Mechanical properties

Mechanical properties are a group of physical properties that describe the behavior of materials under a ***force*** or a ***load***. They are important because most restorative materials must withstand forces in service i.e. during fabrication or mastication. In general, the properties of a solid under applied load are determined by the nature and / or strength of its atomic bonding forces.

The range of masticatory or biting forces in the oral cavity varies markedly from one area to another, from one individual to another, from males to females and from adult to child. The average biting forces on permanent teeth is about 665, 450 and 220 N on molars, bicuspids and incisors, respectively. Patients with fixed bridges exert about 40% of the forces exerted by patients with natural dentition. A further decrease is obtained in patients with complete or removable partial dentures; i.e about 15%.

I Force

The result of an applied force on a body is a change in position of rest or motion of the body. If the body to which the force is applied remains at rest, the force causes the body to deform. i.e. force is the action which causes one of the following reactions or all of them:
(1) Displacement,
(2) Acceleration,
(3) Deformation.

A force is defined by the following characteristics: speed, magnitude, point of application and direction. The speed of the force determines whether the force is static or dynamic.

The point of application and direction determines: whether the force is normal or tangential. The direction of force is characteristic of the type of force. Units of force are Newton (N) or Pound (lb).

Conversion factor 1 lb = 4.4 N.

I.1 Effect of force on a body

Equilibrium statement:
Generally, a body is in equilibrium:
(a) External equilibrium,
(b) Internal equilibrium.

(a) Any type of load should be balanced by an external reaction to be in external equilibrium, or the body will accelerate. e.g.
   (ai) two sets of forces equal and opposite in direction,
   (aii) a body sitting on a table will be balanced by the table.

(b) The body on which the force is applied being in an integral form is in an internal balance i.e. an internal reaction balances the external force. This internal reaction which resists the external force is known as ***stress***.

I.2 Stress

Stress is the internal reaction to the external force and is equal in intensity and opposite in direction to the applied external force. Both the applied force and the internal resistance are distributed over a given area of the body over which they are applied, so that the stress (σ) is designated as the force per unit area.

$$stress = \frac{force}{area} \qquad \text{or} \qquad \sigma = \frac{F}{A}$$

From the above equation we see that the stress in a structure varies directly with the external force and inversely with the area over which it is applied. Since the internal resistance to force applied is impractical to measure, the more convenient way is to measure the external force applied to the cross sectional area, which can be described as the applied stress. The units for measuring stress are Pa = N/m^2, MPa $=MN/m^2 = N/mm^2$ and lb/in^2.

I.2.1 Types of stress

Generally, there are two types of stresses:

I.2.1.1 Normal or Axial:

- Tensile stress (σ_t),
- Compressive stress (σ_c),

I.2.1.2 Tangential:

- Shear stress (τ).

Tensile stress (σ_t):

Tensile stress is induced in a body loaded by tensile force i.e. two sets of axial forces directed away from each other. Molecules making up the body must resist being pulled apart, (figure 21 a).

Compressive stress (σc):

Compressive stress is induced in a body loaded by compressive force i.e. two sets of axial forces directed towards each other. Molecules making up the body must resist being forced more closely together (figure 21 b).

Shear stress (τ):

Shear is the result of two sets of forces being directed towards each other or opposite each other but not in the same straight line i.e. parallel to each other (such that the distance between them will be close to zero). Molecules of such a body must resist sliding past one another. e.g. scissors are often called shears(fig. 21 c).

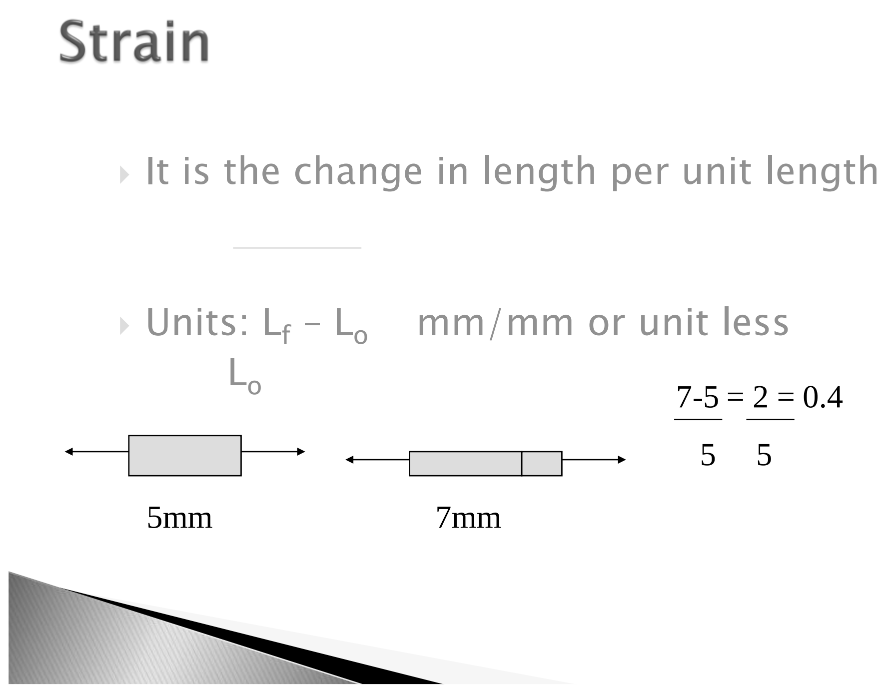
I.2.1.3 Complex stresses:

If the force applied to a dental restoration is not axial, which is in practice most common it may be resolved as a combination of compressive, tensile and shear stresses, or complex stresses pattern in the structure.

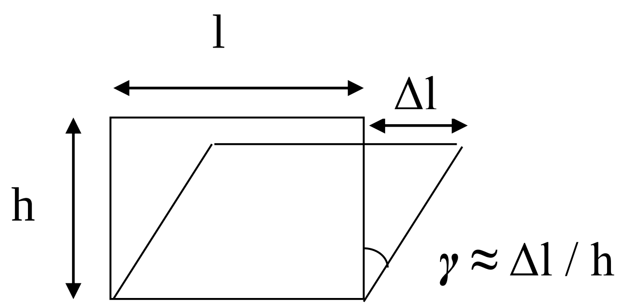
I.3 Strain

The ***deformation*** resulting from axial stress produced within the material is the change in length while the ***Strain*** is defined as the change in length per unit length it is designated by (ε) and is computed as

$$strain = \frac{deformation}{original\ length} \quad \text{or} \quad \varepsilon = \frac{l_{final} - l_{original}}{l_{original}} \quad \text{mm/mm or dimensionless}$$



Distortion results from tangential stresses. It is an angular deformation and it is designated by (γ).



$\gamma \approx \tan \gamma$ when the angle is small and it is measured in radians

I.3.1 Types of strain

Each type of stress is capable of producing a corresponding type of strain in the body i.e. tensile, compressive, shear and complex. Any type of those strains can be either elastic or plastic. ***Elastic*** strain can be recovered when the force or the load is removed. ***Plastic*** strain can not be recovered when the load is removed.

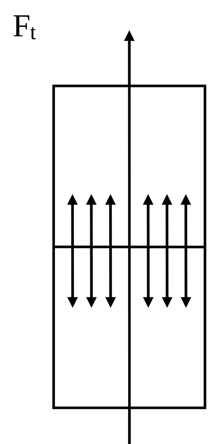


Figure 21 a Tensile stresses σ_t, as a reaction to tensile force F_t .

