MECHANICAL BEHAVIOUR OF DENTAL RESTORATIVE MATERIALS

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INTRODUCTION:

In the oral environment, restorative materials are exposed to chemical, thermal and mechanical challenges. These challenges can cause deformation of the material. The science that studies how biological materials interact and deform is called biomechanics. Mechanical properties need to be considered collectively, because no single mechanical property can give a true measure of quality or performance. Optimization of one property might compromise the performance in another, so it is essential to understand the principle involved in a variety of mechanical properties to optimize the clinical service of a material.

Force is generated by one body interacting with another. Forces may be applied through actual contact of the bodies or at a distance. The result of an applied force on a body is translation or deformation of the body depending on whether the body is rigid or deformable. A force is defined by three characteristics: point of application, magnitude, and direction of application. The direction of force is characteristic of the type of force. The International System of Units (SI) unit of force is Newton, N.

DEFINITION:

Mechanical properties are defined by the laws of mechanics, that is, the physical science that deals with energy and forces and their effects on bodies.

OCCLUSAL FORCES:

- Occlusal forces created between adult teeth are greatest in the posterior region closest to the mandibular hinge axis and decrease from the molar to the incisors.
- Forces on the first and second molars – 400 to 800 N
- The average force on the bicuspids, cuspids, and incisors – 300, 200 and 150 N.

FORCES ON RESTORATIONS:

- The measurement of forces and stresses on intracoronal restorations, single- and multiple – unit fixed restorations are equally important as the study of forces on natural dentition.
- Restoration design and material selection needs to consider the location, opposing dentition, and force – generating capacity of the patient.

STRESS:

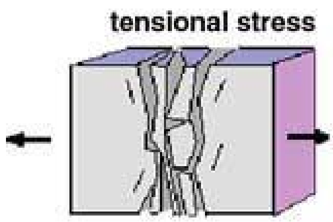
Stress is the force per unit area acting on millions of atoms or molecules in a given plane of a material.

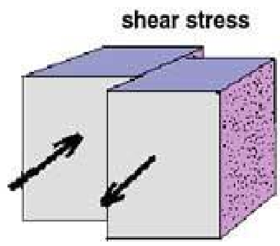
(Glossary of engineering terms)

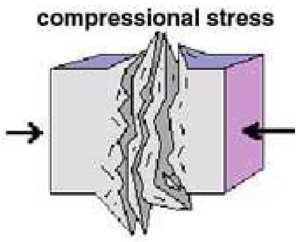
TYPES OF STRESSES:

Tensile stress	Shear stress	Compressive stress

Caused by a load that tends to stretch or elongate a body.	**A shear stress tends to resist the sliding or twisting of one portion of a body over another.**	**Caused by a load that tends to compress or shorten a body, the internal resistance to such a load is called compressive stress.**



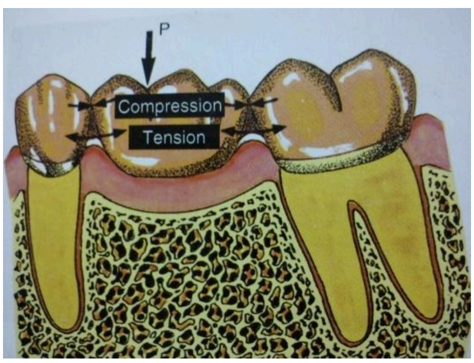


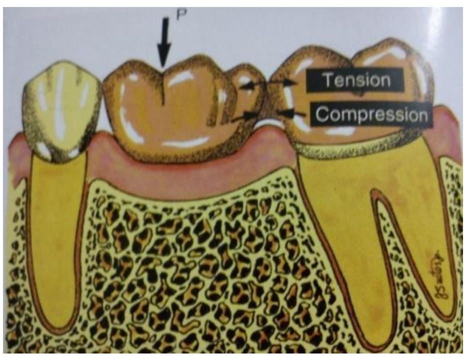


- Individually applied forces may be axial, shear, bending or torsional.
- These directional forces can be resolved into combinations of two basic types – axial and shear.

