Mechanical properties of dental material

<u>Mechanical properties</u>: describe the ability of the material to resist forces and their effects on the bodies. Examples of the mechanical properties are stress, strain, strength and stiffness.

One of the most important properties of dental material is the ability to withstand the various mechanical forces placed during their use. Mechanical properties are important in understanding and predicting the behavior of a material under load, such as the restorative materials must withstand forces either during fabrication or mastication.

- Whenever force acts on a body tending to produce deformation, a resistance that is developed to the external force application. The internal reaction is equal in intensity and opposite in direction to the applied external force and is called as **stress.**

<u>Stress:</u> is the force per unit area induced in a body in response to some externally applied force.

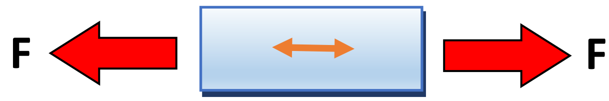
$$\text{Stress } (\sigma) = \frac{\text{Force}}{\text{Unit area}}$$

several types of stress may result when a force is applied to the material, these forces are compressive, tensile, shear, twisting movement and bending movement (flexure). Each type of stress is accompanied by the same type of strain.

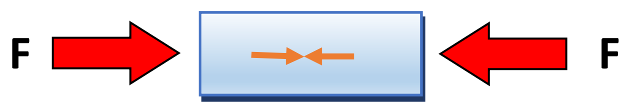
The unit of stress is the unit of force {Newton (N)} divided by a unit of area, and is commonly expressed as Pascal (1 Pa = 1 N/m^2 = 1 MN/mm^2).

Types Of Stress:

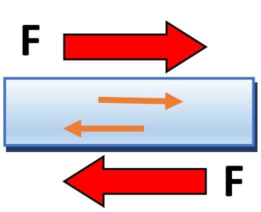
1. **Tensile stress:** it results from two sets of forces directed away from each other in the same straight line or when one end is constrained and the other end is subjected to a force directed away from the constraint; it is accompanied by tensile strain. Examples: enamel: 10 Mpa, dentin: 106 Mpa, amalgam: 32 Mpa.



2. **Compressive stress:** It results from two sets of forces directed toward each other in the same straight line or when one surface is constrained and the other is subjected to a force directed toward the constraint. lt is accompanied by compressive strain. Investment material, restorative materials and models should have high compressive strength. Examples: enamel: 384 Mpa, dentin: 297 Mpa, amalgam: 388Mpa.



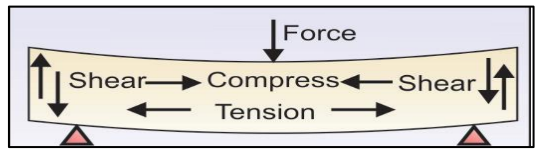
3. **Shear stress:** Shear is the result of two sets of forces directed parallel to each other (not along the same straight line) which is applied to one part of the body in one direction, and the rest is being pushed in the opposite direction. The result is sliding of the molecules over each other. It is accompanied by shear strain . Examples: enamel: 90 Mpa, dentin: 138 Mpa, amalgam: 188 Mpa.



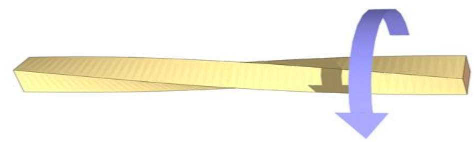
Shear force is the force which causes tearing a paper or a card. If one part of the crown is in occlusion while the rest is not, shear stress will develop.

4. <u>Flexural stress (bending stress):</u> it is the force per unit area of a material that is subjected to flexural loading.it results from an applied bending moment.

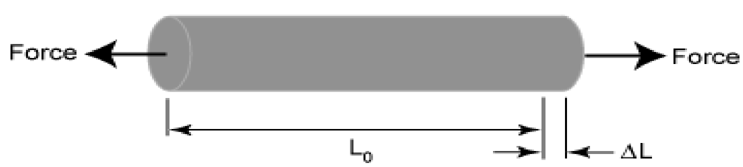
Usually, three types of stresses occur at the same time If a piece of metal is being bending it will exhibit tensile stress on the outer surface, compressive on the inner and shear stress in the middle.



5. <u>Torsion stress:</u> Force per unit area of a material that is subjected to twisting of a body.



- When external force or load is applied to a material the phenomena of **strain** occurs; i.e. the change in the dimensions of the material.



