Guide to All-Ceramic Bonding

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Guide to All-Ceramic Bonding

All-ceramic restorations are favorable alternatives to metal-ceramic and all-metal restorations. All-ceramic restorations have superior esthetics, are biocompatible and are durable. Twenty-five years of experience by THE DENTAL ADVISOR shows that fracture and chipping of all-ceramic restorations are similar to those of ceramic-metal restorations.

There are two major categories of all-ceramic materials: silica-based (feldspathic porcelains, leucite-reinforced ceramics, lithium disilicate ceramics) and non-silica-based (zirconia or Y-TZP, alumina). Because of differences in strength and requirements for bonding or cementation, the selection of cement is important. This article describes characteristics and properties of various types of all-ceramic materials and associated cements.

ALL-CERAMIC MATERIALS

A variety of all-ceramic materials are available today. Products include silica-based ceramics (feldspathic porcelains, leucite-reinforced ceramics, lithium disilicate ceramics) and non-silica-based ceramics (zirconia, alumina) (Table 1). The dentist must choose the optimum all-ceramic material for particular clinical situations. This section describes the composition, properties and case selection of all-ceramic materials.

A summary of the strength of all-ceramic materials is shown in the box below:

Silica-based Ceramics	Flexural Strength
Feldspathic porcelain	65-120 MPa
Leucite-reinforced ceramic	120-140 MPa
Lithium disilicate ceramic	300-400 MPa
Non-silica-based Ceramics	
Alumina	650 MPa
Zirconia	800-1500 MPa

A summary of indications for all-ceramic materials is shown in the box below:

Indications for feldspathic porcelains
- Highly esthetic veneers or anterior crowns in cases where color masking is not an issue

Indications for leucite-reinforced ceramics
- Esthetic veneers and anterior crowns
- As a layering porcelain on leucite-reinforced, lithium disilicate, alumina, or zirconia cores

Indications for lithium disilicate ceramics
- Veneers
- Premolars and molars - inlays, onlays and crowns
- Three-unit bridges – anterior and premolar region

Indications for zirconia-based ceramics
- Anterior and posterior crowns
- Bruxers – full-contour crowns
- Anterior and posterior bridges (maximum 14-unit bridges, span depends on product and number of abutments)
- Endodontically treated teeth
- Implant abutments
- Inlay bridges
- Maryland bridges
- Block-out of darkened tooth structure or cores

Feldspathic Porcelains

Feldspathic porcelain is a silica-based ceramic available in sintered, pressed and milled forms. Examples of feldspathic porcelains are listed in Table 1.

Composition of Feldspathic Porcelains

Feldspathic porcelain is composed of leucite (potassium alumino-silicate) and glass. It has low to medium values of flexural strength (65-120 MPa).

Case Selection of Feldspathic Porcelains

Esthetics is the number one priority for ceramic restorations and feldspathic porcelain is arguably the most esthetic porcelain, since it has superior translucency. It is technique sensitive and fewer laboratories are offering this service. Due its low strength, it is not recommended for bruxers or in high wear areas and it is rarely used for full coverage.

Leucite-reinforced Ceramics

Leucite-reinforced ceramic is a silica-based ceramic available in sintered, pressed and milled forms. Examples of leucite-reinforced ceramics are listed in Table 1.

Composition of Leucite-reinforced Ceramics

Leucite-reinforced ceramics contain up to 45% by volume of leucite. Leucite is a reinforcing phase that results in medium values of flexural strength (120-140 MPa) and compressive strength. Leucite crystals can act as crack deflectors and contribute to increased resistance to crack propagation.

Case Selection of Leucite-reinforced Ceramics

Leucite-reinforced ceramics are recommended when esthetics is the primary objective. These ceramics are less technique sensitive than feldspathic porcelains. They are not recommended for posterior crowns because of their low strength; however, they can be used for inlays and onlays.

Lithium Disilicate

Lithium disilicate ceramic is a silica-based ceramic available in sintered, pressed and milled forms. Examples of lithium disilicate ceramics are listed in Table 1.

Definitions

Adhesive resin cement - cement based on acrylic or diacrylate resin with adhesive monomers that bond well to metal substrates. Adhesive resin cements may require a separate primer for bonding to ceramic and tooth substrates.

Esthetic resin cement - tooth-colored or translucent cement based on diacrylate resin that requires a bonding agent for adhesion to tooth structure and separate primers for bonding to ceramic substrates.

Self-adhesive resin cement - cement with adhesive components that eliminate the need for separate primers for bonding to tooth structure and ceramic substrates.

Bonded restoration - ceramic restoration bonded with resin cement.

Cemented restoration - ceramic restoration that is mechanically retained (luted) on a standard preparation with cement that does not chemically bond to tooth structure.

Silane Primer (Silane coupling agent) – primer based on silane used with silica-based ceramics (feldspathic porcelain, leucite-reinforced ceramic, lithium disilicate ceramic).

Ceramic Primer – primer based on acidic adhesive monomers used with alumina- and zirconia-based ceramics. Ceramic primers may contain silane and metal primers.

Composition of Lithium Disilicate Ceramics

Lithium disilicate ceramics consist of about 65% by volume of highly interlocking lithium disilicate crystals dispersed in a glassy matrix. These ceramics have high flexural strength (300-400 MPa) and high fracture toughness.

Case Selection of Lithium Disilicate Ceramics

Lithium disilicate restorations combine strength with good esthetics. They can be layered with feldspathic porcelain using a cutback technique. Shaded lithium disilicate ingots are available for blocking out dark stumps.

