Bond Strength, Microhardness, and Core/Veneer Interface Quality of an All-Ceramic System

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Alumina; core; veneer; bond strength; microhardness; interface.

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Abstract

Purpose: This study was designed to evaluate three veneering materials for an all-ceramic alumina system in terms of bond strength, microhardness, and core/veneer interface quality.
Materials and Methods: Fifteen In-Ceram cores were constructed for this study, forming three groups of five specimens each divided by the veneering ceramic disc fired on the occlusal surface of the alumina core: Vitadur N, Vitadur Alpha, or VM7. The specimens underwent shear bond and microhardness testing. Gross examination of debonded discs by SEM and EDAX analysis was conducted. Data for shear bond strength (SBS) and microhardness were presented as means and standard deviation (SD) values. One-way ANOVA and Duncan's post hoc test were used for pairwise comparison between the means when ANOVA test was significant.
Results: VM7 showed the highest shear bond value and lowest microhardness values of the three tested veneering materials. No statistically significant difference was evident between the SBSs of Vitadur N and Vitadur Alpha to the alumina cores. Vitadur Alpha showed statistically the highest mean VHN, followed by Vitadur N, while VM7 showed statistically the lowest mean values of VHN.
Conclusions: In-Ceram core/Vitadur N disc debondings appeared to be interfacial by complete delaminations, leaving a shiny visible and quite distinct area, whereas there appeared to be perfect adhesion between the core and VM7 veneering material. VM7 appeared to possess ultra-fine texture with intimate contact to the core, forming what seemed like a transition zone where the ceramic and core appeared to blend for a distance. VM7's finer particle size has improved the core/veneer bond strength and decreased micohardness values. This new veneering material will probably enhance the performance and esthetics of the In-Ceram system.

Interest in all-ceramic restorations has evolved primarily in response to the esthetic limitations of metal–ceramic restorations. To achieve optimum esthetics, strong all-ceramic cores are veneered with a ceramic material, which is built in successive layers, giving the final restoration individual optical characteristics that can barely be distinguished from the surrounding natural dentition. Successful performance and reliability of these restorations may be limited by mechanical integrity and adhesion of the veneering porcelain to the ceramic substrate.[1] The mechanical properties of the core and veneering porcelains should match to achieve a durable bond.[2] The Cohesive Plateau theory states that the strength of a bonded interface should equal the cohesive strength of the substrate with which it is formed.[3] In addition, studies testing the porcelain-to-metal bond strength suggest that shear bond strength (SBS) equal to the shear strength of the veneering porcelain provided an adequate bond.[4]

In a study by Kelly et al[5] on the failure behavior of In-Ceram fixed partial dentures, it was reported that failure occurred in the connectors, none from contact damage, with approximately 70% to 78% originating from the core/veneer interface, indicating that the interface was a location of high tensile stress, in part due to the elastic modulus mismatch across the interface and the presence of structural flaws. The survival of multimaterial clinical structures is also influenced by material thickness ratios, geometric design factors, processing variables, thermal properties, and mechanical and elastic properties of component materials.

Most cracks in multimaterial structures are initiated at the interface of the core and veneer.[5-7] Core ceramics are generally high elastic modulus, high strength materials compared with veneering ceramics. Stress distributions and failure behavior are different in laminate structures, comprised of materials with different elastic properties, than in homogenous structures.[5]

Moreover, interfaces can also be the site of unique defects, boundary phases, and thermal incompatibility stresses.

To ensure structured integrity of layered restorations under functional loads and to prevent chipping and delamination of the veneer ceramic, the core/veneer bond must be of a certain minimal strength. Stress distribution in a two-phase material construction is more complex than a homogenous one-phase material construction; therefore, additional factors must be considered for layered restorations.[8] Thermal expansion behavior, firing shrinkage, interface toughness and roughness, and heating and cooling rates are all factors that must be carefully handled to prevent generation of undesired tensile stresses.[9]

All-ceramic crowns are fabricated into layered structures with esthetic but weak veneer porcelains on stiff and strong ceramic support cores.[10] Hopkins[11] and Zeng et al[12] have shown that a thin layer of veneering porcelain fired on a ceramic material diminishes the strength of 2-layer test specimens. Many authors agree that the core/veneer interface is one of the weakest links of layered all-ceramic restorations and has a significant effect on the restoration success.[5-7,11-13]

Hardness is one of the most frequently measured properties of a ceramic. Its value helps to characterize resistance to deformation, densification, and fracture.[14] One of the main concerns over the use of porcelains is their abrasive potential or wear of the opposing tooth structure. Two major determinants of enamel wear are surface finish and microstructure.[15,29]

Layering high-strength ceramics in a restoration provides improved esthetics but affects the overall performance of a restoration, as each ceramic has different chemical and physical properties and a different coefficient of thermal expansion (CTE). As all-ceramic technology is relatively young, less development has taken place regarding veneering materials for these ceramic coping systems. Thus some early core/porcelain systems were even less esthetic than what was available at the time in metal–ceramic technologies, and many problems with those materials have only been dealt with recently. Problems include poor color stability, abrasiveness, devitrification with multiple firings, and poor core/veneer bonding.

