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Review Article

Flexural Strength is a Critical Property of Dental Materials-An Overview

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Abstract

Numerous dental materials are used in dentistry and in selecting the appropriate one, their mechanical properties are to be evaluated. Mechanical properties are governed by the laws of mechanics which would give us information on what happens when the material is subjected to forces. Restorative materials are expected to withstand forces during the fabrication process and during masticatory function. Materials can be described qualitatively like hard or soft, tough or fragile, flexible or stiff. But these descriptions will not help us in comparing and selecting a suitable material.

In dentistry, testing protocols are defined by different agencies like standard organisations and they have formulated specifications which would be updated from time to time. Strength testing is an important category in which the following properties are included: tensile strength, compressive strength, shear strength, yield strength fracture toughness, flexural strength and many more tests. Dentist is interested to know how the material selected for a restoration will behave in the course time. The restoration should be structurally durable without undergoing permanent deformation or fracture. Test for flexural strength has great predictive value. This overview briefly goes through the definition, numerous testing methods and flexure strength values of commonly used dental materials.

Keywords: Mechanical Properties; Flexural Strength; 3point Bend Test; Biaxial Flexure Strength; Flexural Modulus

Introduction

Flexural strength of a material, otherwise called as bend strength, is a critical property that measures its ability to resist bending or breaking under stress. When a material breaks, it experiences the highest stress. Three different classe of materials viz. metals, ceramics and resins are used for the restorations and replacements of teeth. When one or two teeth are lost, they can be replaced by a fixed prosthesis. At both the ends, it will be fixed on prepared teeth. When a patient bites on a hard substance, the prosthesis bends in the middle. If the prosthesis is not breaking, we understand that the material with which the prosthesis is made has adequate flexural strength. In a cantilever situation, where the prosthesis is fixed only on one end, stresses are generated both in the prosthesis and in the supporting teeth and fracture can occur both in the prosthesis and the supporting teeth. In such a situation we may state that the flexural strength of the material and the tooth are not adequate. In the former situation the load generated can effectively get transmitted through the teeth along its long axis and fracture of tooth material rarely happens. In the latter situation, the load applied acts in an angulation to the long axis of the tooth and hence the possibility of tooth fracture is more. More than the possibility of the fracture of the supporting teeth, the supporting alveolar bone damage is more common, terming it as periodontal tissue damage in cantilever fixed prosthesis (Figure 1,2). When a specimen is bent, it experiences a range of stresses across its depth. At the centre of the concave face of the specimen, the stress will be at its maximum compressive value. At the convex face of the specimen, the stress will be at its maximum tensile value. Most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the specimen fails is its flexural strength. The flexural strength would be the same as the tensile strength if the material is homogeneous (Figure 3).

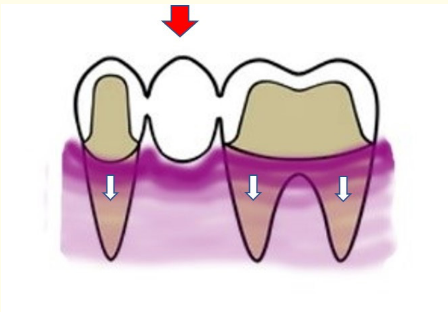

Figure 1: Fixed dental prosthesis with two support teeth.

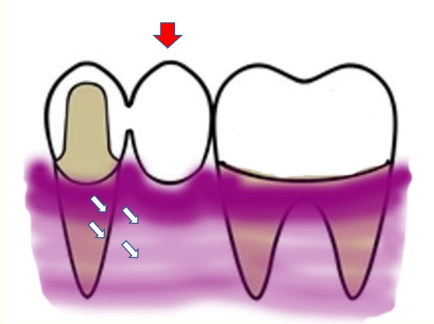

Figure 2: Cantilever fixed dental prosthesis with one support tooth.