Zirconia-based Ceramics

Zirconia (zirconium oxide)-based ceramics have become one of the most popular types of all-ceramic restorations available today. Zirconia-based ceramics utilize CAD/CAM technology for fabrication of copings for crowns, bridges and implant abutments. Zirconia (zirconium oxide, Y-TZP) is milled in the "green" or pre-sintered state and then sintered, during which the material shrinks about 20%. The sintered zirconia coping has very high flexural strength. After the copings are fabricated, a ceramic veneer compatible with the properties of the zirconia coping is either pressed, stacked or milled, creating a uniquely strong and esthetic restoration. Examples of zirconia-based ceramics are listed in Table 1.

TABLE 1 *Examples of All-Ceramic Materials.*

Product	Company
Feldspathic Porcelain	
CEREC Blocs	Sirona Dental Systems
Leucite-reinforced Ceramic	
IPS Empress	Ivoclar Vivadent
Lithium Disilicate	
IPS e.max	Ivoclar Vivadent
Zirconia	
3M ESPE Lava Crowns & Bridges	3M ESPE
Cercon	DENTSPLY Ceramco
CEREC inLab	Sirona Dental Systems
Crystal Zirconia (HS, HT, Diamond Zirconia)	Dental Laboratory Milling Supplies
InCeram Zirconia	Vita
IPS e.max ZirCAD	Ivoclar Vivadent
KATANA	Noritake Dental Supply
KaVo Everest	KaVo
Procera AllZirkon	Nobel Biocare
Versus System	Whip-Mix
ZENO Tec System	Wieland Dental + Technik

TABLE 2 *Examples of Adhesive Resin Cements and Esthetic Resin Cements with Recommended Bonding Agents.*

Product	Company	Bonding Agent or Primer
Adhesive Resin Cement		
Panavia F 2.0	Kuraray America, Inc.	ED Primer A, B
Esthetic Resin Cement		
RelyX ARC	3M ESPE	3M ESPE Adper Single Bond Plus
Calibra	DENTSPLY Caulk	Prime & Bond NT Dual Cure System
CLEARFIL Esthetic Cement EX	Kuraray America, Inc.	CLEARFIL DC BOND
Multilink Automix	Ivoclar Vivadent	Primer A, B
NX3	Kerr Corp.	Optibond All-In-One

TABLE 3 *Examples of Self-Adhesive Resin Cements.*

Product	Company
RelyX Unicem 2	3M ESPE
BisCem	Bisco Dental Products
Breeze	Pentron Clinical
CLEARFIL SA Cement	Kuraray America, Inc.
G-CEM	GC America
Maxcem Elite	Kerr Corp.
SmartCem2	DENTSPLY Caulk
SpeedCEM	Ivoclar Vivadent

Composition of Zirconia-based Ceramics

Partially stabilized zirconia, especially yttria-stabilized zirconia (Y-TZP), is the most common zirconia-based ceramic in dentistry. Values of flexural strength range from 800 to 1500 MPa. Recently, zirconia-based ceramics with higher translucency have become available.

Case Selection of Zirconia-based Ceramics

Zirconia-based crowns are esthetic and can be ideal for restoration of endodontically treated teeth that have become discolored and need an opaque substructure to mask the discoloration. Full-contour zirconia restorations provide esthetic options for patients who are heavy bruxers or have other parafunctional habits. The high flexural strength and fracture toughness of zirconia are beneficial in these cases, but potential wear of opposing dentition is a concern. Zirconia implant abutments are ideal for the restoration of implants in the esthetic zone. The subsequent zirconia-based ceramic crown blends in well with the zirconia implant abutment. For esthetic fixed partial dentures, the connectors do not need to be as wide as other types of all-ceramic fixed partial dentures because of the strength of the zirconia.

RESIN CEMENTS

There are three types of resin cements – adhesive, esthetic, and self-adhesive resin cements – see box below. Examples of adhesive and esthetic resin cements with their recommended primers and bonding agents are listed in Table 2. Examples of self-adhesive resin cements are listed in Table 3.

Characteristics of resin cements are listed in the box below:

Characteristics of Esthetic Resin Cements

- Self-etch or total-etch bonding agent is needed for bonding to tooth substrates.
- Silane or ceramic primer is needed for all-ceramic restorations.
- Curing mode options – can be light- or dual-cured.
- Light-cured cement is available for veneers.
- Stronger mechanical properties than self-adhesive resin cement.
- Multiple shades available.
- Most esthetic resin cements provide water soluble try-in pastes.

Characteristics of Adhesive Resin Cements

- Primer is needed for bonding to tooth substrates.
- Silane coupling agent is needed for silica-based ceramics.
- Can bond directly to zirconia without primer.
- Curing mode options – can be light-, dual-, or self-cured.
- Several shades available.
- May release fluoride.

Characteristics of Self-adhesive Resin Cements

- Self-etching – no phosphoric acid or special primer needed for bonding to tooth substrates.
- Can bond directly to zirconia without primer.
- Curing mode options – can be light-, dual-, or self-cured.
- May release fluoride.
- Usually available in universal, translucent and opaque shades.

Composition of Resin Cements

Resin cements are composed of diacrylate resins and glass filler. They are usually dual-cured resins that can be light activated and can self-cure.

Esthetic resin cements require a bonding agent for adhesion to tooth structure and a primer for adhesion to ceramic surfaces (see following section on Primers for Ceramic Substrates). Adhesive resin cements typically only require a bonding agent for adhesion to tooth structure. These resin cements should be selected when greater bond strength and stronger mechanical properties of the ceramic and cement are desired.