In-Ceram is an all-ceramic system consisting of a high-volume fraction alumina core material veneered with feldspathic porcelain.[5-7] Three veneering materials have been developed for In-Ceram cores, and no authors have compared them. This study was designed to evaluate three core/veneer combinations in terms of bond strength, microhardness, and interface quality, as the veneering material can greatly influence the longevity, wear, and esthetics of all-ceramic systems.

Materials and methods

A stainless steel die was machined to approximate dimensions for a prepared molar (6 mm high, 9 mm diameter). The die had a standard recommended preparation for an all-ceramic crown, including an 8° occlusal convergence and a rounded 90° shoulder of 1 mm width to accommodate an In-Ceram crown.

The materials used in this study were In-Ceram core material with its three veneering materials: Vitadur N, Vitadur Alpha, and the recently developed VM7 powder (Vita Zahnfabrik Bad Sackingen, Germany). A total of 15 In-Ceram cores were constructed for this study. These cores were divided into three groups of five. The specimens of each group were layered with one veneering ceramic disc (2-mm thick, 2 mm diameter): Vitadur N, Vitadur Alpha, or VM7 for shear bond and microhardness testing. The stainless steel die was duplicated 15 times in special plaster (Vita Zahnfabrik) using a special tray and addition silicon impression material (Imprint II, 3M ESPE, Seefeld, Germany).

A split counter die was designed to allow the production of a wax coping of 0.7 mm thickness for standardization of the core dimensions. The wax coping was invested and cast to produce a metal coping of standard dimension. Three rubber impressions were made with the metal coping seated on the stainless steel die to produce three enlarged rubber molds for slip injection of the core. A hole was made in the center of their occlusal surface to inject the slip. Each rubber mold was in turn used five times to inject the slip material after seating it on a plaster die, producing a total of 15 cores. The slip was subjected to its recommended firing cycle then glass infiltrated, fired, sandblasted, and refired. All firing cycles were set according to the manufacturer's recommended cycles.

Five discs of each veneering material were added to the occlusal surface of the 15 cores using a Teflon ring (2 mm radius, 2 mm height). After the first firing, a second firing was required to compensate for porcelain shrinkage and voids, followed by a third firing to mimic the glazing firing. The specimens were now ready for testing.

Shear bond testing

Mounting

Each crown (core + veneer disc) was vertically embedded in an autopolymerizing acrylic resin cylinder made by a Teflon tube (2 cm height, 1.5 cm diameter) in such a way that the flat surface of the core was 1 mm above the acrylic resin, leaving the veneer disc at a higher level to facilitate the SBS test at the core/veneer interface.

Test procedure

All specimens were embedded in resin and individually mounted on a computer-controlled materials testing machine (Model LRX-plus, Lloyd Instruments Ltd, Fareham, UK) with a loadcell of 5 kN. Specimens were secured to the lower fixed compartment of the testing machine by tightening screws. Shearing test was done by compressive mode of load applied at the core/veneer interface using a mono-beveled, chisel-shaped metallic rod attached to the upper movable compartment of the testing machine traveling at crosshead speed of 0.5 mm/min. Failure was manifested by displacement of the veneer disc and confirmed by a sudden drop along the load-deflection curve recorded by computer software. Data were recorded (Nexygen-4.1, Lloyd Instruments).

Shear bond strength calculation

The load at failure was divided by the bonding area to express the bond strength in MPa:

$$\delta = P/\pi r^2$$

where δ is SBS (MPa), P is load at failure (N), π is 3.14, r is radius of ceramic disc (2 mm). The load-deflection curves were recorded using computer software (Nexygen-4.1, Lloyd Instruments).

Microhardness testing

Microhardness of the 15 fractured veneering discs, 5 for each veneering material, was tested using a computerized microhardness tester (Shimadzo Micro Hardness at the NIS, Giza, Egypt). Testing consisted of making a dent in the veneering disc specimen with a load of 5 N (500 grams) in a time of 20 seconds. The Vicker indenter is a square, pyramid-shaped diamond, which leaves a square-shaped indentation on the surface of the material being tested. Hardness was determined by measuring the diagonals of the square, d_1 and d_2, and calculating the average of the dimensions. Three readings were calculated for each disc specimen ensuring that the surfaces of the five veneering discs of each veneering material were represented. Microhardness was measured as Vickers hardness numbers (VHN).

Examination of fractured frameworks

Visual examination

Each fractured specimen from shear bond testing was examined using a magnifying lens (3x), and the fracture pattern of the veneering disc was recorded.

Scanning electron microscopy (SEM)

Selected fractured specimens were prepared for SEM examination. The specimens were mounted on copper stubs with double-sided adhesive tape and coated with Au using a sputter coater (S150 A Edwards, Canemco, Quebec, Canada). The specimens were examined using JXA-840 A Electron Probe Microanalyser (JEOL, Tokyo, Japan). Detection of crystal shape, size of various crystalline components, glassy phase, and pore shape, size, and distribution were evident. The core/veneer interface was identified and examined.

