PHYSICAL QUANTITIES

USED TO CHARACTERIZE DENTAL MATERIALS

Selection of dental materials

Analysis of the problem.

Consideration of requirements.

Consideration of available materials and their **properties** leading to choice of material.

Mechanical Properties

Thermal Properties

Optical Properties

Mechanical properties of dental materials

Comparison of the performance of materials in different mechanical conditions and applications

1. Is the material strong enough to withstand loads it needs to transmit without fracture?

2. Does the stress in dental restorations as bridges produce permanent deformation?

3. Does the material keep its mechanical properties for time long enough?

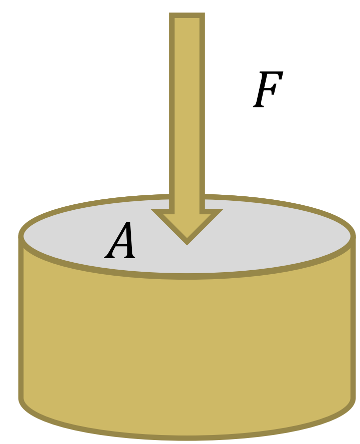
Stress and resulting strain

Are materials *strong* and *tough* enough to withstand biting forces without fracure?

Concepts and definitions

***Stress* (σ) – is a measure of the average amount of force (F) exerted per unit area (A) of the surface on which external forces act within a deformable body:**

$$\sigma = \frac{F}{A}$$



unit: Pascal = Newton/meter^2

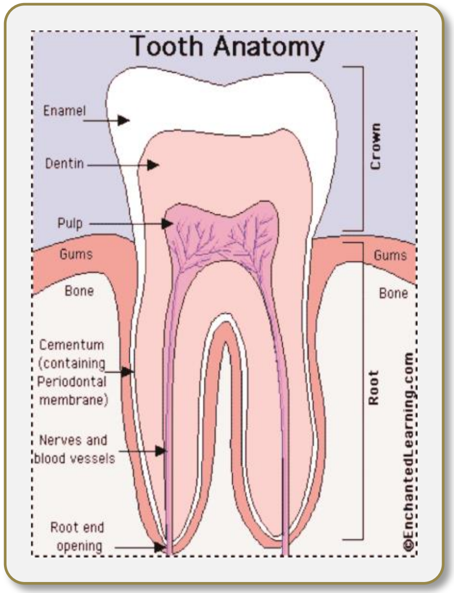
STRAIN - the measure of a material response

$$strain = \frac{change\ in\ length}{original\ length} \qquad \epsilon = \frac{\Delta l}{l_0}$$

HOOKE'S LAW

$$\sigma = E\varepsilon$$

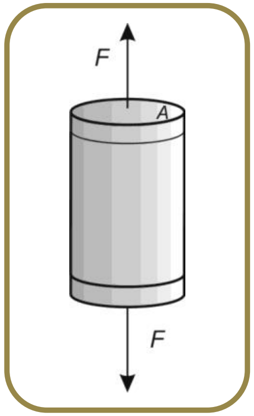
E – modulus of elasticity
(Young's modulus)



Material	Young's Modulus × 10^9 Pa (Elastic Modulus)
Enamel	84
Dentine	17-18
Acrylic denture resin	2.65
Composite resin	16.6
Amalgam	28-59
Feldspathic porcelain	69-70
Gold (type-4) alloy	99.3
Solid bone	11
steel	200

Principal types of stress and their description:

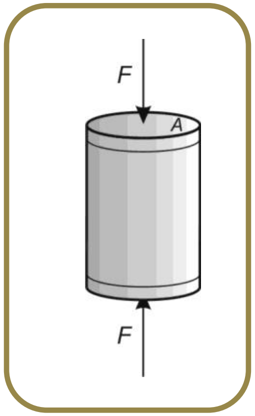
TENSILE STRESS



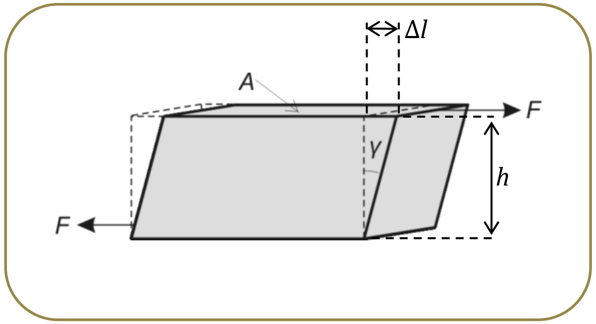
$$\sigma_T = E_T \varepsilon$$

COMPRESSIVE STRESS

$$\sigma_C = E_C \varepsilon$$

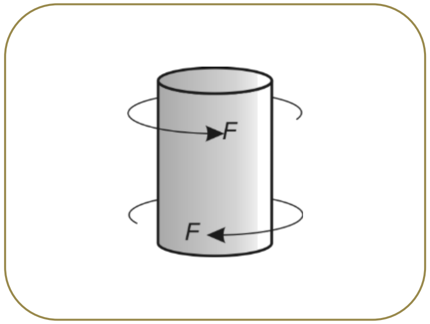


SHEAR STRESS



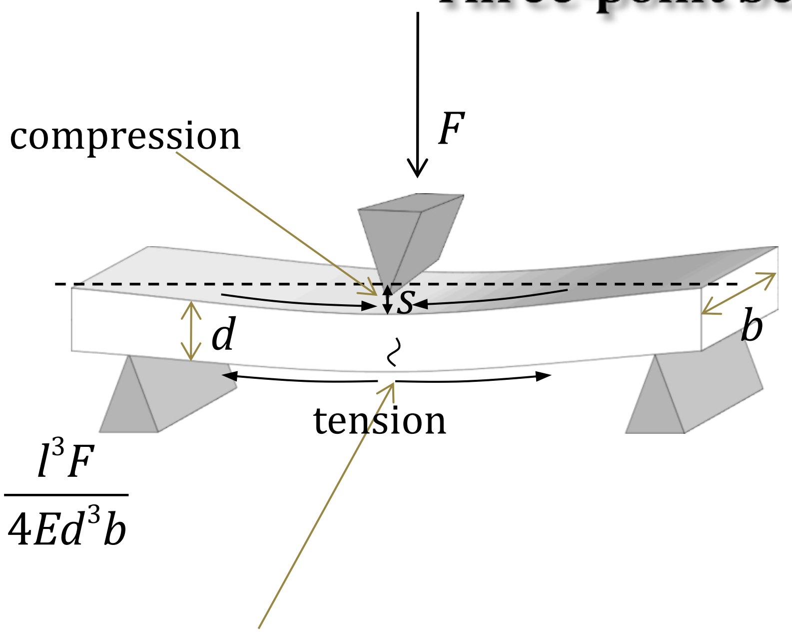
$$\sigma = E_S \frac{\Delta l}{h}$$

$$\sigma_S = E_S \cdot \tan\alpha$$



FLEXURAL BENDING STRESS

Three-point bending (flexural) test



$$s = \frac{l^3 F}{4Ed^3 b}$$

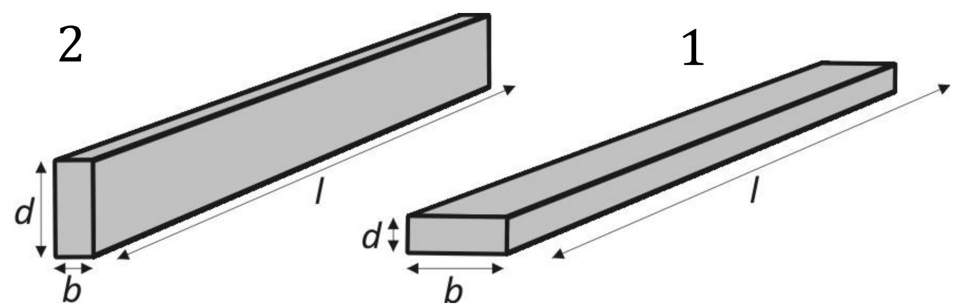
$$d_2 = 3d_1$$

$$b_2 = \frac{1}{3} b_1$$

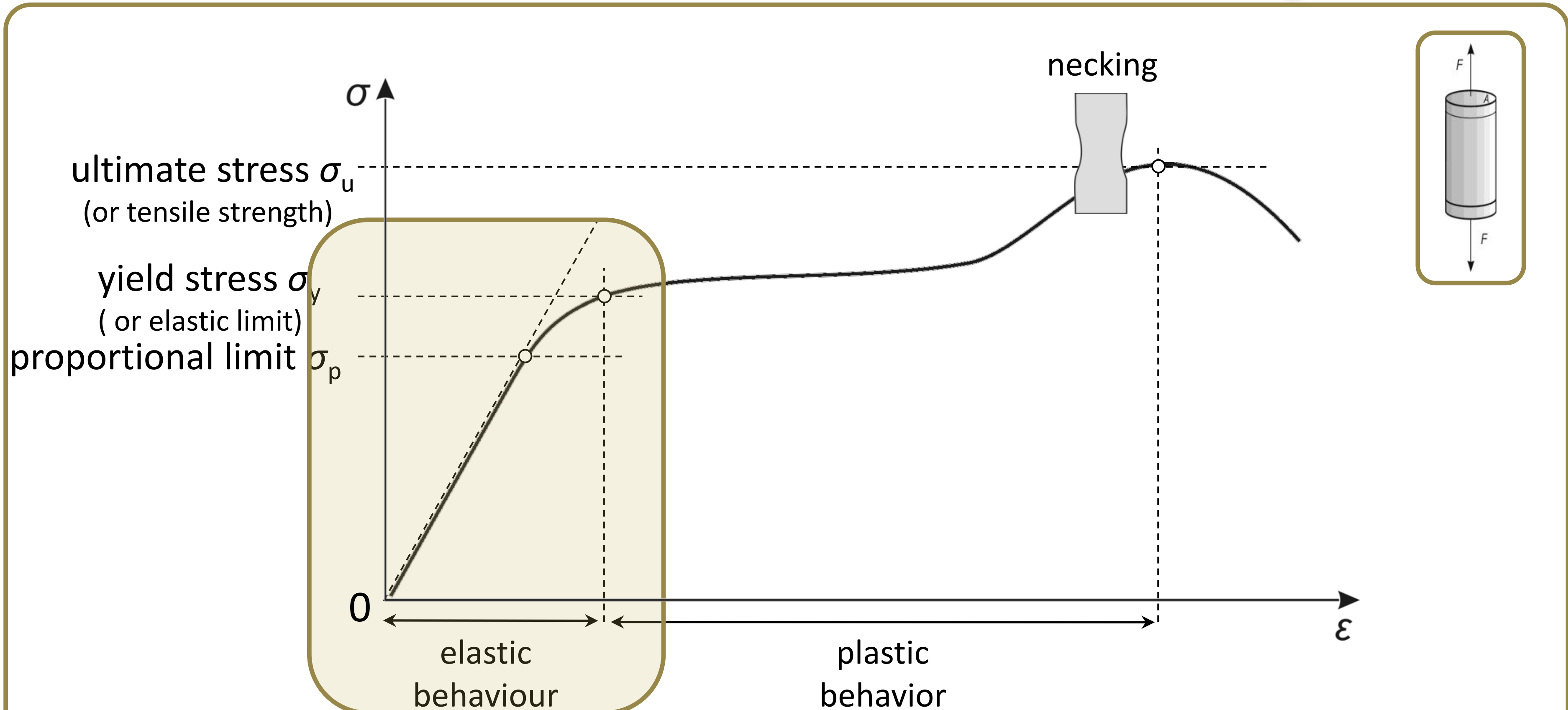
$$l_2 = l_1 \quad E_2 = E_1 \quad F_2 = F_1$$

$$s_2 = \frac{l^3 F}{4E(3d_1)^3 \frac{1}{3} b_1} = \frac{s_1}{9}$$

s - deflection
d - thickness
l - distance between supports
b - width



Tensile stress: the stress-strain digram



a specimen loaded will elongate, but will return to its original shape and size when unloaded

non-reversible changes of shape in response to applied forces -permanent deformation

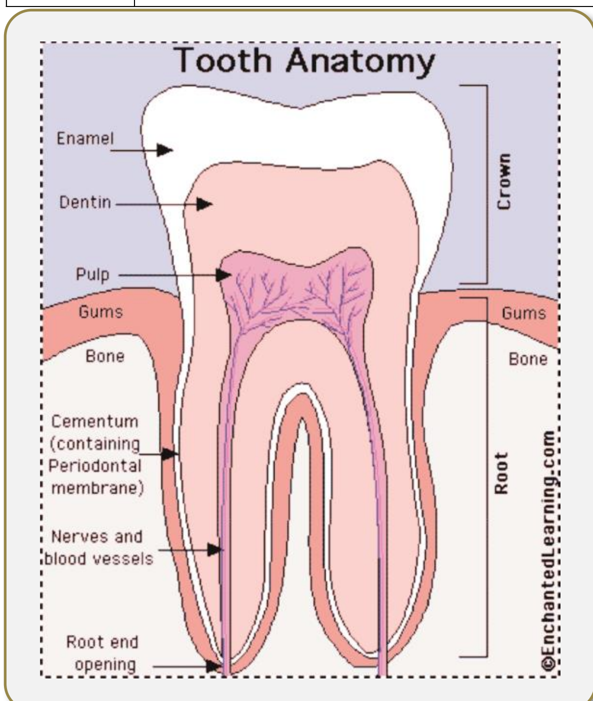
CLINICAL IMPORTANCE:

If at any point of a material restoration the tensile stress exceeds the yield stress, the restoration will deform permanently!

Compressive strength

The ***compressive strength*** of a material is that value of uniaxial *compressive stress* reached when the material fails completely - fractures.

	AMALGAM (High Cu/cut) COMPRESSIVE STRENGTH (MPa)
30 min	59
1 hour	97
1 day	470



<u>Compressive strength (MPa)</u>

Amalgam 470

Enamel: 100 – 380 (Young's modulus 84 GPa)

