propto \Delta L$$

More conveniently, A is the cross-sectional area,

$$F/A = Y \Delta L / L$$



HOOKE'S LAW

$$F/A = Y\Delta L/L$$

Stress (σ)=The Young's Modulus X strain (ε)

Stress = force / cross sectional area

Strain = change in length / original length

$$F/A = Y \Delta L/L$$

The Young's Modulus (Y) of a material is a fundamental property of every material that cannot be changed. It is dependent upon temperature and pressure.

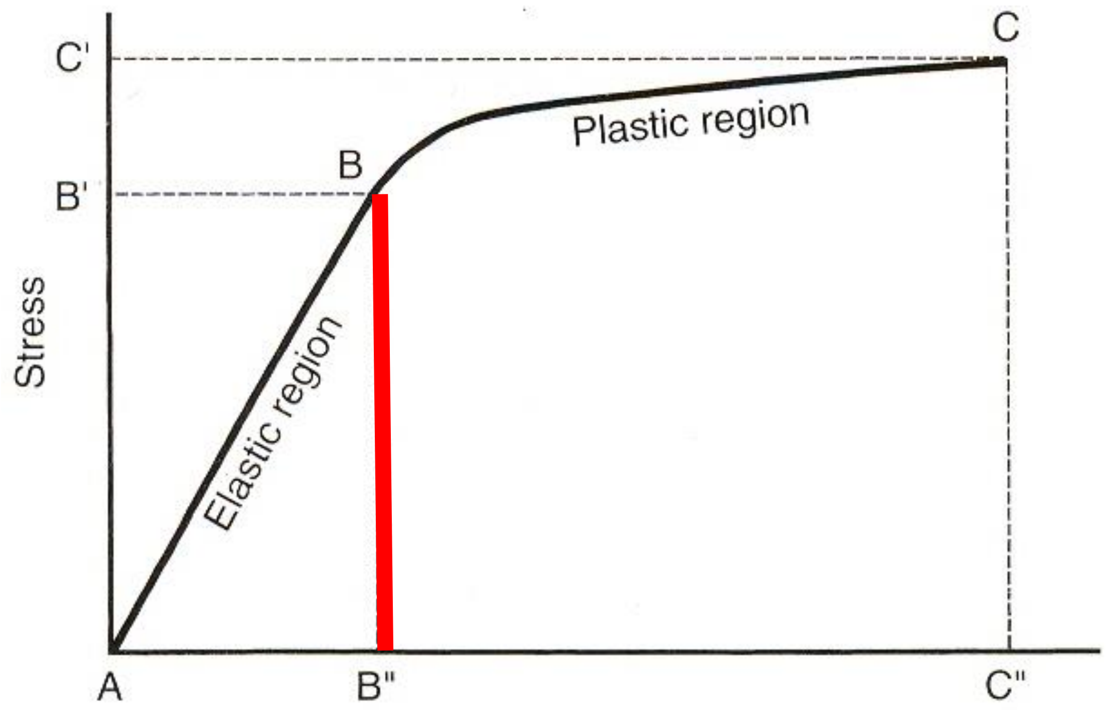
To be more exact, the physics and numerical values are worked out like this:

Young's Modulus = Stress / Strain

Elastic and plastic region

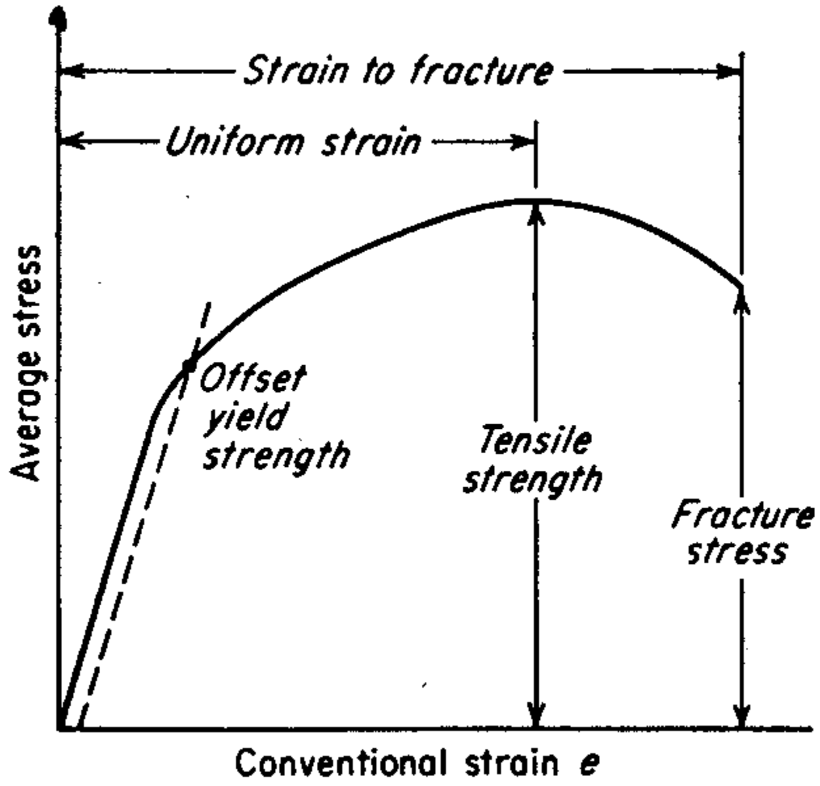
Elastic region– the response is linear, the texture of the tissue hasnt changed; according to the Hooke's Law; F=kx

Plastic region – the response is not linear, the slope of the curve is variable; the texture of the tissue has changed; permanent change in tissue



