

EFFECT OF MULTIPLE FIRING CYCLES ON THE SHEAR BOND STRENGTH AND FAILURE MODE BETWEEN VENEERING CERAMIC AND ZIRCONIA CORES

Mohammad M. Rayyan*

ABSTRACT

Aim : To evaluate the effect of firing cycles on the shear bond strength and failure mode between veneering ceramic and zirconia core.

Materials and method : Twenty-eight specimens of zirconia veneered with feldspathic ceramic were submitted to one (1-firing), two (2-firings), three (3-firings), or four (4-firings) firing cycles to sinter the porcelain. All the specimens were thermocycled for 300 cycles then collected, labeled and stored in distilled water for 48 hours before testing. Shearing test was done by compressive load applied at zirconia-veneer interface using a mono-bevelled chisel shaped metallic rod attached to the upper movable compartment of testing machine traveling at cross-head speed of 0.5 mm/min. Fractured specimens were ultrasonically cleaned, carefully checked under digital microscope (Dino-Lite, 241 Taiwan). All failures mode were analysed.

Results: The highest mean value was observed in group A (6.69 MPa) and the lowest mean value was observed for group C (4.74 MPa). Statistical analysis revealed no significant difference between groups ($P=4.63$). Statistical analysis among groups showed significant difference between groups A and B ($P=0.012$), between groups A and C ($P=0.001$), between groups B and C ($P=0.002$), between groups B and D ($P=0.003$). But no significant differences were found between groups A and D ($P=0.12$) or between groups C and D ($P=1.4$). Regarding mode of failure; 100% of the samples had cohesive failure in the veneering ceramic.

Conclusions: Increase in firing cycles from 1 to 4 cycles had no effect on the SBS. There are no statistically significant differences in SBS between groups. In each group all of the failures (100%) were cohesive in the veneering ceramic, and the mode of failure did not tend to change as the number of firing cycles increased.

KEY WORDS: Shear bond strength, Firing cycles, Zirconia, Veneer.

* Assistant Professor of Prosthodontics, Faculty of Dentistry, Beirut Arab University, Beirut, Lebanon, Assistant Professor of Fixed Prosthodontics, Faculty of Dentistry, Misr University for Science and Technology, Cairo, Egypt

INTRODUCTION

All-Ceramic restorations (ACR) represent the back-bone of esthetic dentistry, especially with the increased demand for restorations that mimic natural tooth color. They offer superior esthetics and biocompatibility compared to metal-ceramic restorations (MCR).^(1,2) Bilayering concept was first adopted by MCR which involves the fabrication of high strength framework layered by a high esthetic veneering material. Zirconia framework substituted metal as a framework material in ACR, due to its high exceptional mechanical properties.⁽³⁾

Data from studies indicated low clinical failure rates for all-ceramic restorations (5-year cumulative failure of 6.7%), but these rates are lower for metal-ceramic restorations (4.4%).^(4,5) Clinical observations have shown that the main mechanical cause of ceramic-zirconia failures is premature fracture of the veneer by cracking, chipping or delamination.^(2,5-10) The frequency of clinical chipping was reported by Vult von Steyern et al.⁽¹¹⁾ as 15% at 24 months of evaluation, 13% at 36 months by Sailer et al,⁽¹²⁾ and 25% at 31 months by Raigrodski et al.⁽⁷⁾

According to Ozkurt et al,⁽¹³⁾ the clinical success and reliability of all ACR depends on the mechanical integrity of the materials and the interfacial bond strength.⁽¹⁴⁾ Failures of this interface may be due to: (1) differences in the coefficients of thermal expansion between the core and veneering ceramic,^(7,15) (2) the processing techniques, (3) firing shrinkage of the ceramic,⁽¹⁵⁾ (4) poor wetting of the zirconia by the ceramic,⁽¹⁶⁾ (5) inadequate design (geometric shape and thickness ratio)^(17, 18) and (6) inadequate heating and cooling rates.⁽¹⁸⁾ Even though manufacturers provide ceramics with similar (compatible) coefficients of thermal expansion, moderate stresses may accumulate in the structure, especially at the interface between different materials.^(19, 20) Many factors can be associated with interfacial residual stresses in layered ceramic structures, such as the differences in mechanical and thermal behavior of ceramic materials.⁽²⁰⁻²³⁾