Self-adhesive resin cements are composed of diacrylate resins with acidic and adhesive groups and glass filler. Self-adhesive resin cements have adhesive components that eliminate the need for separate etchants and primers for bonding to tooth structure or zirconia-based ceramics. Some products recommend use of a silane primer for porcelain and ceramic primer for zirconia. Self-adhesive resin cements are usually dual-cured resins that can be light-activated and can self-cure. During setting, self-adhesive resin cements typically undergo a change in pH from acidic (pH 2-3) to less acidic (pH 5-6). The early acidity of the cement allows it to etch and adhere to tooth structure.

Manipulation of Resin Cements

Esthetic resin cements and adhesive resin cements require etching and priming steps. A silanating agent is required with esthetic resin cements for bonding to silica-based ceramics. A zirconia primer (see the following section on Primers for Ceramic Substrates) is required with esthetic resin cements for zirconia bonding. Follow the manufacturers' instructions on how to apply such bonding systems to get strong bonding and enough working time. The working time of the cements may be accelerated with the primer and the bonding agents. Most of these dual-cured cements are paste-paste system with auto-mix dispensers. Excess cement can be removed easily after brief tack-curing (2-5 seconds) with a curing light.

Self-adhesive resin cements eliminate the etching and priming steps. Most self-adhesive resin cements are paste-paste systems with auto-mix dispensers, but encapsulated and auto-dispensed products are also available.

Properties of Resin Cements

Esthetic resin cements have high mechanical strength, because these cements are made of multifunctional acrylate monomers that are polymerized to a cross-linked polymer matrix without acidic monomers.

The flexural strengths of several self-adhesive resin cements are compared in Figure 1. Typically, self-adhesive resin cements have

TABLE 4 *Mechanical Properties of Self-Adhesive Resin Cements in Dual- and Self-cured Modes.*

	Flexural Strength, MPa		Flexural Modulus, GPa	
Cement	**Light-cured**	**Self-cured**	**Light-cured**	**Self-cured**
Maxcem Elite	86 (11)	90 (17)	5.9 (0.6)	5.2 (0.5)
RelyX Unicem (Clicker)	89 (4)	65 (15)	7.8 (0.5)	4.4 (0.2)
SmartCEM2	94 (7)	86 (7)	4.8 (0.4)	7.1 (0.9)

Yapp R, Powers JM, unpublished data.

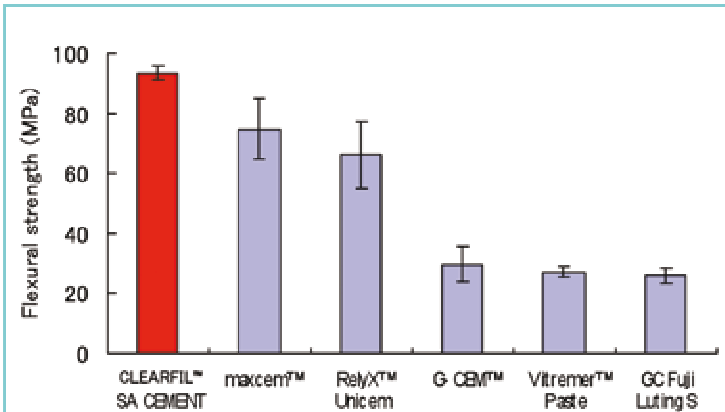


Figure 1. Flexural strength of self-adhesive resin cements. Adapted from H. Yamamoto, T. Nakamura, K. Wakabayashi, A. Okada, S. Kinuta, H. Yatani, Osaka University, 2008.

Clinical Tips

A summary of clinical tips for cementation and bonding of silica- and zirconia-based ceramics is shown in the box below:

Preparation

- Don't over dry the tooth - moisten with wet cotton pellet, if needed.

Choice of Cement

- Never use light-cure only resin cement with more opaque silica- and zirconia-based ceramic restorations.
- Use light-activation whenever possible - dual-cured resin cements typically have increased flexural strength and bond strength when activated with a light vs. self-curing only.
- Translucent shades of resin cement may be sensitive to ambient light.
- Self-adhesive resin cements are contraindicated where there is not enough tooth retention.

Ceramic Primer and Silane Primer

- Self-adhesive and adhesive cements containing acidic monomer usually do not require ceramic primer for bonding to zirconia-based restorations.
- Esthetic cements require a silane primer for bonding to silica-based ceramics or ceramic primer containing acidic monomer for bonding to zirconia-based ceramics.
- Use a silane primer with silica-based all-ceramic restorations.
- For higher bond strength to zirconia-based ceramics, sandblast with 50 um alumina and use a ceramic primer or apply a tribochemical silica coating to the restoration and use a silane primer.
- Some ceramic primers (e.g., CLEARFIL CERAMIC PRIMER/Kuraray America, Inc.) will bond to both silica- and zirconia-based restorations.

Excess Cement

- Excess cement is easy to remove after tack curing, but hard to clean up if you light-cure too long.

higher mechanical properties when light-activated than when allowed to self-cure without light-activation as shown in Table 4. Self-adhesive resin cements generally are not as strong as esthetic resin cements. Self-adhesive resin cements are reported to have values of linear expansion of 0.5 to 1.5% over two months.

A comparison of properties of resin cements and traditional crown and bridge cements is shown in Table 5.