Young's Modulus

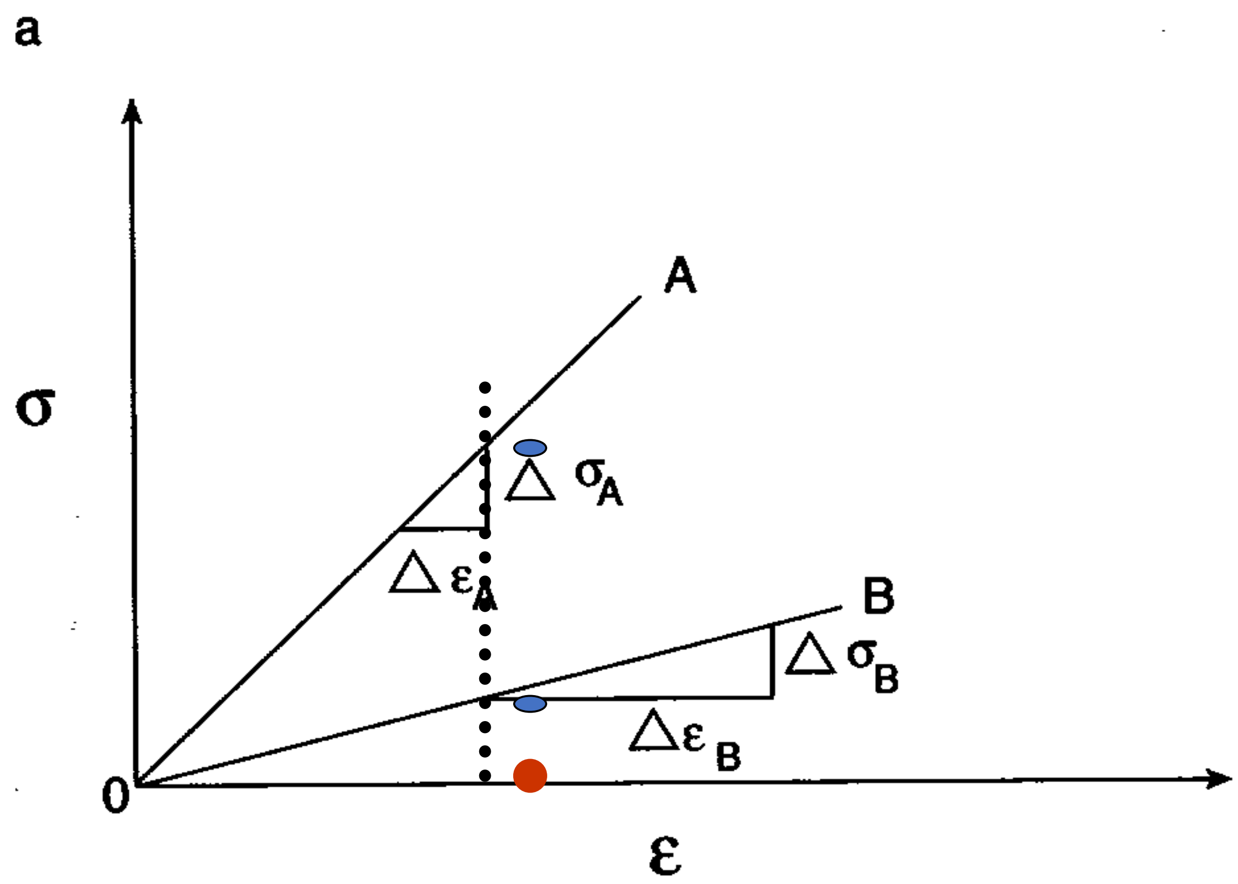
- The Young's modulus is the slope of the initial section of the curve (i.e. m in y = mx + b).



Mechanical properties of the materials

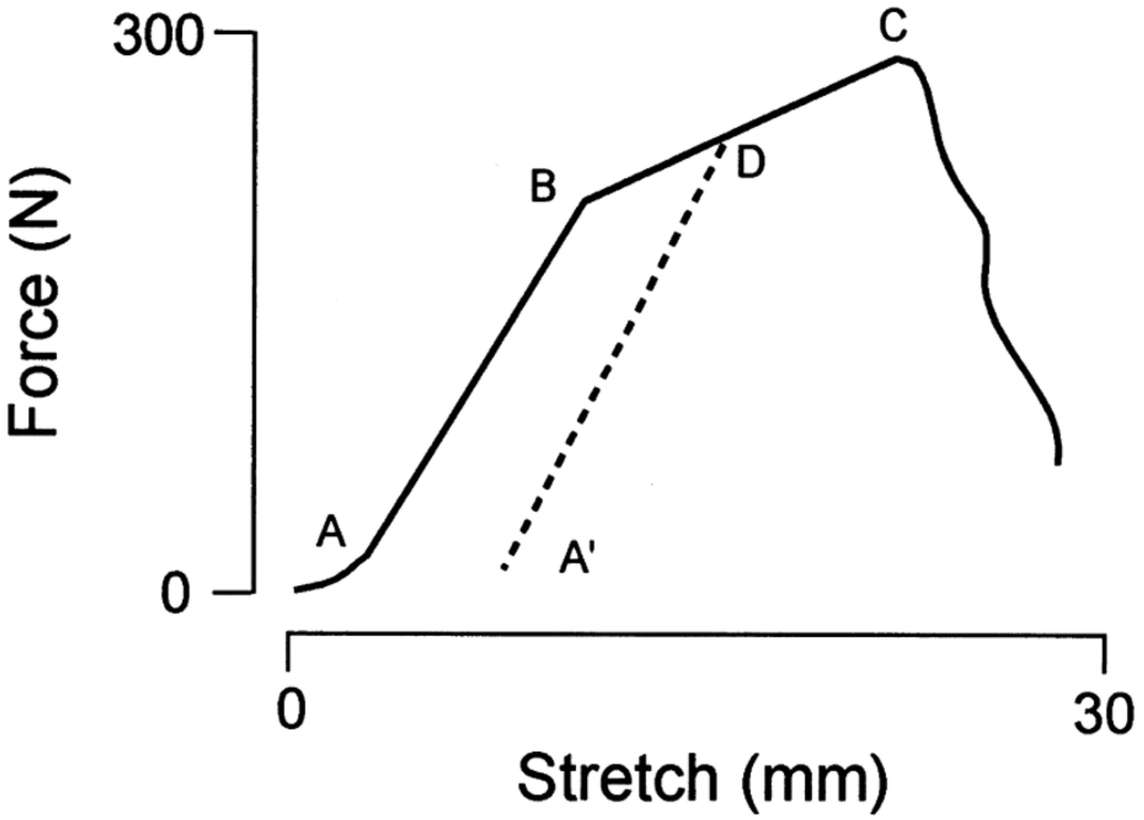
- Stiffness
- Strength
- Elasticity
- Ductility
- Brittleness
- Malleability
- Toughness
- Resilience
- Hardness