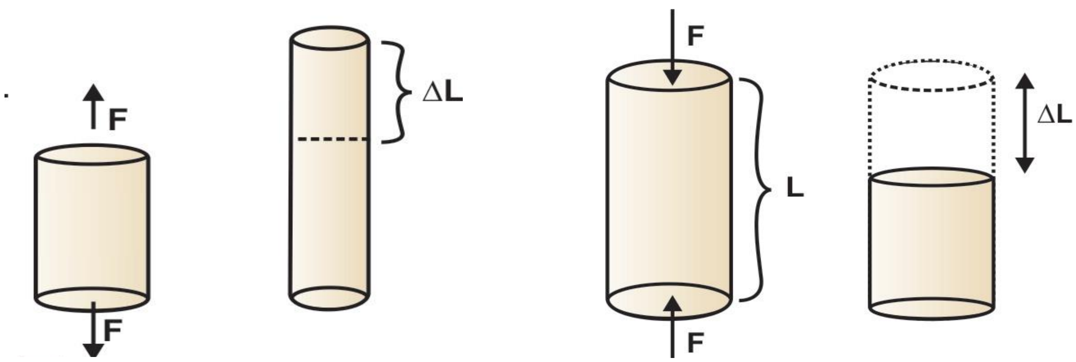
<u>Strain (Ɛ):</u> is the change in length (dimension) or deformation per unit length (dimension) caused by externally applied force. Strain is denoted as 'ε'. It has no unit of measurement. Examples of some dental materials strain are: acrylic: 1.5%, Co/Cr: 4%, stainless steel: 35%.

$$\text{Strain} = \frac{\text{Change in length } (\Delta L)}{\text{Original length } (Lo)} = \frac{L - Lo}{Lo} = \frac{\Delta L}{Lo}$$

L=final length

Lo= original length

- Strain under tensile stress is an **elongation** in the direction of loading.
- Strain under compression is **shortening** of the body in the direction of loading.



Elongation **Shortening**

- **Elongation:** The deformation that results from the application of tensile stress. An alloy with high percent of elongation can be bent or adjusted without danger of fracture.

$$\text{Elongation} = \frac{\text{Increase in length}}{\text{Original length}} \times 100$$

Types of the strain

1. **Temporary of elastic or recoverable strain:** the material is returned to its original length after removal of the applied force.
2. **Permanent or plastic or unrecoverable strain:** the material is **not** returned to its original length after removal of the applied force. The material may remain deformed.

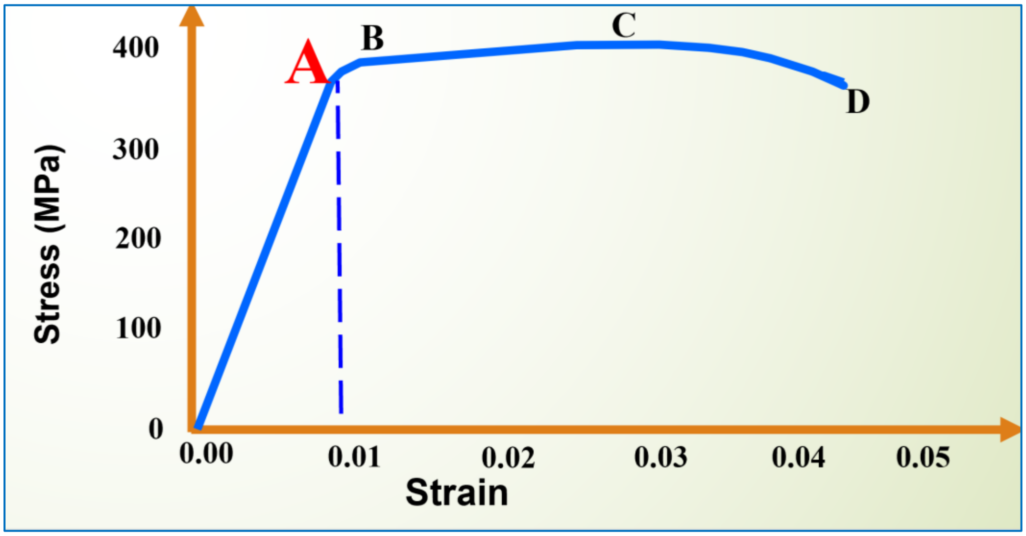
Stress —Strain Curve (S-S curve)

A convenient means of comparing the mechanical properties of materials is to apply various forces to material to determine the corresponding values of stress and strain. A plot of the corresponding values of stress and strain is referred to as "s-s curve". The relationship between stress and strain is used to study the mechanical properties of dental materials. The stress is plotted vertically and the strain is plotted horizontally. As the stress is increased the strain is increased.

