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Facilitation Of Bonding A Densely Sintered High Purity Zirconium - Oxide Ceramic Surface

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Abstract

Zirconia based ceramic systems has become increasingly popular because of zirconia's favorable esthetic characteristics, mechanical properties, and biocompatibility. Achieving a durable bond to densely sintered zirconia remains a challenge. This paper aims to elucidate various methods which facilitate the bonding of a densely sintered high purity zirconium- oxide ceramic surface.

A strong, durable resin bond to ceramics is established by either chemical bonding or by micromechanical interlocking. Successful long-term bonding to zirconia ceramic remains a challenge, requiring special cements and surface roughening by air-borne particle abrasion, which might negatively affect the ceramic. Surface treatments can be done with tribochemical silica coating, plasma spray with hexamethyl disiloxane, selective infiltration etching (SIE) and fusing glass pearls have been discussed; and have shown to influence the bond strength to zirconia surface.

Key Words

Plasma spray, Hexamethyl disiloxane (HMDSO), Selective infiltration etching (SIE), Modified ceramic surface

Introduction

Zirconia based ceramic systems has become increasing popular because of zirconia's favorable esthetic characteristics, mechanical properties, and biocompatibility.[1] During the past few years, partially stabilized zirconia has been integrated into restorative dentistry. First introduced as hip replacement material in 1990s, this material is stabilized with yttrium oxide and exists as Yttria- tetragonal zirconia polycrystals (Y-TZP) at room temperature.[2]

Densely sintered zirconia has the highest flexural strength approx 1000MPa, among all dental ceramics making it the material of choice for the fabrication of conventional or resin bonded FPDs.[3] Fabrication of densely sintered zirconia frameworks utilizes CAD/CAM technology. Machined ceramics, used for fabrication of fixed partial denture (FPD) frameworks, have smooth and even intaglio surface, a significant disadvantage for resin-bonded FPDs, which rely exclusively on adhesive cementation for retention.[4]

Establishing a strong and stable bond with zirconia has proven to be difficult, as the material is acid resistant and does not respond to the common etching and silanation procedures used with other glass containing ceramic materials which react to silane coupling agents. Several surface roughening and coating methods have been used to optimize the surface of zirconia and to improve the bond strength with resin-based cements.[5, 6, 7, 8, 9-11]

This article aims to elucidate various methods which facilitate bonding a densely sintered high purity zirconium- oxide ceramic surface. A broad systematic search of dental literature was designed to identify evidence supporting the various methods which facilitate bonding a densely sintered high purity zirconium- oxide ceramic surface. The literature revealed that a strong, durable resin bond to ceramics is established by

1. : Chemical bonds
2. : Micromechanical interlocking

Chemical Bonding

Achieving a durable bond, especially a stable chemical bond, to densely sintered zirconia remains a challenge.[5] Previous studies have shown that the application of a modified bis-GMA resin luting agent (Panavia 21) containing the adhesive phosphate monomer 10-MDP (methacryloyloxydecyl dihydrogen phosphate) is an important factor in providing durable resin bond to zirconia ceramic.[12, 13]

A recent study showed that a self - etching universal resin cement (RelyX Unicem) demonstrated long term bond strength to zirconia based ceramics.[14] In contrast, conventional bis-GMA resin luting cements do not demonstrate a durable long term bond to high strength ceramics.

Methods Used To Increase Micromechanical Retention

The methods used to increase micromechanical retention to silica based ceramics, such as applying phosphoric / hydrofluoric acid do not produce an acceptable surface roughness in high - strength ceramics.[13] Alteration of the surface roughness in high-strength ceramics is achieved either by adding to the surface or by removing surface material.[5, 6, 7, 8]

The methods which alter the surface roughness in high-strength ceramics by adding to the surface include:

1. Plasma spray with hexamethyl disiloxane
2. Fusing a low fusing porcelain pearl layer
3. Selective infiltration etching technique
4. Use of a modified ceramic surface

Plasma spray with hexamethyl disiloxane (HDMSO)

This method gives improved bonding values even though its bonding energy is still unknown. Plasma is an electrically neutral medium containing ions, electrons, atoms and neutral species. A high frequency generator is then used to ionize gas into plasma. To enable a gas to be ionized in a controlled and qualitative manner, the process is carried out under vacuum. Zirconia surface can be treated with radiofrequency (RF) plasma treatment - HEXAMETHYL DISILOXANE 13.56Hz using a reactor.[15]

Plasma deposition is made in three steps:

1) Activation of surfaces with oxygen
2) Deposition of HMDSO $[(CH_3)_3SiOSi(CH_3)_3]$
3) Activation of polymer with oxygen

Bond strength of surface treated with plasma spray is three times that of the untreated surface.

