Original Article

# Bond strength of heat-pressed veneer ceramics to zirconia with various blasting conditions

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**Abstract** *Background/purpose:* With the technology of dental prostheses and materials progress, the bond durability of the all-ceramic restoration system plays an important role in the oral environment. The purpose of this study was to evaluate the influence of the parameters of blasting on the shear bond strength between zirconia and pressed veneer ceramics.
*Materials and methods:* Zirconia was blasted with different alumina particle size subjected to two types of applied pressures. Heat-pressed and layered veneer ceramic blocks were served as an experimental group and control group, respectively. The shear strength of specimens after thermocycling for 20,000 times was also investigated to simulate oral environment.
*Results:* The results indicated that the surface roughness was increased significantly ($P < 0.05$) with increasing particle size of alumina and blasting pressure. The alumina particle size had statistically significant influence ($P < 0.05$) on shear strength of heat-pressed groups. Among heat-pressed ceramic specimens, the highest and lowest shear strength could be obtained when 50 $\mu$m of alumina was used at pressure of 0.3 MPa and 110 $\mu$m of alumina was used at 0.5 MPa, respectively. The negligible effect of thermal cycle on shear strength of heat-pressed groups can be seen.
*Conclusion:* Blasting with 50 $\mu$m of alumina at 0.3 MPa could enhance the bond strength between zirconia and veneer ceramics.

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## Introduction

Ceramic materials are widely used in the dental applications due to its chemical stability, good biocompatibility, high compressive strength, and superior aesthetics. Novel ceramic materials and fabrication techniques have been proposed to improve the strength and durability of dental ceramic materials. For example, lithium-disilicate, zirconia, and alumina have been widely used for dental applications. Additionally, heat-pressing and computer aided design/computer aided manufacturing (CAD/CAM) techniques provide higher efficiency than traditional layering and casting techniques. Thus, zirconia coping or framework with high bending strength and toughness prepared by CAD/CAM and constructed with other dental ceramics to form porcelain-fused-to-zirconia crown could be utilized to replace the traditional metal—ceramic (MC) prostheses.[1,2] Dental crowns consisting of the metal-free zirconia all-ceramic materials not only improve the optical transparency of crowns, but prevent releasing of metal ions from metal materials through corrosion in oral environment, which could cause gingiva discoloration and allergy.

It is well-known that the nature of ceramic materials suffers from a few problems, such as the brittleness, and low tensile, bending, and impact strength, which restrict their applications in dental restorations.[3] With the popularity of all-ceramics dental restorative materials, failures are mostly due to chipping of porcelain and usually initiate from the crack and chip-off fractures of veneer ceramics in porcelain veneered-zirconia all-ceramic systems.[4-10] The previous studies on evaluating all-ceramic systems indicate that the survival rates for all-ceramic dental restorations range from 74% to 100% after 2—5 years in service.[1,4] Nevertheless, chipping rates of the veneer ceramics are also high (15—25%) after a mean service time of about 3 years.[4,5] The clinical study reports that the zirconia-ceramic fixed dental prostheses (FDPs) are susceptible to clinical problems including extended fracture of the veneering ceramics.[7] Moreover, the clinical failure of veneering ceramics is also attributed to the lack of bond strength because of the interface fracture between the zirconia coping and veneer porcelain.[10,11]

In dentistry, layering (sintering) as processing method has been used to fabricate porcelain-veneered crowns and glass-ceramic layered veneers for decades. Although this method has many advantages, disadvantages of the process are multi-steps and complications of manipulation. Since 1990, heat-pressing technique and glass-ceramics ingots have developed for manufacture of ceramic restorations (such as inlays, onlays, veneers and crowns). This technology has recently been applied to the pressing of veneer ceramics on zirconia core materials. Heat-pressing technique differs from the traditional dental layering process. Its success is attributed to ease of fabrication and timesaving in the fabrication process, along with producing precise and accurate restorations because of the lower firing shrinkage of the ceramics. It is necessary to investigate the bond strength of the pressing veneer-zirconia compared to traditional layering veneer-zirconia.