Energy dispersive X-ray spectroscopy (EDX)

EDX analysis of selected representative specimens was performed to assess the effect of different chemical composition of veneering ceramic on bond strength, microhardness, and core/veneer interface quality.

Results

Data were presented as means and standard deviation (SD) values. One-way ANOVA was used to compare mean bond strength values of the alumina core to the three veneering disc materials. Duncan's post hoc test was used for pairwise comparison between the means when ANOVA test was significant. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 15.0® (Statistical Package for Scientific Studies, Chicago, IL) for Windows.

Table 1 Means of shear bond strength testing (MPa)

Vitadur N		Vitadur Alpha		VM7		
Mean	SD	Mean	SD	Mean	SD	*p*-Value
6.9[b]	1.2	6.4[b]	0.7	11.2[a]	1.9	0.002

Means with different letters are statistically significantly different according to Duncan's test.

Results of shear bond strength

VM7 core showed statistically the highest mean SBS values. There was no statistically significant difference between Vitadur N and Vitadur Alpha, which showed statistically lower means (Table 1).

Results of hardness

The fractured debonded discs were used to test microhardness. Vitadur Alpha showed the statistically highest mean VHN followed by Vitadur N, while VM7 veneers showed the statistically lowest mean values (Table 2).

Examination of debonded disc/core interface

Vitadur N/core interface

Visual Examination: Four debondings appeared to be interfacial, by complete delaminations, while one fracture left a crescent-shaped remnant, amounting to 20% to 30% of veneering Vitadur N material. The surface of the core material where the disc was present appeared circular, shiny, and quite distinct from the remaining core surface.

SEM Examination of debonded Vitadur N alumina core specimens revealed at 30× a circular pattern where the disc was present, with a clear, distinct, circular boundary, suggesting that shearing appeared to leave a thin circular layer of veneering material attached to the alumina core. Examination of the specimen with remnant veneering material showed clear evidence of veneering material on the core surface. The material appears to be granular and coarse (Fig 1); however, at higher magnification (250×), a gap, which varied in magnitude between 204 and 619 μm at the examined site, was evident between the core material and the veneering material, indicating incomplete adhesion between the core and the veneer (Fig 2).

Vitadur Alpha/core interface

Visual Examination: Three of the cores appeared to have remnants of veneering material adhering to them, the quantities of which varied between 10% and 30% of the disc area, while two

Table 2 Means of microhardness testing (VHN)

Vitadur N		Vitadur Alpha		VM7		
Mean	SD	Mean	SD	Mean	SD	*p*-Value
591.3[b]	28	687.5[a]	18.8	528.9[c]	18.4	0.005

Means with different letters are statistically significantly different according to Duncan's test.

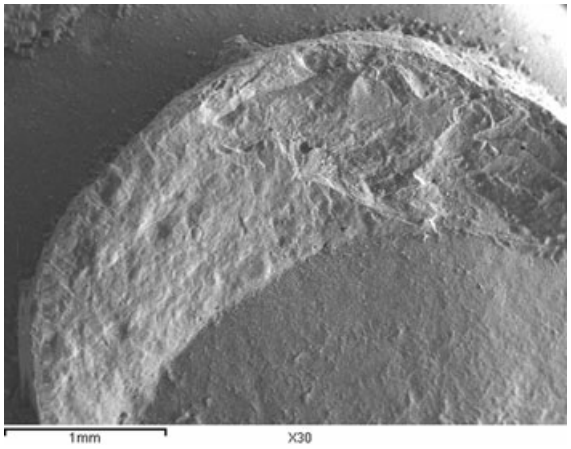

Figure 1 Crescent-shaped remnant of debonded Vitadur N veneer at 30×.

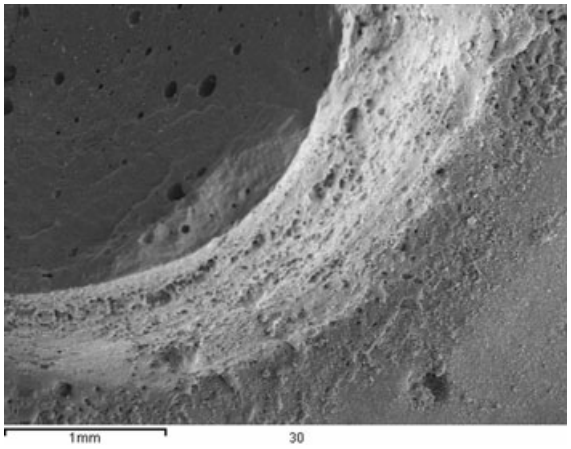

Figure 3 Crescent-shaped remnant of Vitadur Alpha on the core at 30×.

cores showed complete delaminations with detectable circular evidence of the debonded area.