- **Proportional limit** (point A)**:** The greatest stress that a material will sustain without a deviation from the proportionality of stress to strain.

- **Elastic limit** (point A)**:** The greatest stress to which the material can be subjected such that it will return to its original shape and dimension when the stress is removed (maximum stress that a material will sustain without permanent deformation).

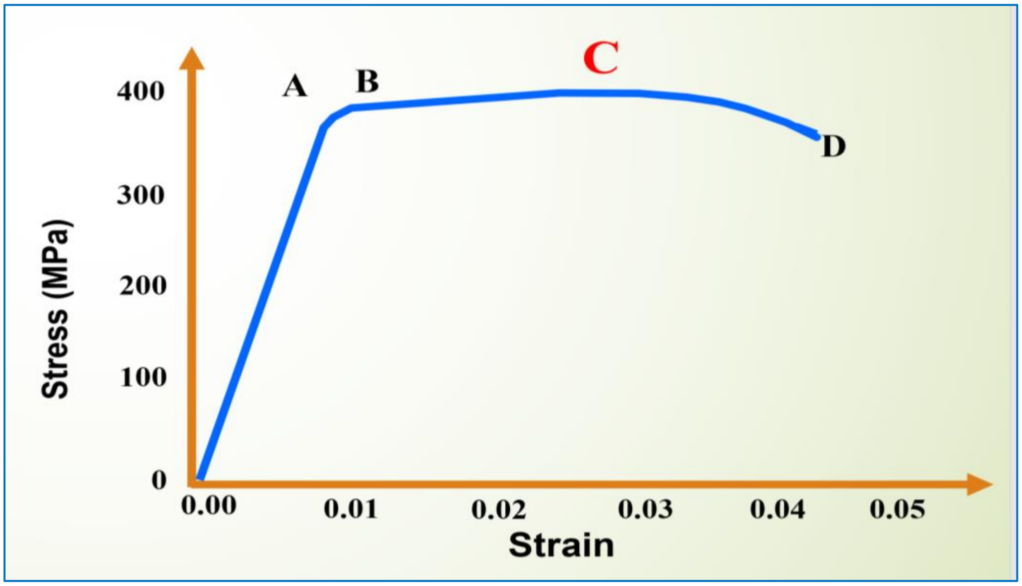
Elastic limit deals only with the elasticity of the material, but proportional limit deals with proportionality stress and strain. Theoretically, the values will be same.



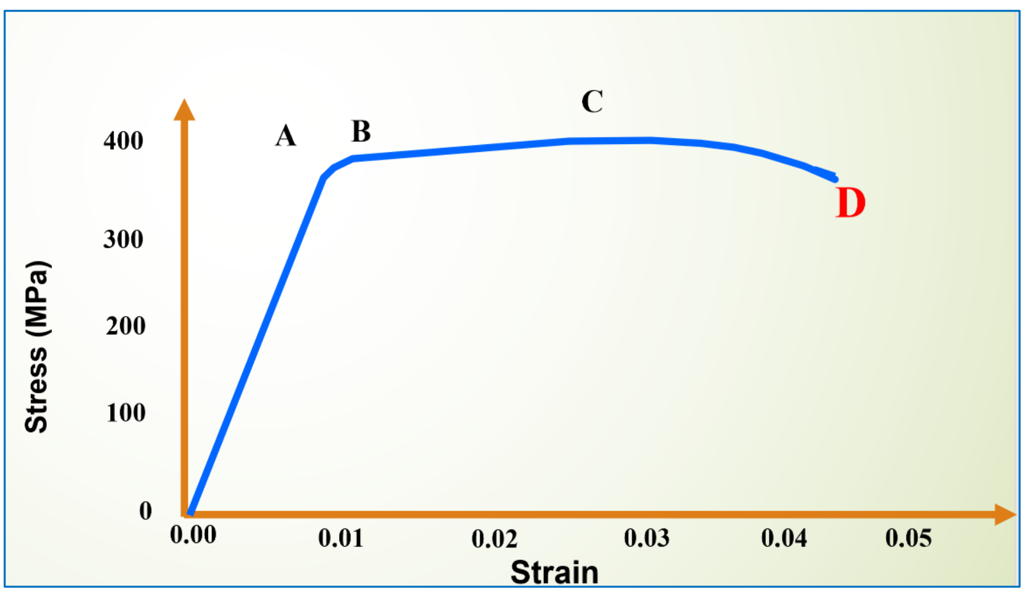
- The region of the s-s curve before the proportional limit is called the **"elastic region"** (from 0 to A).
- The region of the curve beyond this proportional limit is called as **"plastic region"** (from A to D).