Dentin: 250 –350

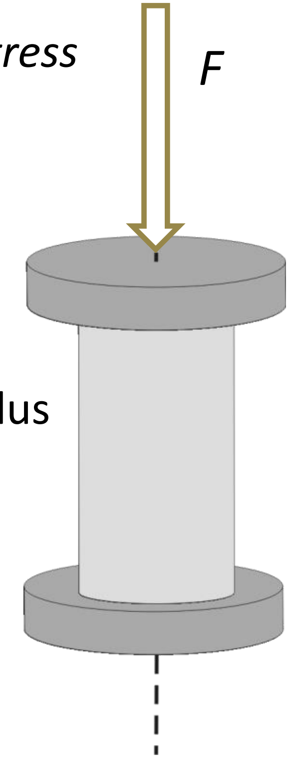
Porcelain 150

Gold: 450

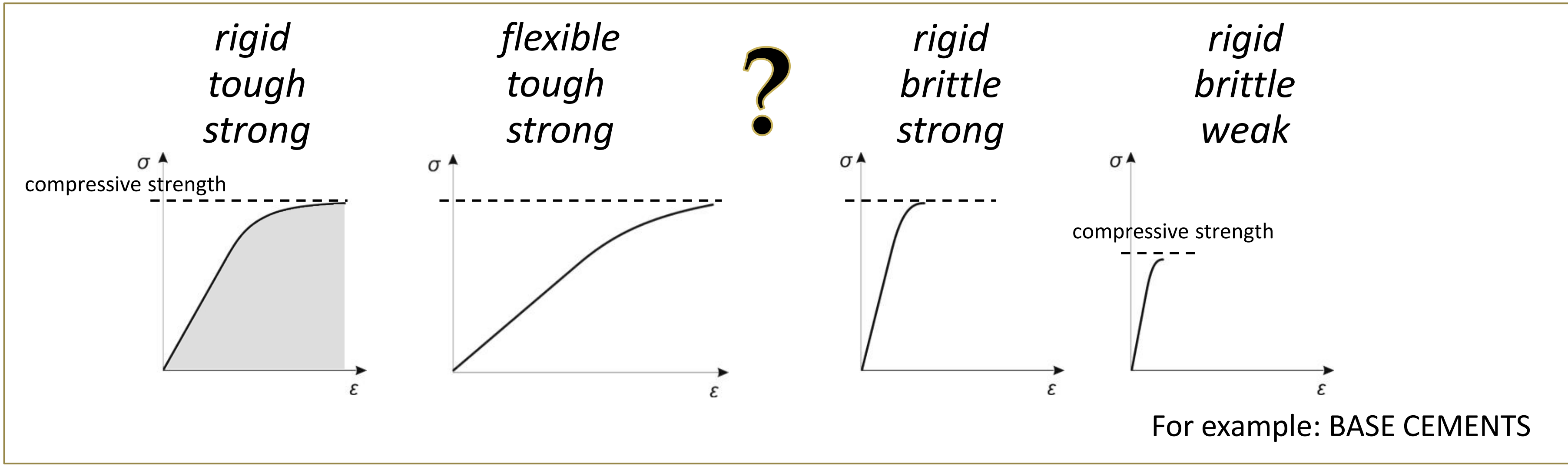
Concrete 50

Policarboxylate cements 80-90

Resin composite 225



Different types of stress-strain diagrams



- *rigid material* - a steep slope – high Young's modulus – *advantageous for restorative material*
- *tough material* – materials capable of absorbing large amount of elastic potential energy before fracture
- *brittle material* - the fracture of a brittle material is sudden, with little or no plastic deformation
- *strong material* – is characterized by high value of the compressive or tensile strength.
- *flexible material* - a shallow slope - low Young's modulus –- *advantageous for impression materials*

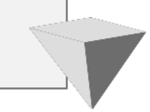
HARDNESS

Hardness is used as:

- **a measure of ability to resist scratching**
- **indication of the abrasion resistance of a material (wearing, grinding, or rubbing away by friction)**

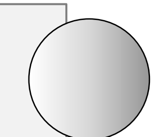
Hardness of a material is calculated from the size of an impression produced under load by an indenter.

- The Vicker hardness test method consists of indenting the test material with a pyramid-shaped diamond indenter.

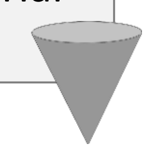


- The Knoop hardness test method
  (applies to very brittle materials - microidentation)

- The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball
  (used in engineering and metallurgy)

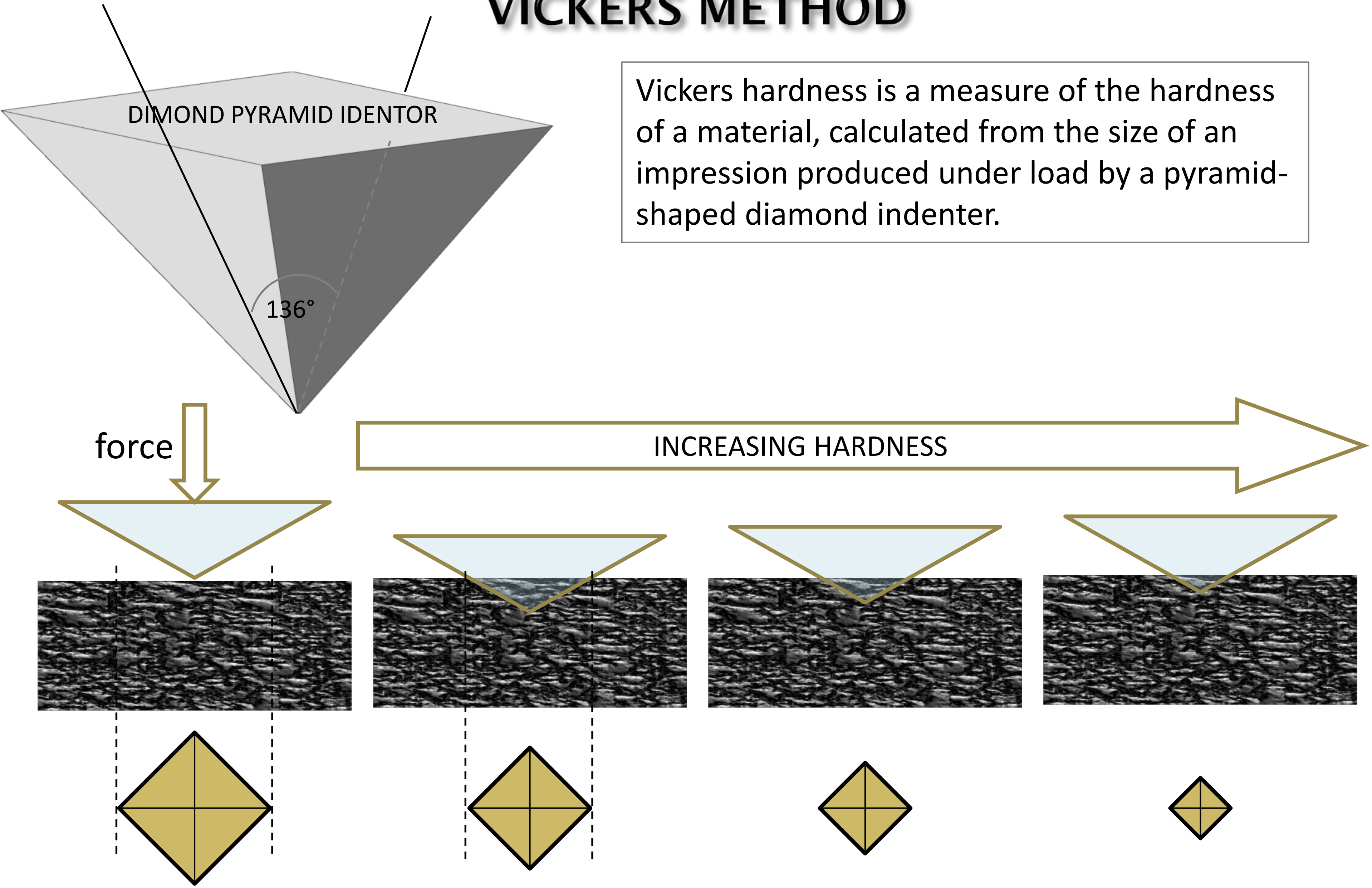


- The Rockwell hardness test method consists of indenting the test material with a diamond cone



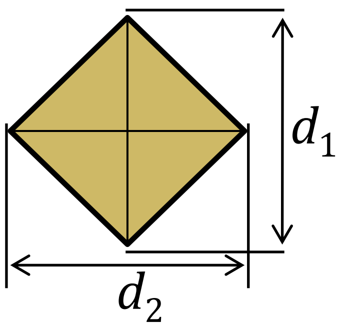
VICKERS METHOD

Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter.



