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Assessment of Mechanical Properties of Dental Restorative Materials

KEY CONCEPTS

- Knowledge of properties of dental restorative materials.
- Ability to differentiate between each type of mechanical properties.
- Understanding of the type of sample preparation required for the different testing modalities.
- Working principle of the equipment used.
- Different applications of the universal testing machine.

In the oral environment, restorations are subjected to stresses from mastication. These forces act on teeth and/ or material producing different reactions that lead to deformation, which can ultimately compromise their durability over time [1–5]. When a specific force or load is applied to a body, a reaction of the same intensity and with opposite direction is produced which causes an internal tension. Hence, it is possible to quantify the reaction that resulted by the applied external load. Since shape and dimensions of specimens under test can be measured, one can calculate stress by the reason between force and unit area.

Depending on the applied load characteristics and consequent stress, different reactions from the tested material may occur. The stress can result in structural alteration of original dimensions. The rate between this alteration by the original dimension results in deformation, that is defined as strain. The stress–strain ratio of a material is relevant to determine its mechanical behavior. For each material, there is a stress–strain proportional relationship, establishing a stress–strain curve. If there is a stress relief during loading and no permanent deformation occurs, it demonstrated its elasticity. This proportion occurs until a limit point that is defined as proportional limit and deformation as elastic deformation. In this point, the maximum stress of a material will withstand without permanent deformation. As stress–strain is proportional until this point, there is a constant proportionality. It determines the elasticity of a material and is calculated by the ratio of stress–strain curve within the elastic limit. This proportionality is defined as modulus of elasticity or Young's modulus. This value will measure the stiffness of such material. However, when the applied load

exceeds this point, irreversible deformation occurs, resulting in permanent or plastic deformation. Each material presents a resistance to deformation, and after this point, it will result in its rupture. In this point ultimate strength value is obtained. Toughness is the resistance of a material to fracture and corresponds to the amount of energy required to cause it [6]. All these concepts can be applied in clinical situations as many complex forces occur in the oral cavity and tend to deform the material (tensile, compressive, shear, bending forces), the knowledge and interpretation of how these materials behave under such forces are important to understand the performance of the material. Thus the various mechanical parameters that are evaluated for the suitability of a product for any application in the field of conservative dentistry are as follows:

Good to Know

The Universal Testing Machine is named so as it is capable of testing compression, tension, bending and flexion.

It works by measuring the stress-strain relationship of each material.

Tensile strength, diametral compression test, compressive strength, flexural strength, resistance to fatigue, hardness, elastic modulus, fracture toughness and bond strength.

Different equipment are used for testing different mechanical properties. Each of these tests may be conducted using either tooth or materials or both (in case of bonded structures). All these tests require variations in the assembly. Most of the tests except hardness require the use of Universal Testing Machine (UTM) where the sample preparations differ for each test. For instance, if tensile testing is done on a sample, the shape of the sample is dumb bell shaped; it is designed so that the specimen can be gripped at each end and stretched. For compressive strength testing, cylindrical-shaped specimens are tested. Bar-shaped specimens are used for flexural strength testing (as shown in Figures 1.1 and 1.2).

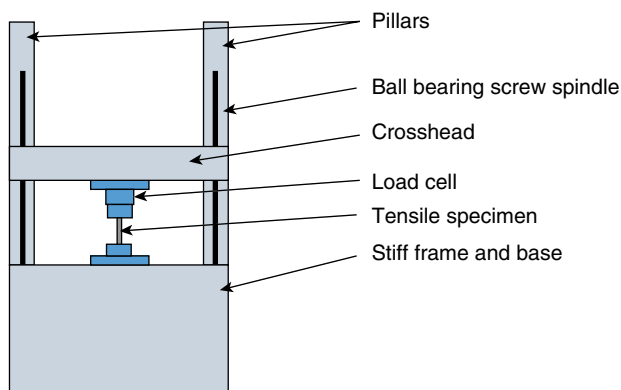


Figure 1.1 Universal testing machine.

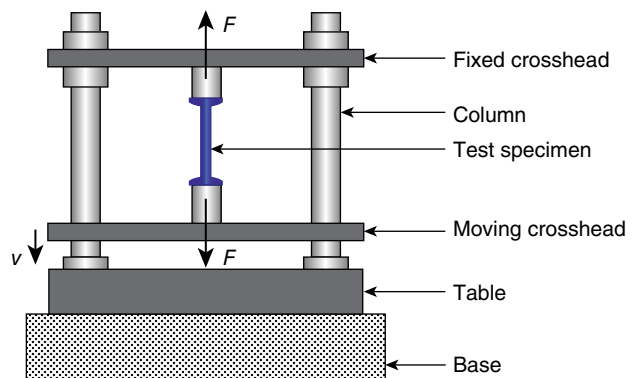
Figure 1.2 Tooth sample testing.