If the stress is increased beyond the elastic limit or the proportional limit, the material will deform and if we remove the stress the material will **not** return to its dimension. This is called **plastic deformation**. If the stress is increased more and more, the material will break.

- **Ultimate Strength** (point **C**): is the maximum stress that a material can withstand before failure. Examples: acrylic: 8000 PSI, Co/Cr:100000 PSI, stainless steel: 15000 PSI.



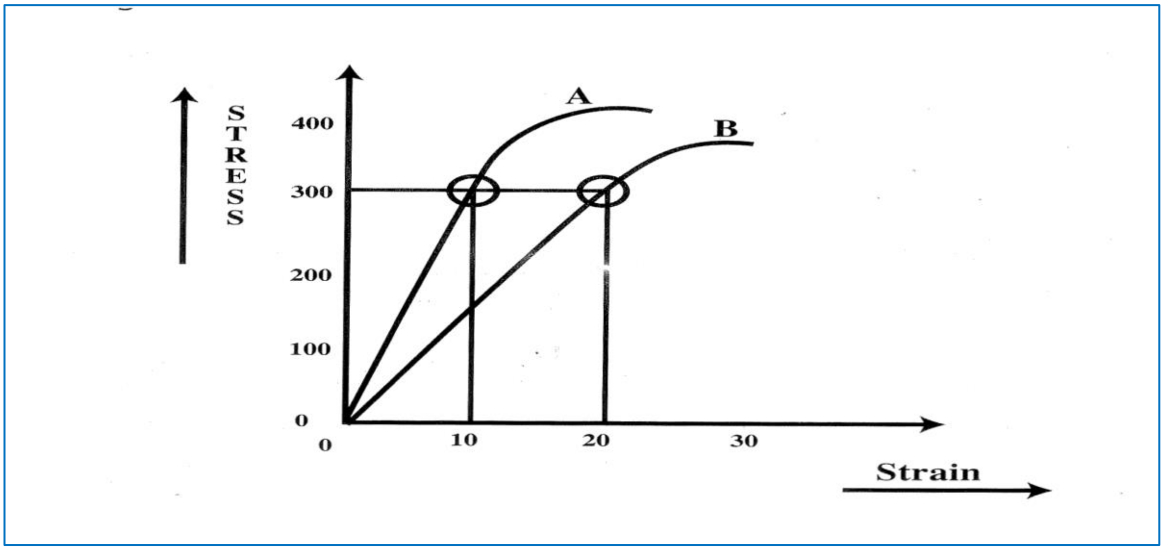
- **Fracture Strength** (point **D**): The stress at which a material fracture. The fracture strength is not necessarily the ultimate stress at which the material will fracture.



- **<u>Modulus Of Elasticity (Elastic Modulus):</u>** represents the stiffness or rigidity of a material within the elastic range. It is the constant of proportionality. If any stress value equal to or less than the proportional limit is divided by its corresponding strain value, a constant of proportionality will result that called the elastic modulus. It can be determined from a stress-strain curve by calculating the ratio between the stress and strain on the slope of the linear region from the following equation: **Modulus of elasticity = Stress / Strain**

Unit of the elastic modulus was same unit of stress.

