REVIEW ARTICLE

Strengthening of Ceramics: A Review

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Abstract

In dentistry, ceramics represents one of the major materials used for the restoration of decayed, damaged, or missing teeth. The word "Ceramic" is derived from the Greek word "keramos", which means "burnt stuff". In 1789, a French dentist named deChemant and a French pharmacist named Duchateau collaboratively developed the first porcelain tooth material. Charles H Land first introduced ceramics to dentistry in 1889 when he patented the all-porcelain crown. Porcelain-fused-to-metal crown was developed by Dr Abraham Weinstein. These materials have crystalline structures with periodic regular atom arrangements and have ionic or covalent bonding. Ceramics are incredibly brittle despite being very strong and will catastrophically fail even with slight flexure. Thus, these materials are strong in compression but weak in tension. This paper describes the methods of strengthening ceramics.

Keywords: Ceramics, Griffith flaws, Thermal tempering.

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Introduction

The term ceramic refers to any material constructed generally from a nonmetallic inorganic substance that has been fired at extreme heat to give it the desirable characters. The material consists essentially of glass. Glass is sensitive to microcracks that appear on its surface.[1] This is a real obstacle in dental practice with ceramics. Ceramics and glasses are brittle, which means they have a high compressive but low tensile strength and can break even under very low stress. The main drawbacks of ceramics are that they are brittle, have low fracture toughness, and have low tensile strength.[2] During the process, technical issues like micro-fractures and porosity cause mechanical damage in ceramic restorations. It is a known fact that the amount of microcracks affects the material's mechanical strength. This includes the number, depth, width, and direction of the micro-cracks, all of which have an impact on the mechanical strength of the material.

Fracture Mechanics Related to Ceramics

Griffith flaws – "Griffith's theory states that a crack will propagate when the reduction in potential energy that occurs due to crack growth is greater than or equal to the increase in surface energy due to the creation of new free surfaces". This theory is applicable to elastic materials that fracture in a brittle fashion. As tensile stress is applied to the glass surface, these tiny surface defects act as "stress concentration centers". Dental ceramics should have a mechanism that prevents these microcracks from forming and propagating in order to improve their mechanical resistance.[3–5] To reduce the effects of tensile stress, the ceramic structure must be supported by metallic or more durable sub-structures. A mismatch in the coefficient of thermal expansion between the porcelain core and veneer, heat production during grinding and adjusting, and repeated and damaging masticatory force in the oral cavity are all potential sources of ceramic microcracks. Ceramics are strong in compression but weak in tension. Tensile forces have a tendency to spread the cracks and widen them. However, compressive stresses tend to approximate the cracks.[5]

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Texture Defects Related to Porcelain Bulk

Inadequate particle fusion during the sintering process or improper fire duration or temperature might result in texture defects. The links or bonds between crystals can be stretched or warped when even one crystal is twisted or misaligned in relation to another, thus weakening the ceramic structure. Ions with the same charge can create electrostatic repulsion, which can lead to strains and eventually result in cracks.[5]

Fatigue

The gradual decrease in strength is referred to as fatigue. Ceramic crowns must perform under wet conditions in clinical settings (externally saliva and internally cement material). Fatigue results from two loading situations, i.e., both static and cyclic stresses. The oral environment combines both stresses (static and cyclic). A chemical reaction between water molecules and the glass surface, followed by enhanced crack propagation due to stress concentration until the stress is removed or released, is one potential cause for the ceramic fatigue process.[5] Strengthening of ceramics from older to newer methods includes (i) optimal design of prosthesis, (ii) development of residual compressive stress, and (iii) interruption of crack propagation.

Strengthening of Ceramics

Development of Residual Compressive Stress within the Material

- Thermal compatibility – bonding to metal.
- Chemical tempering.
- Thermal tempering.
- Glazing.

Interruption of Crack Propagation

- Dispersion strengthening.
- Transformation toughening.

Designing Components

- To minimize tensile stresses.

Development of Residual Compressive Stress within the Material

Thermal Compatibility: Bonding to Metal or Ceramic Core

The fusion of porcelain with oxide-coated metal provides a solid support to prevent crack propagation to the ceramic surface under tensile stresses. The metal–ceramic systems currently in use are:

- Nobel metal alloy systems: High gold, low gold, and gold free.
- Base metal alloy systems: Nickel–chrome, titanium.

The success of the metal–ceramic systems depends on a strong bond between the metal and molten ceramic that is achievable by the following:

a. *Mechanical interlocking*: Porcelain can penetrate the alloy because of the irregularities created by the sandblasting on the surface of the metal. The contact angle and wettability of the liquid porcelain determine how porcelain interacts with metal.
b. *External surface compression*: The coefficient of thermal expansion (CTE) of veneered porcelain should be slightly lower than that of the metal alloy. The porcelain is kept compressed while cooling, which causes the metal to shrink.
c. *Chemical attachment*: An oxide layer forms at the porcelain–metal interface, which is where the chemical bond between metal and porcelain occurs.