1.1 Tensile Strength

When a body is subjected to axial forces in a straight line and in opposite directions, it results in tension. The resistance of the material to this load is called tensile strength. The length alteration that results from the application of a tensile force on a body before its rupture is defined as elongation. Nominal value of tensile strength is determined by the equation of load and cross-sectional area (Kgf/cm^2). Values of stress-strain determine a curve, characterizing the performance of the material under tensile test. From this curve, elastic modulus, ultimate tensile strength, resilience and toughness of such product can be registered [7]. Tensile testing is normally applied to materials which are placed under loading that is generally applied in different directions, as the opposing cusps move over the restoration surface. Loads that stretch or elongate a material cause tensile stresses (as shown in Figures 1.3–1.5).

Figure 1.3 Tensile strength assessment.



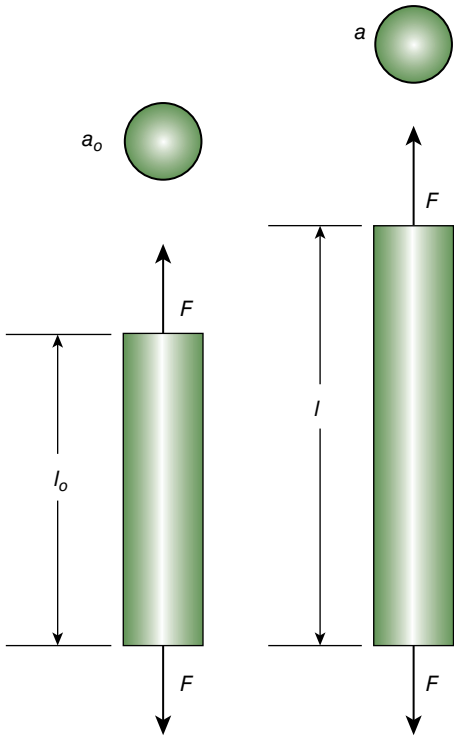


Figure 1.4 Tensile strength assessment.

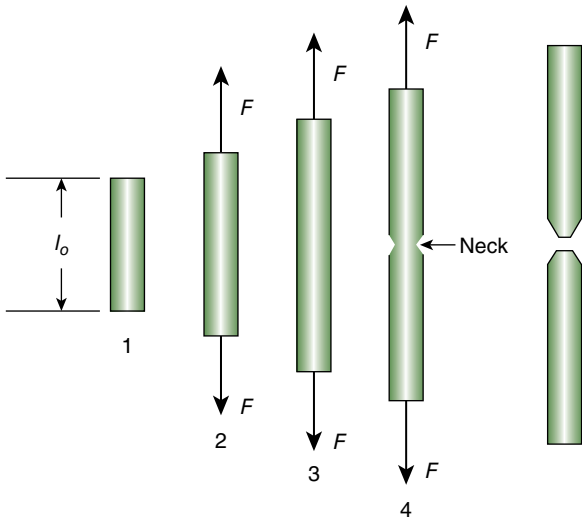


Figure 1.5 1, No load; 2, uniform elongation; 3, maximum load; 4, necking.

Good to Know

For a DTS test, the fracture line doesn't always occur along the central line, thus giving false results and making the test inaccurate.

The diametral tensile strength (DTS) test is useful for materials that exhibit very limited plastic deformation and where information regarding stretching or elongation resistance is required. The DTS is a property described by American Dental Association (ADA)/American National Standards Institute (ANSI) Specification 27 for characterizing dental composite restoratives (DCR). It represents the minimal stress that a body will withstand without rupture when tensile loads are applied. The DTS test is considered useful because masticatory forces are frequently applied obliquely and tend to create tensile stress. A UTM is generally used to determine the tensile strength of a material. Materials which plastically deform would produce erroneous DTS values and also would be expected to display strain rate sensitivity. Composite resins are subjected to complex intraoral forces during mastication and parafunctional habits. Of the three tests used in this study to replicate intraoral forces, diametral tensile is the most difficult to interpret. Failure must occur in the center of the specimen along the diameter due to tensile forces if the diametral test is to yield useful results. The method was used to evaluate the influence of different cross-head speeds on DTS of a resin composite material (Tetric N-Ceram) by Anubhav Sood et al. in 2015 where they found that the cross-head speed variations did not have a significant effect on the DTS of the resin composite [8].

1.2 Diametral Compression Test

Rupture under low tension characterizes fragile materials, susceptible to brittleness. In these cases, tensile strength is not indicated to evaluate material reaction, because of the low cohesive condition. An alternative method of tensile strength is calculated by compressive testing. It is a relatively simple and reproducible test. It is defined as diametral compression test for tension or indirect tension. Disk sample is necessary to conduct this test, where it is compressed diametrically introducing tensile stress in the material in the plane of the force application by the test. This is calculated by the formula: $2P/\pi \times D \times T$, where: P = load applied, D = diameter of the disk, T = thickness of the disk, π = constant [9, 10] (as shown in Figure 1.6).

