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Assessment of biological and mechanical degradation in dentistry :a review

Layla Mahmoud bakir [1,*] and Hebatallah Fathy [1]

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[1] *Department of* Biomaterials Faculty of Dentistry, Cairo University

* Corresponding author e-mail: layla.mahmoud@dentistry.cu.edu.eg

Abstract:. To predict how well the clinical performance of the dental materials will perform in the patient's mouth, it is essential to analyse the causes of structural degradation and failure of the used materials. The pH and temperature changes, a variety of stresses, and microbes make the oral cavity a difficult habitat to live in. bad material selection, bad design, or overuse are the three most common reasons for dental material failure. Additionally, damage can occur while being corrected. To prevent material failure, it's imperative to plan for failure, understand its causes, and take the necessary precautions.

Keywords: *Biological degradation, dentistry, mechanical degrdation.*

Introduction

Analysis of the reasons for structural degradation and failure of the employed materials is crucial in order to forecast how well the clinical performance of the dental materials will perform in the patient's mouth. The oral cavity is a hostile environment that includes germs, changes in pH and temperature, and many stresses. The most frequent causes of dental material failure are poor material selection, poor design, or overuse. Damage might also happen while being repaired. To prevent material failure, it's crucial to plan to avoid failure, evaluate the causes, and implement the necessary preventive actions.[1-4]

1) Assessment of biological degradation

Restorative materials of any type may not attach to enamel or dentin with enough strength to withstand the stresses of contraction during polymerization, wear, or thermal cycling. This is known as microleakage. Along the unsupported border, the gap encourages material breakdown. The gap width widens as a result of this breakdown, allowing larger particles and molecules to enter the pulp chamber. Capillary motion may suck bacteria, food debris, or saliva into the gap between the restoration and the tooth if a bond does not form or if debonding develops, causing pulp tissue infection. It also causes minor stains and poor aesthetics, which may necessitate early replacement.[5]

Methods of Microleakage testing

Microleakage testing has been employed to determine a restorative material's clinical performance. Over the years, many microleakage testing materials have been created and tested. There hasn't been any resolution on which testing method would produce the most accurate results. Simulating oral circumstances and providing a better quantitative picture of microleakage have been attempted.

1. **Direct observation:**

Direct inspection of restorations is the simplest way to assess microleakage, using no agent or tracer. Clinical observation is commonly performed to recognize macroscopic changes in a restoration's marginal integrity.

This can be done:

1) Tactilely with an explorer.

2) Visually by looking for discoloration in the surrounding enamel or a gap between the tooth and the restoration.

Clinical examination is frequently combined with photographic observation. To determine changes in marginal integrity, a macro photographic black and white record of each restoration is made at various time intervals.[5]

2. **Fluorescent dyes method:**

Because the fluorescent dye is non-toxic, it can be used for in vivo experiments both topically and systemically.

This dye:

1. Could be detected at low concentrations.
2. Sensitive to ultraviolet light.
3. Easy to photograph.
4. Allow for more consistent results.
5. Inexpensive.

Under UV light, the difference between the natural fluorescence of the tooth and the dye produced a contrast that made it easy to detect the course of dye penetration. As a result, new fluorescent dyes are now being used to tag restorative products like cavity varnish and glass ionomer cements. The dye is quenched (i.e. the fluorescence disappears) by the zinc oxide eugenol cement, so it cannot be employed with it. The absence of the effect of pulpal hydrostatic pressure on the dye has been a source of criticism for laboratory testing (in vitro). In vivo testing yielded much lower mean microleakage scores than in vitro testing among human subjects. On the other hand, when in vivo teeth to be tested have undergone endodontic therapy, the outcomes were more similar to those of in vitro testing.(5)

3. **Radioisotope method:**

The use of autoradiography, specifically 45Ca (calcium 45), to identify microleakage has gained widespread acceptance. The radioisotope is injected into the specimens' edges. For proper contact between the specimen and the radiographic film emulsion, a flat surface is required. After that, the film is developed, and the radiolucency around the restoration is used to determine microleakage.

With the autoradiograph, even minute amounts can be identified, because the radioisotope can penetrate deeper than the dyes employed. The dye has a molecular size of 120 nm while the radioisotope has a molecular size of 43.2 nm. The radioisotope has two-hour exposure duration, unlike dyes which require 24h or more.

Note: Autoradiography is a technique that uses X-ray film to visualize radioactively labeled molecules or fragments of molecules.(5)

4. **Dye penetration method:**

The most popular procedure is to stain microleakage and nanoleakage with colored chemicals. The dye penetration method includes staining the sites of microleakage with contrasting dyes by immersion in a dye solution, and then examining the tooth–restoration interface for signs of staining. 0.5 % basic fuchsin, 2 % methylene blue (both known as organic dyes), and 50 % silver nitrate are the most frequently used solutions. An image analysis equipment connected to a stereomicroscope was used to analyze dye penetration. The actual length of dye penetration along the contact was measured using digital image microscopy.(5),(6)

Note: A stereo microscope is an optical microscope that allows you to see a specimen in three dimensions. Separate objective lenses and eyepieces are included among its components, so each eye has two independent optical paths. The use of silver nitrate is second to the use of organic dyes. Silver nitrate was chosen because the significant optical contrast of silver particles makes it easy to detect using microscopy. Silver nitrate staining is the most widely utilized agent for nanoleakage evaluation, because of its incredibly small diameter, which allows it to quickly penetrate the interface zone. Silver nitrate molecules can become static after penetration, preventing additional penetration during specimen processing. This method requires immersing the specimens in a 50% silver nitrate solution for two hours in the dark. After rinsing the specimens to eliminate any silver ions on the surface, they are immersed in developing solution and subjected to fluorescent light for six hours. At this point, the silver ions absorbed in the specimens precipitate as silver particles. The microleakage specimens are then sectioned. The degree of leakage can then be determined in the same way as organic dyes. Regarding amalgam restorations, the silver staining procedure was tried, but the results were inconsistent. This was thought to have happened as a result of chemical interactions between amalgam components and silver ions. (5),(6)

The dye penetration assay has a number of benefits over other methods:

1) No radiation or reactive chemicals are used.