Stiffness

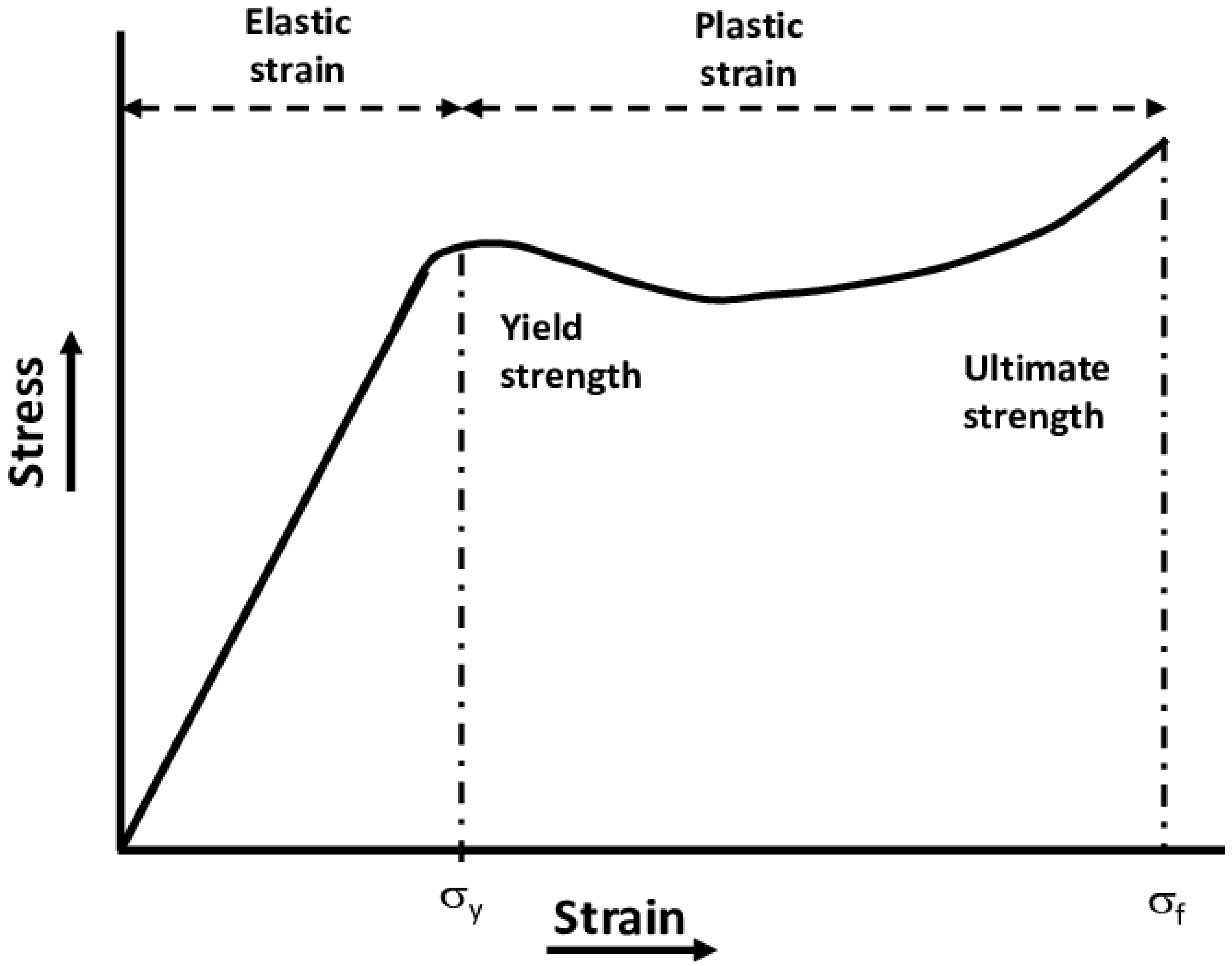


- It is a measure of resistance to deformation of the material
- Expressed as the slope of the stress-strain curve