TABLE 5 *Comparison of Properties of Resin and Traditional Cements*

Cement	Flexural Strength	Compressive Strength	Solubility
Resin Cements			
Adhesive Resin	High	High	Low
Esthetic Resin	High	High	Low
Self-adhesive Resin	Medium	Medium	Low
Traditional Cements			
Glass Ionomer	Low	Low	Medium
Resin-modified Glass Ionomer	Low-medium	Low-medium	Low-medium

Bond Strengths of Resin Cements to Tooth Structure

Bond strengths of CLEARFIL Esthetic Cement EX with several bonding agents to unground and ground enamel tested at 24 hours are listed in Table 6. Bond strengths of self-adhesive resin cements to tooth structure are listed in Table 7, and shown in Figure 2. Typically, self-adhesive resin cements have bond strengths that are typically 20% to 50% higher when light-activated than when allowed to self-cure without light-activation. The separate use of a bonding agent is not recommended with self-adhesive resin cements. Although bonding agents may be compatible with self-adhesive resin cements, their use makes the manipulation more complicated and does not dramatically improve bond strength to tooth structure. Higher bond strengths to tooth structure can be obtained with esthetic resin cements that are bonded with separate bonding agents.

TABLE 6 *Bond Strength of CLEARFIL Esthetic Cement EX with Several Bonding Agents to Unground and Ground Enamel Tested at 24 Hours.*

Bonding Agent	Company	Bond Strength to Unground Enamel, MPa	Bond Strength to Ground Enamel, MPa
CLEARFIL DC BOND	Kuraray America, Inc.	26 (9)	16 (8)
Xeno IV	DENTSPLY Caulk	10 (6)	15 (10)
Adper Scotchbond MP Plus	3M ESPE	20 (7)	15 (7)
Excite DSC	Ivoclar Vivadent	9 (4)	16 (5)

Krishnan G, Yapp R, Powers JM, unpublished data.

TABLE 7 *Bond Strength of Self-Adhesive Resin Cements in Dual- and Self-cured Modes to Tooth Structure.*

	Bond Strength, MPa			
Cement	Enamel Light-cured	Enamel Self-cured	Dentin Light-cured	Dentin Self-cured
Maxcem Elite	15 (6)	12 (2)	11 (2)	12 (4)
RelyX Unicem (Clicker)	10 (3)	4 (1)	19 (5)	3 (1)
SmartCEM2	11 (5)	12 (6)	6 (1)	4 (2)

Powers JM, unpublished data.

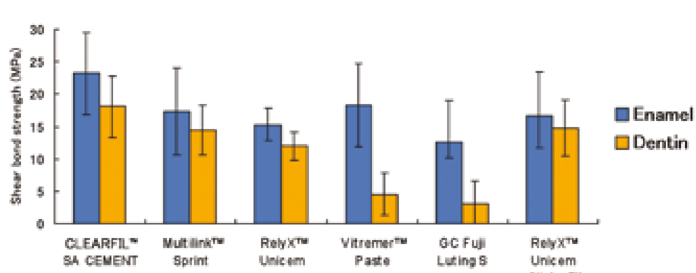


Figure 2. Shear bond strength to tooth structure. Adapted from N. Iwamoto, S. Uctasli, M. Ikeda, M. Nakajima, J. Tagami, Tokyo Medical and Dental Univeristy, 2008.

PRIMERS FOR CERAMIC SUBSTRATES

Primers improve bonding between resin cements and various restorative materials and can be classified based on the substrate (silica-based ceramics, alumina, zirconia, alloy) for which they are intended. Silanating agents are used with silica-based ceramics (feldspathic porcelain, leucite-reinforced ceramic, lithium disilicate ceramic). Modern silanating agents are one-bottle systems with good shelf life.

Ceramic primers based on acidic adhesive monomers are used with alumina- and zirconia-based ceramics. The acidic adhesive monomer used in CLEARFIL CERAMIC PRIMER (Kuraray America, Inc.) is an acidic phosphate ester known as MDP. This primer also contains silane. It works on any type of ceramics as shown in Figure 3. An ethanol solvent is used to maintain the shelf life.

Metal primers based on sulfide methacrylates are used with alloys. Some primers contain several priming agents and can be used on multiple surfaces. Primers for use with silica- and zirconia-based ceramics are listed in Table 8.

TABLE 8 *Primers for Ceramic Substrates*

Product	Company	Substrate	Components
RelyX Ceramic Primer	3M ESPE	Silica-based ceramic	Silane
AZ Primer	Shofu Dental Corp.	Zirconia, alumina	Silane, acidic adhesive monomer
CLEARFIL CERAMIC PRIMER	Kuraray America, Inc.	Silica-based ceramic, zirconia, alumina	Silane, acidic adhesive monomer (MDP)
Monobond Plus	Ivoclar Vivadent	Silica-based ceramic, metal, zirconia, alumina	Silane, phosphoric acid methacrylate, sulfide methacrylate
Z-PRIME PLUS	Bisco Dental Products	Zirconia, alumina, metal	Phosphoric acid methacrylate, sulfide methacrylate

TABLE 9 *Shear Bond Strength of CLEARFIL Esthetic Cement EX and CLEARFIL CERAMIC PRIMER to Two Lithium Disilicate Ceramic Materials utilizing Three Different Surface Treatments.*

Material	Treatment	Bond Strength MPa (SD)	% Adhesion
IPS e.max Press	No treatment	26 (3.0)	100
IPS e.max Press	Sandblast	22.1 (3.7)	99
IPS e.max Press	HF Etch	36 (7.2)	92
IPS e.max CAD	No treatment	5.6 (1.8)	100
IPS e.max CAD	Sandblast	18.1 (2.4)	99
IPS e.max CAD	HF Etch	30 (3.5)	96

Yapp R, Powers JM., unpublished data.

BONDING MECHANISMS OF CEMENTS TO CERAMICS

Bonding to Silica-based Ceramics

In general, restorations prepared from feldspathic porcelain and leucite-reinforced ceramic should be bonded with adhesive or esthetic resin cements. Adhesive resin cement or esthetic resin cements are recommended because of their higher mechanical properties and higher bond strength to tooth structure than others. Adhesive resin cement was reported to increase all-ceramic restorations' fracture strength and to improve marginal sealing significantly, as compared to a self-adhesive cement and zinc phosphate.