Fusing glass pearls to zirconia

To establish a firm bond between zirconia surface and resin luting material glass pearls can be fused. Powder (low fusing porcelain) is stirred in excessive amount of water and immediately painted on ceramic surfaces and fired at 720ºC without vacuum (1min). Fusing glass micropearls to zirconia creates micromechanical retention spots.[15]

Two prerequisites should be fulfilled:

1. It should not interfere with crown fusing and should be incorporated in that scheme to avoid additional fusing.
2. It must not create an increase in thickness over ~5 µm.

This increases the bond strength value by a factor of ten. These pearls can also be silanized prior to cementation to obtain even higher bond strength values.

Selective infiltration etching (SIE)

SIE uses principles of heat induced maturation (HIM) and grain boundary diffusion to transform dense and non-bonding surface of zirconia into highly retentive surface through the establishment of intergrain nanoporosity.[7] It is done by heating the zirconia ceramic to 750°C for 2 min. followed by cooling to 650°C for 1 min.; again reheating to 750°C for 1 min., then cooled to room temperature. HIM-energy rich grain boundaries become destabilized as surface grains tend to expand and shrink during alternate temperature changes. Grain boundaries become prestressed and can be more easily infiltrated by other materials. This process is known as *thermal etching*.

This further utilizes a specific glass infiltration agent that is able to diffuse in grain boundaries and results in creation of 3-D network of intergrain porosity. Structural and chemical analysis of zirconia ceramic interface revealed that ions such as silica, sodium, aluminium and potassium can infiltrate fully sintered zirconia at grain boundary regions.[7] Increased silica content at grain boundaries increased both grain sliding movements of fully sintered zirconia - thus alter surface.

Adhesive resin infiltrates into 3-D network of intergrain porosity created by HIM/SIE surface treatment and interlock underlying Y-TZP resulting in significantly higher microtensille bond strength.

Modified Rough Ceramic Surface

Modified rough ceramic surface used as intaglio surface of high strength ceramic restoration. It is produced by coating a presintered or a fully sintered and milled zirconia framework with slurry containing zirconia ceramic powder and a pore former. The slurry coated ceramic is sintered while the pore former burns off, leaving a porous surface.[4]

Porosities can be modified by using different sizes of pore formers or repeating the coating process. It reveals microporosities which might provide micromechanical interlocking with cement. The advantages includes that it eliminates chairside or laboratory step of airborne particle abrasion and possible risks to airborne particle abrasion.[4] The methods which alter the surface roughness in high-strength ceramics by removing from surface include air borne particle abrasion alone or followed by tribochemical silica coating.[10, 16, 17]

Tribochemical Silica Coating

Tribology is the science and engineering of interacting surfaces in relative motion. Silica is tribochemically transformed and coated on the zirconia ceramic surface to increase the bond strength between composite resin and high strength ceramics.

1. Cleaning: This is done by an airborne particle abrasion with 110 µm high purity alumina particles at 250 kPa for 14 sec. This cleans the surface and creates uniform pattern of roughness.
2. Tribochemical coating: Silica coating is done by 110 µm or less abrasive 30 µm of silica modified high purity alumina, which leaves the surface partially covered with silica. Silica coating "energizes" the substrate surface, which allows the silica to attach to it. Silica is tribochemically transformed and is consequently able to bond to metal alloys and high density ceramics.
3. Conditioning: It is done with silane to improve bond between silica adhered to substrate surface and composite resin matrix.

The advantages include that coating units are available for use both in dental lab and office.[7,17] Other methods were either ineffective with zirconia ceramics or technically complicated.

Various in vitro studies have shown that airborne- particle abrasion with aluminium oxide particles is an essential step in achieving a durable bond to high-strength ceramics. However, despite the increase in shear bond strength, its use is controversial due to the possible introduction of flaws and microcracks; and has been shown to compromise the fatigue strength of zirconia-based ceramic.[5,13]

Aside from mechanical retention, to date, the only effective method to chemically bond to zirconia is by using a phosphate ester monomer, 10-methacryloxydecyl dihydrogen phosphate (MDP), which provides a stable bond that resists hydrolysis during artificial aging procedures.[6,7,8]

Conclusion

The retention and stability of the all ceramic zirconia restorations primarily depend on the adhesive bond strength, which must be strong enough to resist the expected functional loads. Successful long-term bonding to zirconia ceramic remains a challenge, requiring special cements and surface roughening by air-borne particle abrasion, which might negatively affect the ceramic. Surface treatments including tribochemical silica coating, plasma spray with hexamethyl disiloxane, SIE and fusing glass pearls have been discussed; and have shown to influence the bond strength to zirconia surface.

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