SEM analysis at 30× showed apparent adhesion between the core and the veneering material. At higher magnification (100×), no gaps were evident at the interface; however, some defects and porosities are apparent in the veneering ceramic. The particle size of the material appears coarse, granular, and porous (Figs 3 and 4).

VM7/core interface

Visual Examination: Two of the cores were fractured during debonding. Two appeared to have remnants of veneering material adhering to them, the quantities of which varied between 20% and 40% of the specimens, and one specimen showed cohesive fracture within the veneering disc material. No gaps were evident at the interface.

SEM Analysis at 30× showed apparent perfect adhesion between the core and the veneering material, with no porosities at the interface. An intermediate zone was apparent at the core/veneer interface where the two ceramics appear to blend for a distance, together forming a distinct morphology different from both that of the core and the veneer (Figs 5–7). This zone is the probable cause of the high bond strength values recorded during shear bond testing (Table 1). The veneering material appears to be very fine in texture and compact compared to the former materials.

Energy dispersive X-ray spectroscopy

EDX revealed differences in the chemical composition between the tested ceramics. Regarding the alumina core, alumina was present as a major crystalline phase. Silica, lanthanum, and calcium were also detected in different weight percentages (Fig 8).

Discussion

Various test methodologies were previously used to evaluate core/veneer bond strength, including shear test, three-, and four-point loading, biaxial flexural strength, and other commonly

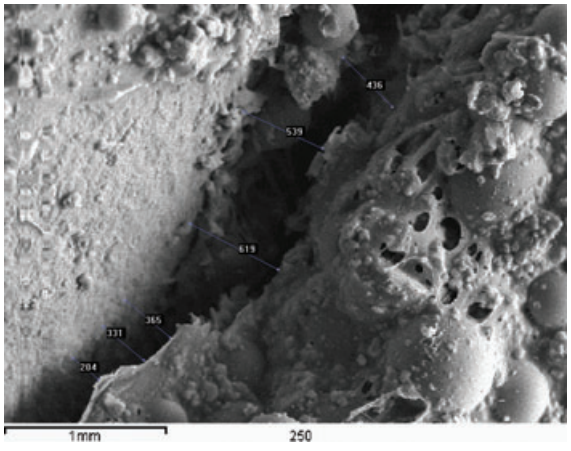

Figure 2 Crescent-shaped remnant of debonded Vitadur N veneer at 250×.

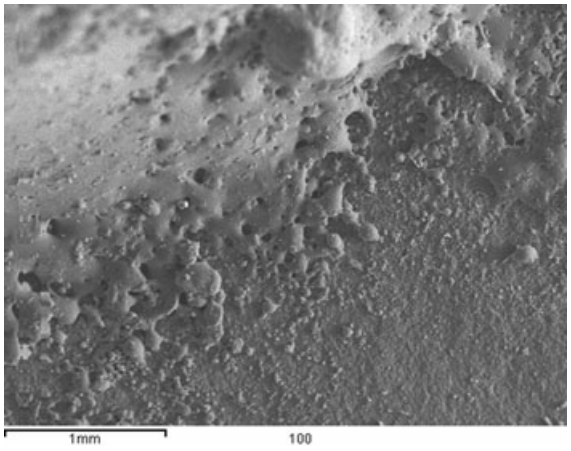

Figure 4 Crescent-shaped remnant of Vitadur Alpha on the core at 100×.

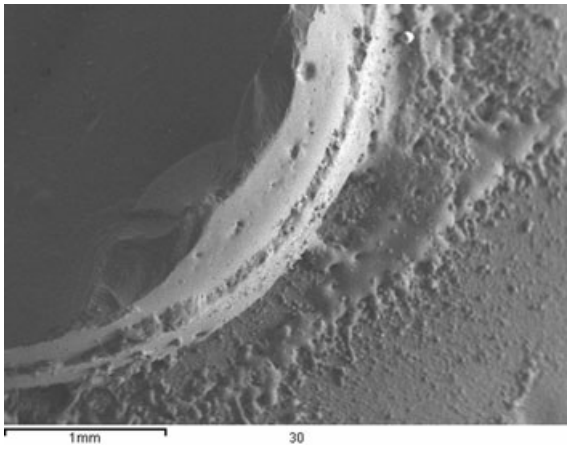

Figure 5 Crescent-shaped remnant of VM7 material.

used methods such as direct compression. Estimating the bond strength values from these tests was often complicated, due to the structural damage associated with the testing method and with the fracture mechanism.[16-18] Recently, microtensile bond strength testing has also been attempted.[19] Each test method has its advantages and disadvantages, but a common limitation in most of them is the difficulty in determining the core/veneer bond strength from the applied load force at failure on the specimen in a specific test set-up.[1,13,18,20-24] Testing the core/veneer bond strength in real tension is not often done, as fixing the test specimens of these brittle materials in the setup is challenging.[19] Dundar et al[25] compared the SBS and microtensile testing methodologies for core and veneering ceramics in four types of all-ceramic systems. Significant differences were found between the two test methods. Dundar et al concluded that both the testing methodology and the differences in chemical composition of the core and veneering ceramics influenced the bond strength between the core and veneering ceramic in bilayered all-ceramic systems. Klocke and Kahl-Nieke[26] stated

