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Review article

REVIEW ARTICLE ON MECHANICAL PROPERTIES OF DENTAL MATERIALS

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ABSTRACT

A wide variety of dental products are available in the market. It becomes difficult for selection of the good materials. Although the mechanical properties do not necessarily represent the actual clinical performance, they are used to guide the effects of changes in their properties. This review article deals with the mechanical properties of various dental materials.

Keywords: Dental Materials, Mechanical Properties, Strength Properties, Stress And Strain.

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INTRODUCTION

Mechanical properties are measures of the resistance of a material to deformation or fracture under an applied force. The failure potential of a prosthesis under applied forces is related to the mechanical properties of the prosthetic material.

STRESSES AND STRAINS

When an external force acts on a solid, a reaction occurs to oppose this force that is equal in magnitude but opposite in direction to the external force. The stress produced within a material is equal to the applied force divided by the area over which it acts. Whenever a stress is present, deformation or strain is induced.

Strain, or the change in length per unit length, is the relative deformation of an object subjected to a stress. Strain may be either elastic or plastic or elastic and plastic. Elastic strain is reversible. When a prosthetic component such as a clasp arm on a partial denture is deformed past the elastic limit into the plastic deformation region, only the elastic strain is recovered when the force is released.

Tensile Stress

A tensile *stress* is caused by a load that tends to stretch or elongate a body. In fixed prosthodontics clinics, a sticky candy can be used to remove crowns by means of a tensile force when patients try to open their mouth [1].

Compressive Stress

If a body is placed under a load that tends to compress or shorten it, the internal resistance to such a load is called a *compressive stress.*

Shear Stress

A *shear stress* tends to resist the sliding or twisting of one portion of a body over another.

Flexural (Bending) Stress

These stresses are produced by bending forces in dental appliances in one of two ways:

1.As shown in Figure1 , tensile stress develops on the tissue side of the FPD; and compressive stress develops on the occlusal side.

2.For a cantilevered FPD the maximum tensile stress develops with the occlusal surface or the surface that is becoming more convex and the opposite surface becomes compressed.

Elastic Modulus (Young's Modulus or Modulus of Elasticity)

Elastic modulus describes the relative stiffness or rigidity of a material. Figure 3 is a stress-strain graph for a stainless steel orthodontic wire that has been subjected to a tensile force.

If the tensile stress below the proportional limit in Figure 2 is divided by its corresponding strain value, that is, **tensile stress/tensile strain**, a constant of proportionality will be obtained that is known as the ***elastic modulus, modulus of elasticity,*** **or** ***Young's modulus***.

Lower the strain for a given stress, the greater the value of the modulus.

Flexibility

In the case of dental appliances and restorations, a high value for the elastic limit is a necessary for the materials from which they are fabricated, because the structure is expected to return to its original shape after it has been stressed and the force is removed (elastic recovery). There are instances, however, in which a larger strain or deformation may be needed with a moderate or slight stress. For example, in an orthodontic appliance, a spring is often bent a considerable distance under the influence of a small stress. In such a case, the structure is said to be *flexible* and it possesses the property of *flexibility [2]*.

Resilience

As long as the stress is not greater than the proportional limit, this energy is known as *resilience. Resilience* is associated with "springiness". Resilience can be defined as the amount of energy absorbed within a unit volume of a structure when it is stressed to its proportional limit.

The area bound by the elastic region is a measure of resilience, and the total area under the stress-strain curve is a measure of toughness.

Poisson's Ratio

Poisson ratio describes a mechanical property that is defined as the ratio *of* strain in the direction of stress to strain in a direction perpendicular to stress.

STRENGTH PROPERTIES

Strength is the stress necessary to cause either fracture *(ultimate strength)* or a specified amount of plastic deformation *(yield strength).*The maximum stress that a structure can sustain before it becomes permanently or plastically deformed, can be described either by the *proportional limit or elastic limit.* The ultimate tensile strength (UTS) is defined as the tensile stress within a structure at the point of rupture.

Proportional Limit

The stress at which plastic deformation begins to develop. It represents the maximum stress above which stress is no longer proportional to strain.

Elastic Limit

If a small tensile stress is induced in a wire, the wire will return to its original length when the load is removed. If the load is increased progressively in smaller increments and then released after each increase in stress, a stress value will be reached at which the wire does not return to its original length after it is unloaded. At this point the wire has been stressed beyond its *elastic* limit.