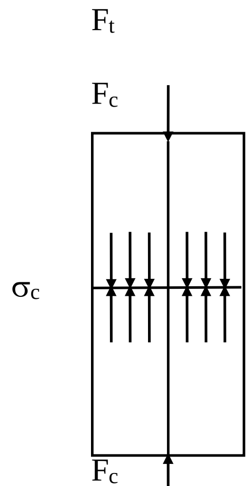


Figure 21 b Compressive stresses σ_C, as a result of compressive force F_C .

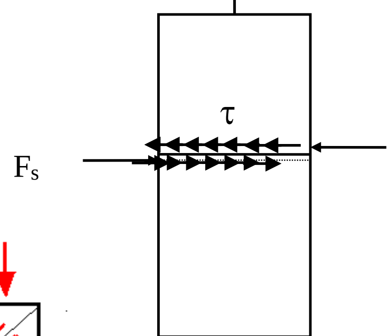


Figure 21c Shear stresses τ as a result of shear force F_s

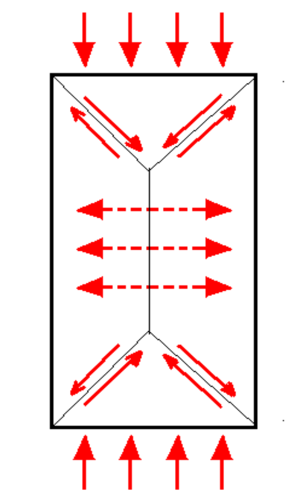


Figure 21d Complex stresses.

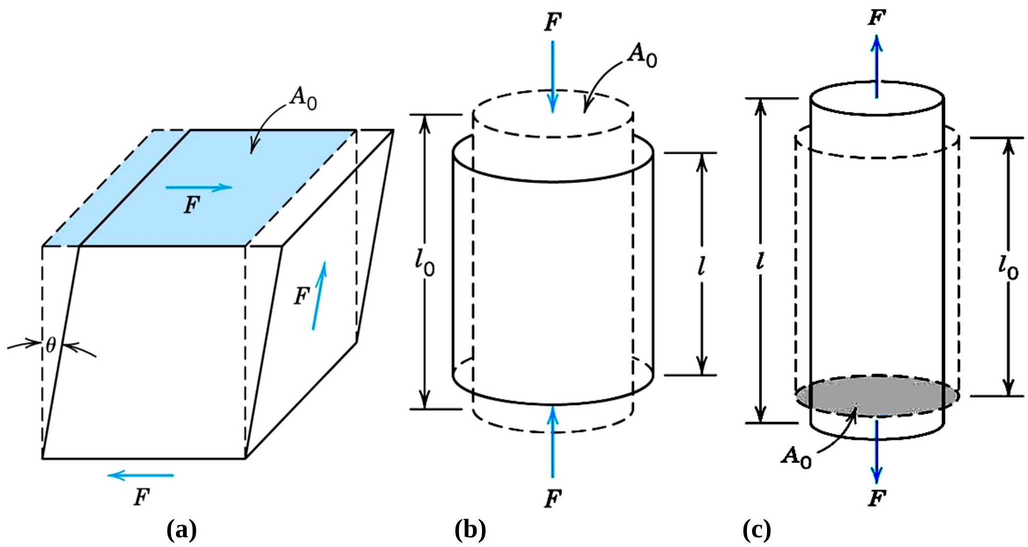


Figure 21 e: Tensile (a), compressive (b) and shear (c) stresses.

I.3.2 Poisson's ratio (μ)

During axial loading i.e. tension or compression, there is a simultaneous axial and lateral strain. e.g. under tensile loading, the material elongates in the axial direction and compressed in the lateral direction. Within the elastic range, the ratio of the lateral to the axial strain is called ***Poisson's ratio*** and is referred to as "μ". Poisson's ratio indicated that the reduction in cross section is proportional to the elongation during the elastic deformation.

$$\mu = \frac{\text{Lateral strain}}{\text{Axial strain}}$$

μ for rubber or plastic isotropic materials is approximately 0.5
μ for most dental material is approximately 0.3

Significance of poisson's ratio:

- It is related to the nature and symmetry of the inter-atomic bonding forces.
- It describes the material's pattern of deformation.
- It indicates the amount of lateral strain exerted by the filling on the axial walls of the cavity e.g. amalgam (μ = o.35) exerts greater pressure on the cavity walls compared to composites (μ = o.24).
- It is an important parameter in stress analysis.

Table 1 Values of Poisson's Ratio of Some Restorative Dental Materials

Material	Poisson's ratio (average value)
Acrylic restorative resin	0.35
Amalgam	0.35
Zinc phosphate cement	0.35
Enamel	0.30
Composite resin	0.24

II Stress-strain curves

If we plot a graph for the stress and the corresponding strain of a dental material subjected to load we find, Figure 22:

Relation between stress and strain:

Until a certain stress value at ***A*** we find that the strain is proportional to the stress induced i.e. if the stress is doubled the amount of strain is also doubled. This part of the curve obeys Hook's law which states that " stress is directly proportional to the strain until a stress value known as the proportional limit ".

II.1 Proportional limit (The value of stress at A)

It is the greatest stress the material can withstand without deviation from Hook's law or from the law of proportionality between stress and strain.

II.2 Elastic limit (The value of stress at B)

It is the greatest stress the material can withstand without permanent deformation resulting. It is therefore, describing the elastic behavior of the material. For most of the materials the proportional limit and the elastic limit represent the same value, they differ however in the fundamental concept.

II.3 Yield strength (The stress value at C)

The stress at which the material begins to function in a plastic manner. At this stress a limited permanent strain has occurred in the material. The amount of permanent strain is arbitrarily selected, may be 0.1%, 0.2% or 0.5% of permanent strain, the amount of which may be referred to as ***percent offset***. e.g. point ***c*** (figure 19) is the yield strength at 0.1%.

The yield strength is defined as the stress at which the material exhibits a specified limited deviation from proportionality of stress and strain. If you remove the load you will find that the material does not return to its original dimensions. This is usually a functional failure.

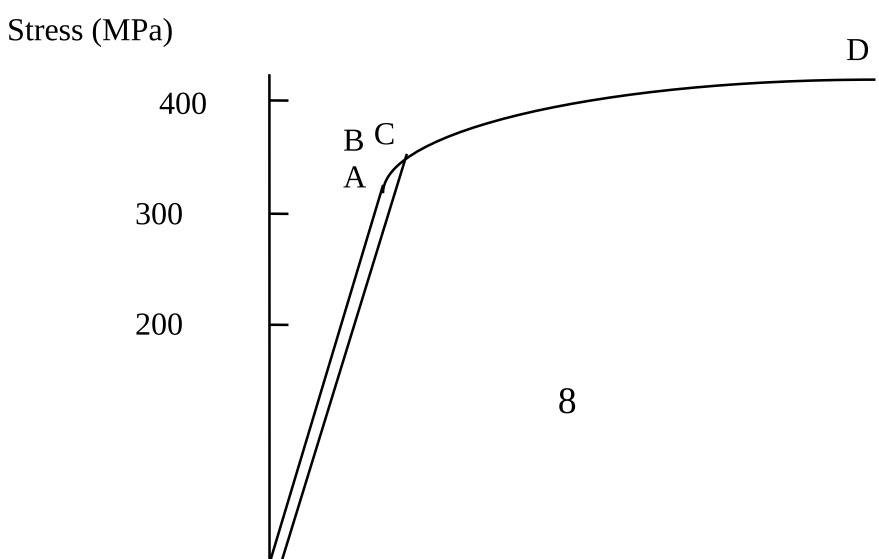
<u>Clinical significance:</u>

- During construction of an appliance from a wire, the applied force should induce a stress greater than the yield strength of the wire's material to allow permanent shaping.
- During adjustment of a metallic restoration, the applied force should induce a stress greater than the yield strength of the material to produce permanent deformation e.g. burnishing.
- During function, the restoration should not be subjected to stresses above the yield strength, otherwise, permanent deformation would occur and the restoration will no more be fitting the purpose in spite of the fact that it did not break. This is considered as a ***functional failure***.