In the case of the precious metal ceramic bond, a layer of tin oxide is electroplated onto platinum or tin foil before an aluminous ceramic is bonded to it. Oxidative firing can cause base metals to form oxides on their surfaces when they are bonded to ceramics.[6]

Disadvantage

The underlying metal color frequently penetrates porcelain, rendering it grayer than the teeth around it. The metal crown is covered with opaque porcelain, nevertheless, its high reflectivity gives it an unnatural appearance. Metal–ceramic restorations are frequently overcontoured to prevent this reflection.[7]

Bonding to High-strength Core Ceramic – All Ceramics

High-alumina cores with aluminous porcelain veneers were used together. Similar to metal–ceramic systems, these laminates are much stronger than ordinary porcelain. The chemical bond at the interface ensures freedom from porosity and improved wettability.[7]

Thermal Tempering

A rigid glass skin surrounds the molten core due to rapid cooling of the glass surface while the center is still hot. The molten core tends to shrink as it solidifies. The outer surface experiences compressive residual stresses as a result of the pull of the molten core, which solidifies as it contracts.

Limitations: For uniform stresses to be distributed, simple shapes are needed. Dental restorations, on the other hand, have complicated shapes, sharp angles, and varying thicknesses.[8]

Glazing

Glazing is done by applying a thin layer of veneering ceramic with a slightly lower CTE to the core ceramic. The core material shrinks slightly more as it cools as a result of this offset, leaving the veneering ceramic with some compression left over.[8]

Ion Exchange or Chemical Tempering

This is the process of substituting smaller Na+ ions (a common component of various glasses) for larger K+ ions. The glass is placed in a bath of molten potassium nitrate, where some sodium ions of the glass particles are exchanged for the potassium ions in the bath. Because the K+ ions are larger than the Na+ ions, there is crowding because the K+ ions in the position that was previously occupied by the smaller Na+ ions cause compressive residual stresses on the glass surfaces.[9]

Limitation: This effect is easily lost after prolonged exposure to certain inorganic acids because the compression zone is less than 100 µm.

Dispersion Strengthening

The crack cannot pass through the alumina particles as easily as it does through the glass matrix, adding a hard crystalline material like alumina (Al_2O_3) to glass, which makes the glass harder and stronger. The following factors influence the strength:

- The variety of crystals, as well as their resistance and geometric form.
- Size of the crystal: smaller crystals are preferable.
- Relative CTE to the glass matrix: In order to improve the strength, the CTE of the crystalline material (alumina) and the surrounding glass matrix must closely match. The spacing between the particles should be close to one another.[9]

Transformation Toughening

Ceramics made of zirconia (ZrO_2) is a good example of this mechanism. The substance is a polymorph that can take three different forms: *Monoclinic* (M) at room temperature, *Tetragonal* (T) at 1170 °C, and *Cubic* (C) at 2370 °C.

A volume reduction of 5% occurs during the monoclinic to tetragonal-phase transition. A volume expansion of 3% occurs when the tetragonal phase is switched over to the monoclinic phase. Stabilizing oxides (magnesium oxide, yttrium oxide) can be added to the material to stop these transformations. These oxides allow the tetragonal-phase particles to exist at room temperature, effectively stopping crack propagation and resulting in high toughness.[10]

Minimizing Tensile Stresses through Optimal Design

- Using thick core materials that are strong because the inner surface is where tensile stresses are distributed (the core material is under tension). They vary in thickness, posing a risk of premature fracture during fabrication, placement, or post-cementing procedures. The appropriate amount of occlusal reduction is needed because too small an interocclusal space during tooth preparation can be a potential cause of fractures with occlusal loading.[11] To avoid stress concentrations, all line angles and transitions must be rounded.
- Accurate registration of the bite, avoiding premature contacts that can serve as stress concentration zones on the ceramics and sufficient room for luting cement (internal relief) to prevent excessive luting cement from causing tensile stresses on the ceramic crown.[11]
- Use a good condensation technique, a programmed firing schedule, high-pressure compaction, and vacuum firing, and avoid porosity during the production process to increase strength.
- Furthermore, gradual cooling is essential to prevent cracking and the development of stresses.[11]

Conclusion

Recent advancements in all-ceramic crowns in esthetics and durability are a highlight of these improvements. In the future, there will be a great revolution in the field of dental ceramics, with the introduction of nanotechnology to improve dental restorations in the areas of form, function, and esthetics and better biocompatibility.

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