resulting indentation

THE HARDNESS SCALE



$d = (d_1+d_2)/2$

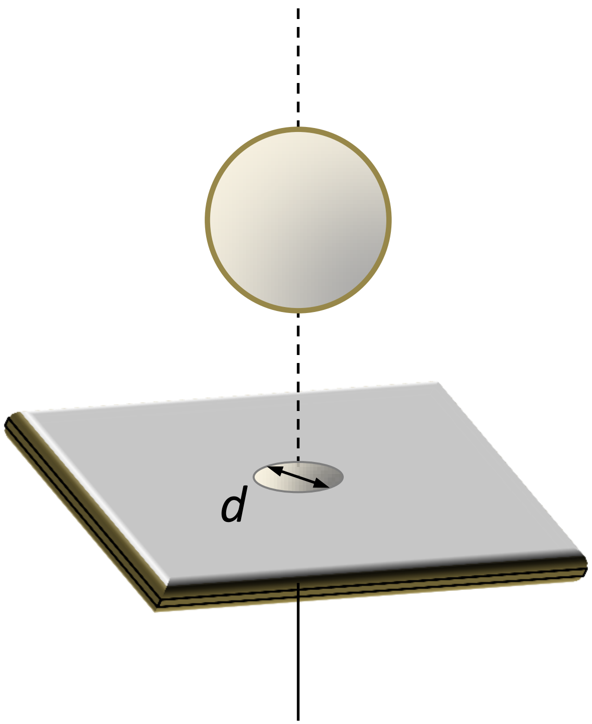
$$HV = 18.2\frac{F}{d^2}$$

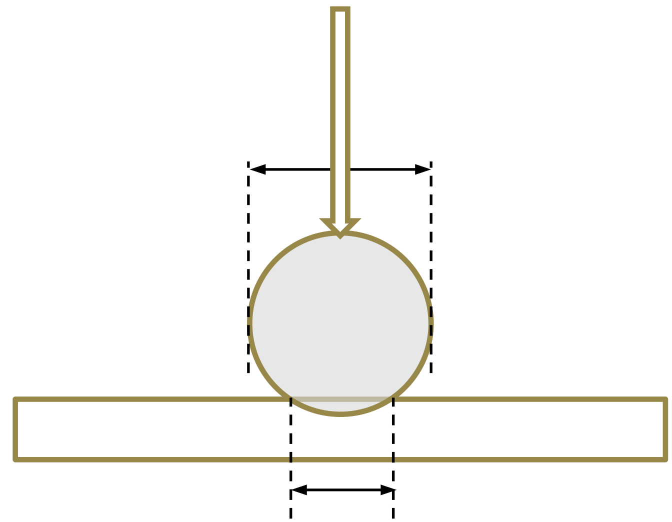
d in milimeters
F in newtons
unit HV = N/mm^2 =1MPa

Material	Vickers hardness number *HV* (or *VHN*) **GPa**
Porcelain	450
Enamel	350
Dental amalgam	110
Dentine	60
Tooth cement	45
Acrylic resin	20

after: John F. McCabe and Angus W.G. Walls

THE BRINELL HARDNESS TEST METHOD

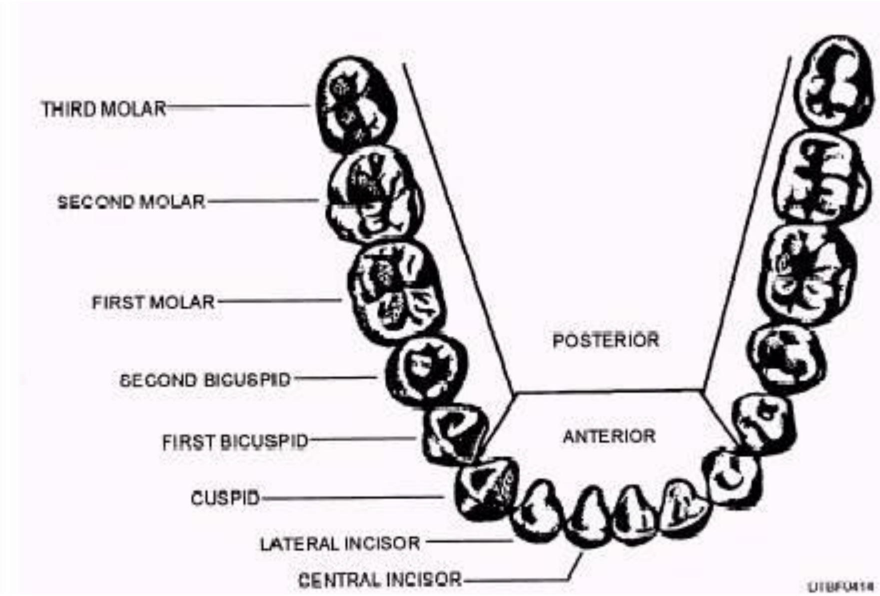




$$BHN = \frac{2F}{\pi D(D - \sqrt{(D^2 - d^2)})}$$

Some remarks

- For the restoration of large cavities involving two or more surfaces of a posterior tooth, a strong material with adequate abrasion resistance is required to withstand the large stresses developed in that region of the mouth.



- For a small interproximal cavity in the anterior region the major factor for consideration may be the abrasion resistance (measured by hardness)

- When materials are subjected to **<u>direct</u>** masticatory loading they should also be able to resist plastic deformation or creep.

CLASSIFICATION OF MATERIALS ACCORDING THEIR RHEOLOGICAL PROPERTIES

VISCOELASTICITY

RHEOLOGY

RHEOLOGY IS THE STUDY OF THE FLOW OF MATERIAL IN RESPONSE TO APPLIED FORCES.

The flow is measured:

- for liquids by the *viscosity* η
- for solids by *creep* and the *viscoelastic* properties

⇩

VISCOELASTICITY

IS THE PROPERTY OF MATERIALS THAT EXHIBIT BOTH ELASTIC AND VISCOUS CHARACTERISTICS WHEN UNDERGOING ACTION OF FORCES.

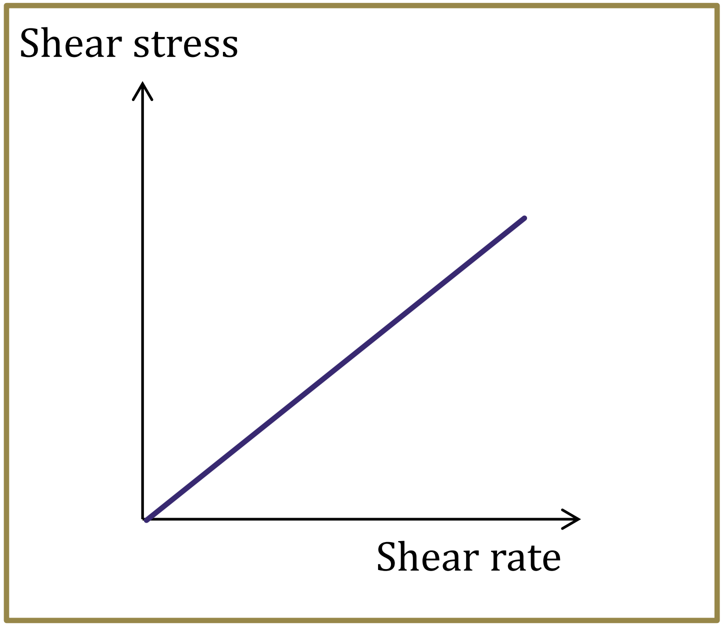
- The rheological properties of materials are important as they have great influence on the handling characteristics of materials!