II.4 Ultimate strength (The stress value at D)

If you carry on stressing the material beyond the yield strength you will find that at a point the sample will fracture (fail). The maximum stress the material can withstand before fracture is called ultimate strength. It can be ultimate tensile, compressive or shear strength depending on the mode of loading.

<u>Significance:</u> Data on dental materials usually specify values for ultimate strength, its use as a criterion for evaluating their relative merits should not be over emphasized. The yield strength is of greater importance than ultimate strength, since it is a gage of ***when***, the material will start to deform.



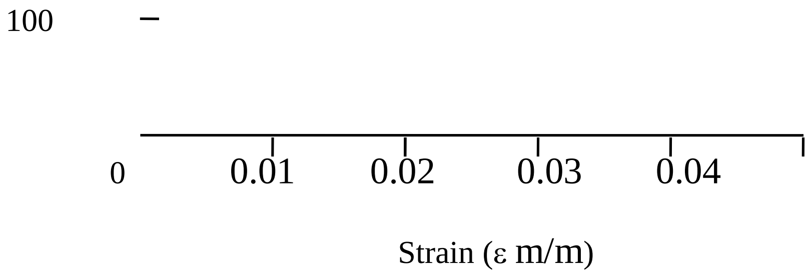


Figure 22a Stress-Strain Curve

II.5 Modulus of elasticity (Young's Modulus) "E"

The modulus of elasticity or Young's modulus denoted by "E" represents the stiffness of the material within the elastic range. It is the constant of proportionality between stress and strain and represents the slope of the elastic portion of the stress-strain curve. It can be calculated from the following relation:

$$E = \frac{\sigma}{\varepsilon} \text{ kg/cm}^2 \text{ or MPa or lb/in}^2$$

The modulus of elasticity of a material does not change either tested under compression or tension.

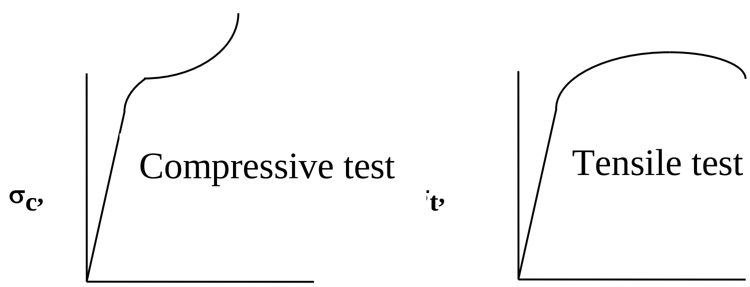


Figure 22b Same slope of the elastic part of both stress strain curves of one material tested under compression and tension

The elastic qualities of a material represent a fundamental property of the material, they depend on the interatomic or intermolecular forces of the material. The stronger the basic attraction forces, the greater are the values of the modulus of elasticity. This property is independent of any heat treatment or mechanical treatment but it is quite dependent on the composition of the material. Materials such as rubber and plastics have a low value for modulus of elasticity and are readily deformed elastically, whereas many metals and alloys have a much higher value as shown in the next table.

Table 2 Values of Elastic Modulus of Some Restorative Dental Materials

Material	Elastic modulus (average value GPa)
Cobalt chromium partial denture alloy	218.0
Gold (type IV) alloy	99.3
Enamel	84.1
Feldspathic porcelain	69.0
Zinc phosphate cement (base)	22.4
Lathe-cut amalgam	21.2
Dentine	18.3
Composite resin	16.6
Zinc phosphate cement (luting)	13.7
Acrylic denture base	2.65
Silicone rubber (maxillofacial)	0.002

Significance: Materials with high modulus of elasticity effect an even stress distribution over the area to which the load is applied. This is an important feature in many restorations:

e.g.- Bridges particularly long span bridges.

- Denture base materials:
  Denture materials with high modulus of elasticity can be used in thinner section without fear of uneven stress distribution e.g. cobalt chromium denture base material compared to gold alloys.

II.6 Modulus of shear

If instead of uniaxial stress, a shear stress is predominant. The shear modulus (G) can then, be calculated from Young's modulus and Poisson's ratio. It is determined by:

$$G = \frac{E}{2(1+\mu)}$$

Since the value of 0.3 for Poisson's ratio is typical, the shear modulus is usually about 40 percent of Young's modulus.

II.7 Flexibility

The maximal flexibility is defined as the strain that occurs when the material is stressed to its proportional limit. It is computed from the following relation:

$$\varepsilon_m = \frac{P}{E}$$

Where, ε_m = maximum flexibility,
P = proportional limit,
E = modulus of elasticity.

Significance: In some dental appliances, a large strain or deformation may be needed with a moderate or slight stress e.g. in an orthodontic appliance, a spring is often bent a considerable distance with a small stress resulting.

II.8 Brittleness

If a material demonstrates no or very little plastic deformation, on load application, it is described as being brittle i.e. it fractures at or very near its proportional limit. This fracture occurs by crack propagation and the fracture surface is characterized by granules.

Significance: In general, brittle materials are weak in tension e.g. the compressive strength of dental amalgam is about 6 times higher than its tensile strength. However, a brittle material is not necessarily lacking in strength, Fig.23.

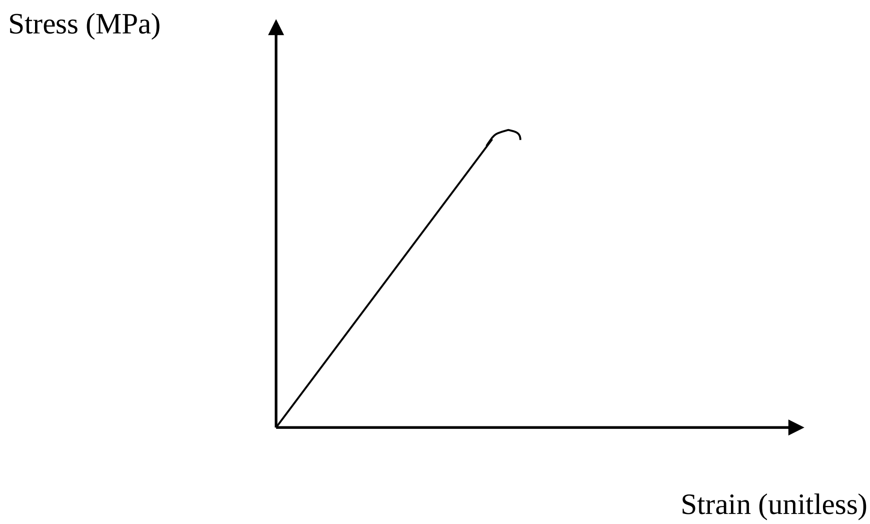


Figure 23 Brittle material

II.9 Malleability and ductility

These are properties of metals and alloys. They indicate the workability e.g. burnishability of the alloy. The malleability of a material is its ability to be hammered into thin sheets without fracturing. While, the ductility of the material is its ability to be plastically deformed under tensile force e.g. drawn into, wire and is indicated by the plastic strain. Ductile fracture results in decrease in the area at the site of fracture due to necking.