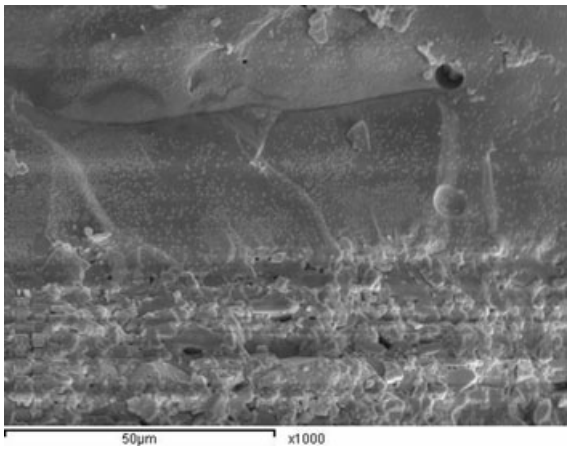

Figure 6 Interfacial zone is apparent where both core and VM7 ceramics seem to bond.

that debonding force location had a significant influence on SBS measurements and bond failure pattern.

The VM7 veneer/core interface showed the statistically highest mean SBS values of the three tested materials. It seems to combine high bond strength values and superior interfacial quality as compared to the formerly produced materials. This is probably due to a slight difference in the percentage of element composition of its components, which may have produced better chemical bonding and perfected the slight mismatch in the CTE during firing (Table 3). Chemical bonding is seen in the zone produced at the interface of both materials, where the two ceramics seem to blend and bond chemically to each other for quite a distance (Fig 6).

De Jager et al[27] studied the influence of different core materials on the stress distribution in dental crowns using finite element analysis. They concluded that the stresses in the veneering porcelain determined the longevity of the restoration. The stress distribution, according to their study, was influenced by the difference in expansion coefficient of the core material and the veneering porcelain, as stiffer core materials did not always result in lower stresses in the veneering porcelain. They also observed that the distribution of tensile stresses was affected by the design of the restoration; otherwise, the contribution of stronger, tougher core materials may be offset by weak veneering porcelain.

Probable factors affecting core/veneer interface include weak infiltration glass, incompatibility stresses caused by thermal expansion, and a weak bond between the infiltration glass and the veneering porcelain.[7] According to the manufacturer, the In-Ceram core must be properly prepared before the veneering process. Preparation involves mechanical removal of excess infiltration glass using rotary instruments and Al_2O_3 air abrasion followed by subjecting the core to 1000°C firing temperature for 10 minutes followed again by air abrasion.[28] Smith et al[6] reported that failure in their study involved crack propagation along the core surface, leaving a thin (10 to 50 μm) layer on the core surface, which was chemically unaltered. Carrier and Kelly,[7] however, microscopically examined cross-sectioned Vitadur N In-Ceram crowns, and showed that core/veneer interfaces with less porosity existed in the presence of excess infiltration glass, contrary to the standard recommended technique, as this was the site of much residual porosity. This is in agreement with the findings of this study for the initially developed veneering material and confirmed by the low magnitude of SBS values (Table 1). A gap, which varied in magnitude at the examined site between 204 and 619 μm, was evident between the core material and the veneering material in this study, indicating incomplete adhesion between the core and the veneer.

VM7 showed the statistically lowest mean VHN, followed by Vitadur N, while Vitadur Alpha showed the highest mean. Wear in the oral cavity is a complex process dependent upon the load applied to the teeth, ingested food, and bathing solution (saliva). These environmental factors interact with the specific restorative material and the patient's enamel, which varies from patient to patient. Two major determinants of enamel wear are surface finish and microstructure. At a microstructure level, previous generation veneering materials had crystalline phases with leucite crystals that possessed an average size greater than 30 μm. These large particles left microscopically rough

