

An Overview on Properties of Dental Materials: A Literature Review

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Abstract

The purpose of this paper is to describe the various different properties of Dental Materials used in Prosthodontics. Mechanical Properties include Force, Pressure, Strength, Stress, Strain, Flexibility, Proportional Limit, Elastic Limit, Yield Strength, Modulus of Elasticity, Resilience, Toughness, Brittleness, Percentage elongation, Percentage compression, Fracture, Dimensional changes and Hardness. Chemical properties include Solubility, Sorption, Tarnish, and Corrosion. Rheological properties include Viscosity, Viscoelasticity, Flow, and Creep. Thermal properties include Thermal Diffusivity, Thermal Conductivity, and Coefficient of Thermal Expansion. Optical properties include Color and color perception, Metamerism, Fluorescence, Opacity, Translucency, and Transparency. Biological properties include Biointegration, Toxicity and Biocompatibility. Adhesive properties include Adhesion, Cohesion, Surface tension, Surface energy and Contact Angle.

Keywords: Optical, Properties, Mechanical, Thermal, Rheological, Chemical

1. Introduction

Dentistry includes the applications of various dental materials. Clinical dentistry depends upon the properties, method of manipulation and use of various dental materials. Properties of materials can be divided into the following categories: physical, chemical, rheological, thermal, optical, biological, and adhesive. Physical properties are based on the laws of physics that describe mass, energy, force, light, heat, electricity, and other physical phenomena.¹⁻³ Mechanical properties are a subgroup of physical properties. Mechanical properties describe a material's ability to resist forces. Mechanical properties are dependent on the amount of material and on the size and shape of the object.¹⁻³ Chemical properties describe the setting reactions as well as the decay or degradation of materials. Rheological properties include the study of the flow or deformation of materials. Thermal properties deal with the study of the effect of temperature changes on the material. Optical properties include the properties which are related to color and esthetic. Biological properties of materials are the effects the materials have on living tissue.¹⁻³

The purpose of this article is to study all the properties that are associated with different impression materials, processing materials, provisional materials and materials used for fabrication of final prosthesis used in dentistry.

2. Mechanical properties

2.1 Force is an action that produces or tends to produce or change the body's motion. The unit of force is Newton, kg or pounds.¹⁻³

2.2 Pressure is the force applied to or distributed on the area of the body. Pressure is measured as force/unit area. The unit is N/m^2 or pounds/in².¹⁻³

2.3 Strength is defined as the ability of a material to resist induced stress without fracture or permanent deformation.¹⁻³

2.3.1 Tensile strength is the length of material that resists fracture when the material is stretched or pulled apart.

2.3.2 Compressive strength is the strength of the material that resists fracture when the material is compressed or squeezed.

2.3.3 Shear strength is the maximum shear stress at the appointment of fracture of a test specimen. It is measured by the push or punch method. It is calculated by $P/\pi dt$

2.3.4 Ultimate strength is the maximum stress that a specimen can withstand before fracture. If higher forces are applied

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DOI <https://doi.org/10.6084/m9.figshare.24182547#147>



applied to a material stress will be created which will eventually reach a point where the material will get a fracture.

2.3.5 Fatigue strength/ endurance limit: When a material is loaded repeatedly several times it can undergo fracture by stress even at a much lower value than the proportional limit. This progressive fracture under repeated limits is known as Fatigue.

2.3.6 Impact strength is the strength of a material that can resist fracture under impact or motion OR energy required to fracture a material under impact force. It is used to describe the reaction of a stationary object to the collision of a moving object. It is measured by the Charpy or Izod method.¹⁻³

2.3.7 Flexural strength is the collective of all the strengths simultaneously applied. It is measured by $3Pl/2bd^2$ where P is pressure, d is thickness, b is breadth, and l is length.¹⁻³

2.4 Stress is defined as force per unit area acting on millions of atoms or molecules in a given plane of material OR Stress is defined as force per unit area within a structure subjected to an external force or pressure.¹⁻³ Stress is measured as Force/Area. The unit of stress is pounds/inch² or kg/m² or Newton/m² or Pascal (Pa). Types of stress are Tensile, Compressive, Shear stress, and flexural stress or bending.¹⁻³

2.4.1 Tensile stress is produced by tensile force. A force that tends to pull an object apart is referred to as a tensile force. A load that tends to stretch or elongate a body causes tensile stress.