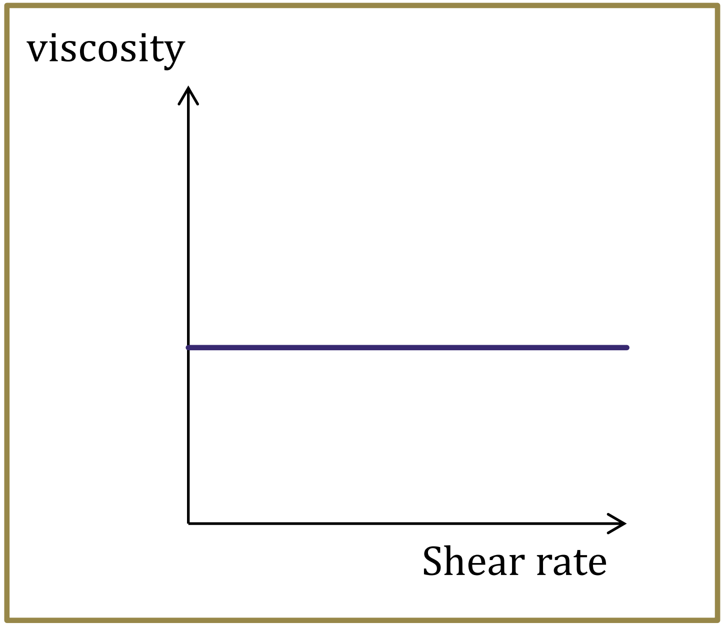
FLUIDS AND VISCOSITY

❖ NEWTONIAN FLUIDS

$$F = \eta A \frac{\Delta v}{\Delta x} \qquad \frac{F}{A} = \eta \frac{\Delta v}{\Delta x}$$

SHEAR STRESS = VISCOSITY × SHEAR RATE

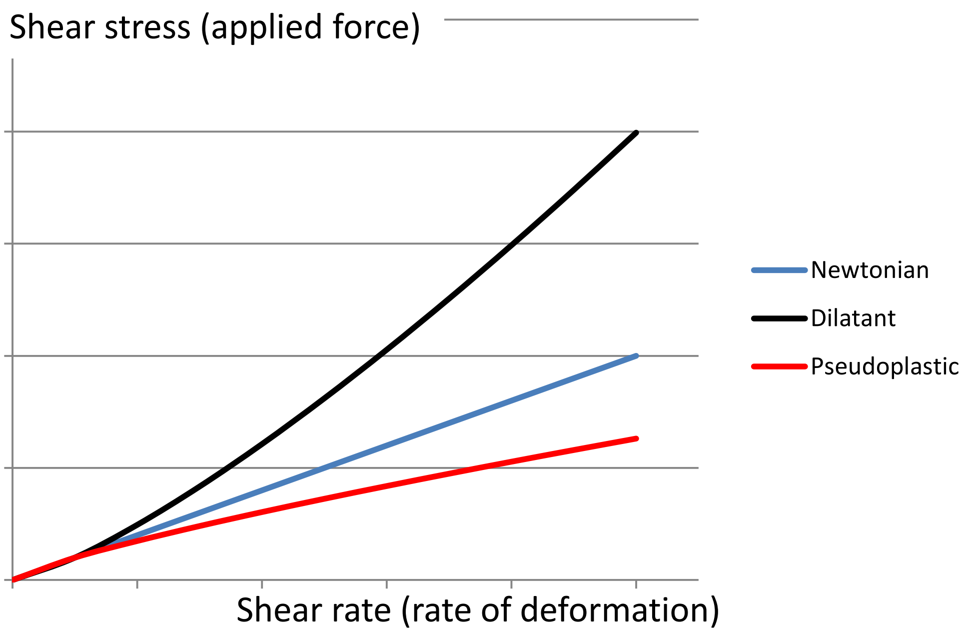


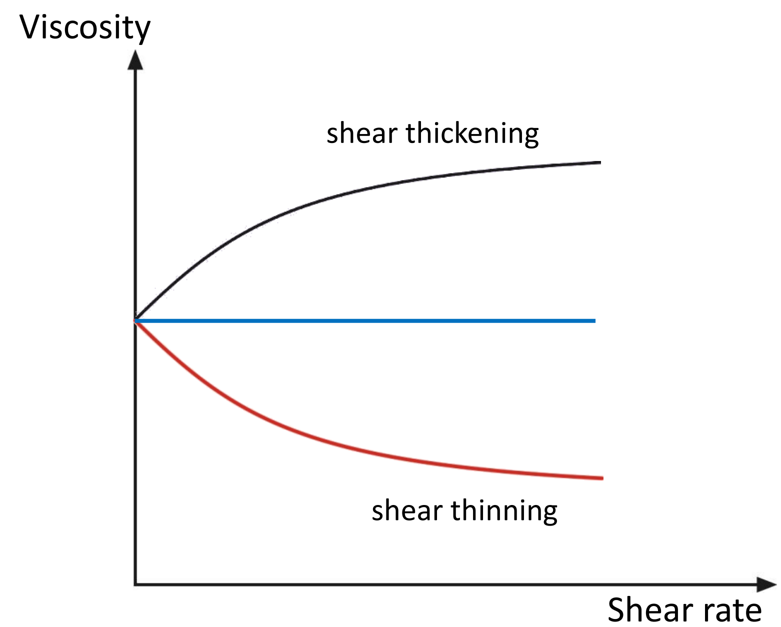


NON-NEWTONIAN FLUIDS

SHEAR STRESS = VISCOSITY × (SHEAR RATE)^n

n – flow index





__Dilatant__ **(n >1) –** *shear thickening*

- the more effort you put into stirring a dilatant material, the more resistant it becomes to stirring; typically the dilatant materials are pastes made up of a high concentration of solids (polymers, metal or oxides) dispersed in liquid

__Pseudoplastic__ **(n < 1) –** *shear thinning*

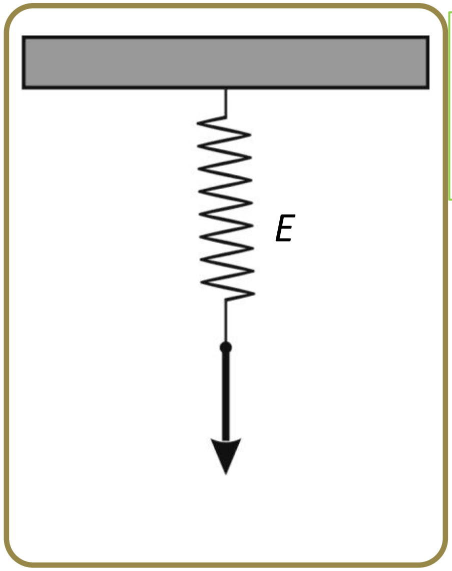
the more effort you put into stirring a pseudo-plastic material becomes easier to mix (silicone impression materials)

__Newtonian fluids__ n = 1

Viscoelasticity

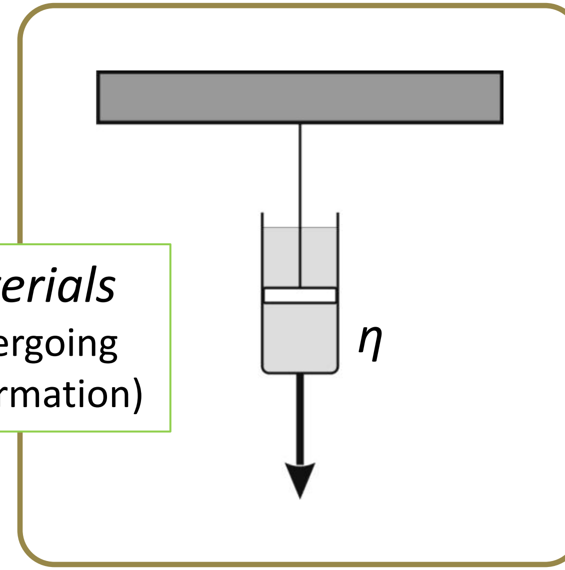
THE PROPERTY OF MATERIALS THAT EXHIBIT BOTH ELASTIC AND VISCOUS CHARACTERISTICS WHEN UNDERGOING ACTION OF FORCES.

$$\sigma = E\varepsilon$$

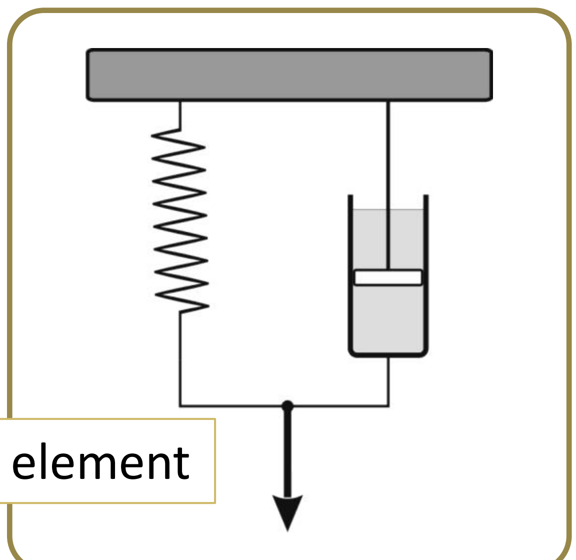


Elastic materials
(i.e. materials undergoing full elastic recovery)