More studies showed that residual tensile stresses are created within the porcelain at or near the ceramic-porcelain interface and could contribute to the porcelain fracture in zirconia systems.⁽²⁴⁾ The stresses are believed -as stated earlier- to have multifactorial origin, potentially involving the ceramic coefficient of thermal expansion (CTE), restoration's geometric factors (i.e. infrastructure design and core-veneer thickness ratio), material's elastic properties (ceramics strength) and poor wetting of the core by the veneer.^(9,21,25,26) Therefore, these factors should be handled carefully to prevent development of high-magnitude tensile stresses.

To achieve improved contour, color, and esthetics, multiple firing procedures are necessary for the fabrication of all-ceramic restorations, especially when using the standard layering technique to match the esthetics of the natural dentition. The effect of multiple firing cycles on the porcelain-zirconia adhesion remains unclear. Residual stresses can likely accumulate during the heating and cooling firing procedures, mainly because of the cooling rate and the CTE mismatch between core and veneer ceramics.^(24,27,28) When additional stresses are applied to the restoration, the probability of failure due to fatigue crack propagation might increase,^(24,29-32) explaining the delamination, which is considered a clinical failure mode. The hypothesis of this study is that ; the increase in firing cycles might decreases SBS between zirconia core and veneer.

MATERIALS AND METHOD

Preparation of zirconia core discs

A disc of 3 mm thickness and 10 mm diameter was drawn on AutoCad 2014 for mac software (AutoDesk, San Rafael, CA, USA) and imported as STL (Standard Triangulation Language) file to CAD CAM milling machine (Zenotec Select, Wieland Dental + Technik GmbH & Co. Germany) . Zirconia compressed powder blank (Zenotec Zr Bridge, Wieland Dental + Technik GmbH & Co. Germany) was mounted in milling machine and twenty-eight

discs were milled according to the same dimension. Discs were cut off the blank using round-end taper diamond bur # S6856 314 018 (Komet, Brasseler, Germany) and then cleaned using air blows and sintered in a ceramic oven (Zenotec Fire Cube, Wieland Dental + Technik GmbH & Co. Germany) using fast sinter program for sintering single-unit restorations (total cycle time approx. 3h). (Fig. 1) Discs were then collected ultrasonically cleaned and randomly categorized in four groups based on the number of firing cycles (1, 2, 3 and 4) for veneering process (7 specimens in each group; Table 1).

Veneering procedure

The zirconia discs were veneered with the necessary amount of feldspathic ceramic (V9, Vita VM9, Vita Zahnfabrik). The ceramic slurry was applied all at once onto the core ceramic using a slightly oversized silicon matrix. Excess moisture was removed using absorbent paper, thereby compacting the ceramic powder, and the corresponding number of firing cycles was performed. Specimens were divided into 4 groups (n = 7) according to number of firing cycles: one (1-firing), two (2-firings), three (3-firings), or four (4-firings), (firing cycle schedule described in Table 2). All the specimens were thermocycled for 300 cycles with the sequence of 20 sec at 5°C and 20 sec at 55°C and 10 sec transport, then collected, labeled and stored in distilled water for 48 hours before testing. (Fig. 2)

Shear bond strength test

A circular interface shear test was designed to evaluate the bond strength. All samples were individually mounted on a computer controlled materials testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK) with a load-cell of 5 kN and data were recorded using computer software (Nexygen-MT; Lloyd Instruments). Samples were secured in a specially prepared metal mold to the lower fixed compartment of testing machine by tightening screws. Shearing test was



FIG. (1) Sintered zirconia disc.