2.4.2 Compressive stress is produced by compressive force. When the application of force tends to compress/squeeze or shorten an object is called compressive force. The internal resistance to such a load is called compressive stress¹⁻³ (Fig. 1).

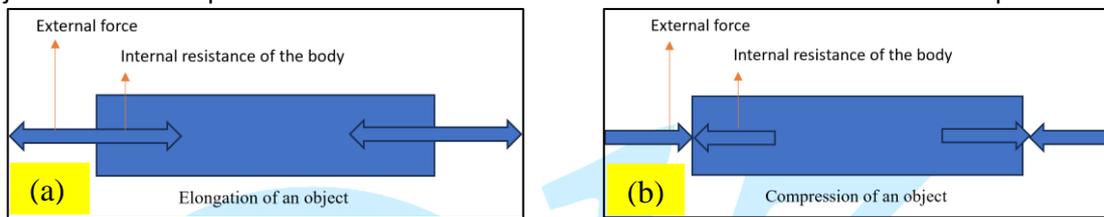


Fig. 1 Types of stresses: (a) Tensile stress (b) Compressive stress

2.4.3 Shear stress is produced by Shear force. A shear stress tends to resist the sliding or twisting of one portion of a body over another¹⁻³ (Fig. 2).

2.4.4. Flexural stress (Bending) is produced by bending forces which is the combination of tensile and compressive stress.¹⁻³

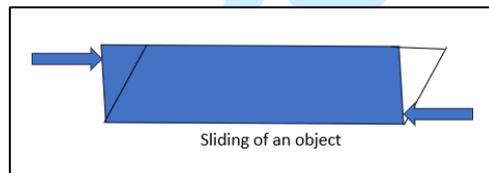


Fig. 2 Types of stresses: Shear stress

2.5. Strain is defined as the fractional change in the dimensions caused by the force OR Strain is the change in length per unit length, which is the relative deformation of an object subjected to stress.¹⁻⁴ Strain is measured as a change in dimension/original dimension. Strain is a unitless quantity.¹⁻⁴ Types of strain are Tensile, Compressive, Shear strain, elastic strain, and plastic strain.

2.5.1 Elastic strain is reversible. The object fully recovers its original shape when force is removed.¹⁻⁵

2.5.2 Plastic strain represents permanent deformation of the material that does not decrease when the force is removed.¹⁻⁵

2.6. Proportional limit is defined as when the ratio of stress to strain is no longer proportional OR is a stress on the stress-strain curve when it ceases to be linear. It indicates stress at which material no longer functions as an elastic solid (Fig. 3).

2.7. Elastic limit is defined as the maximum stress level at which complete recovery of strain occurs on release of the stress (Fig. 4).

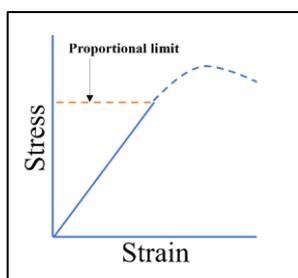


Fig. 3 Proportional limit

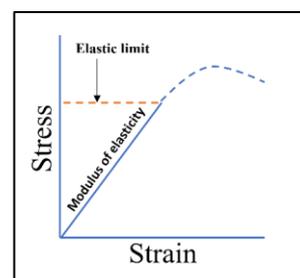


Fig. 4 Elastic limit

2.8 Yield strength or proof stress is a stress at which the material no longer functions as an elastic solid OR the stress at which plastic deformation begins OR the property that represents the stress value at which a small amount of plastic strain has occurred (Fig. 5).