Surface modification of ceramic materials by etching,[12] silica coating,[13] chemical bond agent deposition,[14] mechanical grinding,[12,13] and blasting[15-19] is considered an effective route to improve the bond strength between zirconia-veneering ceramics. In dental laboratory, a zirconia framework is fabricated using a CAD/CAM system, and the surface blasting of the framework is indispensable processed. The ceramics frameworks must be blasted with 25—125 μm $Al_2O_3$ at 0.2—0.5 MPa[18,19] Blasting produces the changes in the surface topography and surface roughness of zirconia,[15] which leads to the enhanced bond strength.[16] However, it is argued that blasting treatment would decrease the strength of dental ceramic prostheses originating from the formation of defects on the ceramic surface.[17] Thus, it is worth investigating the efficiency of blasting treatment for pressed veneer ceramics bound to zirconia.

The purpose of this study was to examine the shear bond strength between heat-pressed ceramics and blasted zirconia that was subjected to different alumina particle sizes at various applied pressure. The layered veneer was used as a control. More importantly, the effect of thermal change simulating the oral environment on the shear strength was also conducted.

## Materials and methods

### Preparation of specimens

The ceramic specimens included the zirconia substrate and two kinds of veneer ceramics (Table 1). The VITA in Ceram YZ-55 zirconia block (Vita Zahnfabrik, Bad Sackingen, Germany) was used as the ceramic substrate. For veneer ceramics, heat-pressed IPS e.max ZirPress ceramic block (Ivoclar Vivadent, AG, Schaan, Liechtenstein) and layered veneer ceramic powder IPS e.max Ceram (Ivoclar Vivadent, AG, Schaan, Liechtenstein) were served as the experimental group and control group, respectively. Zirconia substrates were cut into square shape with diamond saw using low speed cutting machine (BUEHLER IsoMet, Lake Bluff, IL, USA). Zirconia specimens were sintered at 1530 °C for 2 h. All specimens were polished with a series of increasing finer SiC abrasive papers (800, 1000, and 1200 grit) using a grinder-polisher (BUEHLER MetaServ, Lake Bluff, IL, USA), and then ultrasonically cleaned in deionized water for 5 min and air dried. The final dimension of zirconia substrates after pretreatment was $12.5 \times 7.5 \times 3$ mm$^3$. According to the most frequently used blasting parameters in clinical practice, zirconia specimens were blasted with 50 and

**Table 1** Materials used in this study.

| Brand | Material | Application | Production method | Coefficient of thermal expansion $(10^{-6}/K)$ | Glass transition temperature (C) | Flexural strength (MPa) |
|---|---|---|---|---|---|---|
| Vita InCeram-YZ-55 | Zirconia | Core, bridge frameworks | CAD/CAM | 10.5 | N/A | >900 |
| IPS e.max ZirPress/ZirLiner | Fluorapatite | Veneer /Liner | Heat pressing | 9.8 | 530 645 | 110[a] |
| IPS e.max Ceram | Nano-fluorapatite glass-ceramic | Veneer | Layering | 9.5 | 490 | $\geqq 50$[a] |

[a] Biaxial flexural strength.

110 μm of alumina particle for 15 s at two different applied pressures (0.3 and 0.5 MPa), as listed in Table 2. Alumina particles were blasted on the polished specimen surface at an incidence angle of 90° with working distance of 10 mm between the nozzle and the surface using double pen type sand-blaster (Taicrown, Taichung, Taiwan). The blasted specimens were rinsed and ultrasonically cleaned with deionized water, and then air dried.