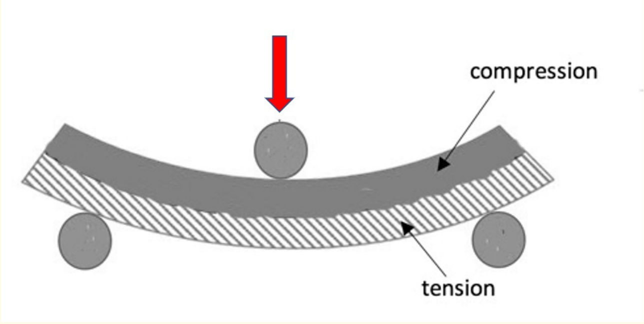

Figure 3: Compression and tension in a flexed specimen.

Three point and four-point flex (bend) test

Three point and four point bend tests are commonly used in the determination of the flexural strength of a dental material. They are almost similar in the operational method. A three point flex test positions rectangular specimens supported by two lower anvils of the universal testing machine. Force is applied from a single upper anvil which is positioned at the midpoint. The load causes flexion and the load application is continued until the specimen breaks or when it causes permanent deformation to the specimen. Resin and ceramic specimens usually break whereas metallic specimens bend permanently [1].

Four-point bending test is similar to three-point bending test except one fact that the load is applied through two upper anvils simultaneously. One point of load application is at one-third distance between the supports and the second is at two-third distance between them four-point tests are used to measure the modulus of elasticity in bending of brittle materials Figure 4 , 5.

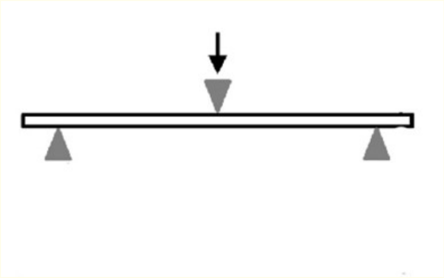

Figure 4: Three point loading - schematic diagram.

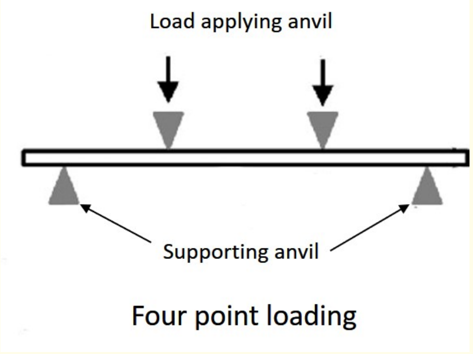

Figure 5: Four point loading - schematic diagram.

Universal testing machines used for testing flexural strength of materials have a sturdy frame and cross head which can move up and down at a constant speed. The loading tip is fixed to the movable cross head. Advanced machines have facilities to programme the speed of movement. The force transducer attached to the machine can measure the load applied (Figure 6) [2,3]. Three and four point bend testing done with Instron is shown in figures 7 and 8.

Flexural strength calculation

When three point bending test is done, flexural strength is calculated by the formula

$\sigma = 3FL/2wd^2$

- **F:** Maximum force applied (Newtons),
- **L:** Length of the specimen measured between the supports (mm),

Figure 6: Instron Universal Testing machine.

Figure 7: Three point bend test.

Figure 8: Four point bend test.

- **w:** Width of the specimen (mm),
- **d:** Thickness of the specimen (mm)
- **σ:** Flexural strength (MPa) (σ - sigma)

When four point bending test is done, flexural strength is calculated by the formula

$\sigma = FL/wd^2$

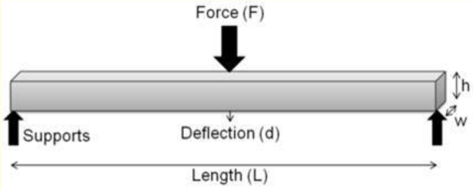

Figure 9: Flexural strength measurement parameters.

Only difference in this formula is that it is without the factor of 3/2. Force applied is multiplied by the length and it is divided by the width of the material multiplied by the square of the thickness of the specimen [4,5].

Biaxial flexure strength

Ceramic materials are commonly evaluated by biaxial flexural strength testing. Biaxial testing uses disc or square specimens which are easier to prepare and uses larger volume of material than in beams. In addition, edge preparation is less critical because maximum stresses applied are remote from edges.