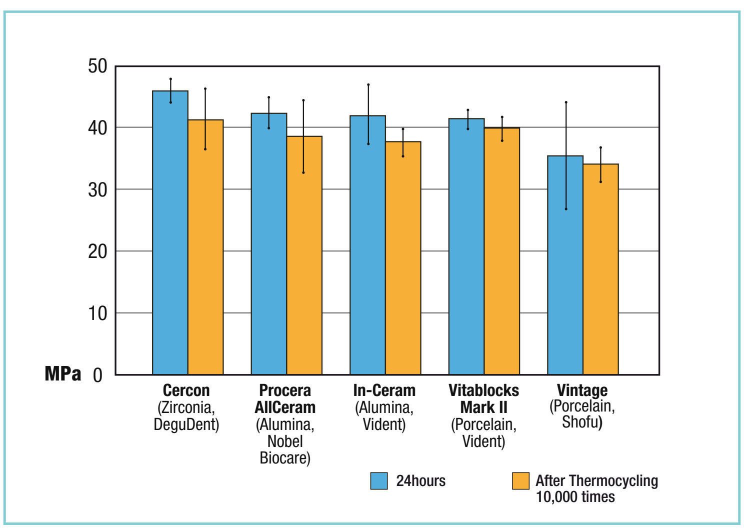


Figure 3. Shear Bond Strength of CLEARFIL CERAMIC PRIMER to Different Ceramic Restorations. K.YOSHIDA and M. ATSUTA, Nagasaki University, Graduate School of Biomedical Sciences, Japan; Int J Prosthodont 2007; 20:417 - 418

The bonding mechanism of silane coupling agent (γ-MPS) to silica-based ceramcis is shown in Figure 4. Lithium disilicate restorations can be bonded with resin cements or cemented with traditional non-adhesive crown and bridge cements.

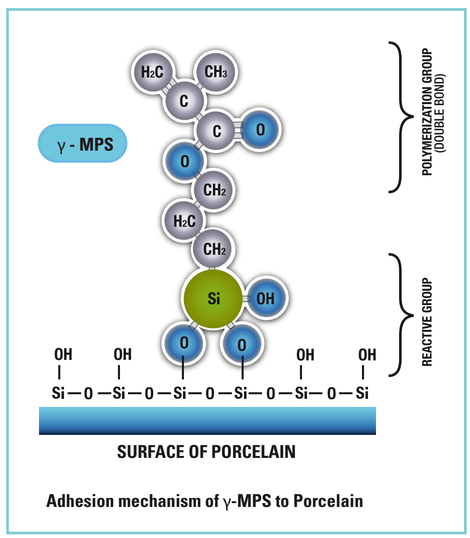


Figure 4. Chemistry of silane coupling agent (γ-MPS) to silica-based ceramics.

Pretreatment Technique for Silica-based Ceramics

Typically, silica-based ceramics are pre-treated with hydrofluoric acid gel (HF) before silanation. HF can dissolve the surface of silica-based ceramics and roughen it. The effect of three different treatments on the bond strength of an esthetic cement with a ceramic primer are shown in Table 9. HF treatment for lithium disilicate results in good bond strength.

Bonding to Zirconia

Zirconia is a non-silica-based ceramic and thus doesn't etch using traditional methods. Retention of zirconia-based ceramic restorations depends on mechanical roughening of the surface and chemical bonding with adhesive monomer in special primers or resin cements. An acidic adhesive monomer such as MDP

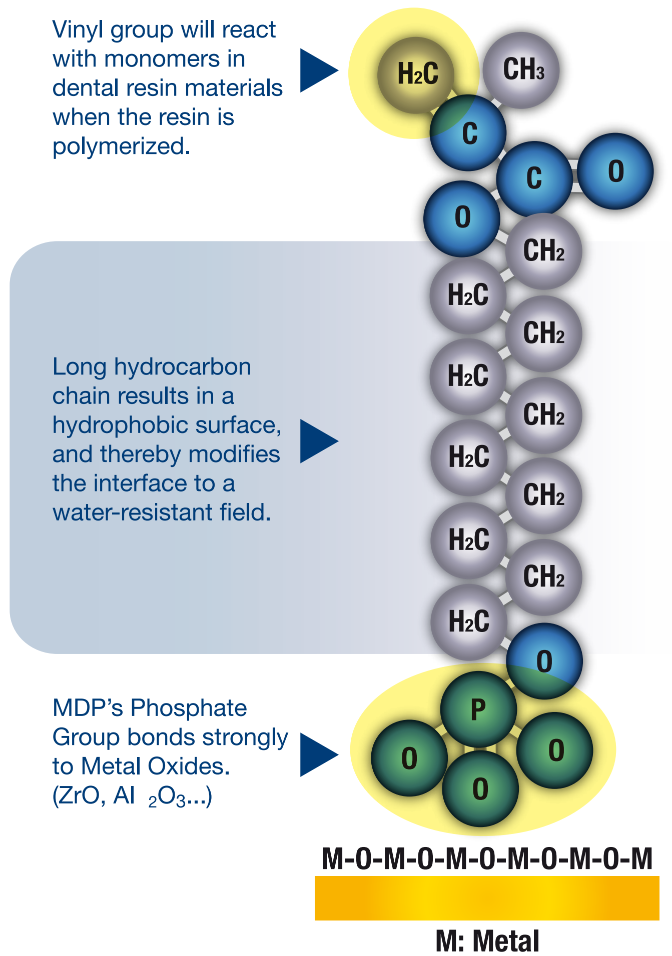


Figure 5. Chemistry of MDP monomer bonded to metal oxide.

bonds to zirconia-based ceramics. The phosphate ester group of the acidic monomer results in chemical bonding to metal oxides (MxOy, oxidized surface of base-metal alloys), zirconia-based ceramics and other ceramics. It is effective, therefore, to use self-adhesive or adhesive resin cement including an adhesive monomer for cementation. In the case of esthetic resin cement, the ceramic primer including an acidic adhesive monomer is needed as a pre-treatment.