TWISTING MOMENT Torsion

BENDING MOMENT Bending





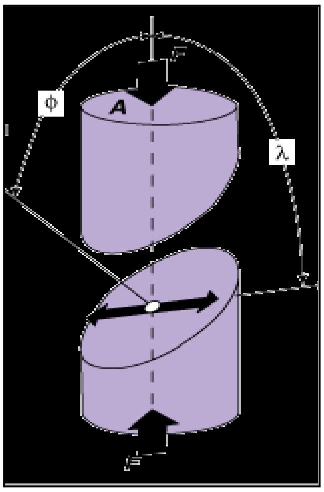
STRAIN:

Strain is the amount of deformation of a deformable body when a force is applied to it. The deformation resulting from a tensile or pulling force is an elongation of a body in the axis of the applied force. The deformation from a compressive or pushing force causes compression or shortening of the body in the axis of loading.

Strain (ε) = Deformation / Original length = $(L-L_{\circ}) / L_{\circ} = \Delta L / L_{\circ}$

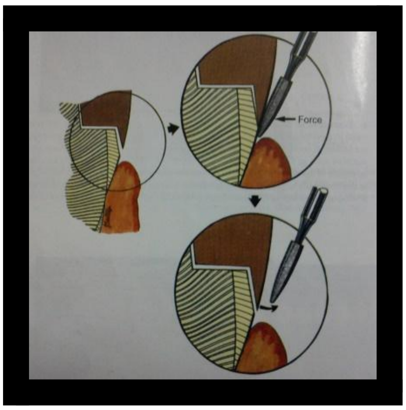
CRITICAL RESOLVED SHEAR STRESS:

Crystalline slip results from the action of a shear stress on the slip plane. Within the range of stresses in natural situations, the component of stress normal to the slip plane does not influence slip. The slip process must be considered in terms of the shear stress resolved on the slip plane in the slip direction.



PROPERTIES BASED ON ELASTIC DEFORMATION:

ELASTIC MODULUS



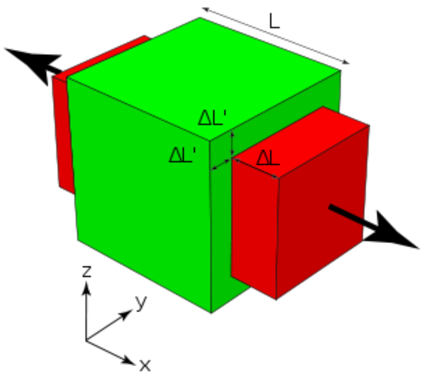
- If the tensile stress or compressive stress below the proportional limit is divided by its corresponding strain value a constant of proportionality will be obtained that is known as Elastic modulus, modulus of elasticity or Young's Modulus.
- Denoted by the letter E.
- The stress strain graph is a measure of the relative rigidity or stiffness of a material.

RESILIENCE:

As the interatomic spacing increases, the internal energy increases. As long as the stress is not greater than the proportional limit, this energy is known as resilience.

POISSON'S RATIO:

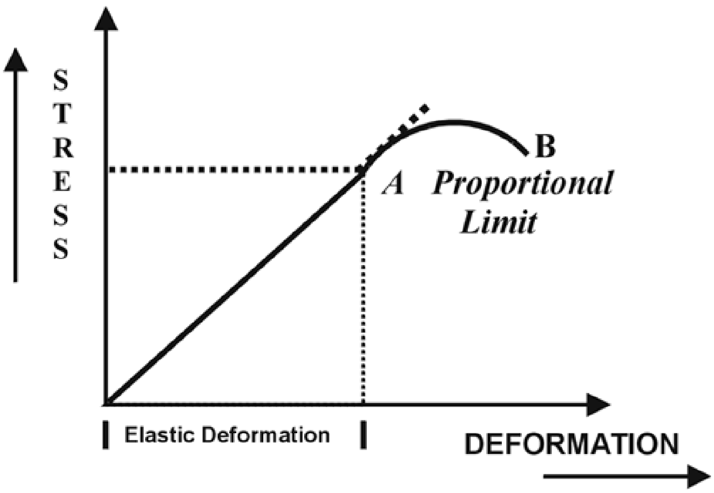
If an axial tensile stress σz, in the z (long axis) direction of a mutually perpendicular XYZ coordinate system produces an elastic tensile strain, and accompanying elastic contractions in the x and y directions, the ratio is known as Poisson's Ratio.