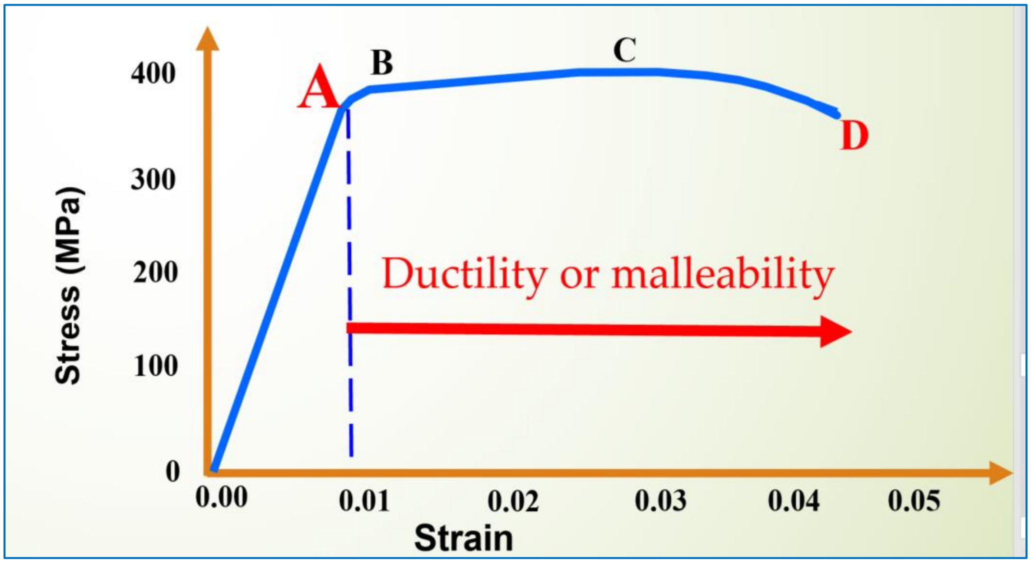
Examples: enamel: 84Gpa, dentin: 17Gpa.



- **<u>Flexibility:</u>** The higher strain which occurs when the material is stressed to its proportional limit (the amount of strain up to the elastic limit), So that flexibility is the total amount of elastic strain in a material.

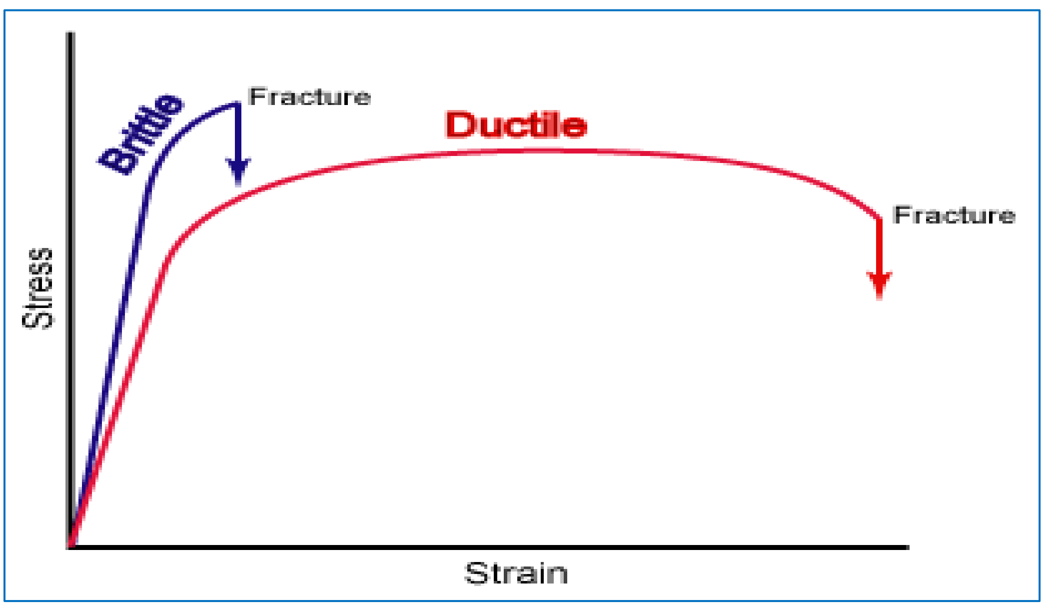
- **<u>Ductility:</u>** It is the ability of the material to withstand permanent deformation under **tensile stress** without fracture; it depends on plasticity and tensile strength. It's the ability of the material to be drawn into a fine wire. Examples: gold: most ductile.

- **Malleability:** It is the ability of the material to withstand permanent deformation under **compressive stress** without fracture. It's the ability of the material to be drawn into a sheet. Examples: gold: most malleable.