TABLE (1) Sample grouping

Group	No. Of firing cycles	No of samples
A	1 firing cycle	7
B	2 firing cycles	7
C	3 firing cycles	7
D	4 firing cycles	7
Total		28



FIG. (2) Veneered zirconia core.

TABLE (2) Firing cycles for veneering ceramic according to manufacturer's directions

	Standby Temperature (°C)	Final Temperature (°C)	Drying Time (min)	Heating Time (min)	Holding Time (min)	Cool Time (min)
Dentine	450	830	6.00	6.00	1.00	4.00
Correction 1	450	820	5.00	6.00	1.00	4.00
Correction 2	450	815	4.00	6.00	1.00	4.00
Correction 3	450	810	3.00	6.00	1.00	4.00

done by compressive load applied at zirconia-veneer interface using a mono-bevelled chisel shaped metallic rod attached to the upper movable compartment of testing machine traveling at cross-head speed of 0.5 mm/min. The load required for debonding was recorded in Newton. (Fig. 3)

Shear bond strength calculation

The load at failure was divided by bonding area to express the bond strength in MPa: ($\tau = P / \pi r^2$) where; τ = shear bond strength (MPa, P = load at failure (N) $\pi = 3.14$ and r = radius of veneer disc (mm)

Failure mode

Fractured specimens (Fig. 4) were ultrasonically cleaned, carefully checked under digital microscope (Dino-Lite, 241 Taiwan). All failures were classified

into three modes:

1. Cohesive in porcelain veneer: Only the remnants of porcelain veneer were seen in the fractured surface.
2. Cohesive in zirconia core: Only the remnants of zirconia core were seen in the fractured surface.
3. Mixed: Both material remnants (Zirconia and porcelain veneer) were detected in the fractured surface.

Statistical analysis

To determine the effects of firing cycles on shear bond strength of specimens, one-way ANOVA was used ($p < 0.05$). SPSS 16.0 v3.0 (SPSS, Inc., Chicago, IL, USA) was used.

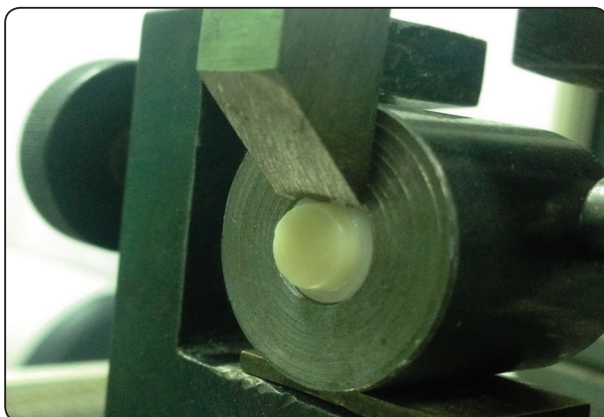


FIG. (3) Samples secured in the testing machine for testing.



FIG. (4) Fractured specimens.

RESULTS

The mean, median and standard deviation values between groups, are summarized in Table 3. The highest mean value was observed in group A (6.69 MPa) and the lowest mean value was observed for group C (4.74 MPa). Statistical analysis revealed no significant difference between groups ($P=4.63$). Statistical analysis among groups showed significant difference between groups A and B ($P=0.012$), between groups A and C ($P=0.001$), between groups B and C ($P=0.002$), between groups B and D ($P=0.003$). But no significant differences were found between groups A and D ($P=0.12$) or between groups C and D ($P=1.4$) (Table 4) Regarding mode of failure; 100% of the samples showed cohesive failure in porcelain veneer (mode 1). (Fig. 5 a&b)

TABLE (3) Mean, Median and standard deviation values of the tested groups.