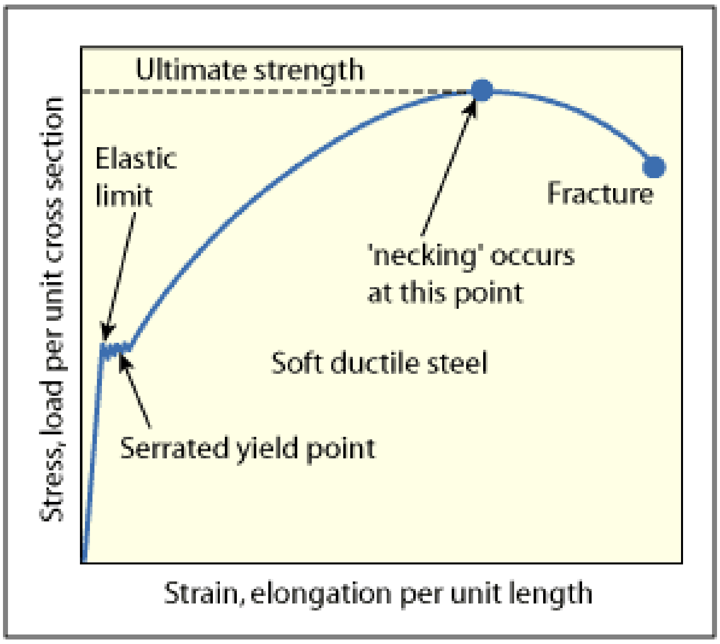
STRENGTH PROPERTIES:

- Strength is the stress necessary to cause either fracture or a specified amount of plastic deformation.

Proportional limit → the stress above which stress is no longer proportional to strain.

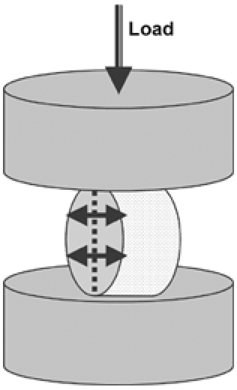


Elastic limit → the maximum stress a material can withstand before it becomes plastically deformed.



Yield strength / proof stress → the stress required to produce a given amount of plastic strain.

DIAMETRIAL TENSILE STRENGTH:



- Compressive force produces a tensile stress that is perpendicular to the vertical plane that passes through the Centre of the disk.

- Fracture occurs along this vertical plane.

$$\frac{2P}{\pi Dt}$$

Where,

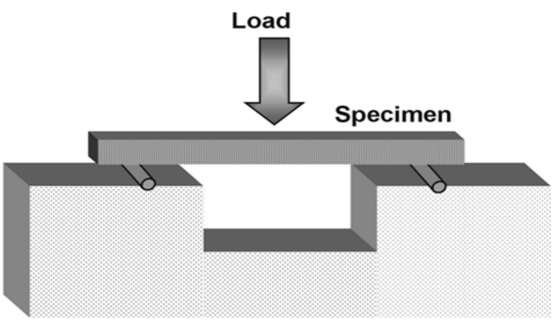
P is the applied load,

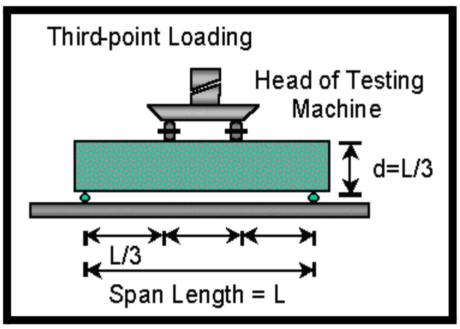
D is the diameter,

t is the thickness.

FLEXURAL STRENGTH:

- The **flexural strength** of a material is defined as its ability to resist deformation under load.