For heat-pressed group, a liner of IPS e.max ZirLiner (Ivoclar Vivadent) was applied to each specimen, and then sintered according to the manufacturer' recommendations. Afterwards, a square-shaped wax with dimension of 4 mm in length, 4 mm in width, and 2 mm in thickness was attached on zirconia substrate. The wax-attached substrate was embedded by phosphate bonded investment (Calibra express, Protechno, Spain) using a powder to liquid ratio of 0.22 in vacuum mixer. After hardening for 1 h, the cast mold was put into a furnace (Programat EP 3000, Ivoclar, Liechtenstein) which was preheated to 700 °C before sintering. Then the furnace was heat up to 900 °C at a rate of 60 °C/min, and the cast mold was sintered at 900 °C for 15 min. The IPS e.max ZirPress ceramic block was pressed into the mold by pressing technique according to the instruction of manufacturer. The final dimension of specimens was tailored to $4 \times 4 \times 2$ mm$^3$. IPS e.max Ceram was fabricated by traditional layered technique with the same dimension as the pressed veneer. Dentin and enamel ceramic layers with different powders were building-up on the zirconia substrate and then fired according to the instruction of manufacturer.

## Surface roughness

The surface roughness (Ra) values of blasted zirconia substrates at different roughening conditions were measured

**Table 2** Sample codes of the veneer-substrate system named by blasting conditions.

| Code | Manufacturing method | Al$_2$O$_3$ particle size (μm) | Pressure (MPa) |
|---|---|---|---|
| L-A 50-3 | Layering | 50 | 0.3 |
| P-A 50-3 | Pressing | 50 | 0.3 |
| P-A 50-5 | Pressing | 50 | 0.5 |
| P-A 110-5 | Pressing | 110 | 0.5 |
| P-A 110-3 | Pressing | 110 | 0.3 |

using a profilometer (Surfcorder SE-40G, Kosaka, Tokyo, Japan) with a transverse length of 2.4 mm and a cut-off value of 0.8 mm. Four measurements of each blasted zirconia surface were made. The data provided for each group were the mean of three specimens.

## Shear strength

The shear strength of specimens was conducted by a universal testing machine (AG-1000E, Shimadzu, Kyoto, Japan) at a crosshead speed of 0.5 mm/min. The following formula was used to calculate the shear strength of specimens:

$$\sigma_f(MPa) = F(N)/A(mm^2)$$

Whereas $\sigma_f$ stands for shear strength; F is fracture load; and A indicates the area. The data provided for each group were the mean of five independent measurements.

## Thermocycling

To simulate the thermal change in oral environment, specimens were repeatedly soaked in a deionized water bath of 5 and 55 °C for 30 s dwell time using a thermal cycle device (TBN-971105, Ten billion, Taiwan). After 20,000 times cycling, the shear strength values of specimens were measured. The data provided for each group were the mean of five independent measurements.

## Surface morphology

The surface morphology of blasted zirconia and junction between zirconia and veneer ceramics were observed by field emission scanning electron microscopy (SEM; JSM-7401F, JEOL, Tokyo, Japan). The fractured surface of zirconia after shear strength test was examined using optical microscope to evaluate the fracture mode of specimens. Image analysis software (Image-Pro® Plus, MediaCybernetics, Inc., MD, USA) was used to measure remained amounts of the veneer ceramics on fractured specimen surface.

## Statistical analysis

The results of surface roughness and shear strength were analyzed with the non-parametric Kruskal–Wallis test and non-parametric multiple comparisons testing to determine

the significant differences in the measurement data under different conditions. The non-parametric Wilcoxon Rank Sum test was also used to examine the significant differences in the shear strength of each group between before and after thermocycling. The amount of remained veneer ceramics on the fractured zirconia specimen surfaces before and after thermocycling was analyzed separately with one-way ANOVA. The significant differences in the amount of remained veneer ceramics of each group between before and after thermocycling were also examined with one-way ANOVA. Statistical calculations were performed using statistical software (JMP13, SAS Institute Inc., NC, USA). The significant was set as 0.05.

## Results

### Surface roughness

Fig. 1 shows the results of surface roughness (Ra) of zirconia subjected to different blasting parameters. According non-parametric Kruskal—Wallis test, the results indicated that the Ra value of blasted zirconia with 110 μm alumina was significantly higher than that with 50 μm alumina ($P < 0.05$). As expected, the Ra became with an increasing blasting pressure. With the same alumina particle size, the surface roughness of zirconia blasted at a pressure of 0.5 MPa showed a larger value than those at a pressure of 0.3 MPa ($P < 0.05$).