1.3 Compressive Strength

Compressive testing is normally applied to materials that are expected to be placed in situations of occlusal loading. Since most of mastication forces are compressive in nature, it is important to investigate materials under this condition. To test compressive strength of a material, two axial sets of force are applied to a sample in an opposite direction, in order to approximate the molecular structure of the material. Here, cylindrical-shaped specimens are tested. The dimensions of the samples should have a relation of length to diameter of 2 : 1. When this proportion is exceeded, it can

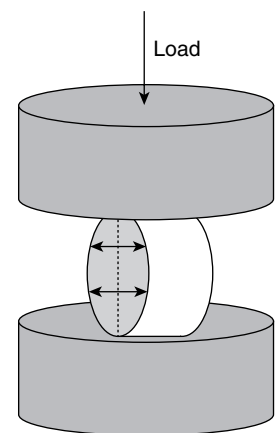


Figure 1.6 Diametral compressive strength assessment. *Source:* Cefaly [9], Cattani-Lorente [10].

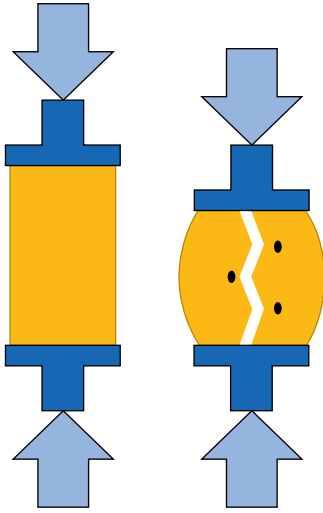


Figure 1.7 Direction of force is perpendicular to the object.

result in undesirable bending of the specimen. In the same manner of tensile strength, nominal value of compressive strength also is determined by the reason of load by cross-sectional area (Kgf/cm^2). Stress-strain curve of investigated material is determined in the same manner as established to tensile tests. Thus, the elastic modulus can also be determined by the stress-strain ratio in the elastic region [11] (as shown in Figures 1.7 and 1.8).

1.4 Flexural 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. This is a measure of the strength of a beam of restorative material supported at each end and subjected to a static load. Stresses on the upper surface of the beam tend to be compressive, whilst those on the lower surface are tensile. This test may be considered to combine elements of tensile and compressive testing. Flexural forces are the result of forces generated in clinical situations and the dental materials need to withstand repeated flexing, bending, and twisting. A high flexural strength is desired once these materials are under the action of chewing stress that might induce permanent deformation. To evaluate flexural strength of a dental material, bar-shaped specimens with dimension of 25 mm in length, 2 mm in width and 2 mm in height (ISO 9917 – 212) are generally used. Specimens are placed on two supports and a load is applied at the center. This test is known as three-point bending test. The load at yield is the sample material’s flexural strength that is calculated by the following formula:

$$3Pl / 2bd^2 \tag{1.1}$$

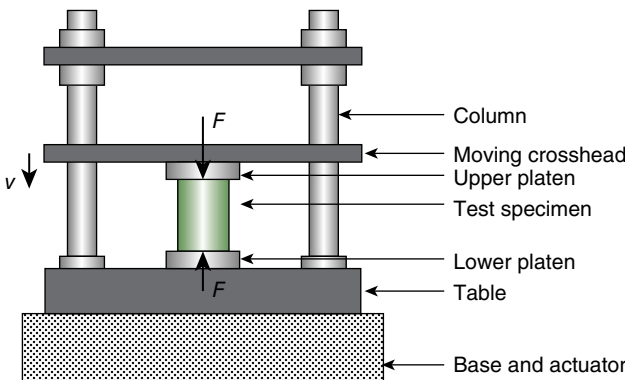
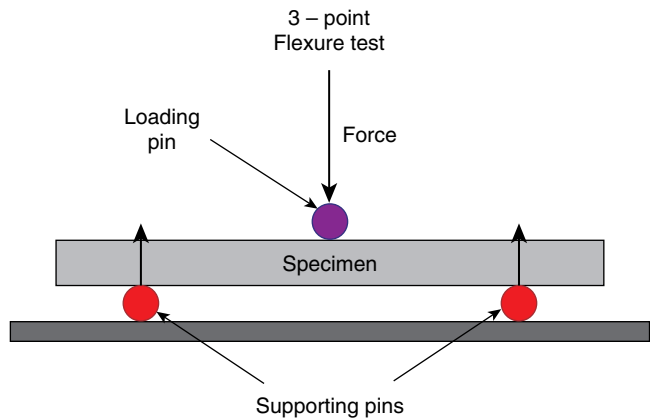


Figure 1.8 Schematic representation of the set-up for compressive strength.