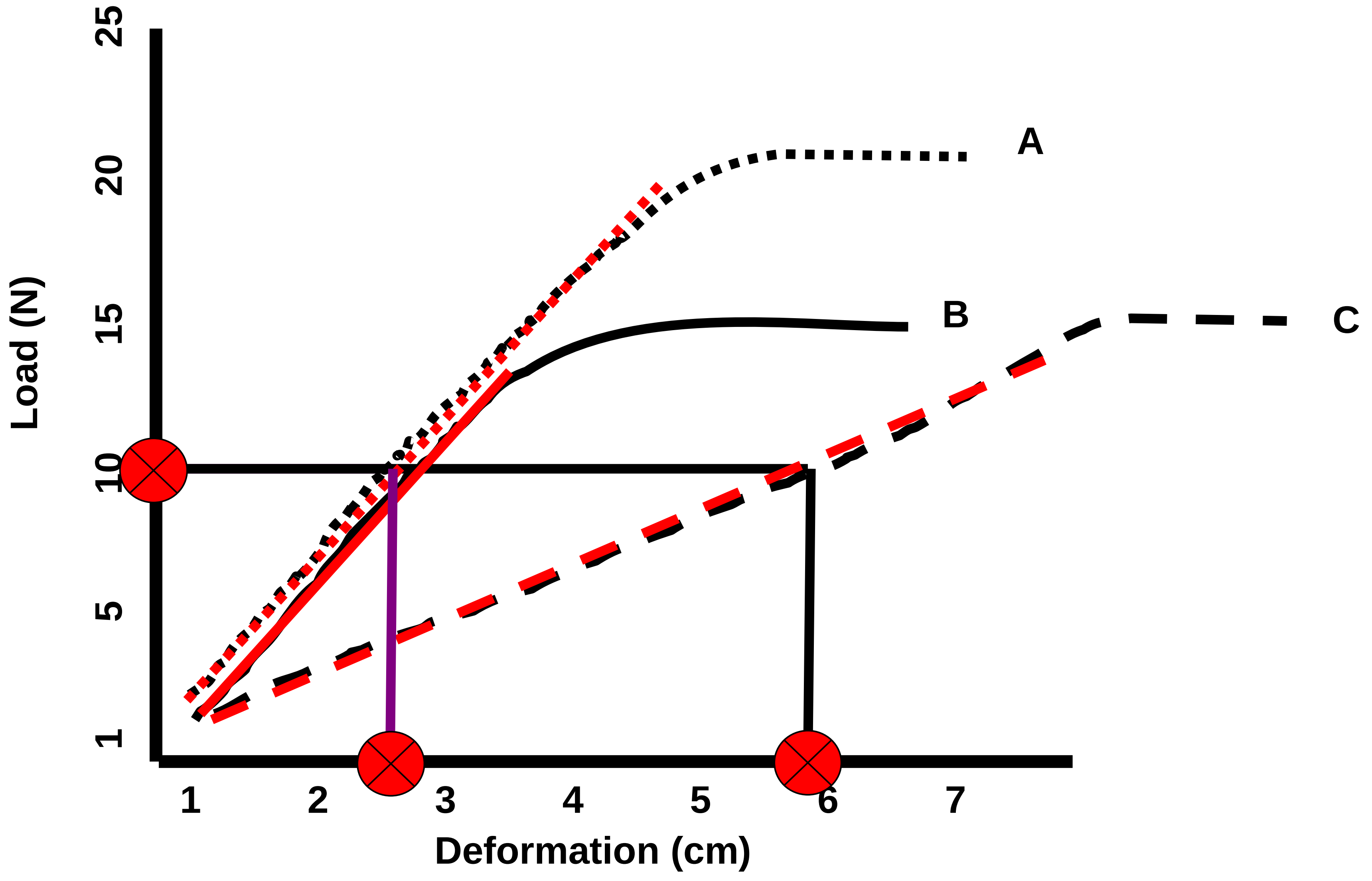
Stiffness



300
0
Force (N)
A
B
C
D
A'
0
30
Stretch (mm)



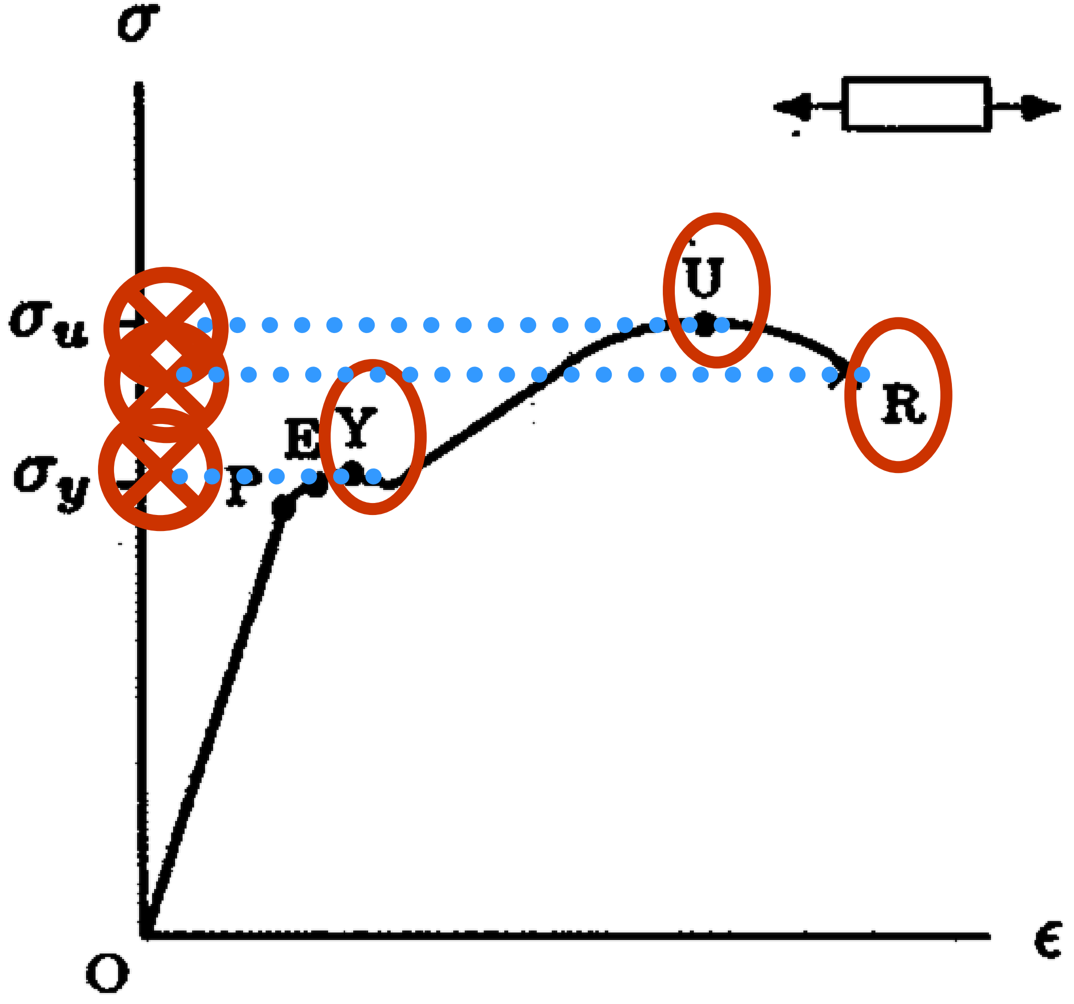
Elastic strain
Plastic strain
Stress
Yield strength
Ultimate strength
σ_y
Strain
σ_f