Pretreatment Techniques for Zirconia-based Ceramics

Pretreatment techniques for promoting bonding to zirconia-based ceramics include air-particle abrasion and tribochemical silica coating. These pretreatments are utilized before chemical bonding with a silane coupling agent, ceramic primer, self-adhesive cement or adhesive cement.

If ceramic primer, self-adhesive cement or adhesive cement that contains an acidic adhesive monomer is used, air-particle abrasion is the easiest way to form a roughened surface to increase mechanical retention. Tribochemical silica coating with impact energy of blasted silicate particles produces bonding between the silicate and the targeted surface by mechano-chemical reaction. After the mechano-chemical reaction, a silane coupling agent is applied to achieve chemical bonding to the silica-coated surface.

Bond Strength to Zirconia-based Ceramics with Tribochemical Silica Coating

Bond strengths of resin cements (PANAVIA F 2.0/Kuraray America, Inc., RelyX ARC/3M ESPE, RelyX Unicem/3M ESPE) to Lava/3M ESPE were improved by grinding and polishing as compared to the untreated intaglio surface and by tribochemical silica coating (Rocatec Soft/3M ESPE) as compared to the sandblasting with 60um aluminum oxide. Tribochemical silica coating resulted in improved stability of bond strength of resin cements during in-vitro thermal cycling. This result indicated that silica particles bonded to the surface of zirconia-based ceramics, and the silane coupling agent with resin cement system bonded to the silica-coated surface.

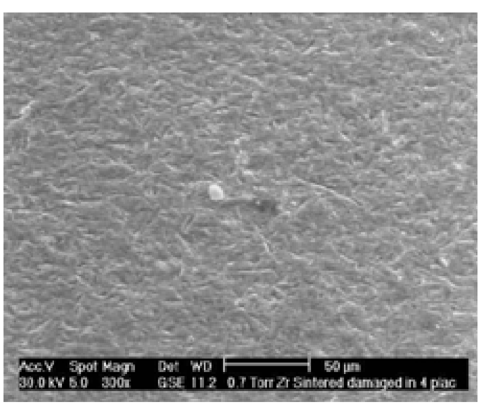


Figure 6. Scanning electron photomicrograph of zirconia-based ceramic surface prepared with 50-um alumina at 30 psi.

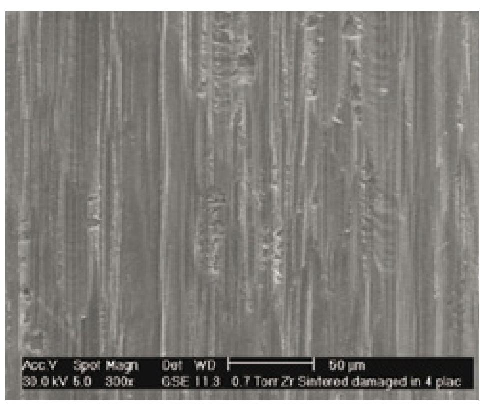


Figure 7. Scanning electron photomicrograph of zirconia-based ceramic surface prepared with a fine diamond. Note the appearance of a smear layer.

Bond Strength to Zirconia-based Ceramics with Air-abrasion and Ceramic Primer

A recommended method of promoting a chemical bond to zirconia-based ceramic is the use of a ceramic primer, examples of which are listed in Table 8. Silane coupling agents alone do not promote chemical bonding to zirconia-based ceramics. It is important to use a ceramic primer containing an acidic adhesive monomer such as MDP for the priming of zirconia-based ceramics. The bonding mechanism of CLEARFIL CERAMIC PRIMER (Kuraray America, Inc.) containing MDP is shown in Figure 5.

The bond strengths of resin cements with ceramic primer to a zirconia-based ceramic are shown in Table 10. These cements have adequate bond strength to the sintered zirconia-based ceramic.

The effects of mechanical roughening on the bond strength of resin cement (CLEARFIL Esthetic Cement EX / Kuraray America, Inc.) with a ceramic primer to a zirconia-based ceramic are shown in Table 11. Sandblasting the sintered surface of the zirconia-based ceramic with 50 um alumina at 30 psi resulted in higher bond strength than abrasion with a fine diamond bur. As shown by scanning electron microscopy, sandblasting with alumina results in a roughened ceramic surface (Figure 6), whereas abrasion with a fine diamond produces a smoother smear layer on the ceramic surface (Figure 7). Both types of mechanical treatment resulted in higher bond strengths than bonding to the sintered surface of the zirconia-based ceramic.

TABLE 10 *Shear Bond Strength of Self-cured Resin Cements to Sintered Zirconia-based Ceramic (IPS e.max ZirCAD) at 24 hours.*

Cement	Bond Strength, MPa
CLEARFIL CERAMIC PRIMER/ CLEARFIL Esthetic Cement EX	22 (5)
Metal-Zirconia Primer/ Multilink Automix	19 (6)
CLEARFIL CERAMIC PRIMER/ Multilink Automix	24 (6)

Yapp R, Powers JM, unpublished data

TABLE 11 *Shear Bond Strength of CLEARFIL Esthetic Cement EX with CLEARFIL CERAMIC PRIMER to Zirconia-based Ceramic (IPS e.max ZirCAD) with Different Surface Treatments Tested at 24 Hours and After Thermal Cycling (3000 Cycles).*

	Bond Strength, MPa	
Treatment	**24 Hours**	**Thermal Cycling**
Cement only – sintered zirconia	14 (3)	10 (2)
Primer/Cement – sintered zirconia	23 (6)	12 (1)
Primer/Cement - bur ground zirconia	27 (5)	19 (6)
Primer/Cement – sandblasted zirconia	36 (9)	27 (8)

Yapp R, Powers JM. Dent Advis Res Rpt 19, Aug 2008.