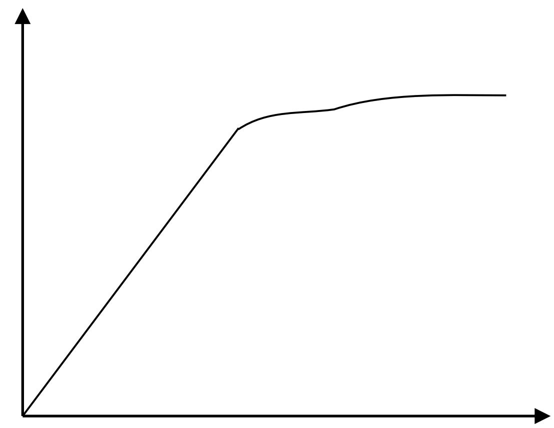


Figure 24 Ductile or malleable material

II.10 Elongation

The deformation that results from the application of a tensile force is elongation. It gives an indication of the workability of an alloy. The percent elongation represents the maximum amount of permanent deformation and it can be calculated as:

% Elongation = (increase in length / original length) x 100

<u>Significance</u>: A material -like many dental gold alloys- that exhibits a 20% total elongation at the time of fracture has increased one fifth of its length, this is a ductile type of alloy. Whereas, a material with only 1% elongation would be considered brittle e.g. Nickel-chromium alloy.

Table 3 Values of Percent Elongation of Some Crown and Bridge and partial denture alloys

Alloy	% elongation
Crown and bridge	
Gold (type lll)	34.0
40% Au-Ag-Cu	2.0
Nickel-chromium	1.1
Partial denture	

Gold (type IV)	6.5
Nickel-chromium	2.4
Cobalt-chromium	1.5
Iron-chromium	9.0
Cobalt-nickel-chromium	8-10

II.11 Resilience

The amount of energy needed to deform the material to its proportional limit. This is called the stored energy because when the load is removed it is released causing complete recovery of the deformed material. It is represented by the area under the straight portion of the stress-strain curve, Fig.25 I. i.e. the area of the triangle. It can be calculated from the relation:

$$Resilience = \frac{1}{2}\sigma\varepsilon \frac{mMN}{m^3}$$

Significance: Resilience is an important requirement of orthodontic wires because their stored energy can be released over the required time to move teeth.

II.12 Toughness

It represents the energy required to stress the material to the point of fracture. It is represented by the area under the elastic and plastic portion of the stress-strain curve, Fig 25 II. The toughest materials are those with high proportional limit and good ductility. However, two different materials can have the same toughness. Toughness is calculated by determining graphically the number of squares in the area and by multiplying this number by the energy per square. The units are m MN/m^3 i.e. energy per unit volume.

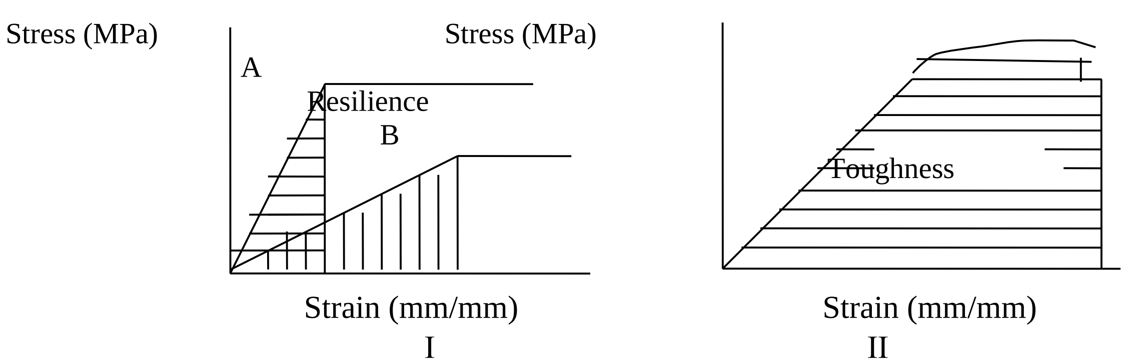


Figure 25 Resilience and Toughness

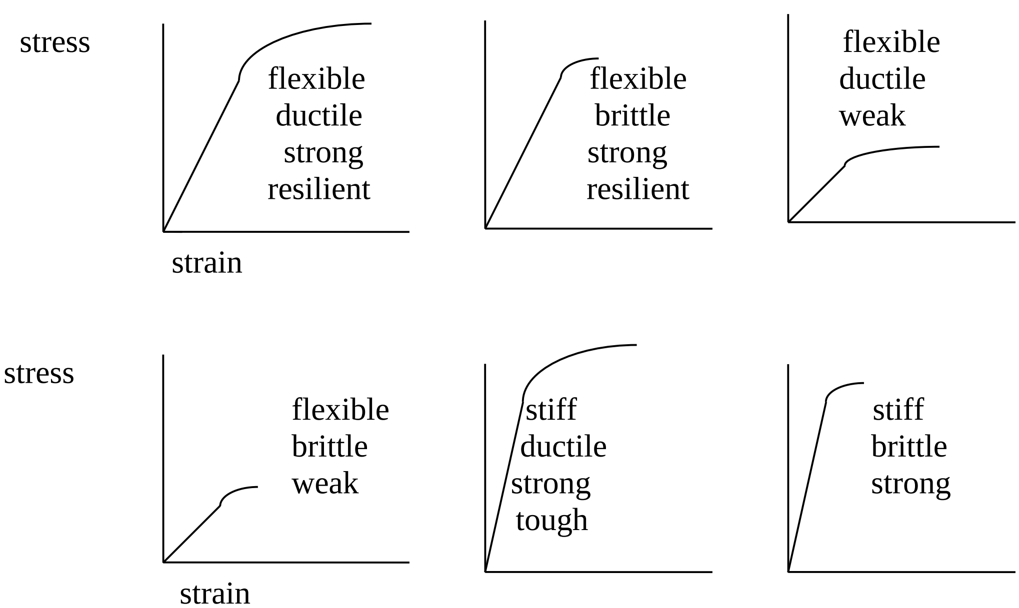
II.13 Fracture Toughness

Fracture mechanics characterizes the behavior of materials with cracks or flaws. When the later are present, less force is needed to cause fracture. This is true with brittle materials while with ductile material (metal), a notch has no effect because ductile material has the ability to plastically deform and redistribute stresses. The ability of the material to plastically deform without fracture, or the amount of energy required for fracture, is the *fracture toughness*. It is a material's property and it is proportional to the energy consumed in plastic deformation.

Significance: brittle materials have low fracture toughness while those of ductile material are higher. e.g. low copper amalgam is usually of higher fracture toughness than high copper amalgam. The increase in copper content decreases the fracture toughness because of the high brittleness of the material.
The addition of 50% zirconia to porcelain and the presence of fillers in polymers increase their fracture toughness. The fillers most probably deflect the crack or obliterate it by this more energy will be needed to propagate the crack leading to higher fracture toughness.