2) A variety of dye solutions are accessible, making the process exceedingly viable and repeatable.

3) Simplicity of use.

4) Inexpensive cost.

The drawbacks of organic dyes include:

1) Some dyes, such as basic fuchsin, can react with dentin, so researches have failed to clearly identify which dyes are appropriate for use.

2) The particle size of the dye utilized, which can impair the test's reliability.

3) Most dyes require a much longer exposure time than other procedures, such as radioisotope.

4) Unless images of the specimens were taken, there were no permanent records.

Because dye penetration varies from one location to another, assessing a single part of the tooth is not representative. Multiple surface scoring methods are thus preferred over single surface scoring methods because the findings are more indicative of the leakage pattern. To effectively assess leakage, it is advised that three segments be used for each restoration.(5)

5. Air pressure method:

Other tests were created to enable the quantification of results. The contact between restorations and cavity preparation walls was penetrated with air pressure. The presence of leaking was confirmed by the appearance of bubbles at the edges. The amount of air pressure required to demonstrate leakage is quantified. The region of leakage cannot be identified because these specimens are examined under water, and photographic records are very challenging to collect.[(5)]

6. **Electrochemical method:**

The electrochemical approach was developed from endodontic research for application in restorative research. The technique allows for reliable identification of the onset of leakage and delivers quantified data over time. The procedure works by inserting an electrode into the root of an extracted tooth, bringing it into touch with the restoration's base. The restored tooth is isolated by nail polish (to prevent electrical leakage via the natural structure) and immersed in an electrolyte bath. Leakage is measured by monitoring the current flowing across a serial resistor when a voltage is introduced between the tooth and the bath.[(5)]

7. **Bacterial microleakage method:**

The investigation of microleakage using bacteria could be the most clinically useful microleakage test. Chromogenic microorganisms were used in a study with extracted teeth that had Class V amalgam or acrylic resin. They were incubated for seven to sixty days in a broth culture. Shavings of the dentin under the restoration were cultured at the end of the test period. Bacteria penetrated the acrylic resin more than amalgam restorations. To avoid cross-contamination with other germs, the procedure requires a sterile environment, so it's a quite meticulous procedure.[(5)]

8. **Secondary caries formation method:**

Bacterial culture or chemical systems are used in the secondary caries approach. This approach has the advantage of connecting artificial caries development to microleakage. The acidified gelatin gel approach has been found to develop lesions with histological characteristics that are similar to early caries.

Around the tooth, an acid-resistant varnish was applied, stopping 0.5 mm short of the restoration margin. The specimens were placed in a 20% gel solution, adjusted to pH 4.0 by the addition of 30% lactic acid, for 10 weeks, 24h after restoration placement. To prevent bacterial growth, thymol was added to the gelatin. Polarized light microscopy was used to examine ground slices of the teeth.[(5)]

2) **Assessment of Mechanical degradation:**

1) **Deformation**

a) **Compression testing**

Since most of the mastication forces are compressive, it's important to investigate material under compression. When an objected to compression, failure may occur due to complex stresses. Compression testing depends on the concept that axial force is applied at a constant strain rate to the cylindrical specimen at each end that causes failure in an opposite direction. The force is applied and resolved to forces of shear along a cone-shaped area at each end, and tensile forces at the central portion. If the test specimens are too short, force distributions become more complicated, and if it is too long, buckling may occur. The cylinder should have twice the diameter for satisfactory results. Compressive strength is useful for comparing brittle materials that can't be tested under tension. Compressive testing is useful in testing amalgam, resin composite, and cement.[7] (Figure 3)

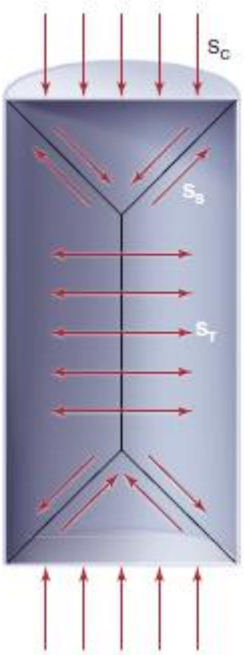


Figure 3: Compressive test

b) Tensile testing

i) Uniaxial tensile testing

Most restorative materials fail by tensile stresses due to the complex loading of their complex geometries. The typical shape of a specimen for tensile testing is like a dumbbell or dog bone with a center region (Gauge length) with a smaller diameter than the ends of the specimen. So this will concentrate the stress in the middle, and ensure failure in the middle. The test is technique sensitive and specimen alignment is critical to make sure that load loading is uniaxial. This test is not used to measure dental composite. It is used to measure the ductility of the material and is used with metallic materials. [8] (Figure 4)