Figure 1.9 Schematic representation of flexural strength assessment. Source: Anusavice [12], Anusavice [13], International Organization for standardization [14].



where P is the ultimate load at fracture, l is the distance of the supports, b is the width of the specimen, and d is the thickness of the specimen [12–14] (as shown in Figure 1.9).

Good to Know

Apart from the three-point bending test, there are four-point bending tests and biaxial bending tests.

The four-point flexure test also employ specimens that are loaded symmetrically at two locations with loading rollers, and the distance between loading points is usually one-third or one-fourth of the support span length. In four-point flexure test, maximum bending occurs between the loading points, whereas in three-point flexure test, the maximum bending occurs below the loading roller.

Bi-axial flexure testing is a commonly used technique for the evaluation of dental ceramics. Here force is given in two axes. Bi-axial flexure testing is independent of specimen geometry and force direction

1.5 Resistance to Fatigue

The behaviour of materials under the action of low but intermittent stresses shows the resistance to fatigue. This method permits measurement of a fatigue limit, with no fracture, at a given number of stress cycles. Compressive fatigue curves are generated when different materials are submitted to cyclic compressive stress. Tests are made with the test machine operation at a given loading frequency. The presence of defects in the microstructure of the restoration or specimen submitted to high or low stresses leads to the development of cracks. As clinical environment influences are critical factors due to the relatively low stress, these cracks will turn into fracture of the material [12] (as shown in Figures 1.10 and 1.11).

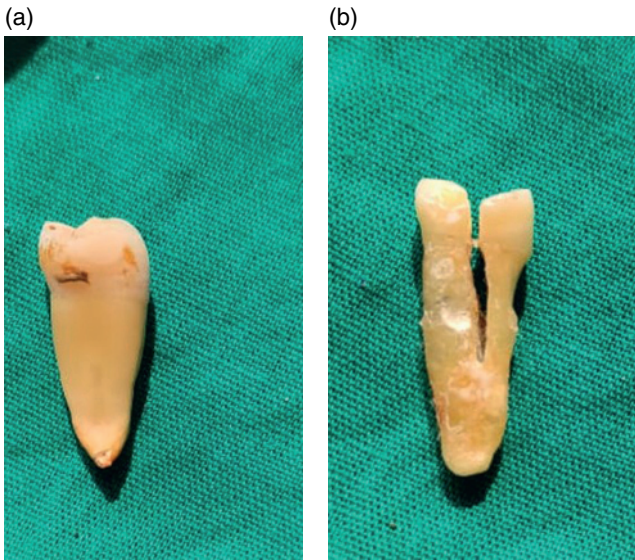


Figure 1.10 (a) Tooth sample, (b) crack propagation.

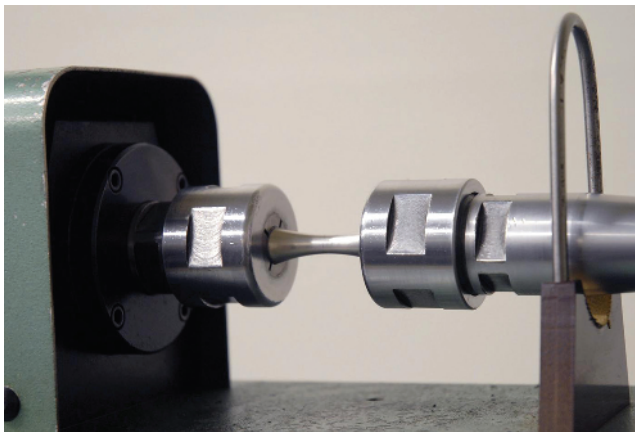


Figure 1.11 Assessment of resistance to fatigue by cyclic compression stress.

1.6 Hardness

Major laboratory tests are performed to investigate products based on their bulk features. Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure. The hardness of a material gives an indication of the resistance to penetration when indented by a hard asperity. The value of hardness, often referred to as the hardness number, depends on the method used for its evaluation. Generally, low values of hardness number indicate a soft material and vice versa.

Hardness measurement can be defined as macro or micro, according to the forces applied and displacements obtained. Macro means large, therefore macro hardness is a measurement of the hardness of a material when a large force of greater than 50 N is applied. Macro

hardness can be regular or superficial. In regular macro hardness, it is applicable to large area with deep penetration, whereas in superficial macro hardness, it is applicable to large area with shallow penetration. Macro hardness tests can be applied with heavier loads than micro indentation tests.