2.9 Modulus of elasticity also known as Young's modulus or elastic modulus describes the relative stiffness or rigidity of a material. It describes the material's ability to resist bending or change in shape. It is measured by the slope of the elastic region of the stress-strain graph. The modulus of elasticity is measured as stress/strain. The unit is megapascal^{1-3,5} (Fig. 6).

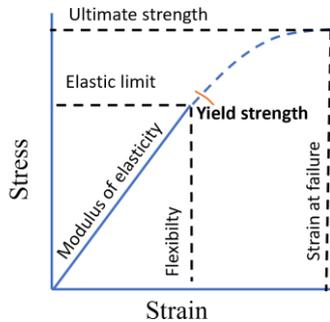


Fig. 5 Yield strength

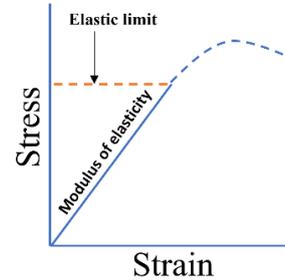


Fig. 6 Modulus of elasticity

2.10 Flexibility is defined as the flexural strain that occurs when the material is stressed to its proportional limit OR The strain associated with the stress at the elastic limit is called maximum flexibility^{1-3,5} (Fig. 7).

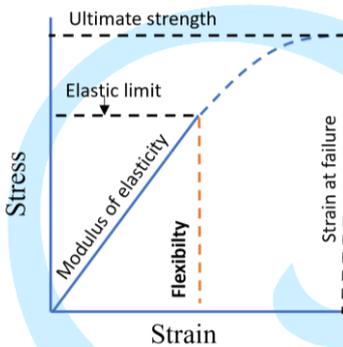


Fig. 7 Flexibility

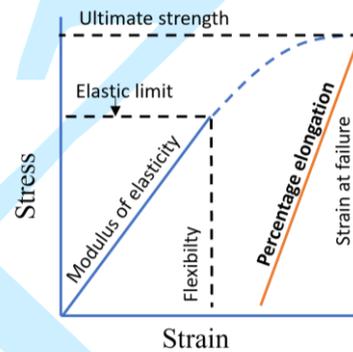


Fig. 8 Percentage of elongation

2.11 Percentage elongation and percentage compression are defined as total plastic deformation that accompanies the stress level of ultimate strength. Percentage elongation is a measure of ductility and percentage compression is the measure of malleability^{1-3,6,7} (Fig. 8).

Ductility represents the ability of a material to sustain a large permanent deformation under a tensile load before it fractures OR It is the property of a material that can be drawn into thin wires OR It is the ability of a material to be stretched or pulled to be drawn into thin wires. Malleability is the ability of a material to sustain considerable permanent deformation without rupture under compression as in hammering OR The property of a metal that can be rolled and compressed into thin sheets^{1-3,6,7} (Fig. 9).

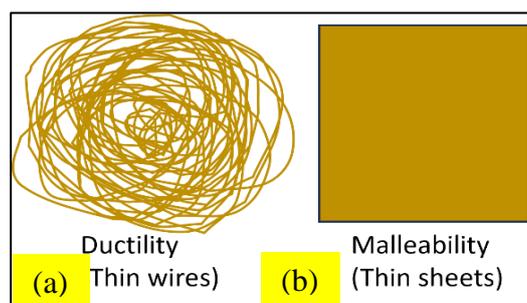


Fig. 9 (a) Ductility (b) Malleability

2.12 Resilience is defined as the amount of energy that a material can absorb below the elastic limit and subsequently deliver to another object. It represents the springiness of the material. Resilience is measured as an area under the linear portion of the stress-strain curve^{1-3,8} (Fig. 10).

2.13 Toughness is defined as the total amount of energy that a material can absorb up to the point of fracture. It's a total area under the stress-strain curve^{1-3,8} (Fig. 11).