The ball-on-3-balls (B3B), piston-on-3-balls, ball-on-ring, and ring-on-ring tests have been found to be effective in testing the biaxial strength. The B3B test was specifically developed to overcome disadvantages like out of flatness of the test specimens. A disc of 32 mm diameter is supported by three 3.2 mm diameter balls, equally spaced on a 25.4 mm diameter circle. On the opposite side, the disc is centrally loaded by a ball or guided punch of 1.6 mm diameter. An alternate method is to use a metallic ring to support the ceramic disc which is loaded by a ball. This is considered as an analogue of three point flexure testing of a bar (Figure 10,11).

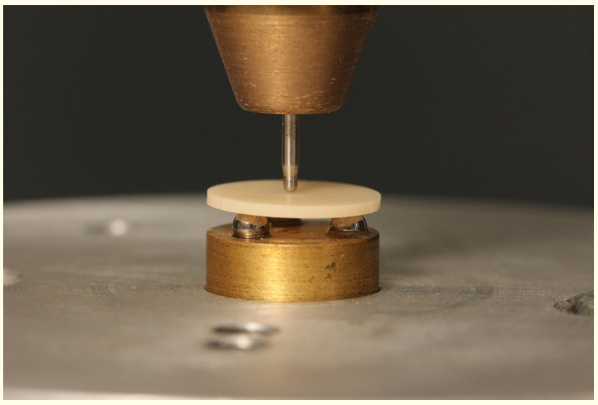

Figure 10: Biaxial flexure test- supported by balls and loaded by piston.

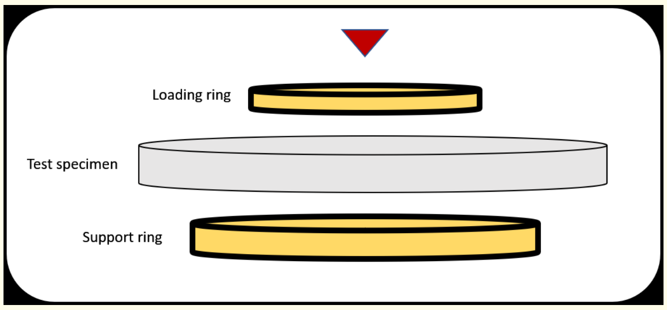

Figure 11: Biaxial flexure test - supported by ring and loaded by ring.

Ring supported/ring loaded flexure strength testing

This is a symmetrical form of loading and is considered equivalent to four-point flexure testing on bars. The testing is done with two rings; one of which is to support the specimen and the other to apply the load and they are placed concentrically on the specimen. The rings are either round or semi-circular in cross section. If the specimen is not flat, it may not make faithful contact with the rings. To avoid the contact discrepancy, a rubber sheet of 1mm thickness is placed between the support ring and the specimen. Rubber sheet permits shear forces and reduces friction. Similarly, a sheet of paper is placed between the loading ring and the specimen. These specifications are incorporated in ISO 6474 for alumina ceramics and ISO13356 for zirconia ceramics. Usually 36 mm diameter test specimens, 30 mm diameter support ring and 12 mm diameter loading ring are used (Figure 11).

In order to find out a reliable bending test method suited for pressed ceramics, three-point, four-point, and biaxial flexural tests were compared. Biaxial flexural strength was not significantly different from other tests. Four point bending test and biaxial flexural test showed a strong correlation. The biaxial flexural test was found to be suitable for ceramic materials which have less capability of plastic deformation [6,7].

Flexural strength values of different dental materials

Approximate values of flexural strength of different dental materials and tissues are given in Table 1. Huge variation is observed between reference sources like text books, published articles, internet resources including 'chat GPT'. However, the values cited in the table can serve as a guideline.