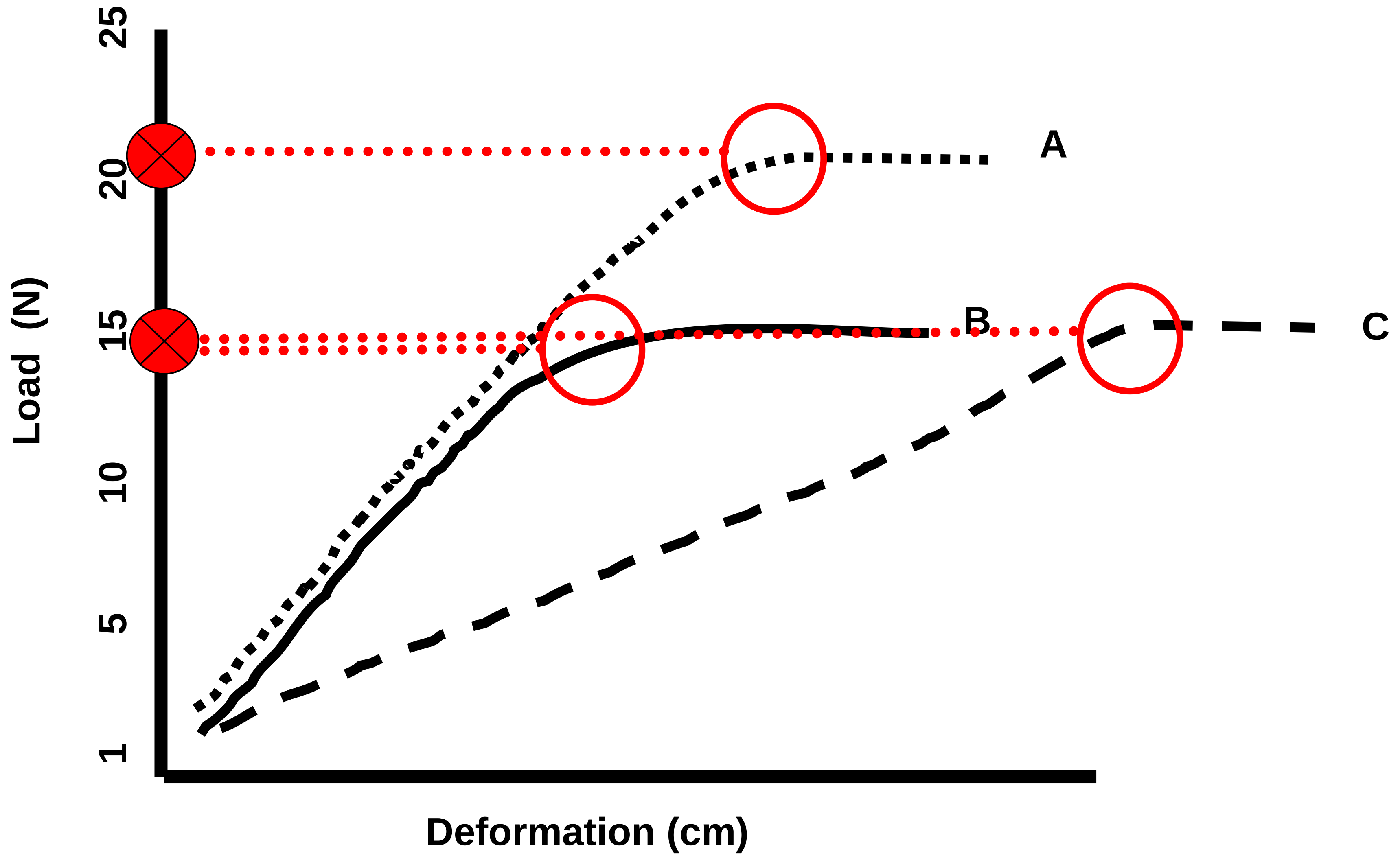
Load (N)
25
20
15
10
5
1
1
2
3
4
5
6
7
Deformation (cm)
A
B
C