	Mean	Median	Standard Deviation
Group A	6.69	6.69	0.78
Group B	5.41	5.45	0.21
Group C	4.74	4.83	0.19
Group D	6	5.93	0.19

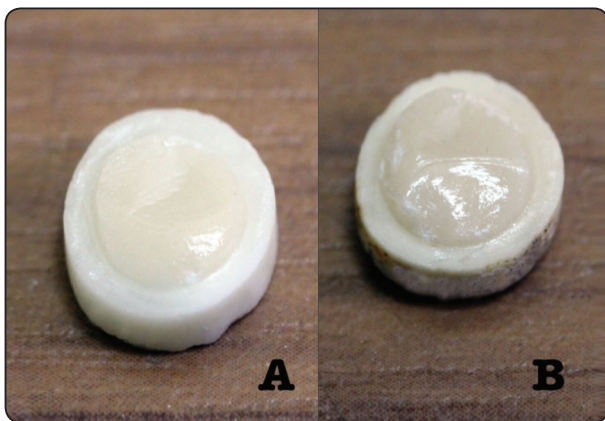


Fig. (5) **A:** Cohesive fracture in veneer in group A. **B:** Cohesive fracture in veneer in group D.

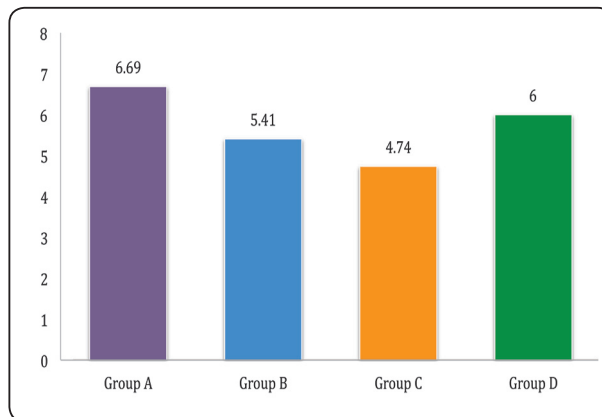


Chart (1) Mean values of tested groups.

TABLE (4) One-way ANOVA values among tested groups.

	Group A	Group B	Group C	Group D
Group A		0.012	0.001	0.12
Group B	0.012		0.002	0.003
Group C	0.001	0.002		1.40
Group D	0.12	0.003	1.40	

DISCUSSION

Multiple firing procedures are essential to achieve better contour, color, and esthetics although there is no scientific data on the precise number of firing cycles to achieve a perfect ceramic restoration. Therefore, an important point to discover is understanding the effect of multiple firing on the zirconia-ceramic system and creating a minimum number of firing cycles required to produce restorations with good performance. It is obligatory to match the coefficient of thermal expansion (CTE) between the core and the veneer material for the endurance of all-ceramic restorations.⁽³⁵⁾ Providing ceramics with similar CTE (less than 1×10^{-6} K of mismatch) is the manufacturers' main goal to escape crack formation and premature failure (incompatibility) of multi-layer ceramic systems⁽²⁴⁾. Nevertheless, even when matching the CTE, bilayer ceramic systems can

exhibit a significant amount of residual stress sealed into the structure.⁽³⁶⁾ Inconsistency in volume, density, and viscosity of the ceramic layer during cooling can result in stress accumulation.^(14,35) Residual compressive stresses localized in the veneer layer have been shown to significantly increase the flexural strength of bilayer structures.⁽²¹⁾ On the other hand, residual tensile stresses can trigger or maximize crack propagation inside the ceramic.^(37,38) Therefore, it is believed that tensile residual stresses at the interface are related to veneer fractures (chipping, cracking, or delamination).⁽³⁷⁾