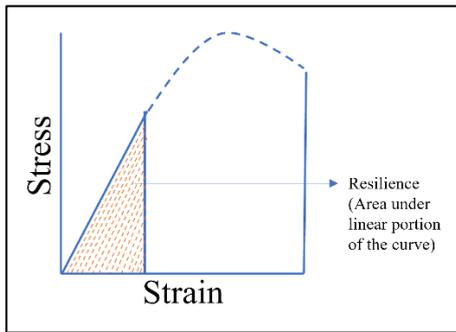


Fig. 10 Resilience

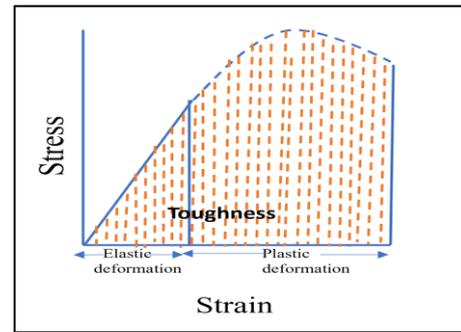


Fig. 11 Toughness

2.14 Brittleness is the relative inability of a material to sustain plastic deformation before fracture OR The material that fractures with no plastic deformation^{1-3,9} (Fig. 12).

2.15 Fracture is the maximum stress that a material can withstand before plastic deformation (Fig. 12).

2.16 Dimensional change is the degree to which the dimensions of a material alter after setting and the measure of it is known as dimensional stability^{1-3,9} (Fig. 12).

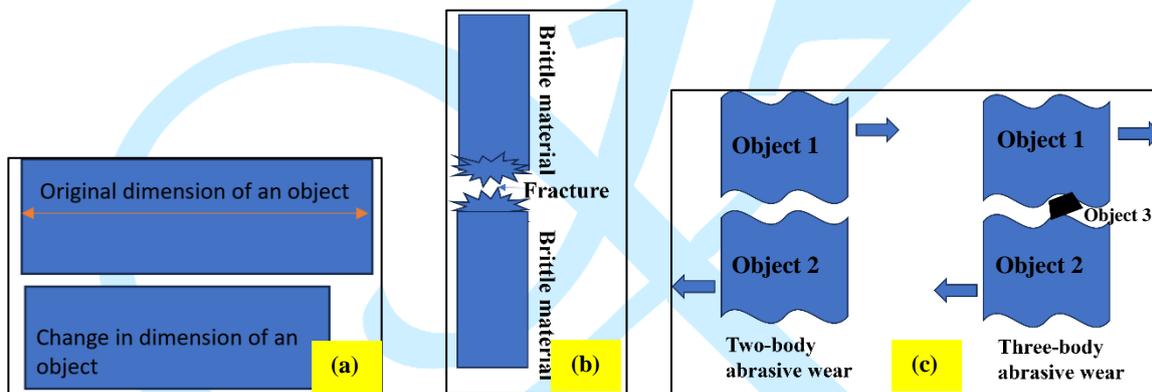


Fig. 12 (a) Dimensional change (b) Brittleness and Fracture (c) Wear

2.17 Wear is the phenomenon that occurs when two surfaces are brought into direct or indirect contact.¹⁻⁴ (Fig.12).

2.18 Elasticity is the ability of the material to undergo elastic recovery immediately after the removal of an applied load.

2.19 Hardness refers to the ability of the material to resist the forces of stretching, abrasion and indentation or penetration OR Resistance of a material to plastic deformation typically measured under an indentation load. The hardness is measured using the Scratch hardness test which includes Moh's scale, Height of elastic rebound test which includes the Shore scleroscope method, Penetration test which includes Shore A and Barcol's durometer and Indentation hardness test which includes the microhardness test and macrohardness test. The microhardness test includes the Knoop hardness test and the Vickers hardness test. The microhardness test includes the Brinell hardness test and the Rockwell hardness test.^{1-3,11}

3. Chemical properties

3.1 Solubility is defined as the measurement of the extent to which material will dissolve in a given fluid.

3.2 Sorption is the uptake of fluids or substances by a material. Absorption is defined as the uptake of fluid by the bulk solid. Adsorption refers to the concentration of molecules at the surface of a solid or liquid. Water Sorption is the term used when some material absorbs water.