Micro hardness is a broadly used term referring to the testing of hardness involving materials by using small applied loads. A more appropriate term to describe this is micro indentation hardness testing. In this testing method, the use of a diamond indenter with a particular shape is used to make an impression called a “test load” or “applied force”, which can be at 1–1000 gf, on the material under testing. Normally, micro indentation tests involve 2 N forces, which are roughly equivalent to 200 gf. This force can produce an indentation of around 50 μm . Because of its specificity, this type of testing is applicable in cases where there is a need to watch for hardness changes on a microscopic level.

Rockwell, Brinell and Vickers hardness tests are applied for macro hardness testing, whereas Knoop hardness and Vickers hardness tests are done for microhardness testing.

Macro hardness testing has industrial applications such as testing hardness of steel, aluminium. Micro hardness test is applicable in dentistry for assessment of tooth samples and dental materials such as metals, ceramics and composites. Micro hardness tests are useful in giving required data when taking measurements of single microstructures situated within a bigger matrix and testing foil-like or thin materials.

The usual method to achieve hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape with a specific force applied for a specific time.

Vickers and Knoop both involve the use of diamond pyramid indenters. In the case of Vickers hardness, the diamond pyramid has a square base, whilst for Knoop hardness, one axis of the diamond pyramid is much larger than the other.

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136° between opposite faces subjected to a load of 1–100 Kgf. The load is normally applied for 10–15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average is calculated. The area of the sloping surface of the indentation is calculated. It is suitable to be applied to determine the hardness of small areas and for very hard materials.

Knoop hardness is more sensitive to surface characteristics of the material. The Knoop indenter is a diamond ground to pyramidal form that produces a diamond-shaped indentation having approximate ratio between long and short diagonals of 7 : 1. The depth of indentation is about 1/30 of its length. When measuring the Knoop hardness, only the longest diagonal of the indentation is measured, and this is used in the following formula with the load used to calculate Knoop Hardness Number (KHN). Knoop hardness test is applied to evaluate enamel and dentine structures. One of the major difficulties is the requirement of a high polished flat surface that is more time-consuming and more care taking compared to other tests.

Comparing the indentations made with Knoop and Vickers Diamond Pyramid indenters for a given load and test material, there are some technical differences as follows:

- Vickers indenter penetrates about twice as deep as Knoop indenter.
- Vickers indentation diagonal is about 1/3 of the length of Knoop major diagonal.

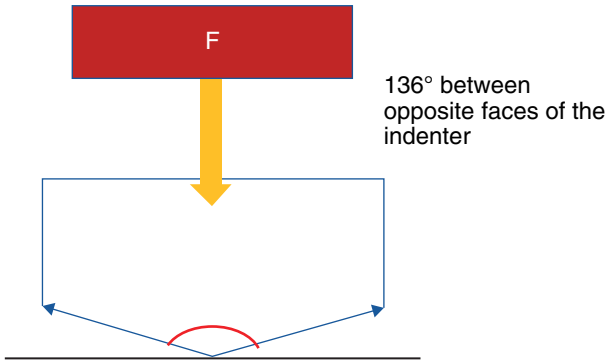


Figure 1.12 Vickers hardness testing.

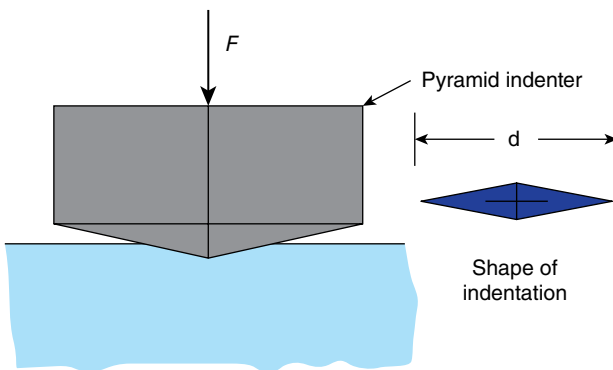


Figure 1.13 Knoop hardness testing.



Figure 1.14 Vickers hardness tester.

- Vickers test is less sensitive to surface conditions than Knoop test.
- Vickers test is more sensitive to measurement errors than Knoop test.
- Vickers test is best for small rounded areas, whereas Knoop test is best for small elongated areas (as shown in Figures 1.12–1.14).

The Brinell hardness test method consists of indenting the material with a 10 mm diameter hardened steel or carbide ball subjected to a load. It is the oldest method to measure surface hardness and is applicable to test metals and alloys (as shown in Figure 1.15).