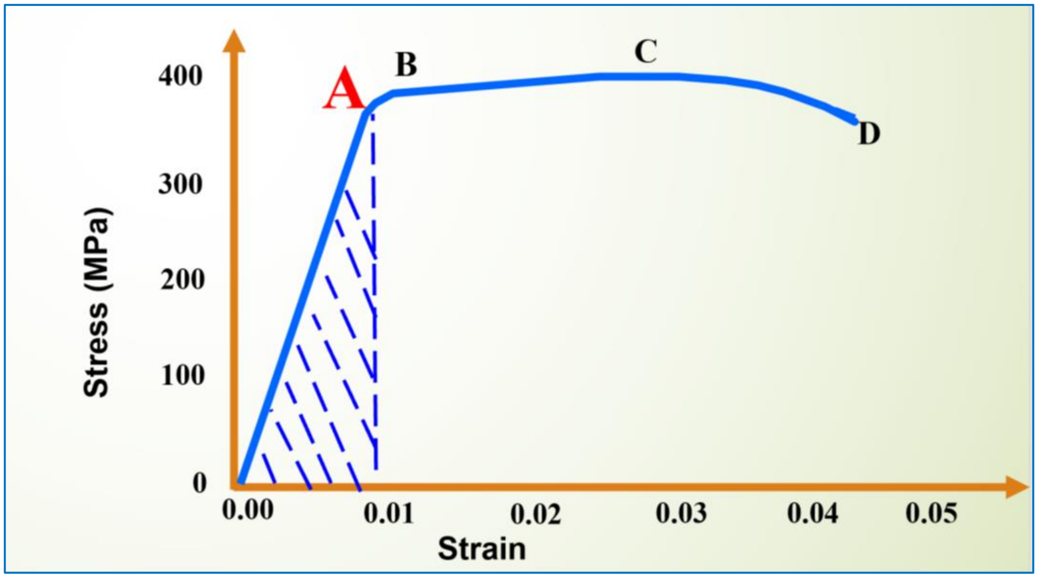


- **Elastic strain = flexibility.**
- **Plastic strain = ductility or malleability.**

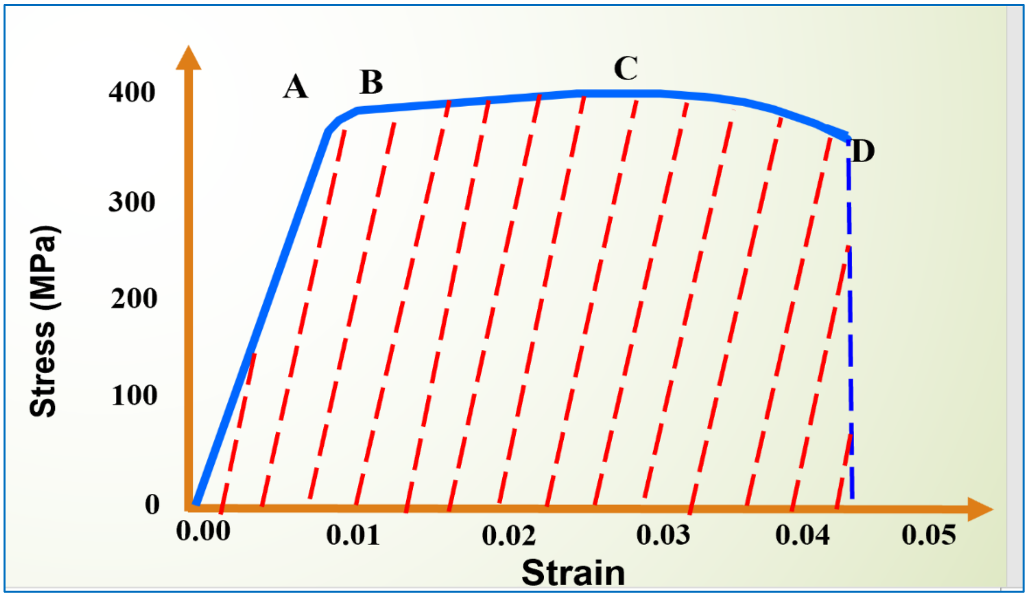
- **Brittleness:** It is the opposite of ductility; it requires lack of plasticity.



- **Resilience:** The amount of energy absorbed by a structure when it is stressed within the proportional limit. Or it is the energy needed to deform the material to its proportional limit.