3.3 Tarnish is defined as surface discolouration on metal OR loss or alteration of surface finish or lustre.¹⁻¹¹

3.4 Corrosion is the deterioration of a metal by a chemical reaction between the metal and its environment. It includes dry or chemical corrosion and electrochemical or wet corrosion. Wet corrosion includes galvanic corrosion, heterogeneous surface corrosion, stress corrosion, and concentration cell corrosion or crevice corrosion.¹⁻¹¹

4. Rheological properties

4.1 Viscosity is defined as the resistance of liquid to flow. The coefficient of viscosity is shear stress acting between two adjacent layers of unit area of fluid to maintain unit velocity gradient for streamlined flow. Unit = MPa / second or Centipoise (cp).¹⁻¹¹

4.2 Viscoelasticity: On the removal of the applied load, if the recovery takes place slowly or if some degree of permanent deformation remains (residual strain), the material is said to be viscoelastic.¹⁻¹¹

4.3 Flow is deformation under static load before the material has completely hardened.

Significance: For recording fine details of the oral cavity¹⁻¹¹ (Fig.13).

4.3.1. Newtonian flow A fluid demonstrates a linear relationship between shear stress and shear rate, it exhibits a constant value of viscosity. Such a fluid is known as Newtonian in behaviour.

4.3.2. Dilatant flow Dilatant liquids show an increase in viscosity as the shear rate, as the rate of deformation increases the liquid becomes more rigid.

Example:- Fluid-Resin denture base material.

4.3.3. Pseudoplastic flow Shows a decrease in viscosity with increasing Strain rate until it reaches a nearly constant such behaviour is called a Pseudoplastic.

Example:- Gypsum material, Fluoride gels.

4.3.4. Bingham plastic The liquid will not flow until an initial shear stress has been reached. The fluid will then flow in a Newtonian fashion.

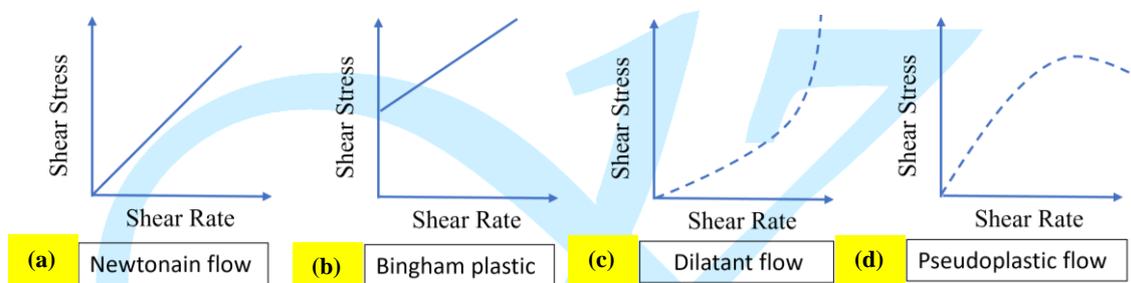


Fig. 13 (a) Newtonian flow (b) Bingham plastic (c) Dilatant flow (d) Pseudoplastic flow

4.4 Thixotropic Some materials become less viscous and more with repeated application of force is referred to as thixotropic

Example:- Toothpaste. Putty, Ketchup.

4.5 Creep is defined as a time-dependent plastic strain of a material under a static load or constant stress OR It may be defined as slow Plastic deformation OR time-dependent deformation of the materials. It is of 2 types, Static Creep is when the stress is constant and Dynamic Creep is when the stress is fluctuating.