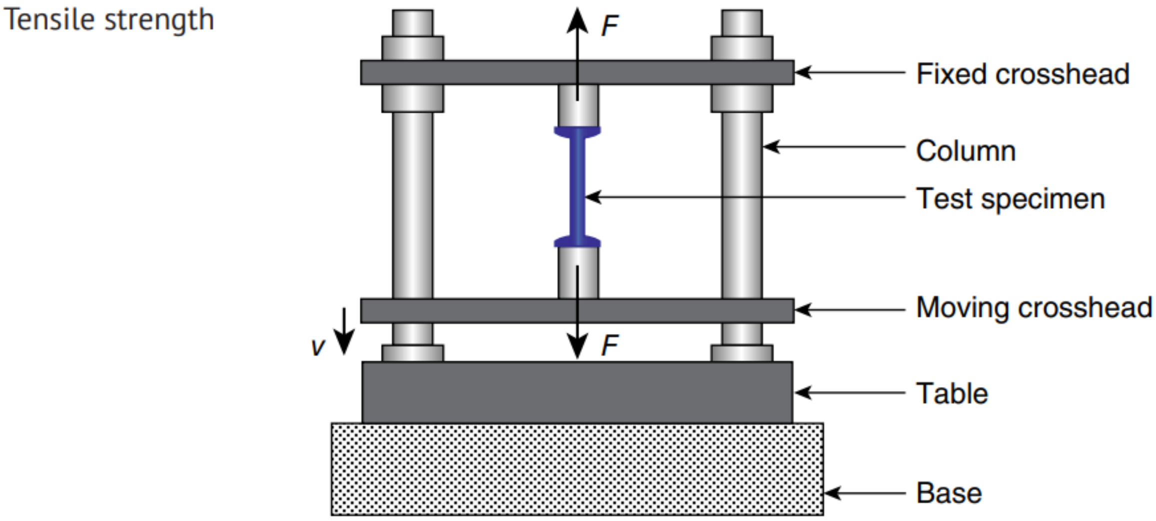


Figure 4: Tensile testing

ii) Diametral tensile testing (Brazilian test)

Due to the difficulty to perform uni-axial tensile tests for brittle materials due to specimen alignment and the difficulty to form dumbbell shape specimens, the diametral test was developed. It is used for dental composites and ceramics.(1)

It involves breaking a disk under compression diametrically till fracture. This compressive stress introduces tensile stresses to the material in the plane of the force application. The specimen production is critical to ensure that the specimen is uniformly loaded. This test is considered accurate when the specimen breaks uniformly. The failed specimen must be two halves, not a distribution of fractured pieces. (7) (Figure 5)

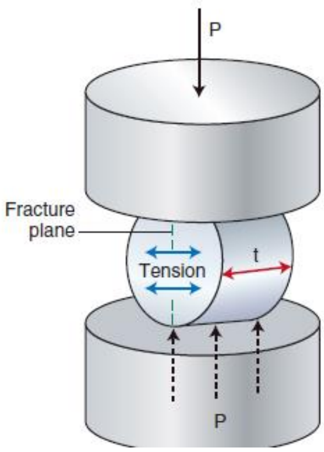


Fig 5: Diametral compressive testing

c) <u>Flexural test</u>

The flexural test is obtained when one loads a simple single beam supported at each end, with load applied in the middle. This test is called the three-point bending test. The maximum stress measured is called flexural strength. Four-point bending is preferred to three points. Four points loading uses two loading elements applying a uniform load to the beam to prevent V-Shaped buckling of the beam. It also prevents stress concentration in the midline when a single loading element is used. Also the three-point flexural test, the failure may not be in the midpoint directly, so a correction must be made. It is used with a long fixed partial denture spans or acrylic partial dentures. For brittle materials such as ceramics, it is preferred than diametral compressive tests because they stimulate stress distribution in dental prostheses and clap arms of removable dental prostheses.[1,7] (Figure 6)

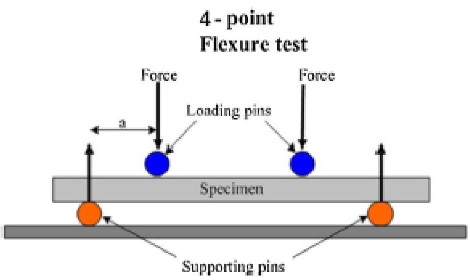


Figure 5 – Four-point flexural strength tests [61].

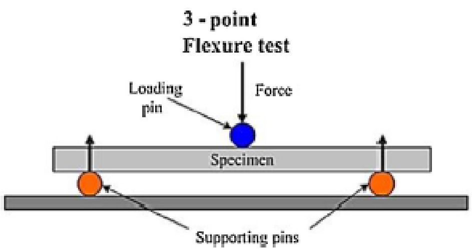


Figure 6: Three point and four point loadings

d) Torsion

Torsion is the variation of pure shear and rotation where the structural member is twisted. Torsion testing involves twisting a sample along an axis. A longitudinal sample is placed in a torsion tester and one end is twisted around the long axis till failure. Most endodontic files and reamers are subjected to twisting. Also, torsion is important on considering implant restorations and orthodontic wires.[7,9]

e) Buckling

This test is used with orthodontic wire or endodontic files. The idea of buckling depends on the application of forces in the axial direction resulting in lateral bending and deformation. A slender thin rod is more likely to buckle than a thick rod. Adequate buckling resistance is important for exploring canal orifices and negotiation of narrow canals. For measuring buckling resistance, the instrument handle was connected to a device, and the file or wire is loaded in an axial direction. The tip was restrained in a point. The maximum load was defined as the buckling resistance. [10] (Figure 7)

Figure 7: buckling

2) Failure due to static overload

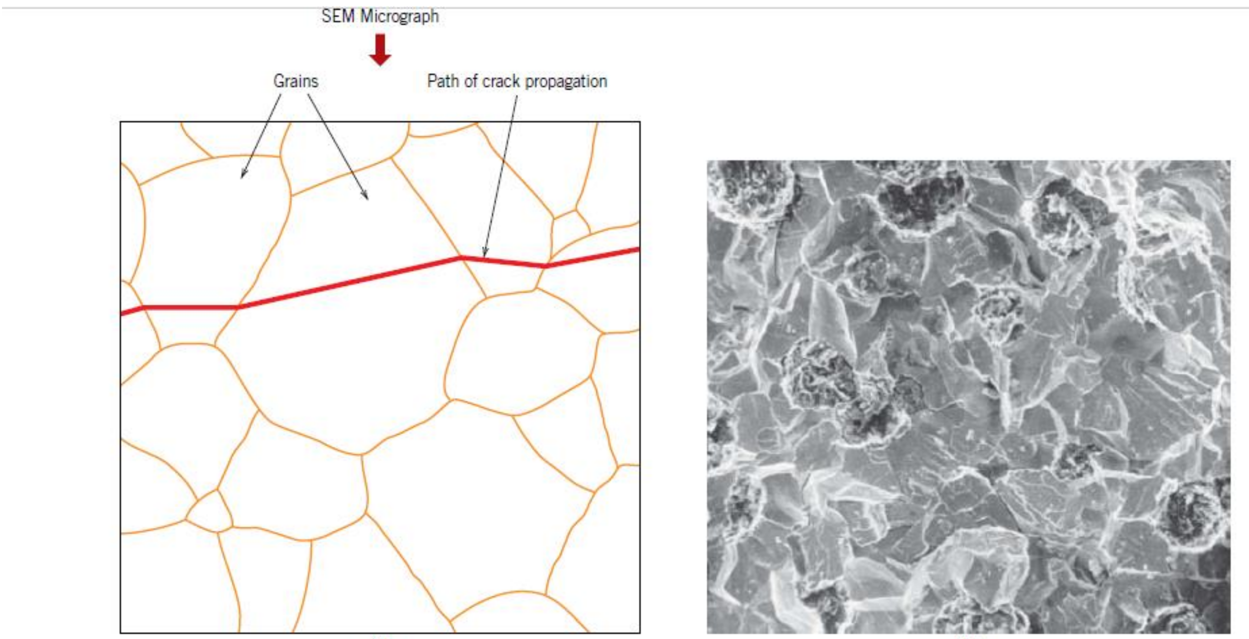
The Fracture usually occurs in the form of ductile or brittle fracture. This is based on the ability to experience plastic deformation.