Measurements are normally made using a microscope since the indentations are often too small to be seen with the naked eye. The hardness is a function of the diameter of the circle for Brinell

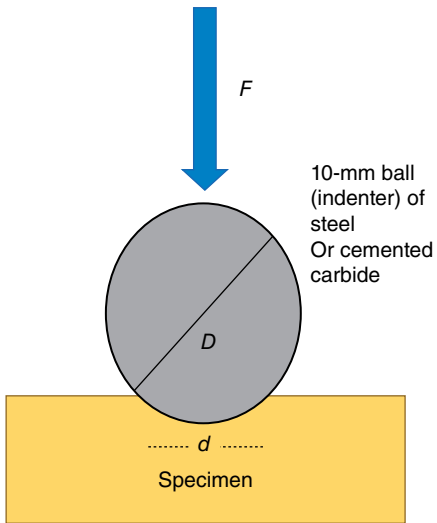


Figure 1.15 Brinell hardness testing.

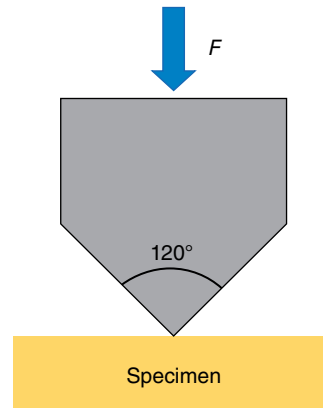


Figure 1.16 Rockwell hardness testing. Source: Vieira [4]. Licensed under CC BY 4.0.

hardness and the distance across the diagonal axes for Vickers and Knoop hardness. Allowance is naturally made for the magnitude of the applied loads. In the case of Rockwell hardness, a direct measurement of the depth of penetration of a conical diamond indenter is made. The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. This method is useful to evaluate surface hardness of plastic materials used in dentistry [4] (as shown in Figure 1.16).

Good to Know

All materials require different hardness testing. The specificity of a hardness tester is dependent on the following factors:

- a) Material of the indenter
- b) Shape and size of the indenter and the sample to be tested.
- c) Loading parameter (amount of force it can apply)

Hardness tests are extremely used and have important applicability on Dentistry. Hardness test can evaluate the degree of mineralization of a dental substrate for example. A specific force applied for a specific time and distance provides important data in studies assessing the ability of enamel and dentin remineralization after different treatments as happens in unbalanced situations of des-remineralization. Another important use of this test is to evaluate the degree of polymerization of resin composite and resin cements.

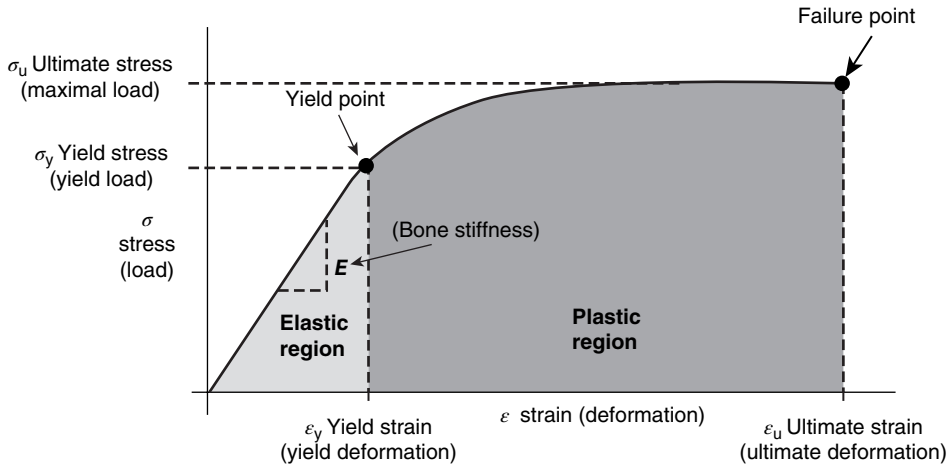


Figure 1.17 Stress–strain curve for assessment of Young’s modulus.

1.7 Elastic Modulus

The modulus of elasticity, or measure of a material’s stiffness, is also important in relation to anticipated longevity of a restoration. An elastic material (one with a low elastic modulus) will deform when a load is placed on it but will return to its original shape once the load falls below the elastic limit of the material. As a general rule, restorative materials need to be very stiff (high elastic modulus), so that under load the elastic deformation will be very small. An exception to this is in the Class V situation. Micro-filled composite materials have a lower modulus of elasticity than hybrid composite materials; this may be why micro-filled materials show higher retention rates in Class V cavities, given that they deform more readily as the tooth deforms at the cervical area under occlusal loading.

Models involving the use of springs and dashpots can be used to explain the elastic and viscoelastic behaviour of materials. When a spring, which represents an elastic material, is fixed at one end and a load applied at the other, it becomes instantaneously extended. When the load is removed, it immediately recovers its original length. This behaviour is analogous to that of a perfectly elastic material. The two things that characterize the material are firstly the perfect recovery after removal of the force and secondly the lack of any time dependency of either the deformation under load or the recovery after removal of the applied force. The extent of deformation under load is characterized by the modulus of elasticity of the material (analogous to the spring constant of the spring) (as shown in Figure 1.17).