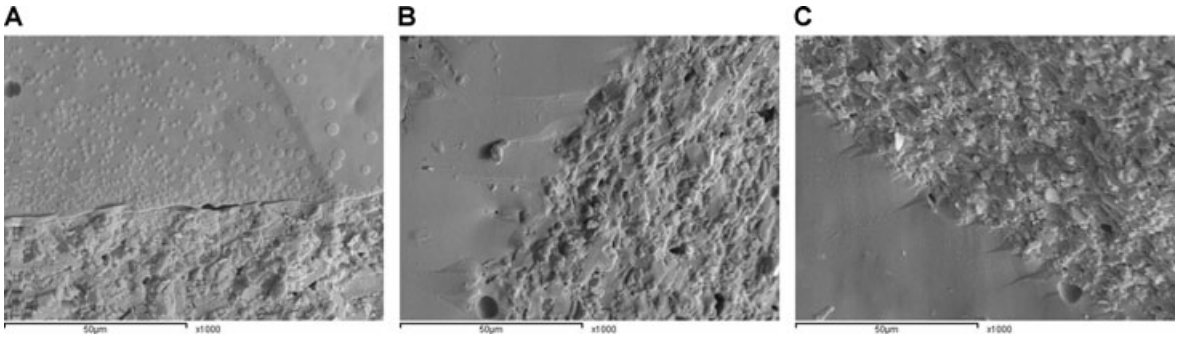

Figure 7 The structural difference in the crystal structure of core and veneering materials is apparent in these SEM pictures. The particle size of Vitadur N veneering material is coarse and granular, while Vitadur Alpha appeared to possess a finer texture in comparison. This agrees with the manufacturer's reported grain size of 30 and 18 μm; however, the finest texture was evident in case of VM7 material (0.7 μm). (A) Alumina core/Vitadur N interface; (B) Alumina core/Vitadur Alpha interface; and (C) Alumina core/VM7 interface.

Table 3 Chemical composition of veneering materials

Element weight %	Si K	Al K	Na K	K K	Ca K	Ti K	Cl K	Total
Vitadur N	65.22	12.46	9.97	8.80	2.10	0.56	0.88	100.00
Vitadur Alpha	65.66	10.04	14.06	7.52	1.80	0.91		100.00
VM7	64.64	10.18	11.37	9.87	2.87	1.08		100.00

surfaces that abraded opposing enamel, thus increasing wear rate. Leucite was added to them as a crystalline phase to strengthen the base glass and enhance esthetics by scattering or refracting light similar to enamel. It also increased the CTE of the material.[15]

Abrasive wear involves a soft surface in contact with a harder surface. It has been studied by measurements of related mechanical properties such as hardness.[29] Vitadur N and Alpha particles were seen to be coarse when compared to the finer texture of VM7 material; they also had very high microhardness values. This has been confirmed by the results of microhardness values in this study, SEM, and EDX analysis (Table 2, Fig 7).

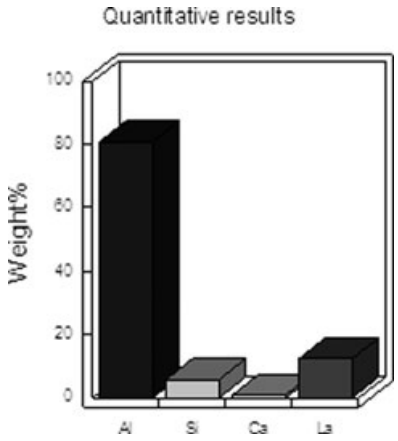

Figure 8 Elemental composition of In-Ceram alumina.

The findings of this study indirectly support some of the claims of McLaren et al[15] concerning the low wear rate of VM7 material ($0.8 \pm mm^2$) compared to Vitadur Alpha ($1.83 \pm 0.09\ mm^2$) simulating that of opposing enamel due to a finer two-phase glass structure with the absence of any crystal phase. McLaren et al claimed no leucite was added in this generation. Two glass phases were mixed, different in size and refractive index, creating different diffraction properties similar to materials with a crystalline phase and a glassy phase, thus reducing wear and optimizing esthetics. These recent materials were incorporated within the glass in a size of 0.7 μm, similar to enamel rods. These smaller particles reduced the VHN of the material, rendering it kinder to opposing natural enamel. They also affected the CTE of the resultant material. EDX analysis in this study shows the composition of the three veneering materials possessing alumina, but in different proportions. This implies that VM7 is not totally glass as previously stated; however, fine texture is evident in the SEM (Fig 7).

Concerning alumina core/Vitadur N disc veneer, most debondings appeared to be interfacial by complete delaminations. The surface of the core material where the disc was present appeared visually shiny and quite distinct, which is in agreement with the findings reported by Smith et al.[6] At 30×, a circular pattern was evident where the disc was present, with a clear distinct circular boundary. It suggests that shearing appeared to leave a thin layer of veneering material attached to the core (Figs 1 and 2). Smith et al[6] reported that failures in their study involved interfacial stresses with crack propagation occurring at or near the core/veneer interface. Most failures in their study occurred by delamination of veneering glass alone, leaving a thin layer of residual glass on the core surface. This

agrees with the findings in this study. Four out of five debondings appeared to be interfacial, by complete delaminations, while one fracture left a crescent-shaped remnant amounting to 20% to 30% of veneering Vitadur N material. The coarse granular nature of Vitadur N (30 μm in size) ceramic seen in the SEM (Fig 7), probably prevented the veneer from penetrating the sandblasted core (50 μ $Al_2O_{3)}$ surface, thus limiting its adhesion.

Smith et al[6] conducted electron microprobe analysis at the core/veneer interface and observed that the residual core infiltration glass was not present on the core surface and that chemical alterations in the veneering glass were apparently limited to a 2 to 3 μm thick layer. Crack propagation occurred through the veneering glass, parallel to the interface running 10 to 50 μm away from the interface, that is, chemically unaltered veneering porcelain.