Yield Strength (Proof Stress)

Yield strength often is a property that represents the stress value at which a small amount of plastic strain has occurred. A value of either 0.1% or 0.2% of the plastic strain is often selected and is referred to as the *percent offset.* The yield strength is the stress required to produce the particular offset strain (0.1 % or 0.2%) that has been chosen [3].

Permanent (Plastic) Deformation

If the material is deformed by a stress at a point above the proportional limit before fracture, the removal of the applied force will reduce the stress to zero, but the strain does not decrease to zero because plastic deformation has occurred.

Diametral Tensile Strength

Diametral compression test is used only for materials that exhibit predominantly elastic deformation and little or no plastic deformation.

In this method, the compressive load is placed by a flat plate against the side of a short cylindrical specimen (disk), as illustrated in Figure 4. The vertical compressive force along the side of the disk produces a tensile stress that is perpendicular to the vertical plane that passes through the center of the disk. Fracture occurs along this vertical plane (the dashed vertical line on the disk). In

such a situation, the tensile stress is directly proportional to the compressive load applied. It is computed by the following formula:

$$\text{Tensile stress} = \frac{2P}{\pi Dt}$$

Where P is the applied load, D is the diameter, and t is the thickness.

Flexure Strength

The flexural strength of a material is its ability to bend before it breaks. It is obtained when the ultimate flexibility of one material is achieved before its proportional limit. To evaluate flexural strength of a dental material, it is generally used, bar-shaped specimens with dimension of 25 mm in length X 2 mm in width X 2 mm in height Specimens are placed on two supports and a load is applied at the center. This test is known as three-point bending test [4]. The load at yield is the sample material's flexural strength that is calculated by the following formula:

$$\frac{3Pl}{2bd^2}$$

Where:
P= the ultimate load at fracture,
l=the distance of the supports,
b= the width of the specimen,
d= the thickness of the specimen

Fatigue Strength

Most prosthetic and restoration fractures develop progressively over many stress cycles after initiation of a crack from a critical flaw and subsequently by propagation of the crack until a sudden, unexpected fracture occurs. Stress values well below the ultimate tensile strength can produce premature fracture of a dental prosthesis because microscopic flaws grow slowly over many cycles of stress. This phenomenon is called *fatigue failure*. *Maximum service stress* or an *endurance limit*-the maximum stress that can be maintained without failure over an infinite number of cycles.

Ceramic orthodontic brackets and activated wires within the brackets represent a clinical system that can exhibit *static fatigue failure*. The delayed fracture of molar ceramic crowns that are subjected to periodic cyclic forces may be caused by *dynamic fatigue failure.*

Impact Strength

Impact strength may be defined as the energy required to fracture a material under an impact force. The term *impact* is used to describe the reaction of a stationary object to a collision with a moving object.

MECHANICAL PROPERTIES OF TOOTH STRUCTURE

The properties of enamel vary somewhat with its position on the tooth, that is, cuspal enamel is stronger than enamel on other surfaces of the tooth. Dentin is considerably stronger in tension (50 MPa) than is enamel (10 MPa). Although the compressive strengths of enamel and dentin are comparable, the proportional limit and modulus of elasticity of enamel are higher than the corresponding values for dentin.

MASTICATION FORCES AND STRESSES

Because of their dynamic nature, the biting stresses during mastication are difficult to measure. The modulus *of* resilience *of* dentin is greater than that *of* enamel and, thus, it is better able to absorb impact energy. Enamel is a brittle substance with a comparatively high modulus of elasticity, a low proportional limit in tension, and a low modulus *of* resilience [5].

Toughness

Toughness is defined as the amount *of* elastic and plastic deformation energy required to fracture a material. As previously noted, the *modulus of resilience* is the energy required to stress a structure to its proportional limit. It can be measured as the area under the elastic, straight-line portion *of* the stress-strain curve. Toughness is indicated as the total area under the stress-strain graph.

Brittleness

Brittleness is the relative inability *of* a material to sustain plastic deformation before fracture *of* a material occurs. For example, amalgams, ceramics, and composites are brittle at oral temperatures. However, a brittle material is not necessarily weak. For example, a cobalt chromium partial denture alloy may have a percent elongation *of* less than 1.5% elongation, but an ultimate tensile strength *of* 870 MPa.

Ductility and Malleability

When a structure is stressed beyond its proportional limit, it becomes permanently deformed. If a material sustains tensile stress and considerable permanent deformation without rupture, it is ductile. The ability of a material to sustain considerable permanent deformation without rupture under compression, as in hammering or rolling into a sheet, is termed *malleability.* Gold is the most ductile and malleable pure metal, and silver is second [6].