a) <u>Brittle fracture</u>

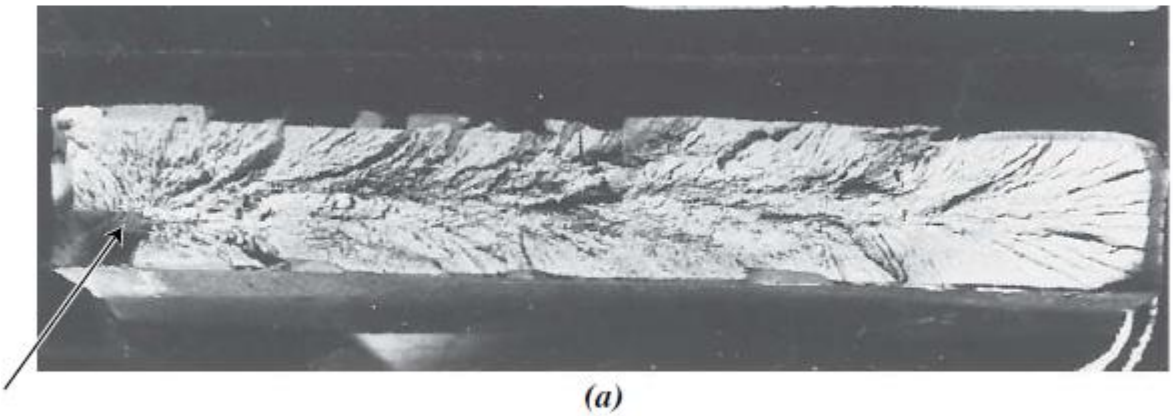
Brittle deformation occurs through rapid crack propagation without any appreciable deformation. The direction of the crack is perpendicular to the applied stress, and it occurs as a flat surface. Brittle fracture in the ceramic glass shows a shiny, smooth surface. [11]

<u>Microscopically</u>:

Brittle materials fracture in the form of a v-shaped marking (Chevron) near the center of the fracture that points back to the crack initiation site. Other brittle fracture surfaces contain lines radiating from the origin of the crack in a fanlike pattern. The fracture may be transgranular because the fracture crack occurs through the grain. The fracture surface may be grainy or faceted texture due to the change in orientation of cleavage planes from grain to grain. In some alloys, crack propagation occurs along grain boundaries which are called intergranular. [11] (Figure 8)



(a) (b)



(a)

Figure 8: Brittle fracture

b) <u>Ductile fracture</u>

Ductile fracture is characterized slowly crack propagation forming necking down to the point of fracture. Ductile metals show a reduction in the cross-section before fracture. After necking, microvoids are formed in the interior of the cross-section, micro voids increase in size and coalesce to form an elliptical crack. The crack grows in a paralleled direction to its major axis. The fracture has a cup and cone fracture form. The central interior has an irregular and fibrous appearance. [11]

Microscopically:

When the cup and cone fracture is examined, it is found to consist of numerous spherical "dimples". Each dimple is half a micro void that formed and separated during fracture. These may be elongated or –shaped.[11] (Figure 9)

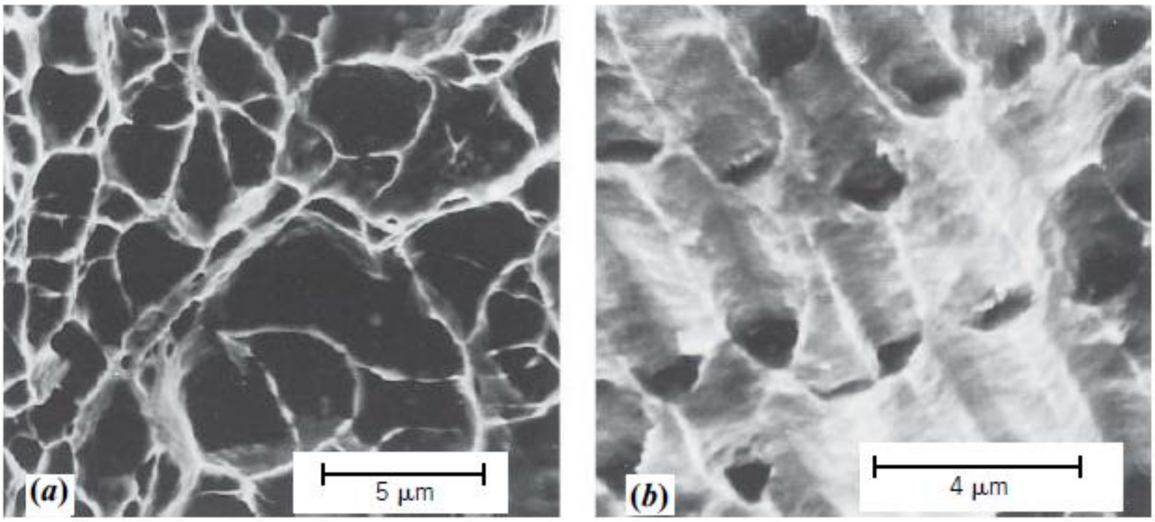


Figure 9: ductile fracture

- **<u>Fracture toughness:</u>**

Fracture toughness is used to describe the fracture resistance of the material. It is used to measure the resistance to brittle failure. Fracture toughness (Klc) is important in measuring amalgam, acrylic denture base, composite, ceramics, and orthodontic brackets. A fracture toughness test is performed using flexure bars with a notch at the tip with the crack of nanometer size tip.[11]