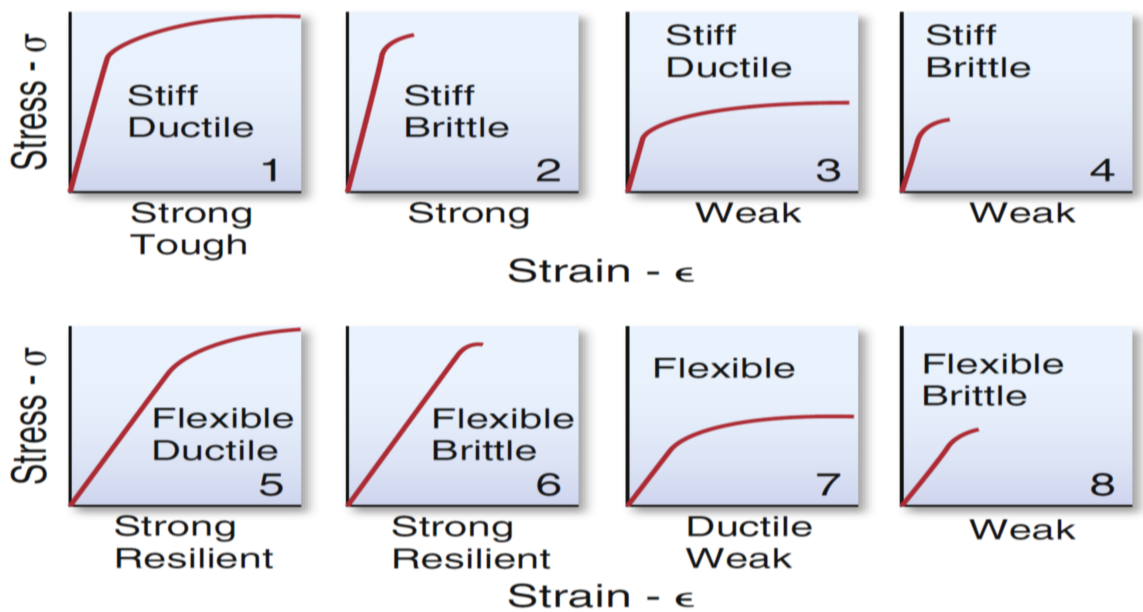


- **Toughness:** It is the total work or energy required to break the material. It's the total area under the stress-strain curve. It requires strength and plasticity.



Properties of Stress-Strain Curves

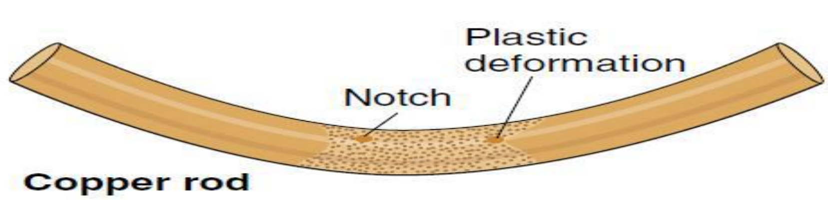
The shape of a stress-strain curve and the magnitude of stress and strain allow the classification of materials as regard to their properties e.g. weak, strong, flexible, stiff, ductile, brittle, resilient and tough.



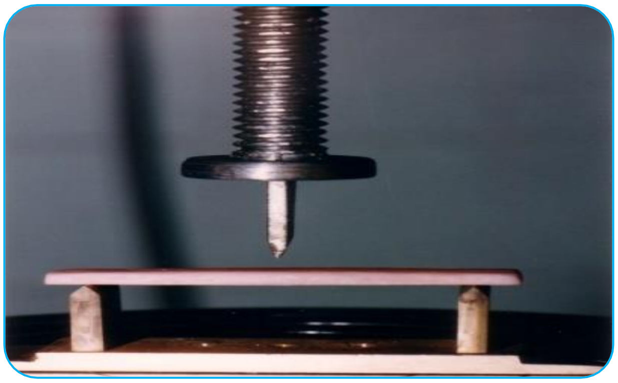
- **Strength:** is the measure of the resistance of the material to the externally applied force.

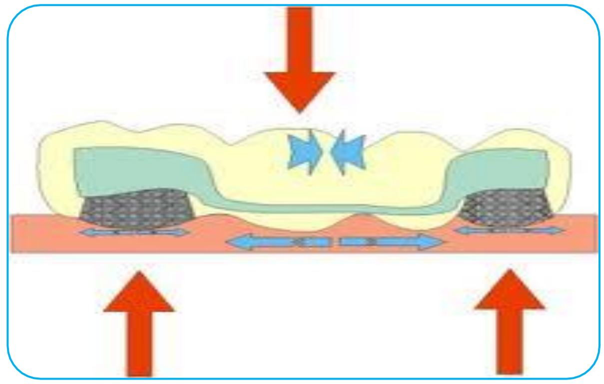
- **Fatigue:** is the fracture of a material when subjected to repeated (cyclic) small stresses below the Proportion limit.