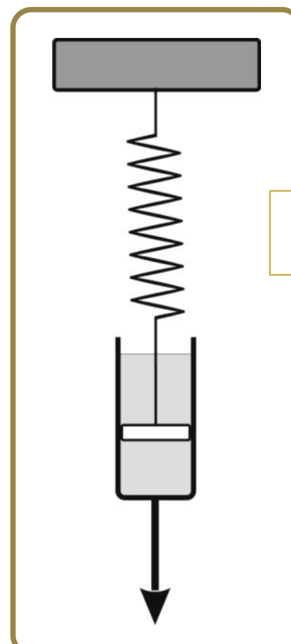
Viscous materials
(materials undergoing permanent deformation)



Visco-elastic materials

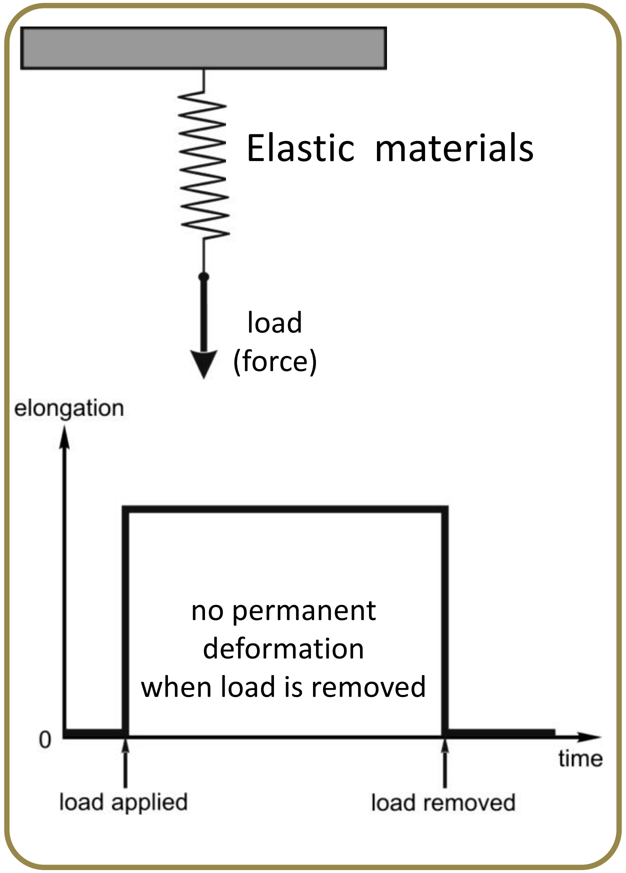


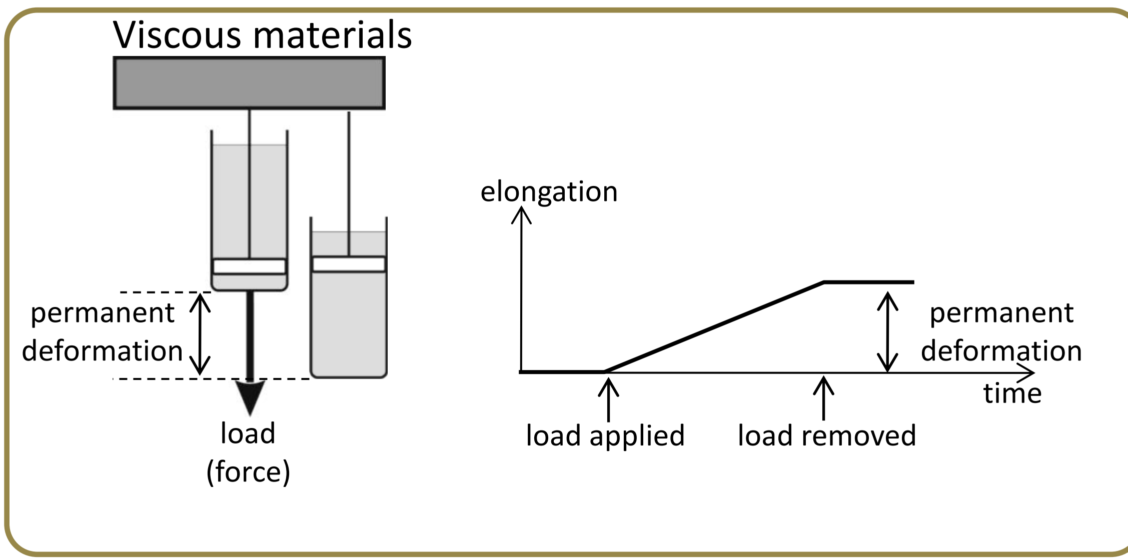
Kelvin-Voigt element



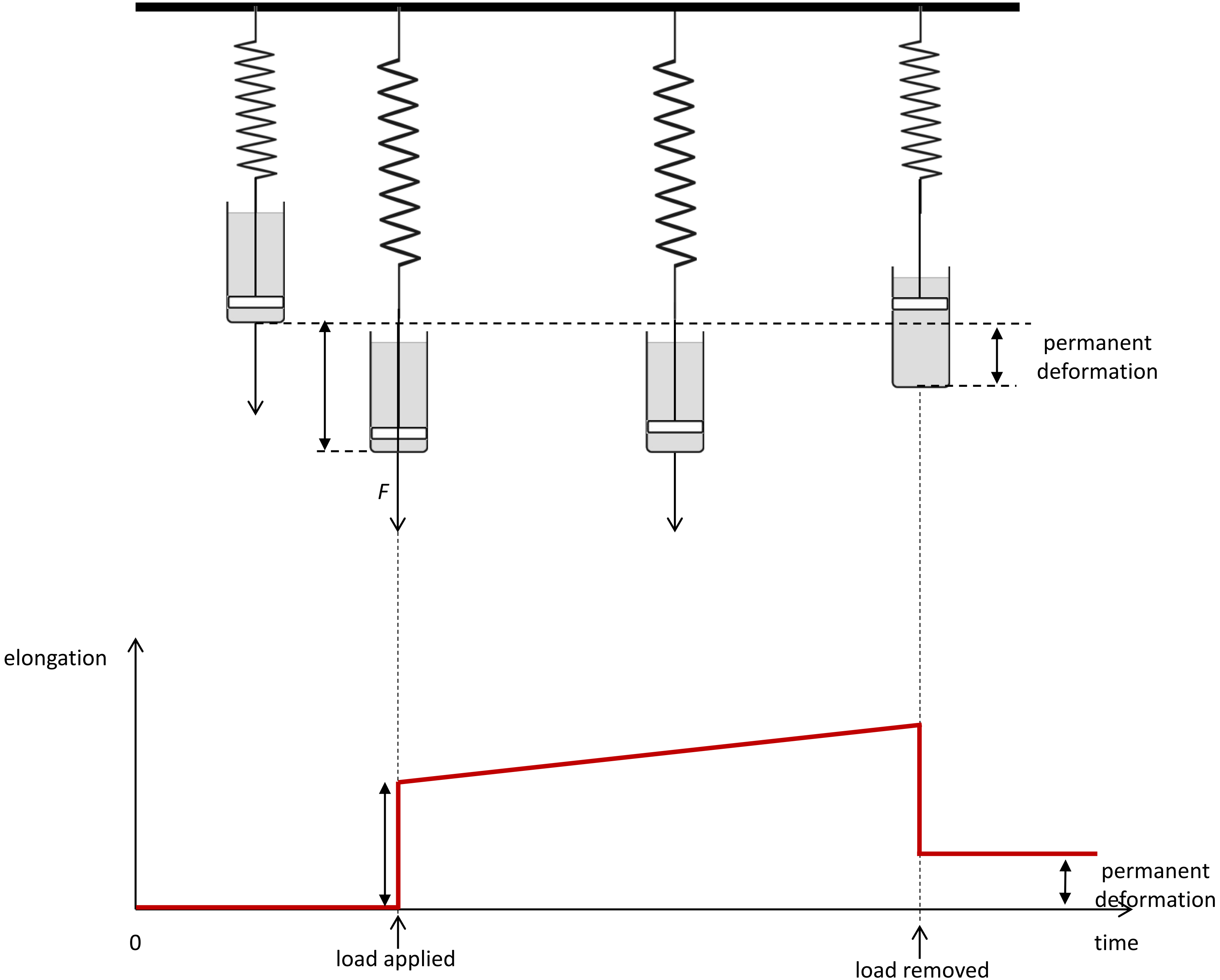
Maxwell element

ISOTONIC CONDITIONS – CONSTANT LOAD

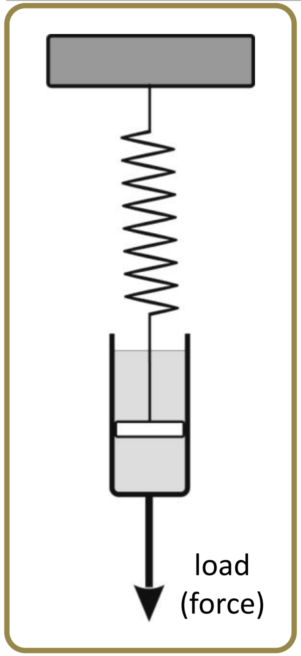


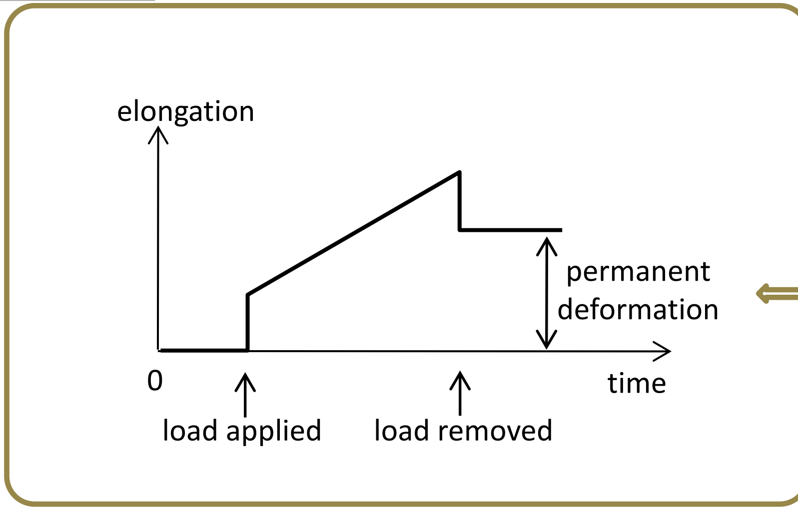