Fracture strength can be obtained according to Griffith's equation:

$$\sigma t = \frac{1}{Y}\frac{klc}{\sqrt{C}critical}$$

Where:

Y is the geometrical factor

Klc is the fracture toughness

Ccrit is the critical size of the crack.

i) Indentation method

Vickers indentation was made in the middle of a beam. The radial crack serves as a pre-crack in the test. This crack takes time to grow, so the beam is loaded after 20-30 minutes at load 19.6 N, and then the sample is subjected to three-point bending set up till fracture. Specimens, where the fracture didn't originate from Vickers indentation, were excluded. (12)

Fracture strength was obtained from the following formula: f= $\frac{3WL}{2bd2}$

ii) Single-edge notched beam method

SEVNB method has been used for measuring the fracture toughness of ceramics due to its simplicity. The methodology involves a bar-shaped specimen that receives a narrow notch on one of the largest surfaces perpendicular to the specimen's long axis. The notch is produced by the diamond disc in a cutting machine. The notch root radius should be up to the same size as the major microstructural feature to validate the test, so it is not used with Yttria-stabilized zirconia. After notch preparation, the specimen is a fracture with the notch on the tensile side. (12) (Figure 10)

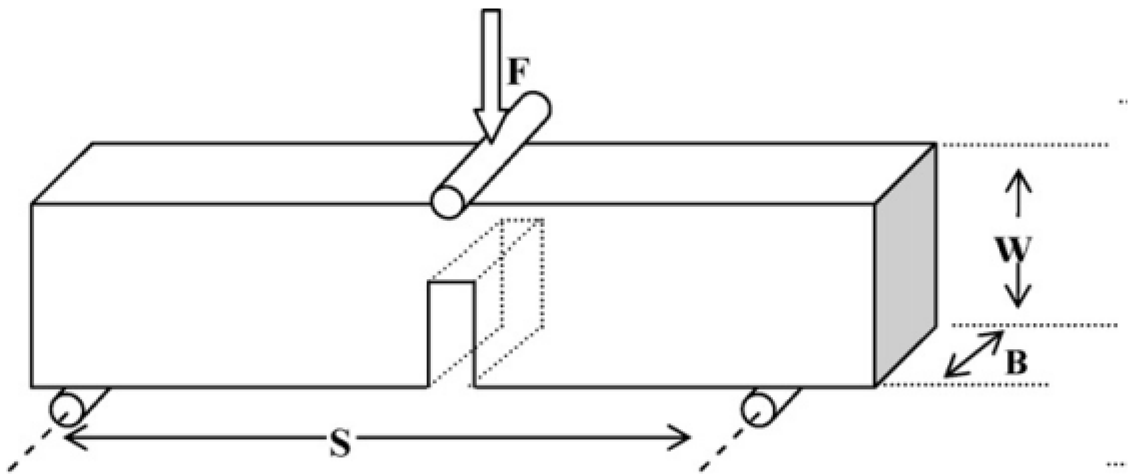


Figure 10: Single edge notched beam method

iii) Chevron notched beam method

Chevron notched beam requires a small amount of material for specimen preparation. The test can be performed with a short rod with the insertion of V shape chevron notch which is difficult to be achieved by cutting discs. During the test, a crack will develop from the tip of the chevron notch and progress as the load is increased till fracture. This method is useful in measuring fracture toughness for ceramics and composites. It can also be used with yttria-stabilized zirconia ceramics.(12,13) (Figure 11)

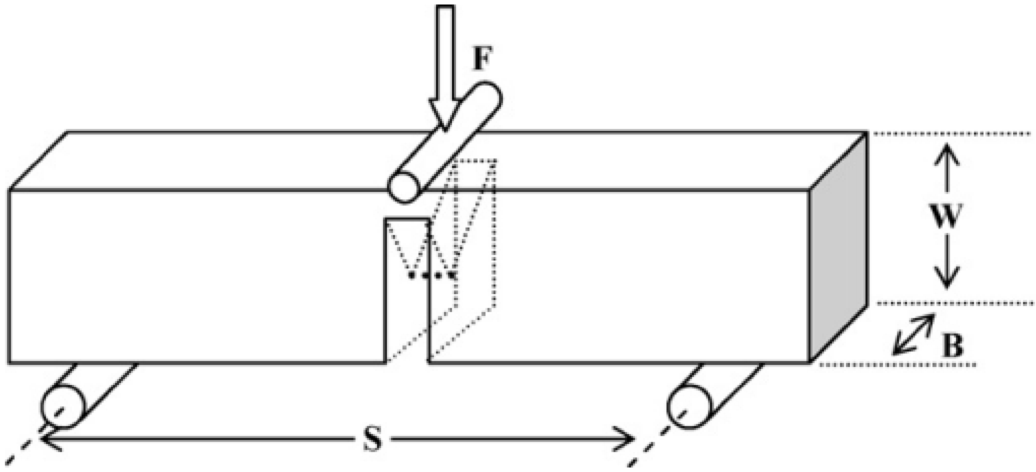


Figure 11: Chevron notched beam method

- **Impact testing**

Impact testing was used to measure the fracture of the material under high loading. The impact failure test is used to describe the behavior of the brittle material. Two standardized tests, Charpy and Izod to measure the impact energy. For both tests, the specimen is a bar or square cross-section, into which a V-notch is machined. The load is applied as an impact blow from a hammer at a fixed height. The main difference between Charpy and Izod techniques is the specimen support manner. Charpy and Izod are used to measure the ductile to brittle transition.[11] (Figure 12)