TABLE 12 *Frequency of Sensitivity Reported with Different Types of Cements.*

	Adhesive Cement	Self-Adhesive Cement	Traditional C&B Cement
Often/Sometimes	14%	10%	16%
Occasionally/Never	84%	84%	82%
Not applicable	2%	6%	2%

Farah JW, Powers JM, eds. Dent Advis 22 (8):5, 2005.

TABLE 13 *Frequency of Marginal Staining Reported with Different Types of Cements.*

	Adhesive Cement	Self-Adhesive Cement	Traditional C&B Cement
Often/Sometimes	8%	8%	14%
Occasionally/Never	84%	84%	80%
Not applicable	8%	8%	6%

Farah JW, Powers JM, eds. Dent Advis 22 (8):5, 2005.

TABLE 14 *Survey of Clinical Consultants of THE DENTAL ADVISOR - Cements Preferred for Specific Procedures.*

	Adhesive Resin Cement	Self-Adhesive Resin Cement	Traditional C&B Cement
All-ceramic inlays, onlays	**62%***	30%	6%
All-ceramic crowns, bridges	**52%**	39%	9%
Cast alloy crowns, bridges	15%	18%	**67%**
High-strength ceramic (zirconia) restorations	33%	**43%**	24%
Implant-supported crowns, bridges	13%	16%	**71%**
Laboratory composite	**66%**	29%	5%
Maryland bridges	**77%**	18%	5%
PFM crowns, bridges	14%	23%	**63%**
Metal posts	**40%**	29%	31%
Esthetic posts	**55%**	35%	10%

Farah JW, Powers JM, eds. Dent Advis 22 (8):5, 2005.

***Bold lettering indicates cement with majority of responses.**

CLINICAL STUDIES

Self-adhesive Resin Cements

CLEARFIL SA CEMENT was evaluated in 570 restorations by 30 Clinical Consultants of THE DENTAL ADVISOR. The product received a 96% clinical rating at placement. Consultants reported that the cement was easy to dispense using the auto-mix syringe. The cement has excellent viscosity with a film thickness that allows complete seating off the restoration. There were no reports of post-operative sensitivity during the evaluation.

CLEARFIL SA CEMENT was evaluated in 196 lithium disilicate and zirconia-based restorations at six months and one year by THE DENTAL ADVISOR. The lithium disilicate restorations were primed using CLEARFIL CERAMIC PRIMER, whereas the zirconia-based restorations were not primed. This product combination received a 98% clinical rating at one year. The debonding rate at one year was 2%. Few patients reported sensitivity. Two crowns were removed due to prolonged sensitivity. No marginal staining was observed at one year.

A zirconia-based ceramic (3M ESPE Lava Crowns and Bridges) was studied clinically over a period of seven years by THE DENTAL ADVISOR. Lava restorations were placed beginning in 2003. Well over 1500 restorations have since been placed and documented. These restorations included anterior and posterior crowns, three- to six-unit bridges and implant abutments. Most restorations were cemented with self-adhesive resin cement (3M ESPE RelyX Unicem Self-Adhesive Resin Cement). Five hundred and seventy-four restorations were recalled at seven years. 3M ESPE Lava Crowns and Bridges was rated as 95% at the seven-year evaluation period. Resistance to fracture was rated as 91% and resistance to marginal discoloration was rated as 94%. Over 96% of Lava restorations received an excellent rating for resistance to wear.

Post-operative sensitivity and marginal staining in restorations with self-adhesive, adhesive and traditional crown and bridge cements were studied by THE DENTAL ADVISOR. Self-adhesive resin cements and adhesive cements

SELECTION OF CEMENTS FOR ALL-CERAMIC RESTORATIONS

The box below presents simple rules for selecting the best cement for use with silica- and zirconia-based ceramics:

Feldspathic Porcelains

- Feldspathic porcelains require resin cement bonded to both tooth structure and ceramic.
- Use a dual-cured esthetic resin cement with a dual-cured total-etch (etch-and-rinse) bonding agent for thicker or more opaque veneers.
- Etch the porcelain with hydrofluoric acid etchant.
- For bonding to the porcelain, use a silanating agent or appropriate ceramic primer.

Leucite-reinforced Ceramics

- Leucite-reinforced ceramics require resin cement bonded to both tooth structure and ceramic.
- Use dual-cured esthetic resin cement with a dual-cured total-etch (etch-and-rinse) bonding agent for thicker or more opaque veneers.
- For the tooth, use an adhesive resin cement or a dual-cured esthetic resin cement.
- Etch the ceramic with hydrofluoric acid etchant.
- For bonding to the ceramic, use a silanating agent or an appropriate ceramic primer.

Lithium Disilicate Ceramics

- Lithium disilicate ceramics should be bonded with an esthetic resin or an adhesive resin cement for best retention and esthetics.
- Use a dual-cured esthetic resin cement with a dual-cured total-etch (etch-and-rinse) bonding agent for thicker or more opaque veneers.
- For bonding to tooth structure, use an adhesive resin cement or a dual-cured esthetic resin cement.
- Etch the ceramic with hydrofluoric acid etchant.
- For bonding to the ceramic, use a silanating agent or an appropriate ceramic primer.
- Lithium disilicate ceramics can be cemented with traditional crown and bridge cements when retention is adequate.