4.6 Vapor pressure is a measure of a liquid's tendency to evaporate and become a gas.

5. Thermal properties

5.1 Thermal diffusivity indicates the speed with which the temperature change will spread through an object when one surface is heated.

5.2 Thermal conductivity is a measure of the rate at which heat flows (calories per second) through a given thickness of material (1cm), with a cross-section of 1cm^2 when one side of the material is maintained at a constant temperature of 1 degree celsius higher than another side.

Unit:- $\text{Cal}^{-1}\text{sec}^{-1}\text{cm}^{-1}\text{c}^{-1}$ SI unit:- $\text{Watt m}^{-1}\text{K}^{-1}$

5.3 Coefficient of thermal expansion The linear coefficient of Thermal Expansion is defined as the fractional increase in the length of a body for each degree centigrade increase in temperature.

Unit:- parts per million per degree centigrade (ppm/°c) Significance:- Dimensional changes in the elastomer are due to the High coefficient of Thermal Expansion. If the COTE of restorative material is not the same as that of enamel and dentin it leads to thermal mismatch.

5.4 Heat of fusion is the amount of energy required to melt a material.

5.5 Heat of vaporization is the amount of energy required to boil a material.

5.6 Heat capacity of a material is a measure of the amount of thermal energy that a material can hoard. Some materials require more energy than others to heat. The specific heat capacity of a material is the amount of energy needed to raise the temperature of one unit of mass of that material by 1°C. Specific heat capacity is measured as $\text{cal g}^{-1} \text{K}^{-1}$

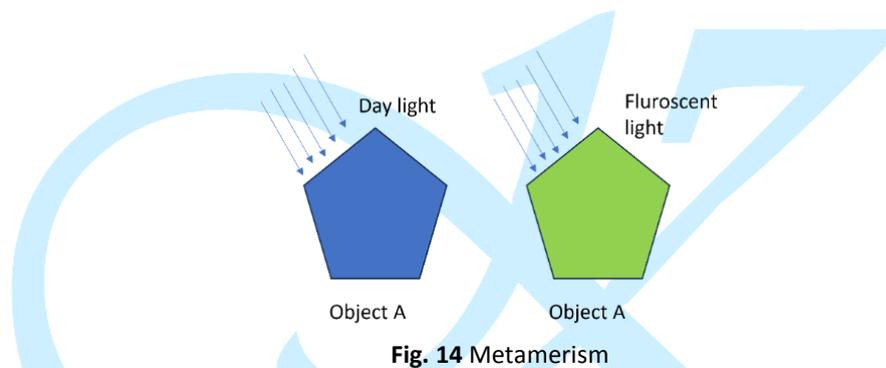
6. Optical properties

6.1 Color & color perception Color is a sensory perception that may be defined as the physiological response to a physical stimulus. Hue refers to the dominant color of the object. It depends on 3 Primary color Red, Blue, and Green. Chroma represents the degree of saturation of a particular hue. Value is the relative lightness or darkness of a particular color which can be measured independent of Hue. Measurement of colour can be done by several color measuring systems such as:

1. The Munsell (a visual system): is a coordinate system -It defines colour quantitatively.
2. The CIE color system (Commission Internationale de l'éclairage)¹⁻¹¹

6.2 Metamerism Objects that appear to be of similar colour matched under one type of light may appear different under another light source. The phenomenon that objects can change colour under the influence of different light sources is known as metamerism (Fig. 14).

6.3 Fluorescence Substances giving off a certain type of light when struck by invisible ultraviolet rays are described as Photoluminescent substances and may be divided into two groups: Phosphorescent substances, which continue to emit Visible light after UV rays fall on them and Fluorescent substances, which emits visible light only when the UV rays fall on the object.¹⁻¹¹



6.4 Opacity is defined as the property of the material that prevents the passage of light. It is the material that does not transmit light but instead absorbs light or reflects or scatters from the surface (Fig. 15).