To evaluate flexural strength of a dental material:

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

where:

P= the ultimate load at fracture,

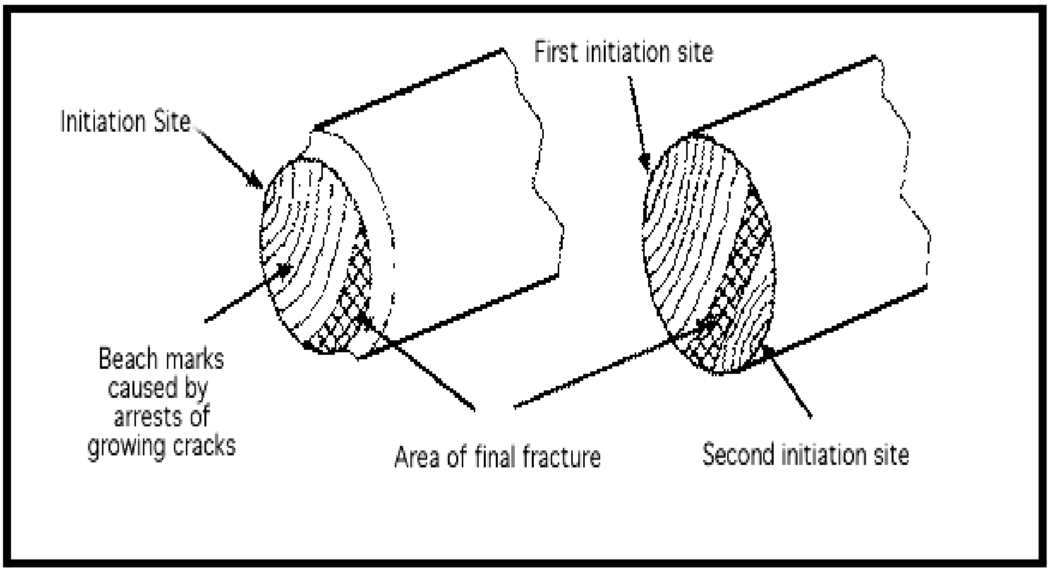
l= the distance of the supports,

b= the width of the specimen,

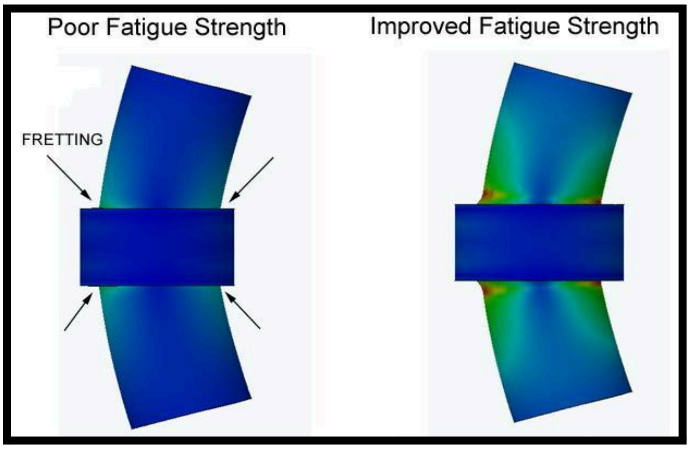
d= the thickness of the specimen.

FATIGUE STRENGTH:

- It is determined by subjecting a material to a cyclic stress of a maximum known value and determining the number of cycles that are required to produce failure.



- The behavior of the materials under the action of stresses, which are relatively low but intermittent, 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. (Wang et al, J Applied Oral Science, 2003)

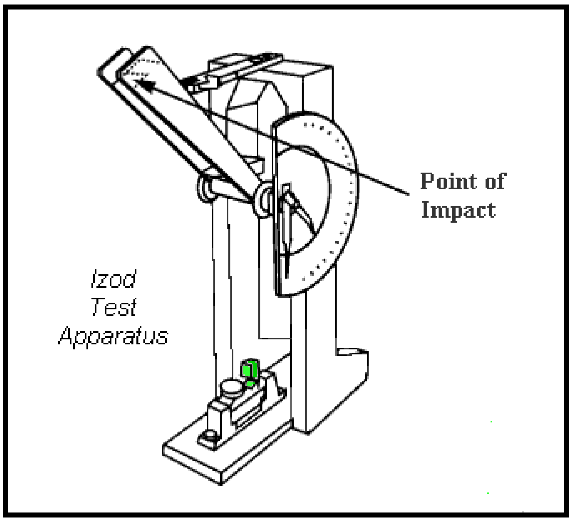


It is stated that fatigue loading will substantially reduce the fracture strength of dental amalgam. (Wilkinson and Haack ,1958)

Investigation of intergranular cracking and a 45° crack growth direction distinguishes dental amalgam from classical failure of most engineering alloys at room temperature, in which Stage II crack growth normally occurs trans granularly and at 90° to the maximum tensile stress. (Dieter, 1976)

IMPACT STRENGTH:

- The energy required to fracture a material under an impact force.