Advantages of high flexural strength

Posterior dental arch is considered as high stress bearing area and restorations planned and fabricated for this zone should have high flexural strength to withstand the masticatory load. If bruxers require crowns, materials with high flexural strength will be a

Dental Material	Flexural strength (MPa)
Zirconia ceramic	900-1200
Lithium disilicate ceramic	400-500
Resin composite	100-150
Feldspathic porcelain	~65
Amalgam	250-350
Acrylic resin	~65
Glass ionomer cement:	50-100
Resin cement	66 - 121
Cobalt-Chromium (Co-Cr) alloy	1000-1300
Nickel-Chromium (Ni-Cr) alloy	500-900
Gold-Palladium (Au-Pd) alloy	350-450 MPa
Titanium (Ti) alloy	900-1200 MPa
Silica fibre post	~879
Cast gold post	~1545
Dental Tissues	
Dentine	212 -227
Enamel	~179
Cortical bone	100 - 230
Trabecular bone	2 - 12

Table 1: Flexural strength values of dental materials/tissues.

wise choice. Similarly increase in span length of restorations necessitates material choice with high flexural strength. Long span restorations technically flexes more and to counteract the possibility of fracture, restorative material should have high flexural strength. Minimally invasive restorations protect the biology of the tooth but at the same time we have to ensure the structural durability of the restoration. For this, restorative material should have adequate flexural strength and fracture resistance.

In terms of flexural strength, the best performing restorative material is zirconia. Low translucency zirconia has flexural strength of 1200 MPa whereas high translucency zirconia has flexural strength between 600 to 900 MPa. It is an interesting fact to note that aesthetics and strength do not maintain a direct proportionality. Airborne particle abrasion operated with low pressure can increase the flexural strength of zirconia. However, grinding and cyclic loading of zirconia can cause considerable reduction of the strength of both low and high translucency zirconia [8].

Flexural strength of restorative resins and beverages

Determination of flexural strength served as a good evaluation tool to find the effect of Coca Cola like acidic beverages on restorative resins. A few brands of restorative resins showed considerable deterioration in flexural strength after I week and 1 month immersion. Control specimens of different brands showed flexural strength ranging from 58 to 148 MPa in a three point loading test. While restoring teeth with resins, clinicians should critically evaluate the properties not only from catalogues but also from published literature [9].

Flexural modulus

The flexural modulus is a mechanical property that indicates the stiffness of a material; in other words, the resistance a material can offer to a bending action. The flexural modulus of a material can be calculated graphically from the stress strain curve by calculating the slope of the linear portion of the graph. The value is calculated by dividing the change in stress by the corresponding change in strain. If the flexural modulus is high, it is very difficult to bend or flex the material. A material that has low modulus, flexes easily and it cannot be qualified as a restorative material (Figure 12). Another example is the comparison of a cast clasp and a wrought wire clasp. Wrought wire clasps flex easily and its ability to retain the prosthesis is comparatively lower than that of the cast clasp for a similar under cut.

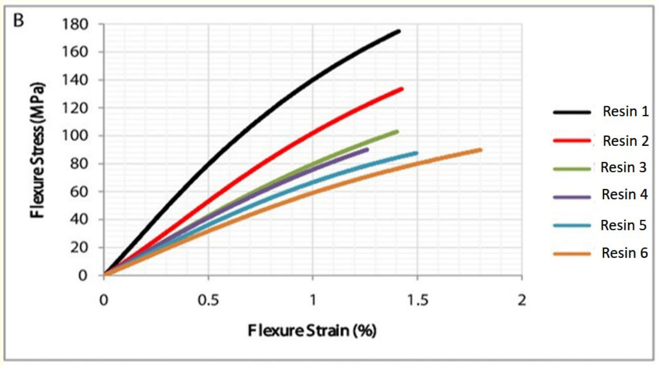

Figure 12: Comparison of flexural strength of different restorative resins.

Conclusions

Dentists and engineers very often try to understand the behaviour of numerous materials they make use of but uniaxial tensile or compression tests may not reveal all the necessary information. When a test specimen flexes or bends, it is subjected to multiple forces viz. compression, tension and shear. Hence flexural testing is commonly used to gauge the changes that are expected in the materials when realistic loading situations arise. Data obtained from flexural strength testing will provide an insight into the support requirements while designing a fixed prosthesis and selecting the appropriate materials. Dentists should try to go through the available data obtained from physical and mechanical tests conducted at recognised laboratories before a new material is tried in the clinic.

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Figure credits

Figure 6, 7 and 8. Instron calatalogue
Figure 9. https://civiljungle.com/modulus-of-rupture/
Figure 11. Austin J Dent. 2015;2(2): 101