Examination of the specimen with remnant veneering material showed clear veneering material on the core surface; however, at higher magnification (250×; Figs 1 and 2), a gap, which varied in magnitude at the examined site between 204 and 619 μm, was evident between the core material and the veneering material, indicating incomplete adhesion between the core and the veneer, which might have caused the low magnitude of shear test values (6.9 MPa) and the common failure pattern by delamination. This suggests incomplete adhesion at the core/veneer interface with gaps and voids present at the boundary. It looks like the crystals of alumina appeared rounded, which suggests that further veneer firing may have altered their angular appearance and caused some kind of crystal coalescence.

As for the Vitadur Alpha/core interface, some of the cores appeared to have remnants of veneering material adhering to them, the quantities of which varied between 20% and 40% of the specimens (Figs 3 and 4). SEM analysis at 30× showed apparent adhesion between the core and the veneering material. At higher magnification (100×), no gaps were evident at the interface; however, some defects and porosities are apparent in the veneering ceramic. The particle size of the material appears coarse and porous.

Finally, regarding the VM7/core interface, visual examination revealed that two of the cores fractured during debonding, two others appeared to have remnants of veneering material adhering to them, the quantities of which varied between 20% and 40% of the specimens, and one specimen showed cohesive fracture within the veneering disc material. No gaps were evident. There appeared to be perfect adhesion between the core and the veneering material, with no porosities at the interface (Fig 7). The veneering material appeared to be very fine in texture, perfectly adhering to the core to a distance, forming what seemed like a transition zone in between the two ceramics where the ceramics appear to blend physically and chemically and were not identifiable from each other (Figs 5–7). This may have been the probable cause of the high bond strength values recorded during shear bond testing (Table 1). The fine texture (Fig 7C), in addition to the new CTE values reported,[15] must have enhanced adhesion of the core and veneer, improving the bond strength to be almost equal to the cohesive strength of the veneering material in two specimens and the core in two others. This is the ultimate quality of core/veneer interface recommended by many authors.[2-4]

The Cohesive Plateau theory states that the strength of a bonded interface should equal the cohesive strength of the substrate with which it is formed.[3] In addition, former studies testing the porcelain-to-metal bond strength suggested that SBS equal to the shear strength of the veneering porcelain provided an adequate bond.[4] VM7 was reported to possess a flexural strength of 104.1 (8.4) MPa, as compared to 78.3 (7.6) MPa for Vitadur Alpha,[15] while that of Vitadur N was reported to be 62 MPa.[30] These values are in agreement with the bond values obtained in this study, as the tensile field lateral to any point contact on a ceramic, such as created by a knife edge in this study, could be the site of initiation of failure as in the "shear" test. Hence, the values found are in accordance with reported shear values.

EDX analysis revealed differences in the chemical composition between the tested ceramics (Fig 8, Table 3). Regarding In-Ceram alumina core, alumina was present as a major crystalline phase. Silica, lanthanum, and calcium were also detected in different weight percentages (Fig 8). EDX analysis revealed differences in the percentages of chemical components of the veneering materials, which probably accounted for their behavioral differences concerning the shear bond and microhardness test results. These findings agree with those of other authors;[6,29] however, Pellier et al[31] reported higher alumina weight percentages in their study.

Finally, the ideal tangential and radial tensile stress is ensured if the CTE of the ceramic has been optimally matched with the CTE of the alumina core material. The CTE of In-Ceram alumina core is reported by the manufacturer to be 7.2 to 7.6 × 10^{-6}°C while that of Vitadur Alpha is approximately 6.7 × 10^{-6}°C, [15] and VM7 veneer is 7.2 to 7.9 × 10^{-6}°C. This may explain the perfect interface between the two latter veneering materials as opposed to the formerly developed material. This is in addition to the slight differences in weight percentages of the chemical elements as evident in Table 3. Furthermore, it may be assumed that the fine grain veneer evident in the SEM (Fig 7C) probably allowed better wetting of the veneer and penetration of the micro-irregularities in the sandblasted core surface, thus promoting the bond through interlocking. Thus it may be assumed that micromechanical, chemical, and compressive bonding were established in VM7, creating the perfect bond, contrary to previous generation materials. The EDX analysis of the veneering materials yielded slight compositional weight percentage differences (Table 3), which disagrees with the claims of McLaren et al[15] that the structure of VM7 was a refined two-phase glass that did not contain any crystal phase.

Conclusions

In accordance with the limitations of this study, the following conclusions can be drawn:

1. VM7 showed the highest shear bond value and lowest microhardness values of the three tested veneering materials.
2. No statistically significant difference was evident between the SBSs of Vitadur N and Vitadur Alpha to the alumina cores.

3. Vitadur Alpha showed statistically the highest mean VHN, followed by Vitadur N, while VM7 showed the lowest mean values of VHN.
4. In-Ceram core/Vitadur N disc debondings appeared to be interfacial, whereas there appeared to be perfect adhesion between the core and VM7 veneering material. VM7 appeared to possess ultra-fine texture with intimate contact to the core, forming what seemed like a transition zone where the ceramic and core appeared to blend for a distance.