Zirconia-based Ceramics

- Zirconia-based ceramics with ideal retention can be cemented with traditional crown and bridge cements or bonded with resin cements.
- Zirconia-based ceramics with less than ideal retention require a resin cement bonded to both tooth structure and ceramic.
- Use adhesive resin cement, dual-cured esthetic resin cement, or self-adhesive resin cement when bonding is required.
- Sandblast (MicroEtcher IIA, Danville Materials) the intaglio surface of zirconia using 50 um alumina at 30 psi for increased bond strength.
- Use zirconia primer on the intaglio surface of zirconia when increased bonding is required.
- Silanating agents are not compatible with zirconia.
- Hydrofluoric acid is not compatible with zirconia.

had a lower incidence of sensitivity than traditional crown and bridge cements, as shown in Table 12. Marginal staining of self-adhesive resin cements and adhesive resin cements was reported to be lower than that of traditional non-adhesive, crown and bridge cements, as shown in Table 13.

A survey of 105 Clinical Consultants of THE DENTAL ADVISOR from throughout the United States showed that self-adhesive resin cements were most commonly selected for cementation of zirconia-based ceramic restorations, as shown in Table 14.

Esthetic Resin Cements

CLEARFIL Esthetic Cement EX was evaluated in 223 restorations by 20 Clinical Consultants of THE DENTAL ADVISOR. The product received a 96% clinical rating at placement. The cement can dispensed directly from the auto-mix tips into the restoration. Consultants reported that the try-in pastes accurately represented the final cement color. No post-operative sensitivity was reported during the evaluation.

Ceramic Primer

CLEARFIL CERAMIC PRIMER was evaluated in 240 restorations by 27 Clinical Consultants of THE DENTAL ADVISOR. The product received a 96% clinical rating at placement. Consultants reported that product was easy to dispense and wetted ceramic surfaces well. This ceramic primer can be used with both silica-based and zirconia-based ceramic substrates.

Self-adhesive resin cements are the best choice for zirconia-based ceramic restorations, when the restoration does not require the highest retention. They are less technique sensitive than bonding with adhesive or esthetic resin cements and offer more retention and better marginal sealing of tooth structure than the traditional glass ionomer cements. No separate bonding agent is necessary, reducing much time and effort. Cleanup is also easy with self-adhesive resin cements. The cement can usually be peeled off the marginal areas, with the advantage of leaving less cement in the area after cementation. Post-operative sensitivity of self-adhesive resin cements has been reported to be less than traditional crown and bridge cements (see Table 12).

When more retention is needed due to a short clinical crown or an over-tapered preparation, adhesive resin cements, or dual- or self-cured esthetic resin cements should be used to bond the restoration. Both adhesive resin cements and esthetic resin cements usually include various types of compatible primers or bonding agents that are to be applied to the tooth and ceramic restoration. If the zirconia is sandblasted with aluminum oxide particles, or blasted with a tribochemical silica coating (Rocatec Soft/3M ESPE) before placing ceramic primer, the bond of resin cement to the restoration will improve. Dual- and self-cured resin cements are usually not compatible with light-cured bonding agents. All types of bonding agents contain acidic monomers that affect the self-cure chemistry of the resin cement. It is critical to follow the manufacturers' instructions for proper bonding of the restoration to tooth structure.

When Should Lithium Disilicate and Zirconia-based Ceramic Restorations be Bonded?

Suitable for Cementation with Self-adhesive Resin Cement

- Tooth preparation with adequate cervical-occlusal height: h > 3 mm
- Tooth preparation with adequate taper: a = 2 – 5 degrees

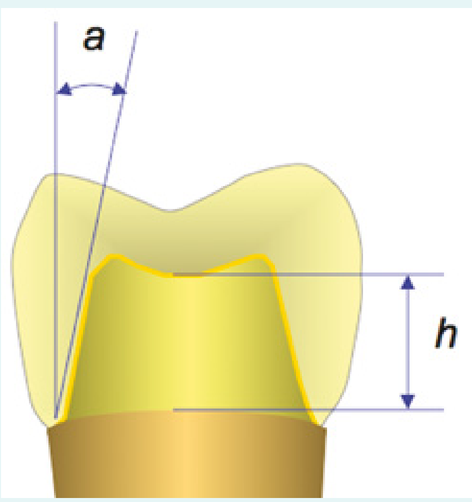
Bonding with Adhesive Resin Cement or Esthetic Resin Cement

Recommended

- Tooth with short clinical crown: h < 3 mm
- Tooth with over-tapered preparation: a > 5 degrees

Note: Occlusal reduction of preparations for zirconia-based ceramics

- Non-functional cusps: > 2.0 mm
- Functional cusps: > 2.5 mm



SUMMARY

Silica-based ceramics (feldspathic porcelain, leucite-reinforced ceramic, lithium disilicate ceramic) should be bonded with adhesive or esthetic resin cements using appropriate bonding agents and primers.

Zirconia (zirconium oxide)-based ceramics are a rapidly growing type of esthetic restoration. Due to their high strength, they have more indications than other all-ceramic restorative choices. In addition, because of their high strength, zirconia-based ceramic restorations can be cemented with traditional cements or bonded with adhesive resin cements. Self-adhesive resin cements offer less technique sensitivity than traditional cements, making them excellent choices for the cementation of appropriate zirconia-based ceramic restorations. When additional retention is required, zirconia-based restorations can be bonded with adhesive resin or dual-cured esthetic resin cements using tooth and ceramic primers.

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