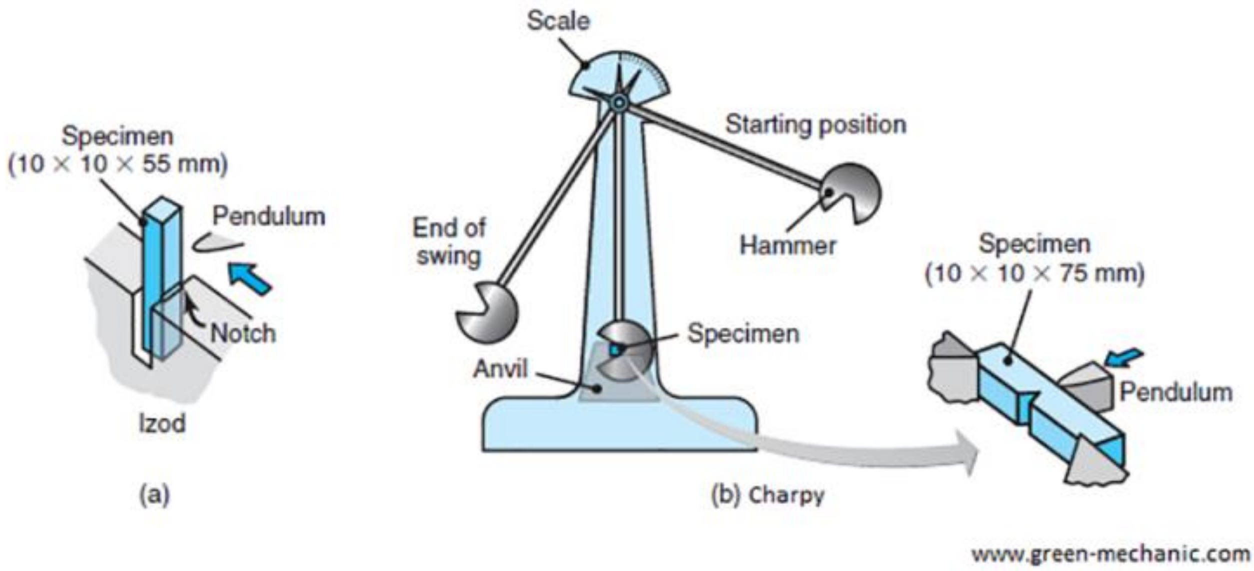


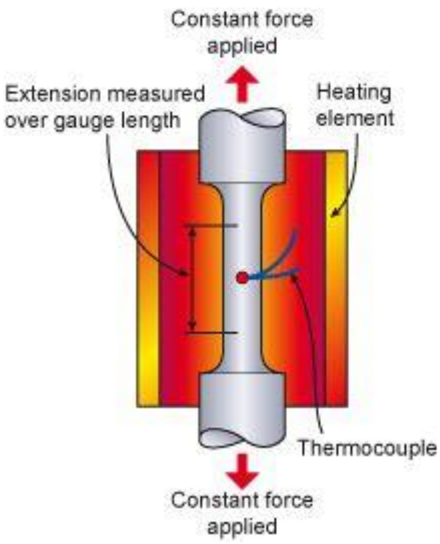
Figure 12: a) Izod test b) Charpy test

3) **<u>Creep</u>**

Creep is time-dependent permanent deformation when subjected to constant load or stress. Creep is observed when the temperature is greater than 0.4, the melting temperature. [11]

1) Tensile creep testing:

The Creep test is performed by a tensile specimen to whom constant stress is applied by simple methods of suspending weights from it. Around the specimen is a thermostatically controlled furnace. The temperature is controlled by a thermocouple attached to the specimen usually in the gage length. A constant tensile stress machine allows evaluation of tensile creep at 0-60°. A special loading arm, as the specimen lengthens by creep, and this reduces its cross-section, the moment arm shortens. Temperature control is achieved by heated water baths controlled by thermistors. This test is used with metallic materials.[14] (Figure 13)



(figure 13: tensile creep testing)

2) Compressive creep testing

The creep test is performed by applying compressive loading to eliminate the growth of cavities and their opening, so the creep rate in compression is slower than tension. Creep tests are better to be performed under uniaxial conditions such as tension or compression because the analyses of the uniform stress results are simple. According to ISO specification (ISO 1559), and ADA no.1 for amalgam testing creep refers to the deformation of amalgam under compressive stresses of 36 MPa of the specimen. The specimen of 4 mm in diameter and 7 mm in height were subjected to the compressive stress of 36 MPa for 4 hours at 37" C The change in length between one hour and four hours shall be recorded after they had been stored at 1, 2, 4, 7 days. The reduction in length was measured using a disc transducer. Uniaxial compression testing is conducted with brittle materials. [15]

3) <u>Creep rupture test</u>

The creep rupture test is also called the stress rupture test. These tests are continued until the specimen fractures. The creep rupture test is a method of measuring the amount of creep material to withstand until it ruptures. This includes given stress and temperature at a definite hour. The specimen is heated using a furnace with a temperature-controlled device to ensure that the specimen temperature is maintained. The required load is applied by a system of dead weights. The length of the specimen is monitored using an extensometer attached to the specimen. Creep ductility of the material is obtained by comparing the length of the specimen after the rupture with the initial length. After a series of tests at different stresses, the time to rupture is measured as a function of the initially applied stress [16]

4) <u>Fatigue</u>

Fatigue strength is measured when the repetitive application of a small load to a material results in a fracture. Fatigue strength is measured by bending or twisting a test sample and counting repetitive stress cycles. Fatigue failure is an indication of failure on repetitive loads over a long period. A test apparatus should be designed to duplicate the service stress conditions (Stress level, time-frequency, stress pattern). The most common type of test is the rotating bending beam with alternating tension and compression stresses of equal magnitude as the specimen is bent and rotated. During rotation, the lower surface of the specimen is subjected to tensile stress whereas the upper surface experiences compression (negative stress). In service, conditions may call for conducting the fatigue tests using either uniaxial tension-compression or torsional stress cycling instead of a rotating bending beam. [11] (Figure 14)