References

1. Al Dohan H, Yaman P, Dennison J, et al: Shear strength of core-veneer interface in bi-layered ceramics. J Prosthet Dent 2004;91:349-355
2. Blatz MB: Long-term clinical success of all ceramic posterior restorations. Quint Int 2002;33:314-326
3. Gwinett AJ: A new method to test the cohesive strength of dentine. Quint Int 1994;25:215-218
4. Yamada NH: Dental Porcelain: The State of the Art (ed 1). Los Angeles, University of Southern California School of Dentistry, 1977
5. Kelly JR, Tesk JA, Sorensen JA: Failure of all ceramic fixed partial denture *in vitro* and *in vivo*: analysis and modelling. J Dent Res 1995;74:1253-1258
6. Smith TB, Kelly JR, Tesk JA: In vitro fracture behavior of ceramic and metal-ceramic restorations. J Prosthodont 1994;3:138-144
7. Carrier DD, Kelly JR: In-Ceram failure behavior and core-veneer interface quality as influenced by residual infiltration glass. J Prosthodont 1995;4:237-242
8. White SN, Miklus VG, Mclaren EA, et al: Flexural strength of a layered zirconia and porcelain dental all ceramic system. J Prosthet Dent 2005;94:125-131
9. Kononen M, Kivilahti J: Fusion of dental ceramics to titanium. J Dent Res 2001;80:848-854
10. Lawn BR, Deng Y, Thompson VP: Use of contact testing in the characterization and design of all ceramic crownlike layer structures: a review. J Prosthet Dent 2001;86:495-510
11. Hopkins K: An investigation into the role of porcelain thickness in determining the load carrying capacity of porcelain laminates. Br Dent J 1989;67:201-204
12. Zeng K, Oden A, Rowcliffe D: Evaluation of mechanical properties of dental ceramic core materials in combination with porcelain. Int J Prosthodont 1998;11:183-189
13. Isgro G, Pallav P, Zel JM, et al: The influence of the veneering porcelain and different surface treatments on the biaxial flexural strength of a heat-pressed ceramic. J Prosthet Dent 2003;90:465-473
14. Yilmaz H, Aydin C, Gul BE: Flexural strength and fracture toughness of dental core ceramics. J Prosthet Dent 2007;98:120-128
15. McLaren EA, Giordano R A, Pober R, et al: Material testing and layering techniques of a new two-phase all-glass veneering porcelain for bonded porcelain and high-alumina frameworks. Quintessence Dent Technol 2003;26:69-81
16. Tinschert J, Natt G, Mautsch W, et al: Fracture resistance of lithium disilicate, alumina and zirconia-based three-unit fixed partial denture: a laboratory study. Int J Prosthodont 2001;14:231-238
17. Dundar M, Ozcan M, Comlekoglu E, et al: Bond strengths of veneering ceramics to reinforce ceramic core materials. Int J Prosthodont 2005;18:71-72
18. Guazzato M, Proos K, Quach, et al: Strength, reliability and mode of fracture of bilayered porcelain. Zirconia (Y-TZP) dental ceramics. J Biomaterials 2004;25:5045-5052
19. Aboushelib MN, Jager N, Kleverlaan CJ, et al: Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater 2005;21:984-991
20. Thompson GA: Influence of relative layer height and testing method on the failure mode and origin in a bilayered dental ceramic composite. Dent Mater 2000;16:235-243
21. Deng Y, Miranda P, Pajares A, et al: Fracture of ceramic /ceramic /polymer trilayers for biomedical applications. J Biomed Mater Res 2003;67:828-833
22. Ban S, Anusavice KJ: Influence of test method on the failure stress of brittle dental materials. J Dent Res 1990;60:1791-1799
23. Luthardt RG, Sandkuhl O, Reitz B: Zirconia-TZP and alumina advanced technologies for the manufacturing of single crowns. Eur J Prosthodont Restor Dent 1999;4:113-119
24. Neiva G, Yaman P, Dennison JB, et al: Resistance to fracture of three all ceramic systems. J Esthet Dent 1998;10:60-66
25. Dundar M, Ozcan M, Gokce B, et al: Comparison of two bond strength testing methodologies for bilayered all-ceramics. Dent Mater 2007;23:630-636
26. Klocke A, Kahl-Nieke B: Influence of force location in orthodontic shear bond strength testing. Dent Mater 2005;21:391-396
27. De Jager, de Kler M, Van Der Zel JM: The influence of different core materials on the FEA-determined stress distribution in dental crowns. Dent Mater 2006;22:234-242
28. Vita Inceram: Directions for use. Vita Zahnfabrik publication #487E-11190, Bad-Sakingen, Germany
29. Powers J, Sakaguchi R: Craig's Restorative Dental Materials (ed 12). St. Louis, MO, Mosby, 2006, pp. 85
30. O'Brien WJ: Dental Materials and Their Selection (ed 4). Chicago, Quintessence, 2008, pp. 337
31. Pellier B, Giordano RA, Campbell SD, et al: Dimensional and compositional analysis of Inceram alumina and die material. (Abstract) J Dent Res 1992;71:253

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