III Properties of stress-strain curve

The slope of stress-strain curve and the magnitudes of the stress and strain allow classification of materials with respect to their general properties as seen in (Figure 26).



stress

stiff ductile weak

stiff brittle weak

strain

Figure 26 Stress-strain curves for materials with various combinations of properties

IV Other mechanical properties and tests

IV.1 Diametral compression test

This is an indirect tensile test used to estimate tensile properties for brittle materials (amalgam, cements, ceramics, plaster, etc.). A compressive load is applied on the diameter of a short cylindrical specimen as in (figure 27) Because of the specimen's shape the compressive stress introduces a tensile stress in the plane perpendicular to the applied force. It is computed as follows:

$$\text{Tensile stress} = 2P / \Pi DT$$

Where, P = load,
D = diameter,
T = thickness.

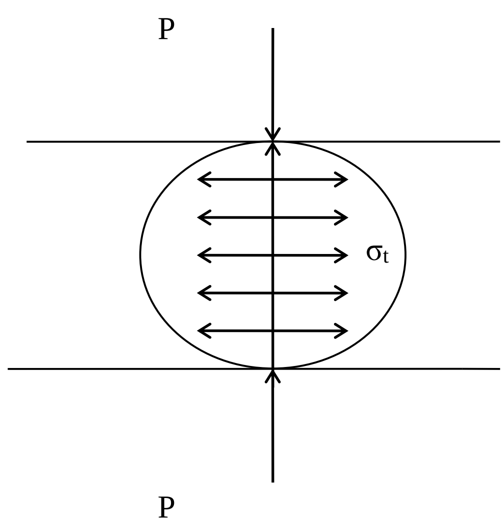


Figure 27 Diametral compression test

Table 4 Values of Tensile Strength for Some Restorative Materials

Material	Diametral tensile strength (MPa)
Amalgam	54.7
Composite resin	45.5
Zinc phosphate cement	8.1
High-strength stone	7.66
Calcium hydroxide	0.96

IV.2 Transverse strength (modulus of rupture or flexure strength)

The test is performed by subjecting a simple beam supported at each end to a static load at the middle, Fig. 28.

$$S = 3PL / 2bd^2$$

Where, S = flexure strength,
P = load,
L = distance between supports,
b = breadth of the specimen,
d = depth of the specimen.

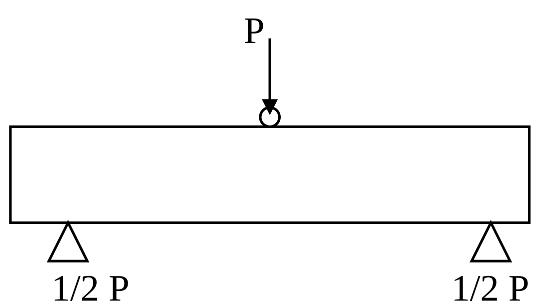
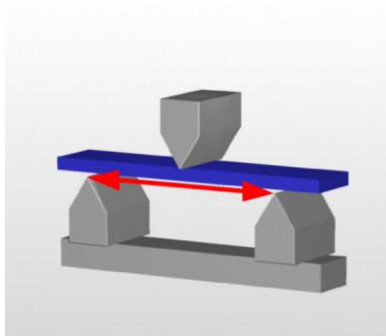


Figure 28 : Measurement of transverse strength

$$e = PL^3 / 4bd^3 E$$

Where, e = deformation,
E = transverse modulus of rigidity.



Ssignificance: This test is useful in comparing and designing denture base materials and long span bridges. The deformation varies as the cube of the length and the depth or thickness of the beam.

IV.3 Cantilever bending

Bending properties are usually measured by clamping the sample at one end and applying a load “P” at a fixed distance, Fig.29.. As the force is increased and the sample is bent, corresponding values for the angle of bending and the bending moment are recorded.

Significance: Bending properties of many materials (e.g. stainless-steel wires, endodontic files and reamers.) are as important as their tensile or compressive properties.

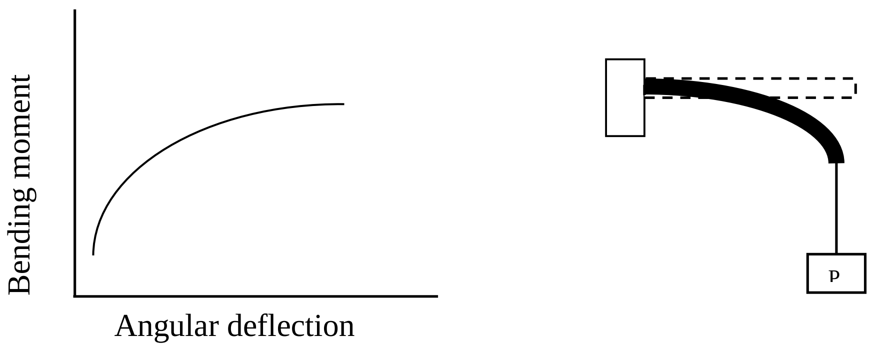


Figure 29: Cantilever bending

IV.4 Fatigue strength test

Fatigue is defined as a progressive fracture under repeated loading. **Fatigue strength** is the maximum stress at which material fails at repeated loading. Practically, materials are subjected to fluctuating stresses (e.g mastication). The gradual accumulation of minute amount of plastic strain produced by each cycle of fluctuating stresses leads to **fatigue failure** of the material**.** Fatigue can lead to failure at stresses well below the yield stress of the material.

The **fatigue strength test** involves subjecting samples of the material to cycles of stresses well below the proportional limit until fracture occurs. The stress values and corresponding number of cycles to failure are graphically plotted to obtain fatigue curve (S-N curve, figure 30). From the curve, the higher the stress induced in the material, the fewer the number of cycles until failure.

Some materials can stand an infinite number of cyclic loading without failure at a stress magnitude called ***the endurance limit***. Some other materials do not have an endurance limit e.g aluminium i.e. even under small stresses the material will eventually fail. For such a material, the fatigue properties can be described by identifying the fatigue strength. The number of cycles performed until fracture under a specified cyclic stress represents the ***lifetime*** of the material in service. Acrylic resin can be used in different restorations having different lifetimes

e.g. as temporary crown : fatigue strength 40 MN/m2 at 10000 cycles

as denture base material : fatigue strength 17.2 MN/m2 at 1500000 cycles.

Tensile, compressive, shear, bending and torsional fatigue tests can all be performed.

Significance: Dental materials are subjected to alternating forces during mastication rather than static loading. Therefore, fatigue properties can help the dentist designing his restoration.