### Surface analysis

In SEM images (Fig. 2), the surfaces of all blasted zirconia specimens presented rough and irregular morphology, regardless of the used blasting condition compared to the polished zirconia surface.

### Cross-sectional structure

The zirconia ceramics was well attached on the veneer ceramics from the cross-sectional SEM images of the specimens, as shown in Fig. 3. However, structural defects were observed in the veneer ceramics of both groups and at the
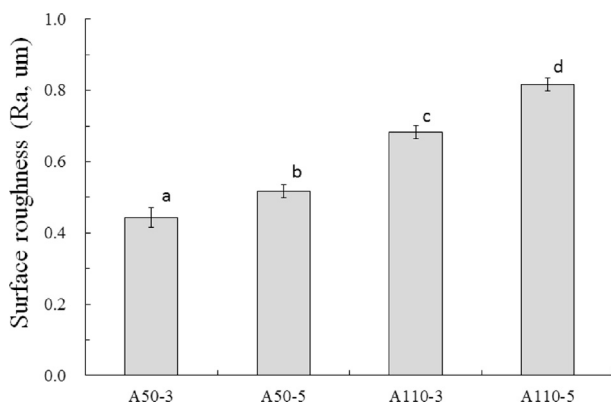
interface to the zirconia ceramics, indicating by the arrows. It seems that the micro-pores between veneer ceramics and zirconia appeared to be more in the 110 μm alumina groups compared with 50 μm alumina groups. Micro-pores sized from 10 to 50 μm within the veneer ceramics were observed in heat-pressed group, while the control group had pores ranging from 10 to 125 μm.

### Shear strength

Fig. 4 reveals the results of shear strength of different groups before and after thermocycling. In heat-pressed ceramics, the specimens blasted with 50 μm alumina before thermocycling showed higher shear strength than those with 110 μm. Specimens blasted with 50 μm alumina at 0.3 MPa before thermocycling had the highest shear strength among the heat-pressed specimens. On the contrary, 110 μm alumina at 0.5 MPa resulted in the lowest shear strength of the specimens. There was significant difference between these two groups ($P < 0.05$). Moreover, the results of the Kruskal—Wallis test indicated that the shear strength of the control group was significantly higher than those of the others ($P < 0.05$).

In comparison, the results of the non-parametric Wilcoxon Rank Sum test showed that there were no differences in shear strength between specimens before and after thermocycling in all groups ($P > 0.05$). The effects of blasting condition revealed similar trends before and after thermocycling. The strength of heat-pressed specimens blasted with 50 μm alumina after thermocycling was remarkably higher than that with 110 μm alumina ($P < 0.05$). Although the specimens blasted by 50 μm alumina at 0.5 MPa after thermocycling showed slight higher shear strength than that at 0.3 MPa, no significant differences were observed by comparing the strength of heat-pressed specimens blasting with different blasting pressure after thermocycling, regardless of 50 or 110 μm alumina. The Kruskal—Wallis test revealed that the strength of the control group was significantly higher than the others after thermocycling ($P < 0.05$), due to the veneering ceramic type.