Strength

stiffness ≠ strength

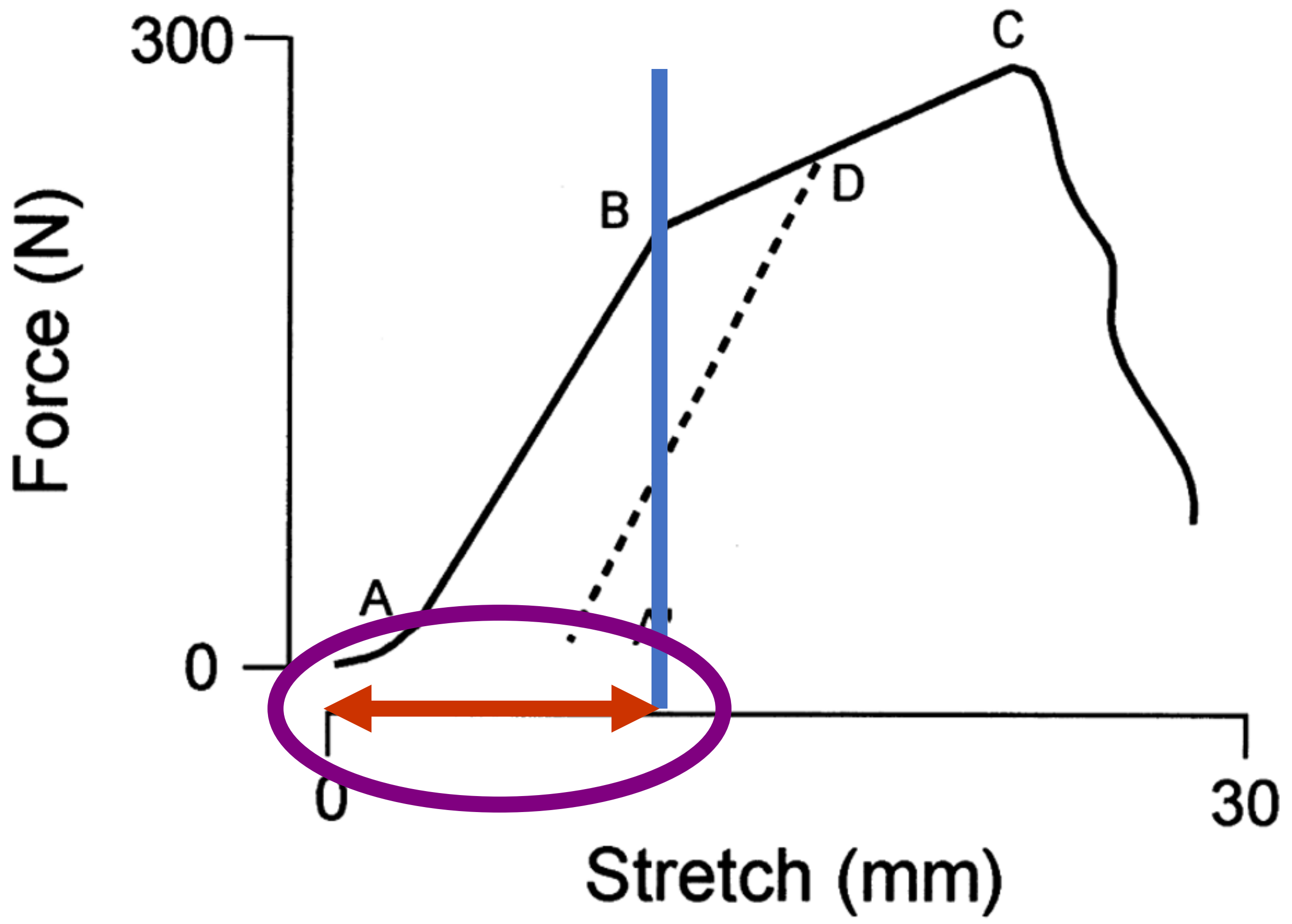


- Yield
- Ultimate Strength
- Failure

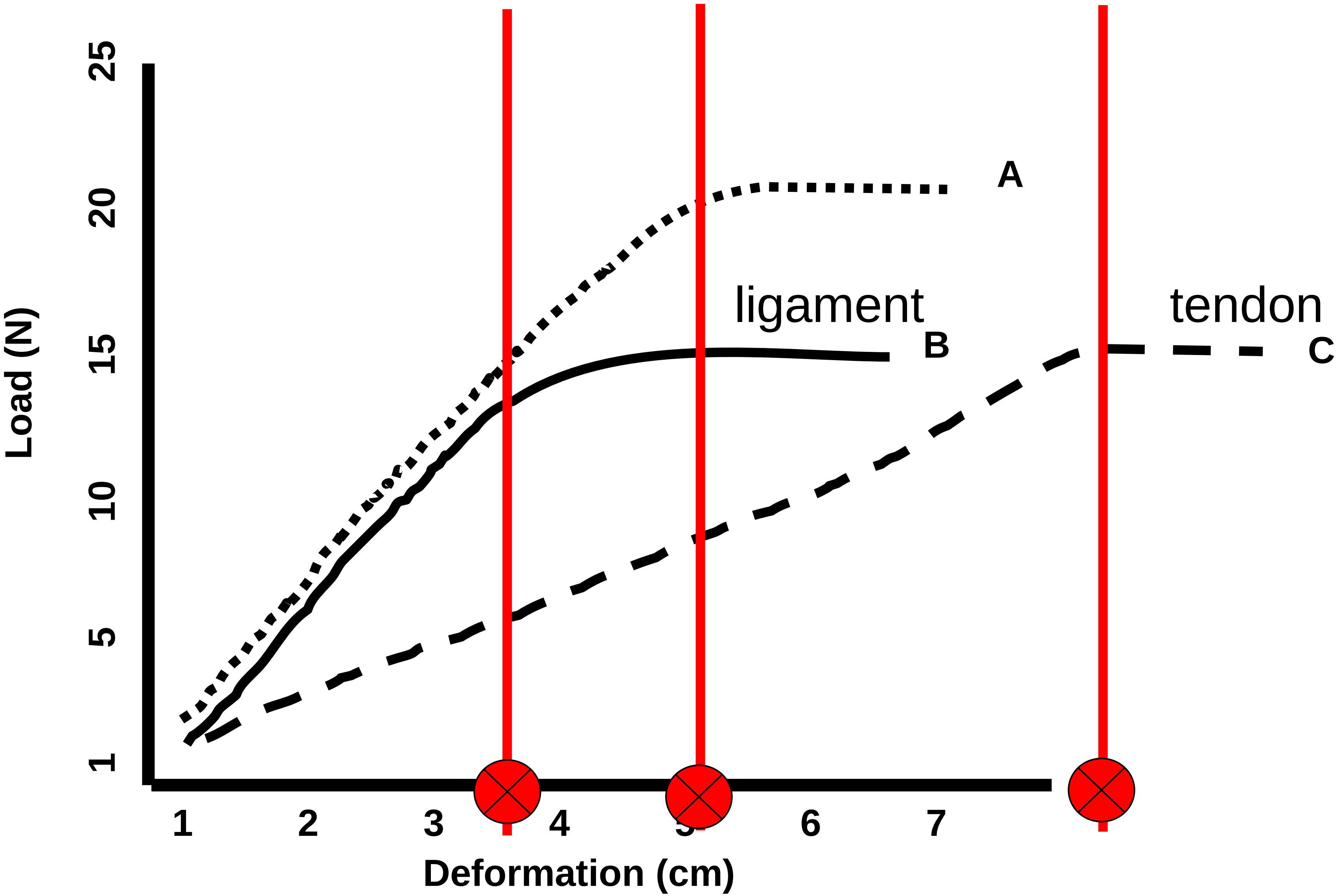


25
20
15
10
5
1
Load (N)
A
B
C
Deformation (cm)