6.5 Translucency is defined as the property of the material that permits the passage of light but disperses the light to such an extent that the object cannot be seen (Fig. 15).
example- Porcelain, Dental Resin

6.6 Transparency is defined as the property of the material that permits the passage of light in such a manner that little distortion takes place and objects are clearly seen through them (Fig. 15).

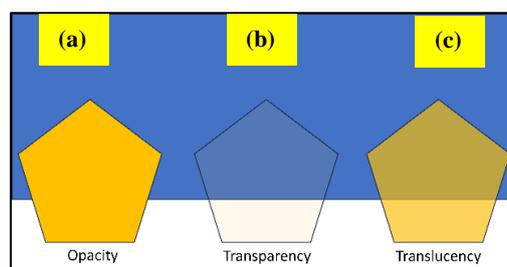


Fig. 15 (a) Opacity (b) Transparency (c) Translucency

7. Biological properties

7.1 Biointegration The process of forming an interface between bone or other living tissue and an implanted material with no intervening space.¹⁻³

7.2 Toxicity The relative ability (dose-related effect) of a material to cause injury to biological tissues, ranging from improper biochemical function, organ damage, and cell destruction, to death.¹⁻³

7.3 Biocompatibility The ability of a biomaterial to perform its desired function with respect to a medical (or dental) therapy, without eliciting any undesirable local or systemic effects in the recipient or beneficiary of that therapy, but generating the most appropriate beneficial cellular or tissue response in that specific situation, and optimizing the clinically relevant performance of that therapy.¹⁻³

8. Adhesive properties

8.1 Adhesion It is defined as the forces of attraction or energies between atoms and molecules at an interface that holds two phases together. The material film used to cause adhesion is known as Adhesive and the material to which it is applied is called as Adherend. It is simply a surface attachment process. It is usually qualified by the specification of the type of intermolecular attraction that exists both adhesive and the adherend.¹⁻¹²

8.2 Cohesion is defined as the force of attraction between the molecules of atoms within a given material (i.e. not on the surface).

8.3 Surface tension The unbalanced force acting on the free surface of liquid tending to reduce surface area minimum. It is measured as Force acting on unit straight-line imaging on a free surface of liquid stretching the molecules apart. Unit: dyne/cm or N/m^2 .¹⁻¹²

8.4 Surface energy The increase in energy per unit area of the surface is known as Surface energy.

8.5 Contact Angle is the angle formed at the interface of the adhesive and the adherent.

For good wetting the contact Angle should be low i.e. 0° -To produce adhesion the liquid must flow easily over the entire surface and adhere to the solid. This characteristic is known as wetting. The tendency of liquid to spread increases as the contact angle decreases, the contact angle is the useful indicator of Wettability.¹⁻¹²

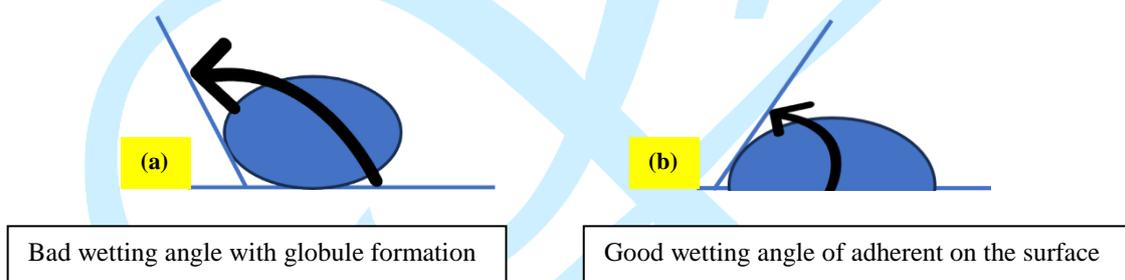


Fig. 16 (a) Bad wetting angle (b) Good wetting angle

9. Conclusions

This article gives an insight into various different properties applicable to dental materials. A brief description of all the properties will help the dentist to understand the different terminologies and their applications.

Funding Information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Conflict

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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