A 90% success rate has been reported over 5 years of service although very few clinical studies report the longevity of dental restorations with zirconia core.^(39,40) The main type of failure has been reported as porcelain veneer fracture with little or no bulk fracture of core material.⁽⁴¹⁾ It has been shown that CTE mismatch between layered ceramics, and zirconia core may accumulate residual stresses in the interfacial regions of the layered ceramic restorations.⁽⁴²⁾ The repeated firing seems to be a major problem in changing thermal specifications of the layered restorations, and so the aim of this study was to investigate whether multiple firing cycles of layered zirconia have the potential to adversely affect the SBS of zirconia core to porcelain veneer. The results showed no statistically significant difference in SBS between firing cycles. Also all of the failures (100%) in all groups were cohesive in porcelain veneer, and the mode of failure did not tend to change as the number of firing cycles increased. Aboushelib et al⁽⁴³⁾ observed that many specimens which presented adhesive failures had voids or bonding discontinuities at the interface. The mixed failures observed at the ceramic/zirconia interface in other studies maybe explained by the large differences in the flexural strengths between the two ceramics, with the failure mode shifting from adhesive to cohesive within the ceramic with glassy matrix (ceramic). But when the veneer material becomes capable of filling the voids and flaws of the zirconia surface, this allows the system

to behave as a monolayer ceramic when submitted to loads.⁽⁴⁴⁾

Only few studies have agreed with the effect of different surface treatments on bond quality.^(43,46-48) On the other hand, Tada et al⁽⁴⁹⁾ observed that surface roughness showed no impact on bond strength. Their results showed that fracturing occurred on the veneering ceramics near the zirconia surface. Bonding of a veneering ceramic to a polished zirconia surface has been also investigated. Fischer et al⁽⁵⁰⁾ observed no differences in shear strength between the polished and air-abraded surfaces. A strong bonding of the veneering ceramics to polished zirconia surfaces after shear testing suggest that chemical bonds were established during firing. Thus, surface roughness created by airborne particle abrasion may be unnecessary for bond improvements. Since no treatment was applied on the zirconia surface in the present study, it can be suggested that the chemical bonding was established during the firing and increased with multiple firing. Also, it has been suggested that the bond strength at the adhesive interface can be higher than the cohesive strength of veneering ceramic.⁽⁴⁹⁻⁵¹⁾ Therefore, the strength of restorations made of zirconia and veneering ceramics might be improved by a veneering ceramic with better strength.

Trindade FZ et al, stated that⁽⁵²⁾ Specimens submitted to a single firing cycle presented the lowest bond strength values (14.1 MPa), two firing cycles provided intermediate bond strength values (15 MPa) and the other groups presented equivalently high values (18.1 - 18.4 MPa). Opposite to the results of this study which clearly showed that an increase in firing cycles from 1 to 4 cycles didn't influence SBS, and all four groups have no statistically significant differences in SBS. After firing, porcelain consists of two phases: crystalline phase and glassy matrix. The crystalline phase is Lucite, which controls porcelain's CTE. Lucite also has a major role in porcelain strength.⁽⁴⁵⁾ During the porcelain cooling process, Lucite crystalline

transforms from the cubic to the tetragonal phase. Lucite crystals contract more than the glassy matrix because larger thermal expansion coefficients and compressive stresses will be produced around Lucite crystals.⁽⁵³⁾ Finally, although differences in core and veneer coefficients of thermal expansion, firing shrinkage, and speed of increasing and decreasing the temperature may lead to SBS reduction of the core-veneer zirconia-based all-ceramic restorations, the maximum failures were in the veneering porcelain. The major reasons for this phenomenon seem to be:

1. Change in Lucite content of veneering porcelain after multiple firing cycles.
2. Microcrack formation between Lucite phase and glassy matrix because of the differences in coefficients of thermal expansion of Lucite and glassy matrix.

The hypothesis of the study was not fulfilled as firing cycles had no effect on SBS between zirconia and veneering ceramics. Further investigations are needed to test more types of zirconia and under oral simulation conditions.

CONCLUSIONS

Under the limitations of this study, the following could be concluded:

1. An increase in firing cycles from 1 to 4 cycles had no effect on the SBS.
2. There are no statistically significant differences in SBS between groups.
3. In each group all of the failures (100%) were cohesive in the veneering ceramic, and the mode of failure did not tend to change as the number of firing cycles increased.

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