Elasticity



Extensibility



Brittleness

- It is the measure of the absence of plastic deformation before fracture
- It breaks suddenly
- There is no yield point
- Ultimate strength= rupture strength

Which one is less brittleness? (1)

Which one has more Strength? (2)

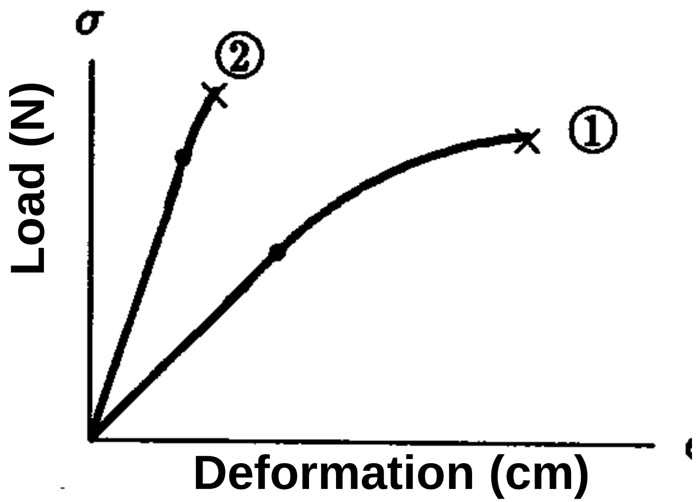


Figure 14.34 ***Material 1 is more ductile and less brittle than material 2.***

Ductility: refers to the characteristic of a material that undergoes large plastic deformation before rupturing under tensile load.

Resilience

- The ability of a material to stand large loads without exceeding the elastic limit
- It is measured by calculating the area of the elastic part of the curve,
- Objects that back rapidly to their original shape are called resilient objects.

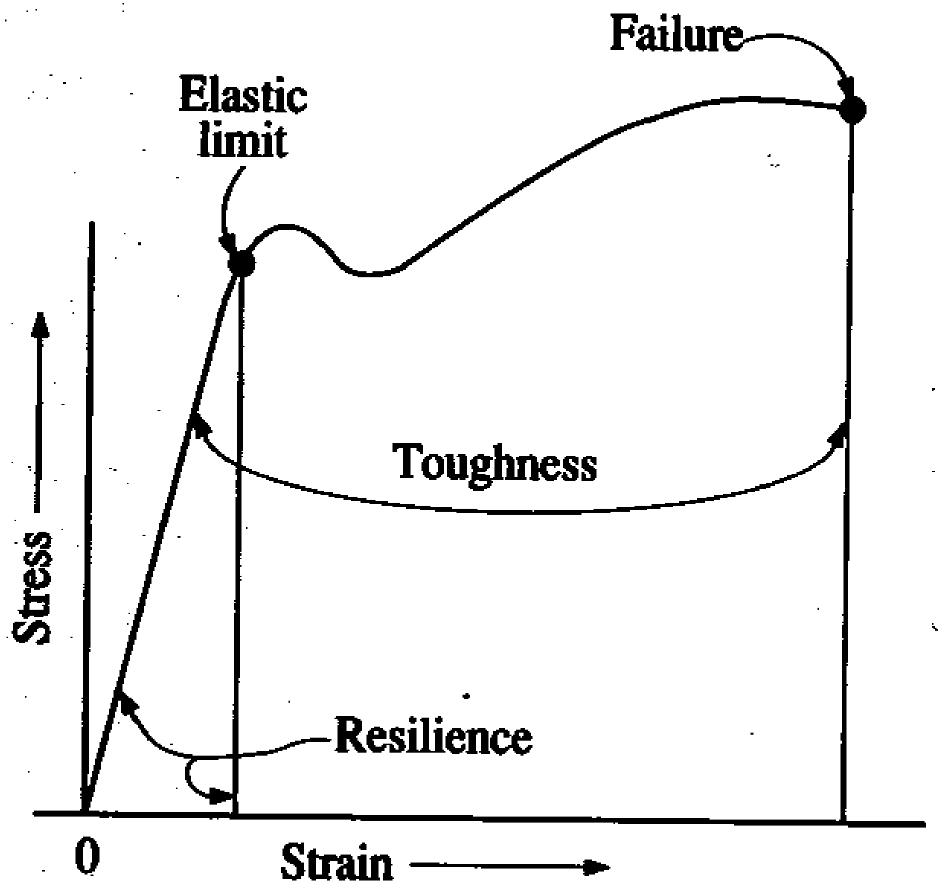


FIGURE 10–6 Resilience and toughness.