1.8 Fracture Toughness

Fracture toughness determines the resistance of a material to the propagation of a crack. This test has been considered to be efficient given that other parameters can be derived from it. It should be kept in mind, however, that fracture toughness measures the failure of a material after one continuous period of loading, whereas fatigue strength experiments

measure crack propagation after repeated applications of a small cyclic load. A UTM (Instron) is used to apply a central load to the specimen in a three-point bending mode at a cross-head speed of 0.125 mm/minute. Fracture of the specimen is identified by a sudden drop in load during the test. Visual examination of the fractured parts is performed to ensure that the fracture plane is through the notch, and that it is perpendicular to the vertical and horizontal planes through the center of the specimens.

The fracture toughness was then calculated by:

$$K_{Ic} = \left(PL / bw^{1.5} \right) f(a / w) \quad (1.2)$$

The variables are defined as: K_{Ic} is the stress intensity factor, P is the load at fracture, L is the span, distance between the supports, w is the width of the specimen, b is the thickness of the specimen, and a is the crack length.

Good to Know

Cross-head speed is also known as deformation rate. It is measured in mm/min. Every material has different average cross-head speeds recommended by ISO 4049. For e.g. resin-based composites have a speed of $(0.75 \pm 0.25 \text{ mm/min})$.

1.9 Nanoindentation

With nanoscience gaining popularity, nanoindenters have advantages over traditional mechanical testing by providing both elastic modulus and hardness data of the tested samples. Nanoindentation is conducted with a calibrated Berkovich diamond indenter tip. A Berkovich tip is a three-sided pyramidal indenter.

During the nanoindentation process, a calibrated indenter tip approaches the surface of the sample. The force–displacement data is used to determine the point of contact. After the sample is contacted, the force is linearly increased and the tip indents into the surface of the sample. A short dwell time occurs at the maximum force and then the sample is unloaded. At the initial point of unloading, the stiffness is measured.

1.10 Bond Strength

Longevity of a restoration is predicted to some extent by its adhesive ability, and this in turn can be measured by bond strength testing. An ideal bond strength test should be accurate, clinically reliable and less technique-sensitive. It should involve the use of relatively unsophisticated and inexpensive test protocols. Static tests are categorized into macro-tests where the bond area is $>3 \text{ mm}^2$ and micro-tests with $<3 \text{ mm}^2$ bond area [15].

1.10.1 Macro-Test Methods

The macro-bond strength can be measured in shear, tensile or using a push-out protocol.

1.10.1.1 Macro-Shear (SBS) Test

In a shear bond test, two materials are connected via an adhesive agent and loaded in shear until fracture occurs.

1.10.1.2 Macro-Tensile (TBS) Test

In a tensile bond test, load will be exerted on either sides of the test specimen. The specimen can be held by active or passive gripping methods. Active gripping method involves mechanical fastening of specimen to gripping device, such as glue or clamps, whereas in passive gripping method, specimen is placed in a testing device without the aid of glue or mechanical gripping. It can be used to measure, for instance, the bond strength of cements to hard materials such as ceramics and metal alloys [16].

1.10.1.3 Push-Out (PO) Test

In this method, load is applied through a plunger mounted in the UTM. The plunger must provide near-complete coverage of the testing material without touching the substrate. This method is useful to test adhesion of root canal sealers and retention of posts luted in root canals [17].

1.10.2 Micro-Test Methods**1.10.2.1 Micro Shear Test**

Shear bond strength (SBS) testing with bonded cross-sectional areas of 3 mm^2 or less is referred to as “micro” SBS. It permits efficient screening of adhesive systems, regional and depth profiling of a variety of substrates and conservation of teeth. Micro-shear tests remain an extremely useful test for those substrates with properties such as glass ionomers or enamel that make them particularly susceptible to the specimen preparation effects and testing conditions of μ TBS testing [18].

1.10.2.2 Micro Tensile Test

Micro-tensile bond test (μ TBS) allowed additional research designs that the “macro” tests did not, such as the elimination of tooth dependency through balanced designs. However, there is a difficulty in measuring bond strengths lower than 5 MPa [19].

1.10.2.3 Micro Push-Out Bond Strength

Micro-push-out test is a modification of push-out test where the specimen thickness is less than or equal to 1 mm^2 [15].

Key Points

- 1) Tensile strength, diametral compression test, compressive strength, flexural strength, resistance to fatigue, hardness, elastic modulus, fracture toughness are the various mechanical properties that are measured in the field of dental material sciences.
- 2) Universal Testing Machine (UTM) is used for most of the tests with the only difference being that the sample preparations differ for each test. Hardness testing depends upon the material to be tested.