It is when the material is constantly subjected to change in shape due to frequent application of force. The repeated application of small stress (below the Proportion limit) to an object causes tiny (very small) cracks to be generated within its structure. These tiny cracks do not cause failure immediately, with each application of stress, the cracks grow until the material breaks. Metal, ceramics can all fail by fatigue.

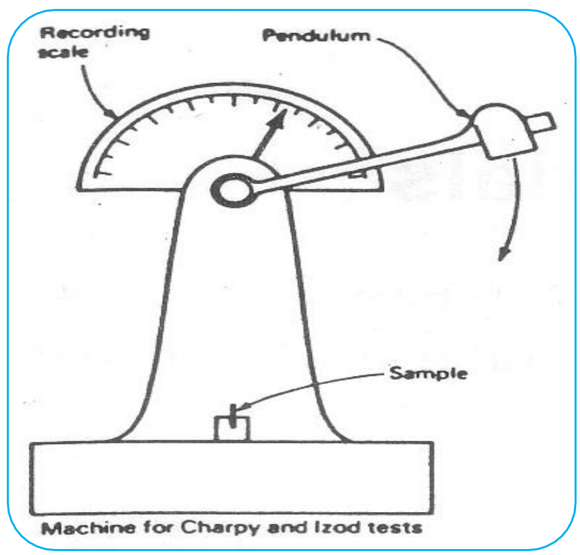


- **<u>Transverse strength:</u>** It is the strength of the middle of a beam, which is supported only at its ends. It is important in dental bridges. Examples: composite: 139Mpa, amalgam: 124Mpa.

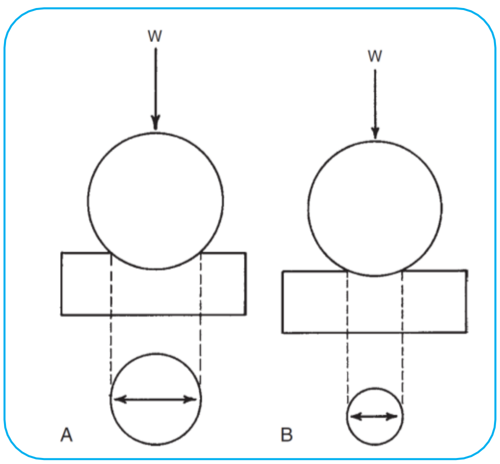




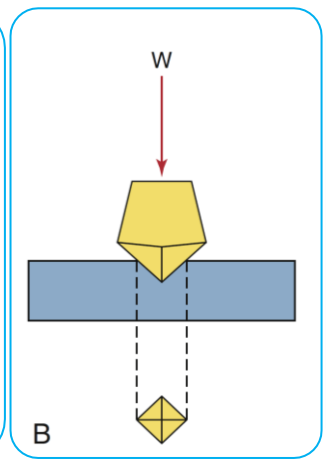
- **<u>Impact strength:</u>** It is the ability of the material to break on sudden impact. Low impact strength means brittle material, like dropping of the denture.



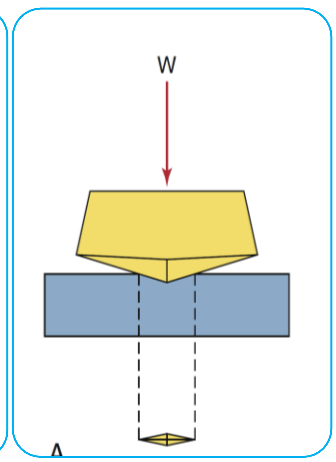
- **<u>Hardness:</u>** It is the resistance of the material to deformation caused by penetrating or scratching the surface. It is done either by using steal ball (Brinell or Rocwell test) or using diamond (Vickers and Knoop test). The higher the number, the harder the material. Examples: **Brienell hardness number**: acrylic: 22, dentin:65, gold: 250. **Knoop hardness number**: enamel: 343, dentin:68, Co/Cr: 391.Kg/mm^2.



Brinell's hardness test



Vickers hardness test



knoop hardness test