Toughness

- **The capacity of a material to withstand permanent deformation**
- If the material can bear high stress and deforms without breaking, It is mean the strength is good.
- Fragile materials have small strength (less plastic deformation before fracture)

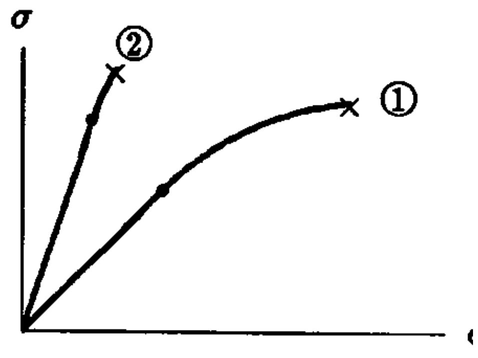


Figure 14.34 *Material 1 is more ductile and less brittle than material 2.*

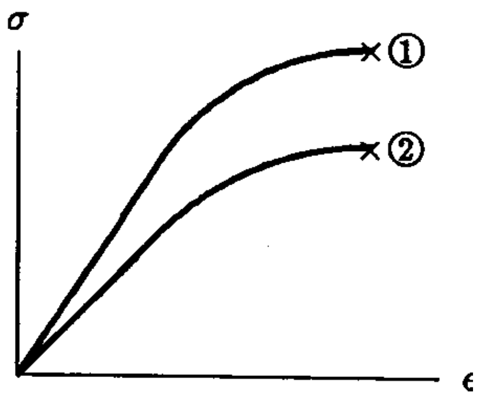
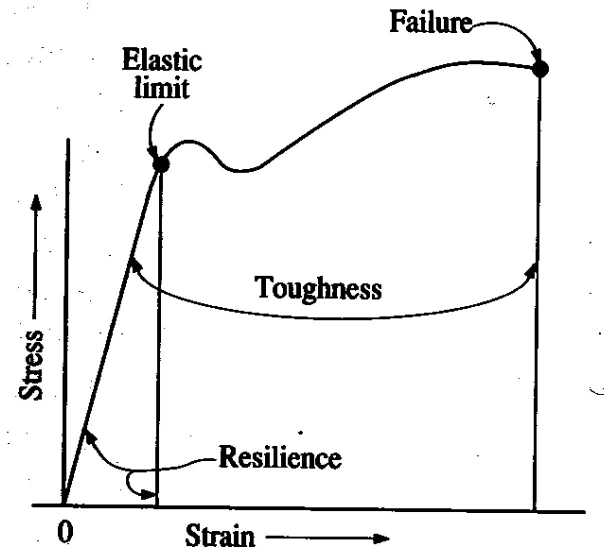


Figure 14.35 *Material 1 is tougher than material 2.*

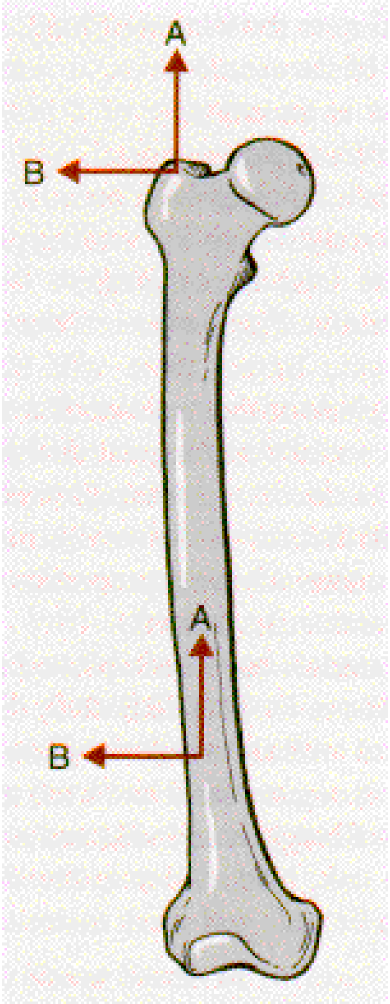


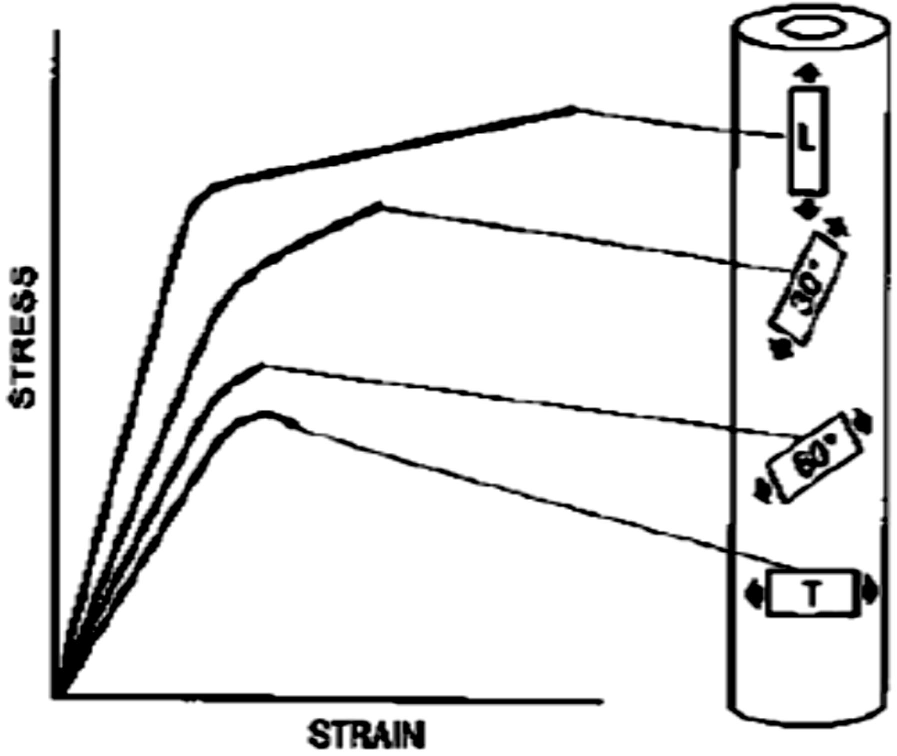
Specific characteristics of biological materials

- Anisotropic
- The bone responds differently depending on the direction of the applied load. The stress-strain curve changes according to the direction of the load.

  - In which direction is bone more fragile to the load applied?

  - In which direction is the bone more resistant to the load applied?





Specific characteristics of biological materials

- Anisotropic
- The bone responds differently depending on the direction of the applied load. The stress-strain curve changes according to the direction of the load.

  - In which direction is bone more fragile to the load applied?
    - T
  - In which direction is the bone more resistant to the load applied?
    - L