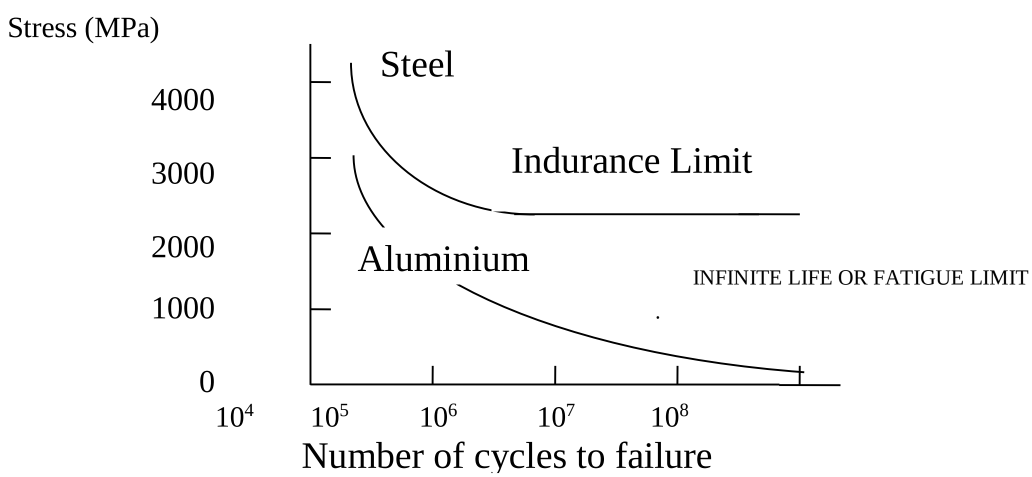


Figure 30 Fatigue strength test.

Factors affecting fatigue strength:

1. Stress magnitude.
2. Surface finish of the material, i.e. roughness decreases fatigue strength.

3. Environmental agents e.g.:
- Temperature
- Humidity
- Aqueous media
- Biological substances.
- pH deviation from neutral
- Corrosive environments lower the fatigue strength.

IV.5 Impact strength

The impact strength may be defined as the energy required to fracture a material under impact force. Impact test simulates a sudden blow from accidents or dropping of a restoration. Specimen in this test is supported as a beam and struck by a sudden blow with a weighed pendulum. (Figure 28). α is the angle before striking the specimen while β is the angle after striking the specimen. The angle α > β, the difference in the swinging angle is due to the energy used to break the specimen.

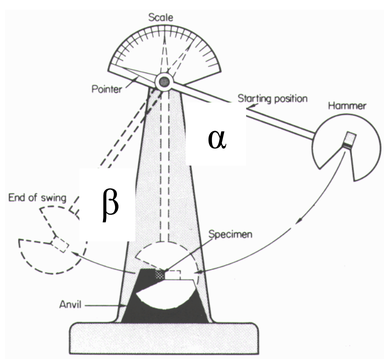


Figure 31: Impact test

α Before striking the specimen β After striking the specimen

α > β

The difference in the swinging angle is due to energy used to break the specimen.

Significance: The impact strength value is important because it predicts the behavior of the material under such conditions. Materials like fused glasses, cements, amalgam, and some plastics have low impact strength values.

Most widely used impact tests:

a) Charpy test:

The specimen is supported at both ends and struck at the middle.

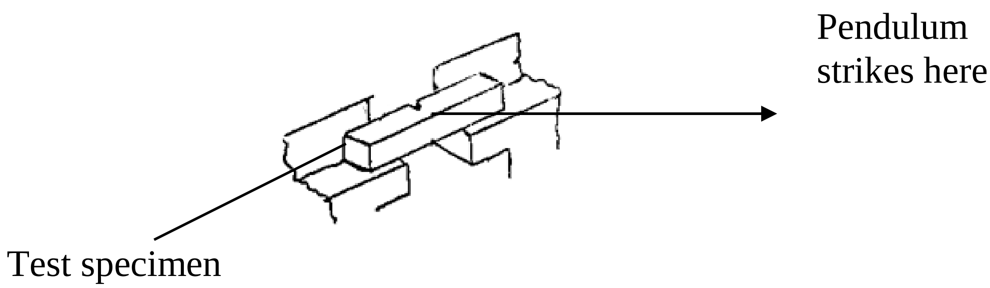


Figure 31 a: Charpy test

b) Izod type:

The specimen is supported at one end and struck at the other end.

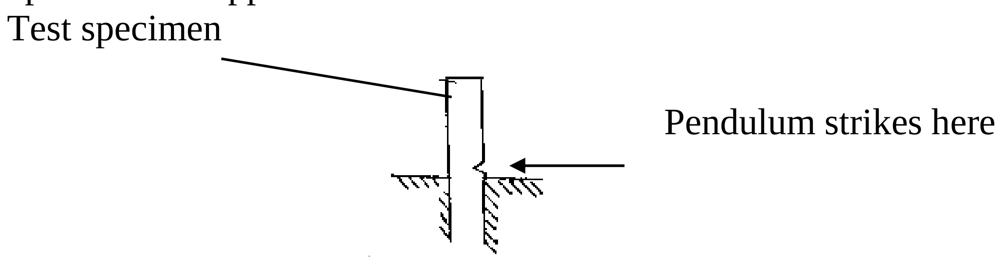


Figure 31 b: Izod test

V Surface mechanical properties

V.1 Hardness

It is a surface property. It is defined as the resistance to permanent indentation or penetration. Some of the most common methods of testing hardness are the Brinell, Knoop, Vickers, Rockwell and Shore A hardness tests. They all have a common principle in that each depends on the penetration of some small symmetrically shaped object into the surface of the material being tested. The indenter may be a steel ball, steel cone, diamond pyramid or similar form. A standardized force or weight, which varies with each test method is applied to the penetrating point through an appropriate mechanism for a specific time, such a force application to the indenter produces a symmetrically shaped indentation that can be measured for depth, width or area of the indentation produced according to the test used. The dimension of the indentation will vary inversely with the hardness of the material being tested. i.e. Small indentation refers to a hard material while large indentation is obtained from a soft one. The indentation dimensions are related to tabulated hardness values.

Comments on the test:

(1) Brinell test:

It produces relatively large indentation area and as a result it is good for determining average hardness values (BHN) and poor for determining very localized values, Fig. 32. Its indenter is a steel ball and it is used for metals and alloys. It may fracture brittle materials. It may cause elastic deformation rather than indentation with dental polymers that exhibit elastic recovery.

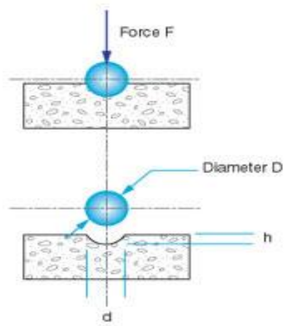


Figure 32 : Brinell hardness test

(2) Knoop test:

It is a microindentation test. Its indenter is diamond pyramid in shape producing area of indentation (KHN). The advantage of this test is that the material can be tested with a great range of hardness simply by varying the test load. The disadvantage of this method is that it needs highly polished and flat test samples and the relatively long time for testing. It is used to determine the hardness of enamel, dentine, metals and alloys.

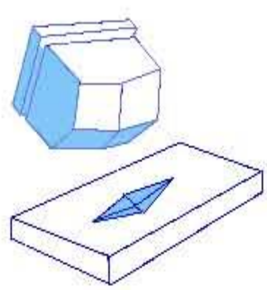


Figure 33: Knoop hardness test

(3) Vickers test: (The 136 diamond pyramid test)

It has a square pyramid indenter producing area of indentation (VHN). It is especially useful in measuring the hardness of small areas and very hard materials. e.g. dental gold castings, brittle materials, tooth structure, Fig.34.