- 3) The samples are prepared as per ISO standards to get optimum results. Also, the area which is subjected to the force differs due to the size of the stick/blade.
- 4) Axial forces in a straight line and in opposite directions result in tension in the body of a material, and the resistance of the material to this load is called tensile strength. Nominal value of tensile strength is determined by the equation of load and cross-sectional area (Kgf/cm^2).
- 5) The diametral tensile strength (DTS) test is useful for materials where information regarding stretching or elongation resistance is required and the failure has to occur along the center of the specimen.
- 6) Compressive strength is used to test materials which are subjected to occlusally directed forces in the oral cavity.
- 7) Flexural forces are the forces that generate repeated flexing, bending and twisting of the materials.
- 8) Resistance to fatigue is the measurement of a fatigue limit, with no fracture, at a given number stress cycles.
- 9) Hardness of a material gives an indication of the resistance to penetration when indented by a hard asperity.
- 10) Types of hardness: macro hardness and micro hardness.
- 11) Macro hardness has force application greater than 50N, and micro hardness has force application less than 10N. Macro hardness test is done using Vickers, Rockwell and Brinell hardness tester, whereas micro hardness test is done using Vickers and Knoop hardness tester.

References

- 1 Albers, H.F. (1996). *Tooth-Colored Restoratives*, 8e. Santa Rosa: Alto Books.
- 2 Craig, R.G. (1997). *Mechanical Properties. Restorative Dental Materials*, 10e, 56–103. St. Louis: Mosby.
- 3 Craig, R.G. (1997). *Optical, Thermal, and Electrical Properties. Restorative Dental Materials*, 10e, 30–55. St. Louis: Mosby.
- 4 Vieira, D.F. (1965). *Propriedades mecânicas. Propriedades dos materiais odontológicos*, 31–89. São Paulo, Universidade de São Paulo.
- 5 Vieira, D.F. (1965). *Propriedades ou constantes físicas. Propriedades dos materiais odontológicos*, 92–105. São Paulo: Universidade de São Paulo.
- 6 Wang, L., Henrique, P., Gonzaga, L., and Carlos, J. (2003). Mechanical properties of dental restorative materials: relative contribution of laboratory tests. *J. Appl. Oral Sci.* 11 (3): 162–167.
- 7 Darvell, B.W. (2000). *Mechanical testing. Materials science for Dentistry*, 6e, 1–34. Hong Kong: University of Hong Kong.
- 8 Sood, A., Ramarao, S., and Carounanidy, U. (2015). Influence of different crosshead speeds on diametral tensile strength of a methacrylate based resin composite: An in-vitro study. *J. Conserv. Dent.* 18: 214. <https://doi.org/10.4103/0972-0707>.
- 9 Cefaly, D.F.G., Franco, E.B., Mondelli, R.F.L. et al. (2003). Resistência à tração diametral e sorção de água de cimentos de ionômero de vidro usados no Tratamento Restaurador Atraumático. *J. Appl. Oral Sci.* 11 (2): 96–101. <https://doi.org/10.1590/S1678-77572003000200003>.

- 10 Cattani-Lorente, M.A. (1999). Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass ionomer cement. *Dent. Mater.* 15: 21–32.
- 11 International Organization for Standardization (1993). *Technical report ISO 9917*. Switzerland: Dental water-based cements.
- 12 Anusavice, K.J. (1993). Recent developments in restorative dental ceramics. *J. Am. Dent. Assoc.* 24: 73–84.
- 13 Anusavice, K.J. (1983). *Propriedades mecânicas dos materiais dentários. Phillips materiais dentários*, 10e, 28–43. Rio de Janeiro: Guanabara Koogan.
- 14 International Organization for standardization (1998). *Technical report ISO 9917-2 Dental water-based cements- Part 2*. Switzerland: Light-activated cements.
- 15 Castellan, C.S., Santos-Filho, P.C., Soares, P.V. et al. (2010). Measuring bond strength between fiber post and root dentin: a comparison of different tests. *J. Adhes. Dent.* 12: 477–485.
- 16 De Munck, J., Mine, A., Poitevin, A. et al. (2010). Testing bond strength. A review of the literature. *Dent. Mater.* 26: e139–e140.
- 17 Jainaen, A., Palamara, J.E., and Messer, H.H. (2007). Push-out bond strengths of the dentine – sealer interface with and without a main cone. *Int. Endod. J.* 40: 882–890.
- 18 Armstrong, S., Geraldeli, S., Maia, R. et al. (2010). Adhesion to tooth structure: a critical review of “micro” bond strength test methods. *Dent. Mater.* 26: e50–e62.
- 19 Pashley, D.H., Carvalho, R.M., Sano, H. et al. (1999). The microtensile bond test: a review. *J. Adhes. Dent.* 1: 299–309.