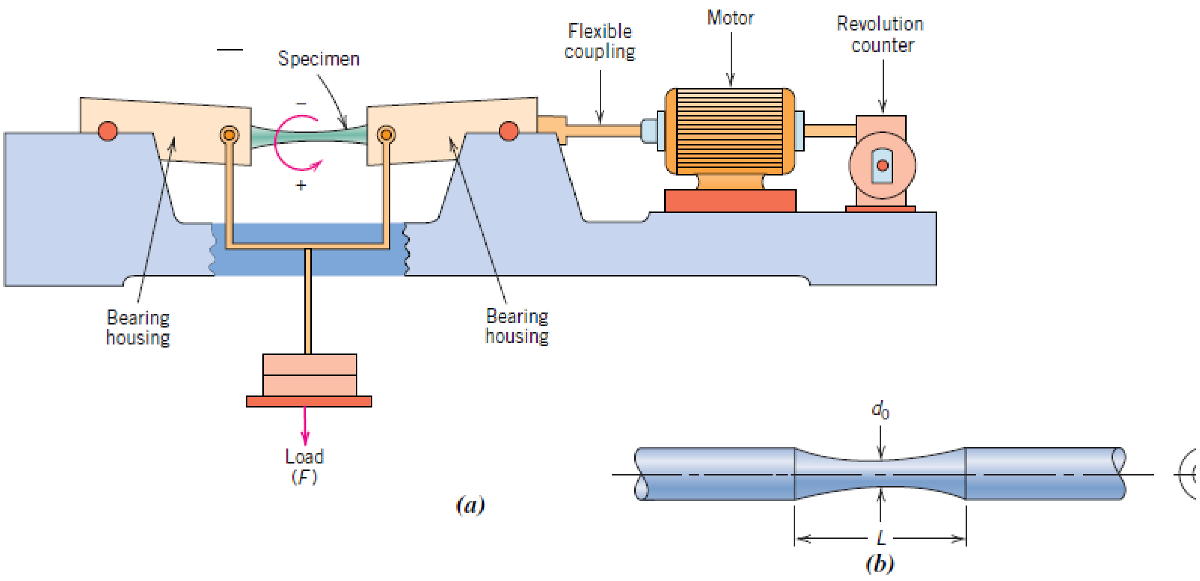


Figure 14: Rotating bending beam

Microscopic features:

Cyclic loading produces microscopic discontinuities resulting from the dislocation slip and cracks initiation sites. The region of the surface fracture appears as benchmarks and striations. This indicates the position of the crack at some point and as concentric ridges that expand from the crack initiation site. Benchmarks are of macroscopic dimensions. They are found as interruptions during the crack propagation stage. Each beachmarks represents a time over which crack growth occurred. However, fatigue striations are microscopic and can be seen by TEM or SEM. Each striation represents the advance distance of a crack during a single load cycle. Beachmarks and striations are fatigue fracture surfaces having similar appearances but from different origins and sizes. There may be thousands of striations within a single beachmarks.[11] (Figure 15)

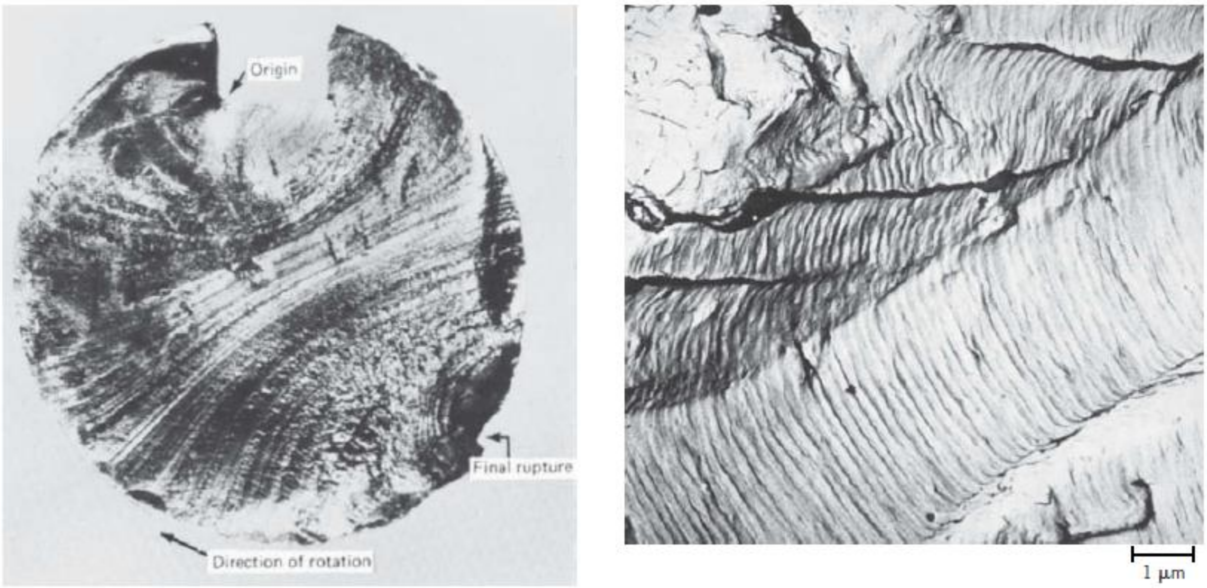


Figure 15: Beachmark and striations

5) **<u>Hardness</u>**

Hardness test is defined as a measure of how the material resists localized deformation. This can be done by applying a standard weight to an indentor. This produces a symmetrically shaped indentation that can be measured under a microscope for depth, area, and width. (1)

a) Knoop hardness testing

Knoop hardness testing was developed for ceramics, plastics, and thin metal sheets. In general knoop microhardness testing uses loads of no greater than 1kgf and the indentor is pyramidal shape. (7)

b) Vickers hardness testing

It has a diamond indentor to form a square-shaped indentation. It's used with brittle materials. It's used to determine the degree of polymerization of dental composite resin. (7) (Figure 16)