Hardness

The relative hardness of a substance is based on its ability to resist scratching. It is the "resistance to indentation." Among the properties that are related to the hardness of a material are compressive strength, proportional limit, and ductility. The tests most frequently used in determining the hardness of dental materials are known by the names Barcol, Brinell, Rockwell, Shore, Vickers & Knoop. The Knoop and Vickers tests are capable of measuring the hardness in small regions of thin objects.

The Rockwell and Brinell tests give average hardness values over much larger areas.

Fig:1

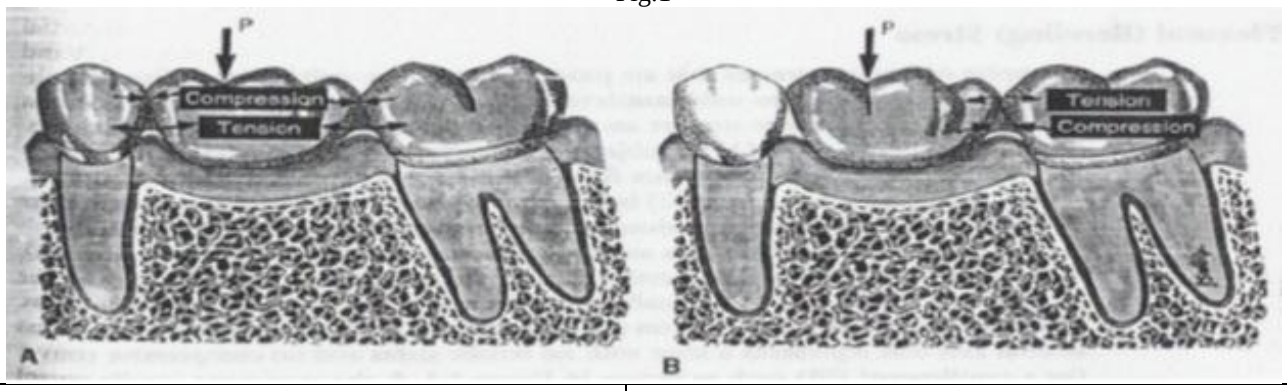


Fig 2

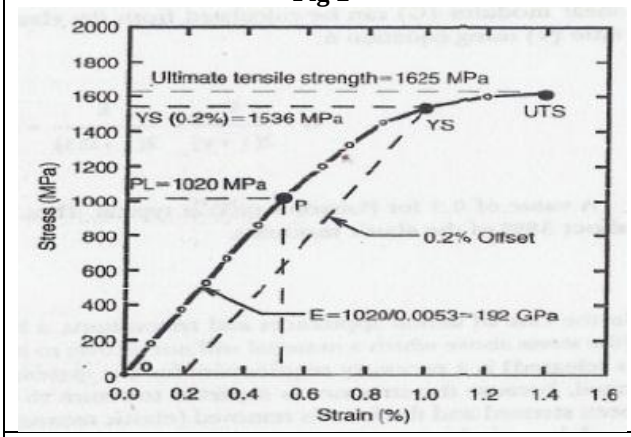


Fig.3

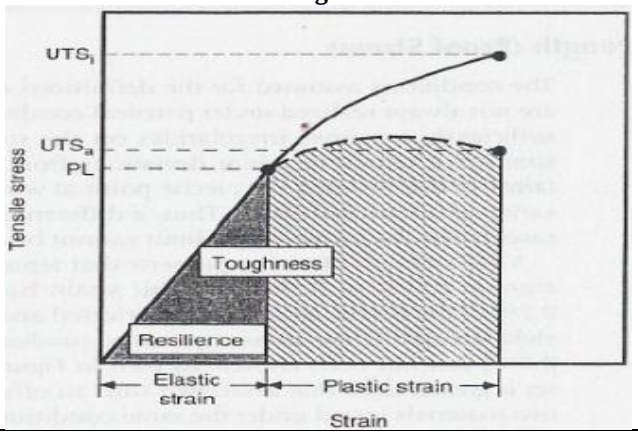


Fig.4

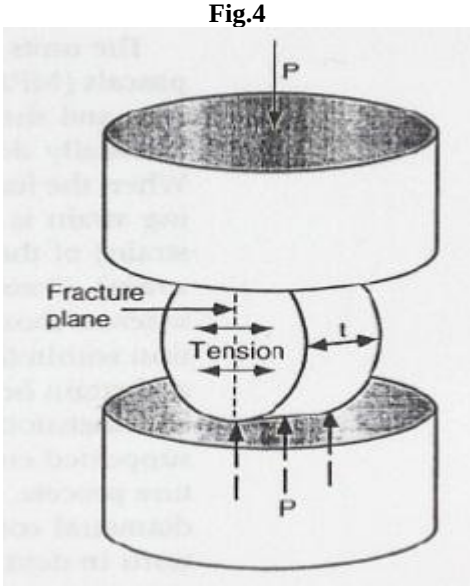