The Maxwell Element



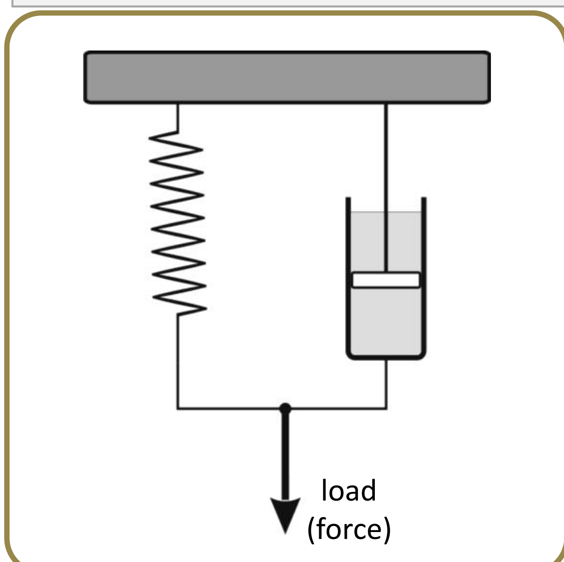
The Maxwell Element

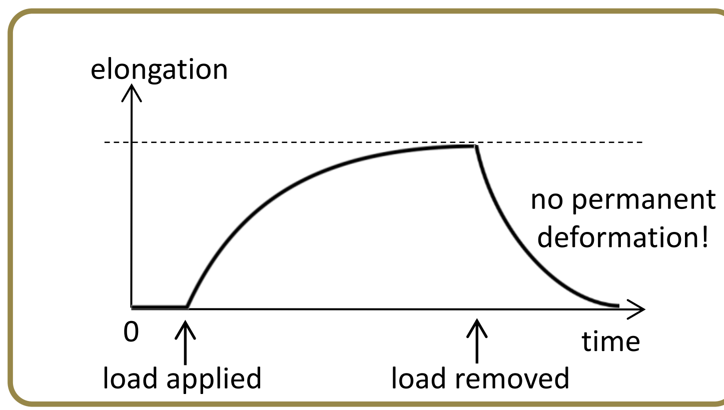




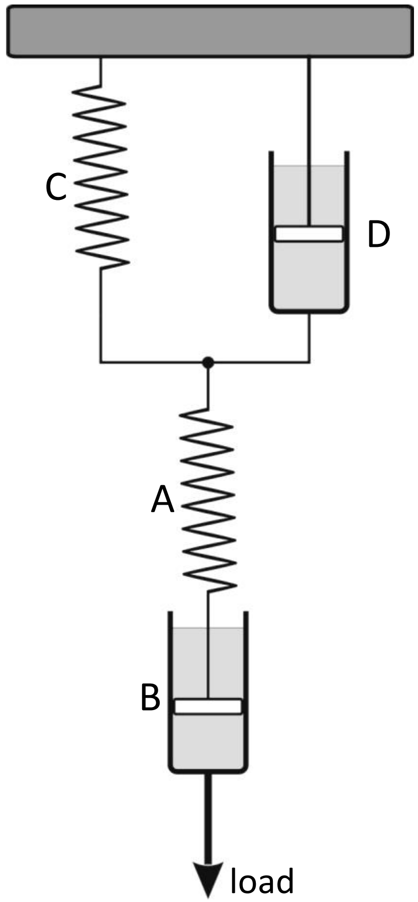
THE MAGNITUDE OF PERMANENT DEFORMATION IS A FUNCTION OF TIME!

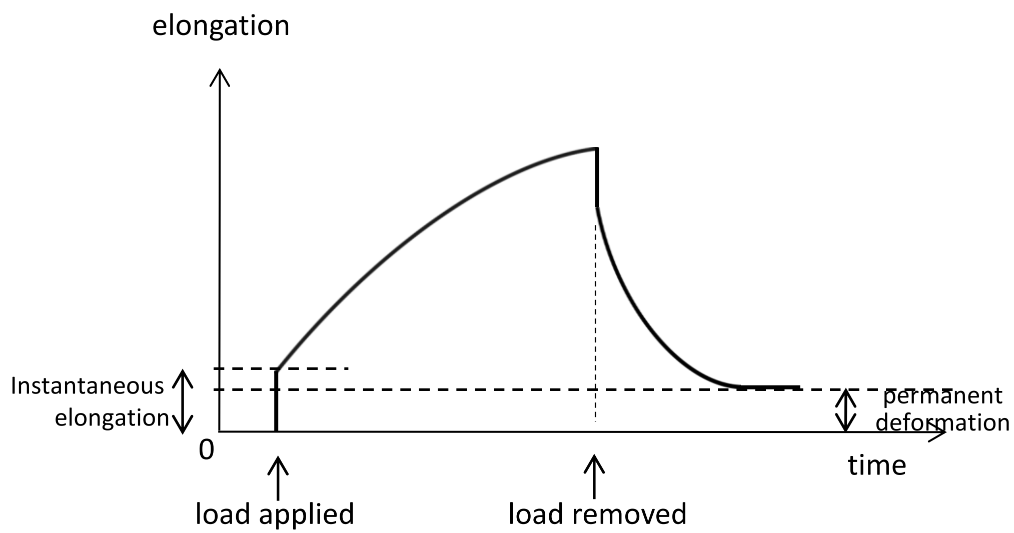
The Kelvin-Voigt Element





Combination of the Maxwell and Kelvin-Voigt element





CLINICAL SIGNIFICANCE:

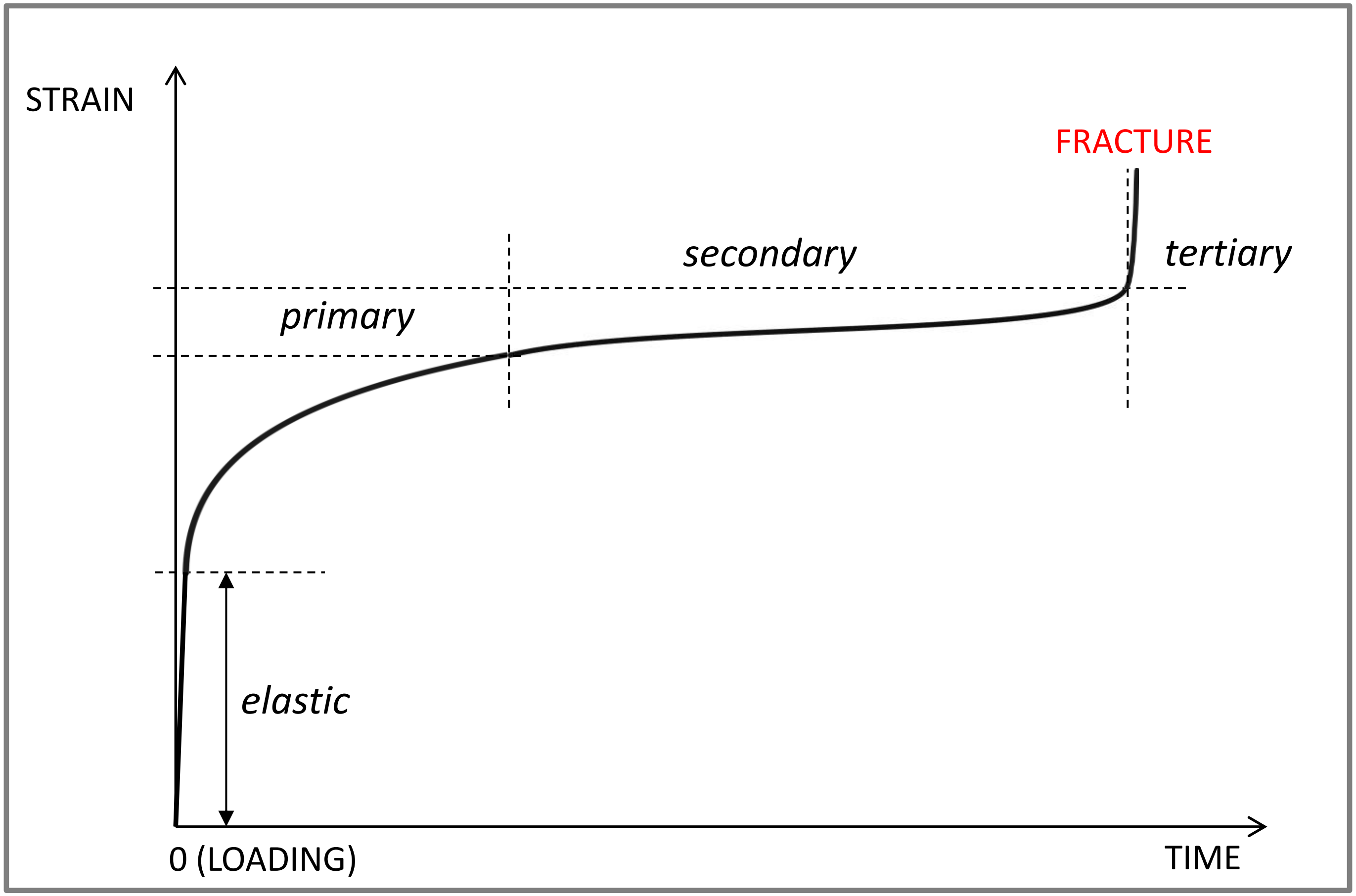
A NUMBER OF DENTAL IMPRESSION MATERIALS EXHIBIT VISCOELASTIC PROPERTIES. SUCH MATERIALS MAY BY DISTORTED DURING REMOVAL FROM MOUTH (ELASTOMERIC IMPRESSION MATERIALS)

THE DEGREE OF DEFORMATION DEPENDS ON THE:

- FORCE APPLIED,
- <u>TIME (!)</u> FOR WHICH THE FORCE IS APPLIED.

CREEP

- time dependent deformation under <u>constant stress</u>



If a load on a material being tested is applied for ***time long enough*** a permanent deformation may occur even though the stress on the material is below the yield stress (the elastic limit)!

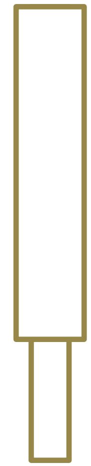
CREEP CAN BE A PRECURSOR TO FRACTURE OF A MATERIAL!

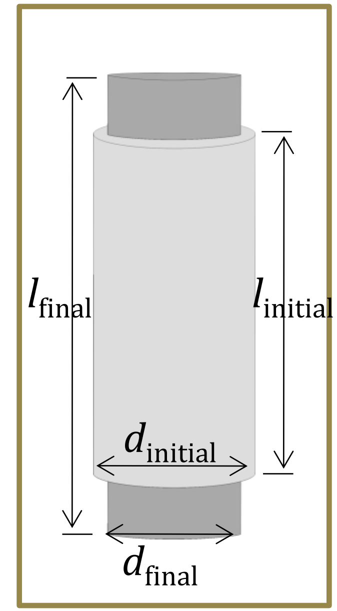
AS A SAMPLE MATERIAL IS SUBJECTED TO TENSILE STRES THE REDUCTION IN DIAMETER OCCURS

THICKNESS VS. LENGTH:

<u>POISSON'S RATIO</u>

The ratio of *transverse strain* $\varepsilon_{trans.}$ (measure of the <u>decrease</u> in thickness) of a body being pulled (under a tensile force) to its *axial strain* (measure of the <u>increase</u> in length, extension).





$$\varepsilon_{trans.} = \frac{d_{initial} - d_{final}}{d_{initial}}$$

$$\varepsilon_{axial} = \frac{l_{initial} - l_{final}}{l_{initial}}$$

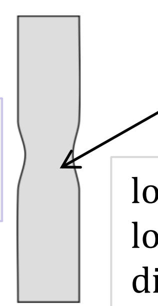
<u>POISSON'S RATIO:</u>

$$\nu = -\frac{\varepsilon_{trans.}}{\varepsilon_{axial}}$$

Concrete	0.1 - 0.2
Enamel	0.33
Rubber	~0.5

NECKING:

NECKING
-reduced cross-section in localised region



local inhomogenity, local variaton in dimensons

Example:
Poisson ratio for rubber

$$\varepsilon_{trans.} = \frac{d_{initial} - d_{final}}{d_{initial}}$$

$$\varepsilon_{trans.} = \frac{d_{initial} - 0.5\, d_{initial}}{d_{initial}} = 0.5$$

$$\varepsilon_{axial} = \frac{l_{initial} - l_{final}}{l_{initial}}$$

$$\varepsilon_{axial} = \frac{l_{initial} - 2l_{initial}}{l_{initial}} = -1$$

$$\nu = -\frac{\varepsilon_{trans.}}{\varepsilon_{axial}} = -\frac{0.5}{-1} = 0.5$$