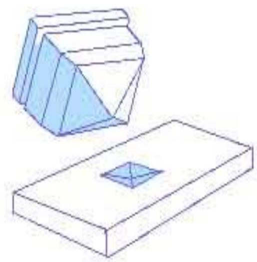


Figure 34: Vickers hardness test

(4) Rockwell test :

The Rockwell hardness test is used primarily for determining the hardness of steels. It uses different hardened steel balls or diamond cones and different loads. Each combination forms a specific Rockwell scale (A, B and C scales are the most common). The different scales are used for materials of different hardness ranges, Fig.35.

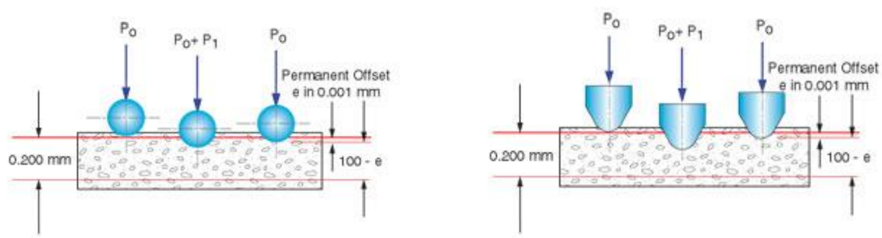


Figure 35: Rockwell hardness test

(5) Shore A hardness test:

It uses a dial gage 0 (complete penetration)-100(no penetration). No reading is obtained while the indenter is in the specimen. It is used for measuring the hardness of rubbers.

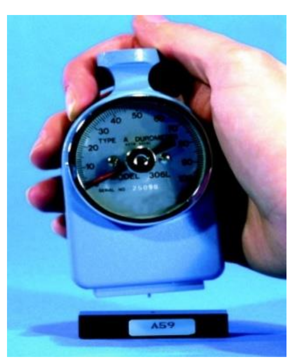


Figure 36: Shore A test

(6)Barcol hardness test:

It is used to test the depth of cure of resin composite. The indenter is a spring loaded needle 1 mm diameter. If no penetration the scale reads 100 and it decreases with penetration.

(7) Nano indentation:

Special indentation techniques have been introduced to accurately measure the properties of the microphases in materials. These techniques, referred to as nano-indentations are able to apply loads in the range of 0.1-5000 mgf (milligram force) resulting in indentations approximately 1 μm in size. The indentation depth is continuously monitored and should be imaged to compute the mechanical properties, in addition to the hardness Young's modulus can also be measured. For brittle materials, yield strength and fracture toughness may be determined. The following table summarizes the different hardness tests particulars:

General comments:

1. Knoop and Vickers hardness tests are classified as microhardness tests. They employ loads less than 9.8N and produce indentation less than 19 μm. They are capable of measuring hardness of small regions and of thin objects.
2. Rockwell and Brinell tests give average hardness over large areas.
3. Shore A and Barcol tests are less sophisticated. They measure hardness of rubbers and plastic types of dental materials.
4. Traditional hardness tests use loads as high as several kg and result in an indentation as large as 100 μ.

Significance: Hardness is an important property to consider in order to avoid scratching structures like teeth or restorations e.g.

- Natural teeth should not be opposed by harder materials like porcelain.
- Avoid scratching of soft materials (model and die materials) because it decreases their accuracy.
- Restorations made of hard material like cobalt chromium is:
  * Very difficult to finish and polish
  * Once it is polished it maintains its polished surface with no scratches.

V.2 Wear

Wear is the loss of material resulting from mechanical action. It is a material removal process that can occur when surfaces slide against each other. Wear is usually undesirable but during finishing and polishing procedures wear is highly desirable. Wear of tooth structure and restorative materials may result from mechanical, physiological and pathological condition. Normal mastication may cause attrition of tooth structure and materials particularly in populations that consume unprocessed food. Bruxism is an example of a pathological form of wear. Improper use of tooth brushing may cause an abrasive form of wear.

Abrasion resistance

It is the resistance of the material to wear. It can be measured by hardness test. The harder the material, the higher the abrasion resistance. Rubber tire is much less hard than metal tire, yet, they have a better wear resistance which is an exception.

Other factors affecting abrasion:

Abrasion is a complex mechanism in the oral environment that involves interaction of many factors:

1. Hardness is a limited predictor.
2. Biting force
3. Frequency of chewing
4. Abrasiveness of diet
5. Composition of the intraoral liquids
6. Temperature changes
7. Physical properties of the material and surface texture e.g surface roughness and irregularities.

Significance:

* Excessive wear of teeth opposing ceramic crown is more likely to occur in the presence of high biting force and rough ceramic surface.

* Although dentist can not control the biting force of a patient, they can adjust occlusion to create broader contact area and reduce the localized stresses. They can polish abrading ceramic surface to decrease the rate of enamel wear.

VI Viscoelasticity and Creep

VI.1 (Strain rate sensitive materials)

The effect of the rate of loading has not been considered in the stress-strain curve. It is however, important when we deal with strain rate sensitive materials particularly polymers and soft tissues.

The mechanical properties of many dental materials e.g. agar, alginate, rubber impression materials, amalgam, plastics, waxes, dentine, oral mucosa and periodontal ligament all are dependent on how fast they are stressed. Increasing the rate of loading produces a different stress-strain curve with higher value of the properties.

Material's behavior according to their strain-time sensitivity can be interpreted in terms of their molecular structure i.e. the molecular structure of a material will function as elastic, viscous, anelastic, viscoelastic or a combination of more than one behavior.

VI.1.1 Ideal elastic material

If a material behaves as an ideal elastic solid, an instantaneous amount of strain will result for a given amount of stress applied below the proportional limit. The strain remains constant with time. When the load is removed (at the time t_1) the strain instantaneously decreases to zero, Fig.37. In other words, the strain is independent of the rate of loading or the length of time in which the load was applied.

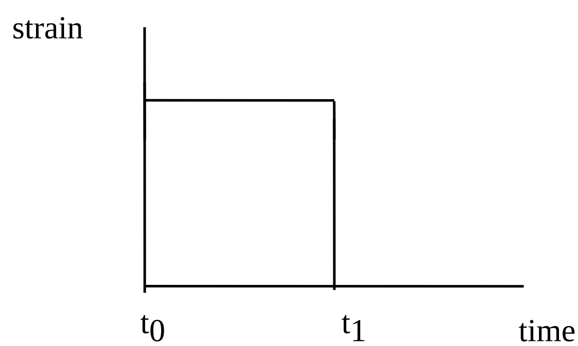


Figure 37: Ideal elastic material

VI.1.2 Ideal viscous material

An ideal fluid immediately begins to strain when stress is applied at (t_0 time), and the strain proceeds uniformly until the stress is removed (at t_1 time), Fig 38. The total strain is directly proportional to the total time of stress application, and none of the total strain is recovered when the stress is removed.

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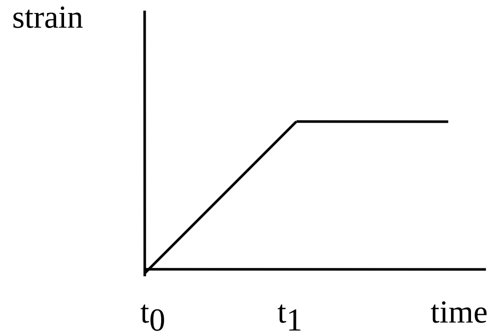


Figure 38: Ideal viscous behavior

VI.1.3 Anelastic material (delayed elasticity)

Solids, such as plastics and rubbers, which do not exhibit ideal elastic behavior and release strain gradually but completely if you give them enough time (time dependent) to recover. These solids are termed anelastic. Fig.39 shows, a non linear increase of the strain with time on load removal at t_1 the strain will decrease to zero with time in a non linear manner.