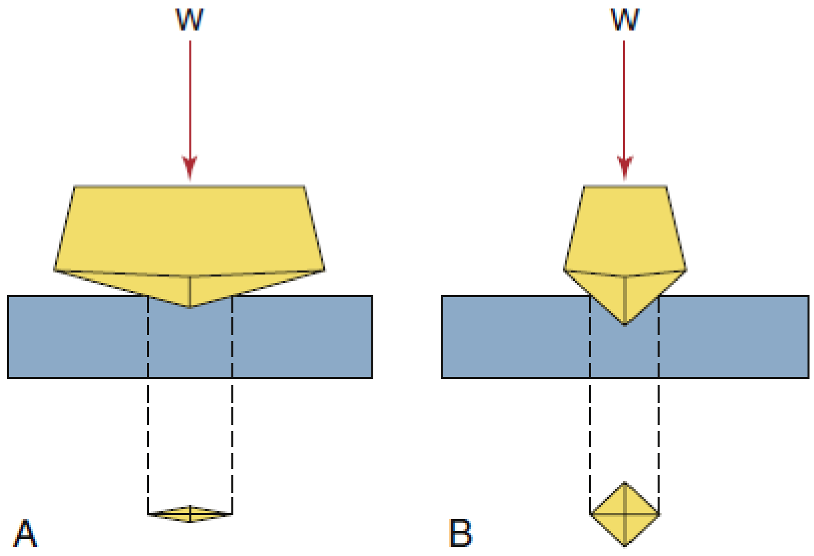


Figure 16: A) knoop hardness testing b) Vickers indentation

c) Rockwell hardness testing

Rockwell test is suitable with viscoelastic materials. It has a steel ball indentor. It applies a minor load of 3kg and then a major load exceeding 10 kg is applied. (7)

d) Shore A:

It is used with elastomer as rubber to measure the relative hardness. It is used with soft denture liners and mouth protectors. The instrument consists of a bluntly pointed indenter 0.8 mm in diameter that tapers to a cylinder of 1.6. If the indentor completely penetrates the specimen the reading is 0, and if no penetration, the reading is 100.(7)

6) Wear measurement

a) Pin on disc tribometer:

It is one of the most common methods for wear testing. The base of method is based on using a disc-shaped sample surface on a pin body in the form of a roller or non-rotating ball. At a chosen distance from the sample center, the PIN is stressed by a predetermined force. The disc starts rotating with a selected speed and number of rounds.(17) (Figure 17)

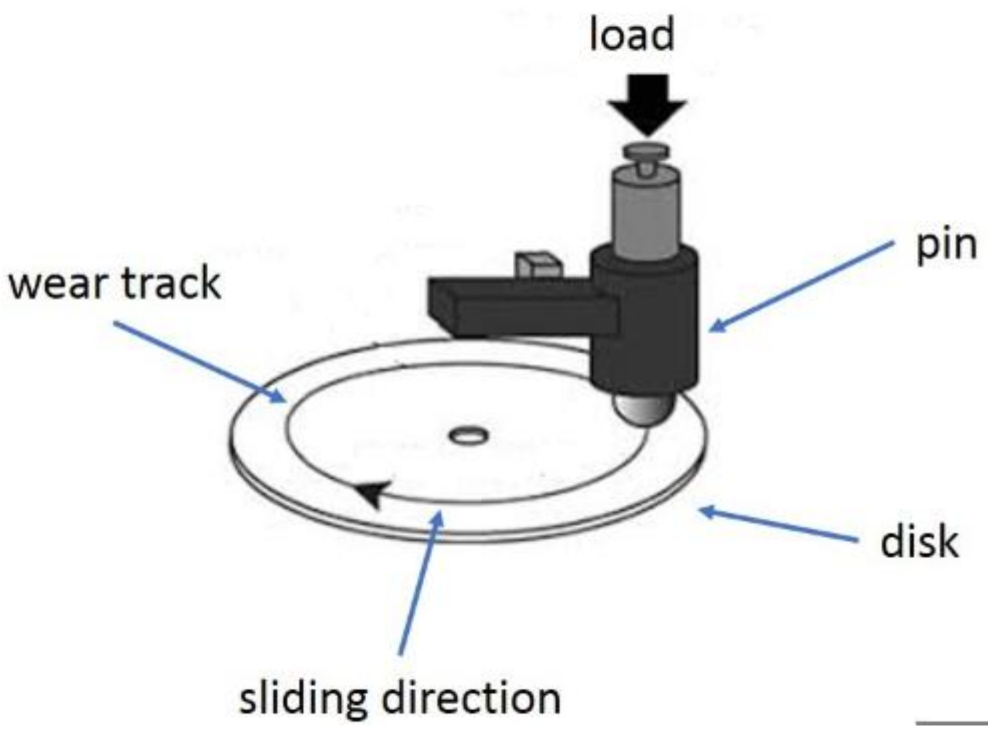


Figure 17: Pin on disc tribometer

b) Reciprocating tribometer

Similar to the tribometer, a pin or a ball is in contact with a flat specimen under a vertical force causing constant pressure, but it moves along a linear stroke alternately back and forth with a known frequency. It is commonly used with prosthesis material. It can be used with artificial saliva. (17)

c) Chewing simulator

Chewing similar is the only equipment to reproduce impact and sliding motion occurring during mastication. It can simulate vertical and horizontal movement by a definite stroke for horizontal sliding and a height for the descending movement. (17)

7) Tear strength

Tear strength measures the resistance of the material to tearing forces. It is an important property for polymers and impression materials. It is tested using a specimen crescent-shaped and notched. The tear strength is measured by dividing the maximum load by the thickness of the specimen. A high rate of loading will result in higher tear strength. (7)

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