- A pendulum swings on its track and strikes a notched, cantilevered plastic sample. The energy lost (required to break the sample) as the pendulum continues on its path is measured from the distance of its follow through.

FRACTURE TOUGHNESS:

- It is the amount of elastic and plastic deformation energy required to fracture a material.
- Expressed in units of stress times the square root of crack length / Mpa.m^1/2

From the compilation of Lloyd (1983)

It is apparent that the currently available restorative materials are of a lower fracture toughness.

Dental cements are in the range 0.1 - 0.5 MN. (m) $^{-1\cdot 5}$

Amalgams in the range 1.0 - 1.6,

Composites in the range 0.6 - 2.0.

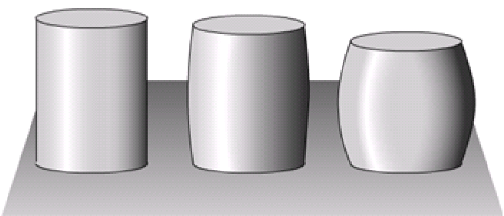
Human dental enamel also has a low fracture toughness, within the range 0.7 to

1.27 MN. (m) $^{-1\cdot 5}$, according to Hassan et al. (1981).

DUCTILITY AND MALLEABILITY:

- Ductility represents the ability of a material to sustain a large permanent deformation under a tensile load before it fractures.

Brittle Failure



Ductile Failure

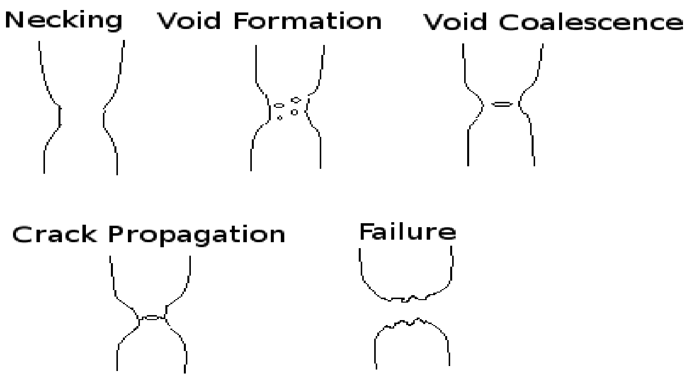
- Malleability is the ability of a material to sustain considerable permanent deformation without rupture under compression.

MECHANICAL PROPERTIES ACTING ON TEETH:

CRACK PROPAGATION:

- The presence of defects in the microstructure of the restoration 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.



FAILURE MODES IN HUMAN TEETH:

Margin cracks appear to originate from intrinsic tufts within the enamel at the DEJ. Median cracks appear to initiate from extrinsic defects within a *quasi-plastic* yield zone immediately below the contact. Slippage interfaces or 'shear faults' are well-known in brittle ceramics to act as stress intensifiers for crack initiation. (Lawn and Evans, 1977)
Except that, in teeth, the slip faults and ensuing cracks generate preferentially on inter-prism surfaces. (He and Swain, 2007, 2008); (Lee et al, JDR, 2009)

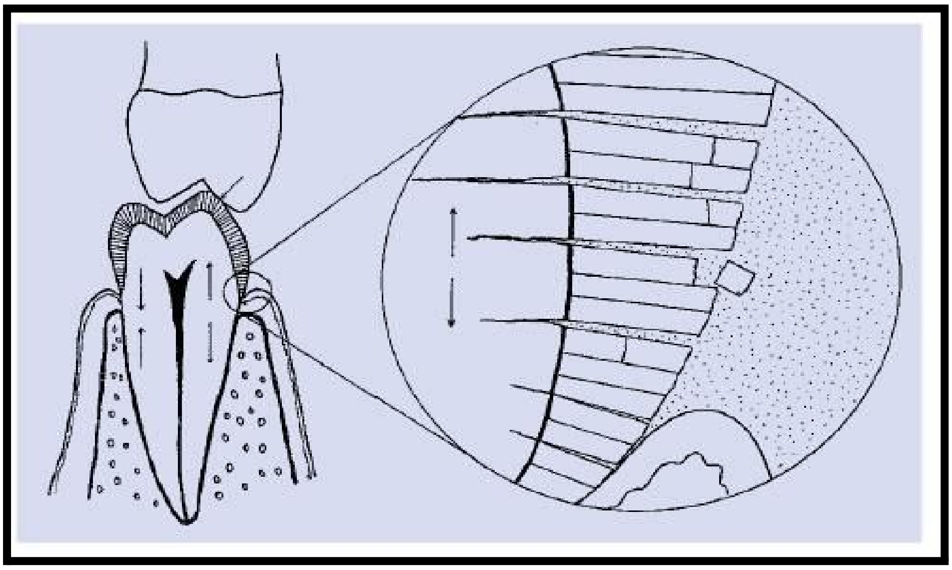
WEAR:

- As a result of sub-surface fatigue phenomena. In view of the unfavourable wear characteristics of the resin-modified glass ionomers and the high early wear of the conventional glass ionomers, including the metal reinforced glass ionomers, it was concluded that none of these materials can yet be recommended for use in high stress - bearing situations.

The degree of antagonistic tooth wear was less in zirconia than feldspathic dental porcelain, representing that the zirconia may be more beneficial in terms of antagonistic tooth wear. Composite resin restorations wear down a little bit faster than natural teeth. Silver amalgam restorations has wear resistance higher than a modern composite resin.

MASTICATION FORCES & STRESS:

- Energy of the bite is absorbed by the food bolus during mastication as well as by the teeth, periodontal ligament. And bone.



- Modulus of resilience of dentin is greater.

MECHANICAL PROPERTIES ON RESTORATIONS:

DENTAL AMALGAM:

- Compressive strength – 37 Mpa to 70 Mpa in 15 min to 388 Mpa to 545 Mpa in 24 hrs.
- Tensile strength – 4Mpa to 15 Mpa in 15 min to 48 Mpa to 62 Mpa in 24 hrs.
- Creep – ranges from 0.1% to 1.6% in 24 hrs.
- Stress transfer:

External biting loads transfers through enamel to dentin as compression.

↓

Dentin deformation occurs leading to flexure.

The amalgam demonstrated a frequency dependence and a significant reduction in fracture strength due to fatigue loading. The fatigue crack path was primarily intergranular in the $\gamma 1$ phase and inclined at approximately 45° to the principal stress axis.

GLASS IONOMER CEMENTS:

- As a lining cement:

1. Elastic modulus – 1820 Mpa
2. Compressive strength – 128 Mpa
3. Diametrial tensile strength – 24 Mpa
4. Flexural strength – 46 Mpa

- As a restorative cement:

1. Compressive strength – 120 Mpa
2. Flexural strength – 20 Mpa
3. Flexural modulus – 12.9 Gpa

COMPOSITES:

- Flexural modulus – ranges from 4.4 Gpa to 10.3 Gpa
- 3 pt flexural strength – ranges from 52 to 124 Mpa
- Biaxial flexural strength – in hybrid and flowable composites from 113 to 183 Mpa
- Diametrial tensile strength – from 24 to 42 Mpa
- Fracture toughness is highest in hybrid composites

DIRECT FILLING GOLD:

- Mat or powdered gold have lower flexural strengths when compared to gold foil.
- Low elastic limit → large restorations cannot distribute occlusal stresses without plastic deformation.

CERAMICS:

- Hardness – least in glass ceramic (3.72 Gpa) and highest in glass infiltrated alumina (9.82 Gpa)
- Elastic modulus – 65 to 286 Gpa
- Flexural strength – 229 to 446 Mpa
- Fracture toughness – 1.65 to 4.61 Mpa.m^1/2

CONCLUSION:

- **Amalgam –** has greater compressive strength and tensile strength.
- **Composites** – has greater wear resistance in comparison to amalgam.

  - has high biaxial flexural strength.

- **Glass ionomer cements** – greater wear and cannot be used in areas of occlusal stresses.
- **Ceramics** – greater flexural strength and flexural modulus.

  - highest wear resistance.

Author names;

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REFERENCES:

- Science of dental materials – 11th edition Phillips
- Science of dental materials – 10th edition Anusavice
- Art & Science of operative dentistry – Sturdevant
- Textbook of dental materials – Craig
- Journal of Dental Research
- Journal of American Dental Association