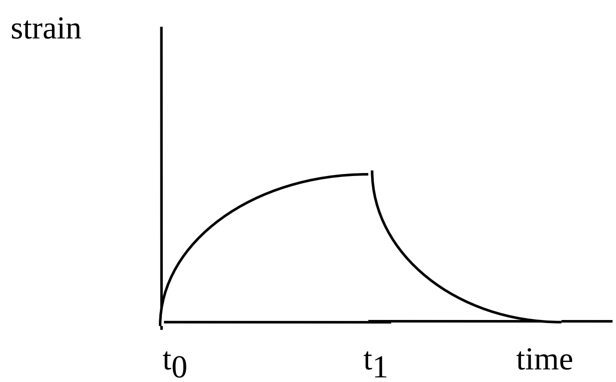


Figure 39: Anelastic behaviour

VI.1.4 Viscoelastic behaviour

Many solids exhibit a combination of elastic, anelastic and viscous behavior. This combination strain or viscoelastic strain is time dependent. The elastic and anelastic portions are recovered but the purely viscous components are not. A partial time dependent recovery will occur on load removal leaving an amount of permanent strain, Fig 40.

Elastic impression materials are an example. Upon release of stress, the elastic strain is immediately recovered and the anelastic strain is gradually recovered. However, some viscous strain is not recovered which results in some permanent deformation (1% -3%). This unrecovered residual strain reduces the accuracy of the impression.

Significance: Strain-time curve of such materials (elastic impression materials) shows that more permanent strain occurs with these impression materials the longer the load is applied. However, impression must be removed rapidly from the mouth to minimize the permanent deformation as a result of viscous deformation during removal. Also, they should have higher strength when removed rapidly i.e. less chance to tear. Furthermore, on removal from the mouth they should be given time to recover before a die can be poured. In reality, materials exhibit more complex behavior than previously described i.e. they exhibit more than one behavior of the above e.g. elastic impression materials.

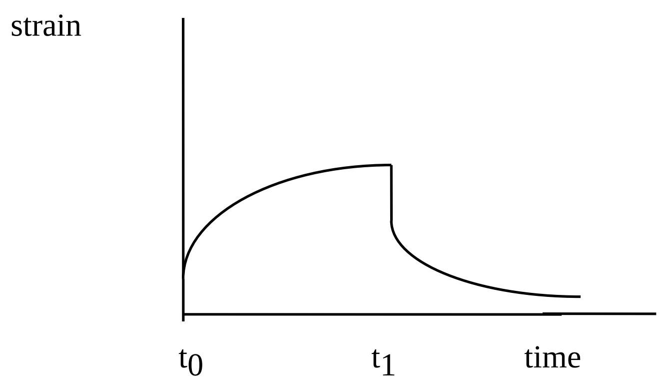


Figure 40: Viscoelastic behavior

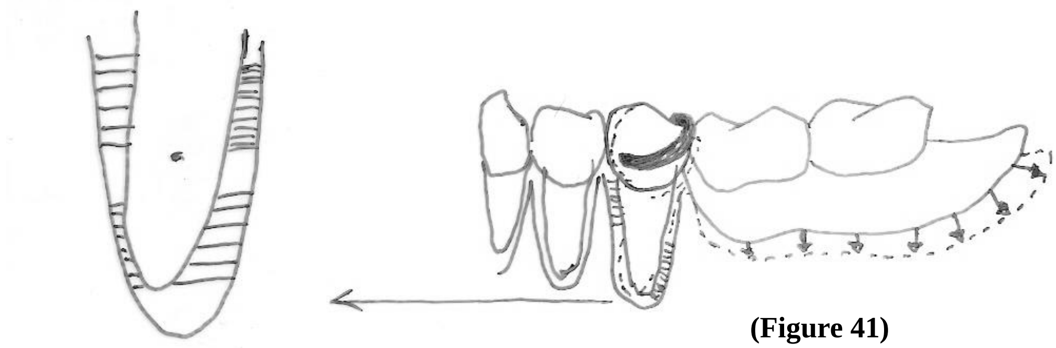
Compressive strength of the strain-rate dependent materials:

The compressive strength of such materials is a function of the rate of loading since it depends on the strain rate. The higher the rate of loading, the higher the recorded compressive strength. As a result, when comparing the compressive strength of materials' samples it is imperative that they be tested at the same rate of loading. e.g. for amalgam, A.D.A requires a rate of 0.25 mm/min to test the material.

Viscoelasticity of oral tissues:

- Palatal mucosa have little resistance to loading compared to periodontal ligament
- Dentures supported by palatal mucosa experience more displacement as a function of load, while dentures supported by teeth experience less displacement.

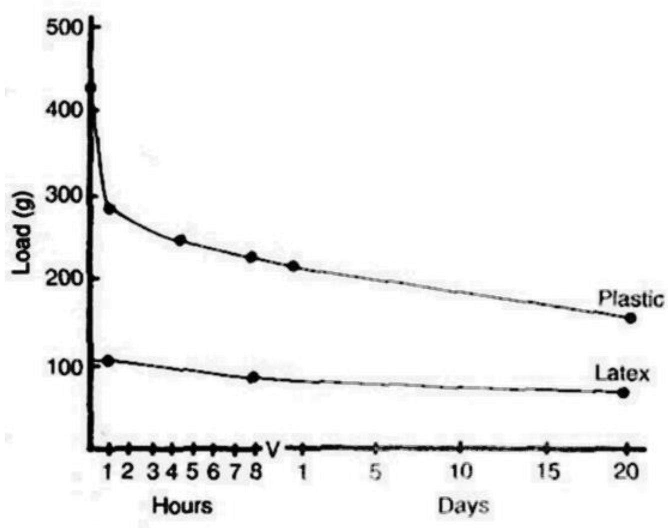
- Viscoelastic deformation of the oral mucosa is sustained and prolonged therefore tissues recovery takes hours.
- Recording the mucosal tissues under load results in denture base and artificial teeth be initially at a position superior to the natural teeth, on loading they are displaced and level up. (Fig. 41)



(Figure 41)

Orthodontic elastic bands:

- Work on the principle of load relaxation i.e. the reduction in stress in a material subjected to constant strain.
- Time taken for load relaxation depends on the amount of deformation effected by the load and the type of material used e.g plastic bands are useful for applying high forces through the force decrease rapidly with time whereas, latex bands can effect lower forces through slower force decrease with time (Fig. 42).



(Figure 42)

VI.2 Creep

Creep is simply a time dependent permanent deformation. It is the slow flow causing permanent deformation of materials held for long periods of time at stresses well below their conventional yield strengths. This mechanism usually occurs only at temperatures near the softening point of a material.

Significance: Since the softening temperature of most metals and ceramics is far above room or mouth temperatures, they do not creep in dental application. However, many polymers such as waxes, rubbers and plastics are near their softening point at room or mouth temperatures and can creep considerably. As an example, take an inlay pattern made from a piece of dental wax and place a small weight on it. No immediate deformation will be apparent, indicating that its yield strength has not been surpassed. However, in several days it will have flowed to a shapeless blob. Care must be used in selecting materials in which the amount of creep is negligible over the total time period in which the material is used.