Fig.5 Dynamic fatigue failure stress for a brittle material as a function of surface roughness and number of stress cycles.

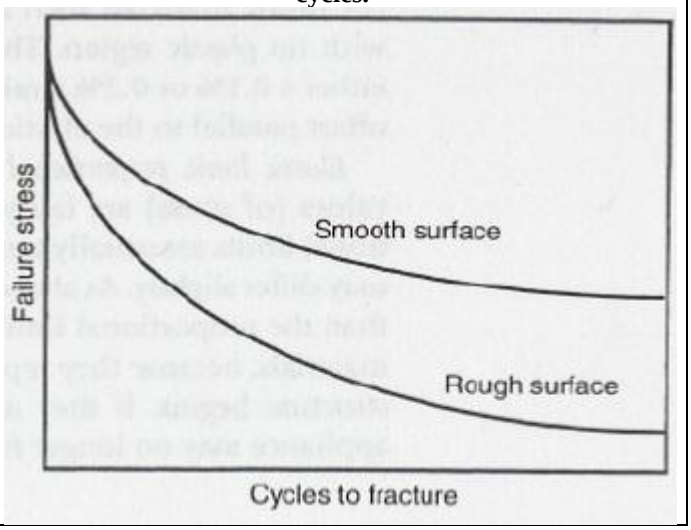


Fig:6

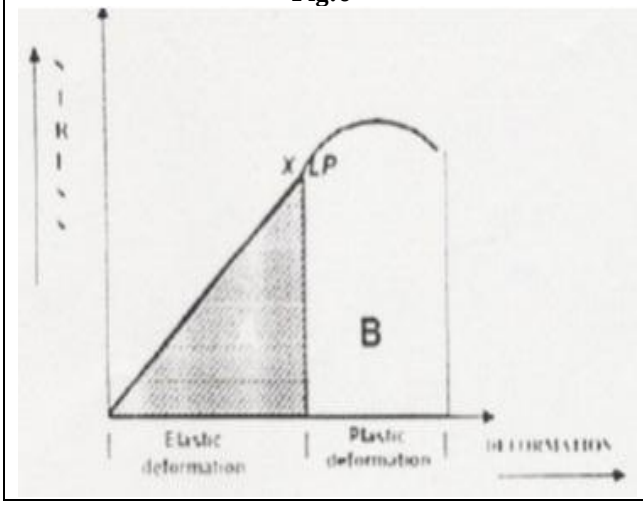
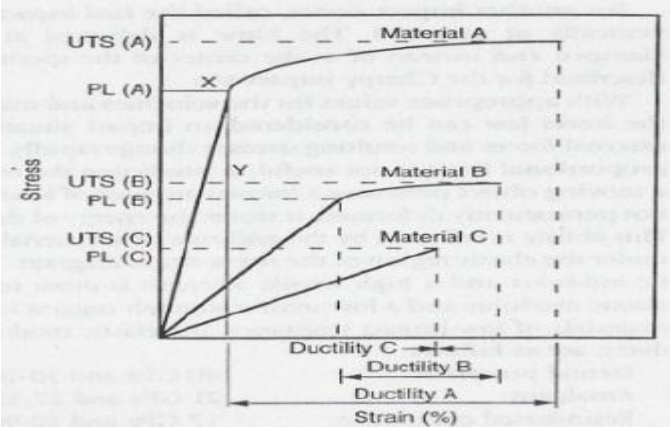


Fig. 7 Stress-strain plots of materials that exhibit different mechanical properties. UTS, ultimate tensile stress; PL, proportional limit.



CONCLUSION:

Mechanical properties are therefore important in understanding and predicting materials' behavior under load. The knowledge of mechanical properties helps in the diagnosis of causes of clinical failures, whether they are caused by material deficiencies, human errors or patient factors. It also helps in understanding the design modifications that will improve the fracture resistance of restorations.

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