### Fractured surface analysis

In general, there are three modes for fracture patterns between dental composites such as metal-ceramic or zirconia-ceramic including the adhesive, cohesive, and mixed modes (Fig. 5 (a)). I The results of fracture surface analysis indicated that the fracture of the specimens were occurred mostly at the veneer ceramics, and the junction between veneer and zirconia, except one case that a fracture only was appeared at the veneer ceramics (Fig. 5(b) (c) and Table 3). The failure mainly indicated a mixed mode of cohesive and interfacial fractures. Regarding groups before cycling, the amounts of remained veneer ceramics on blasted zirconia with 110 μm alumina were more than those on the 50 μm alumina group in heat-pressed group. The greatest amount of remained veneer ceramics was on blasted zirconia with 110 μm alumina at 0.5 MPa before and after cycle among all groups. Specimens blasted with 110 μm alumina at 0.5 MPa remained the
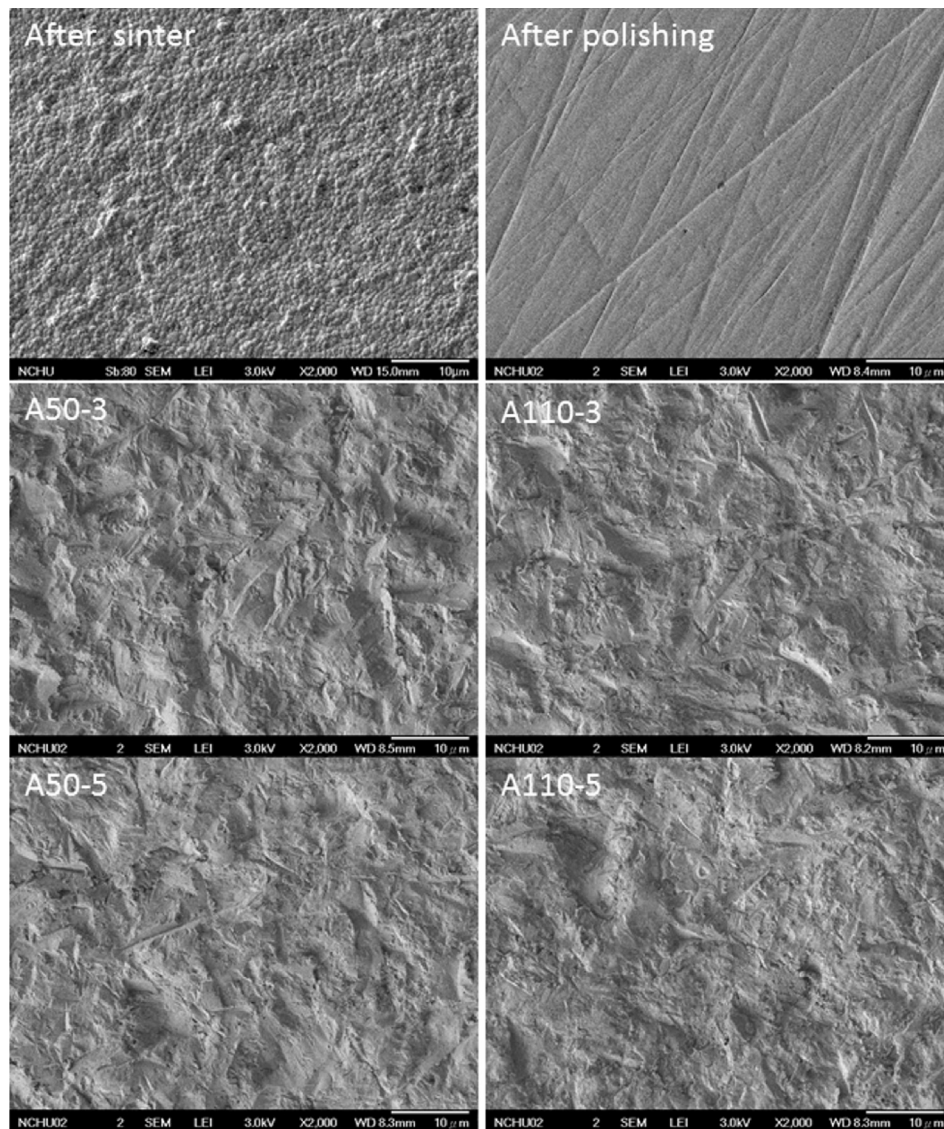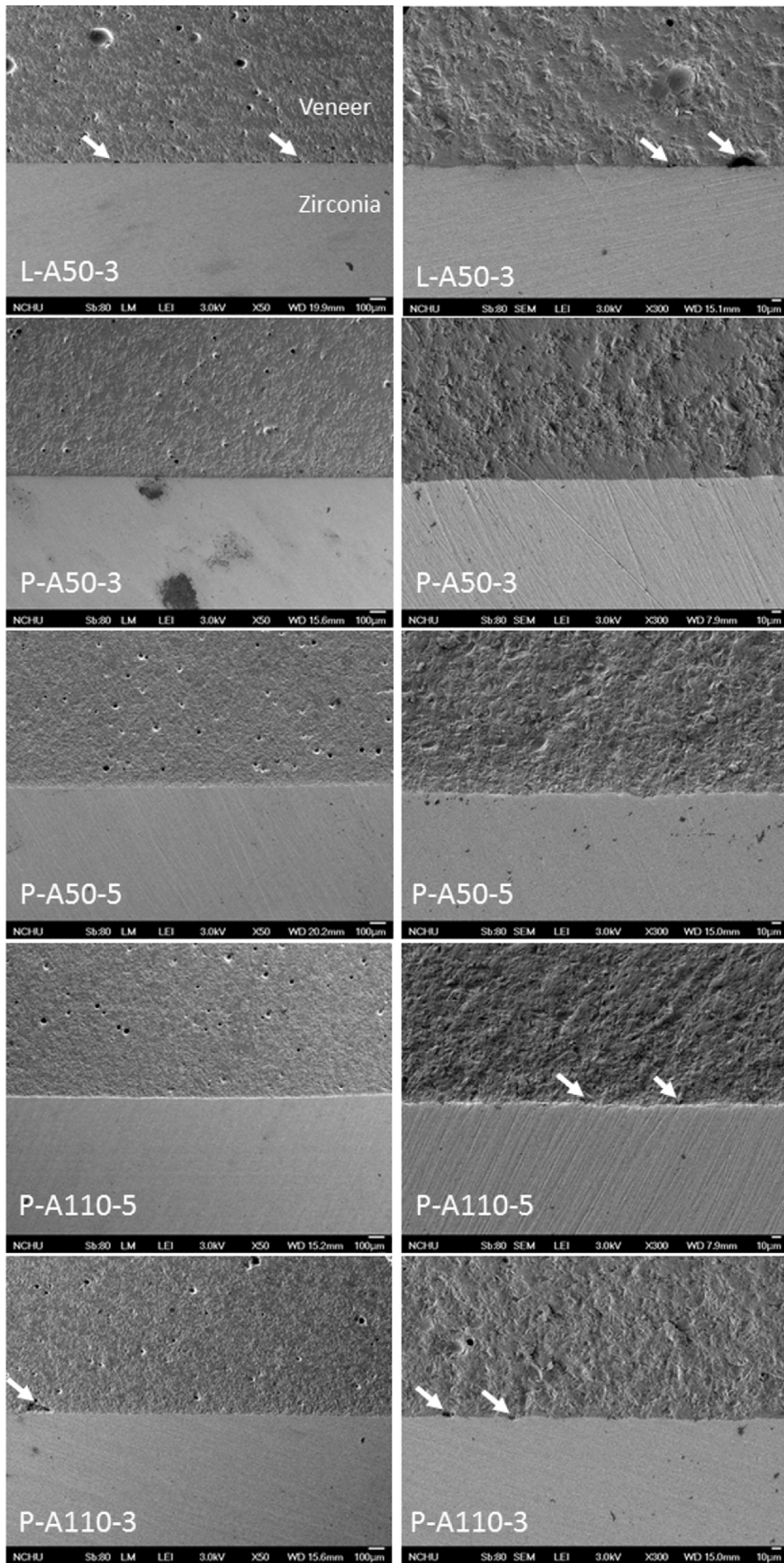


**Figure 1** The Ra values of the zirconia specimens with different blast conditions. The same letter are not significant differences ($P > 0.05$).

**Figure 2**   SEM photomicrographs of blasted zirconia surfaces showing roughed morphology.

highest amount of veneering ceramics among the heat-pressed specimens. On the contrary, the lowest amount of veneering ceramics would be obtained for blasting with 50 $\mu$m alumina at 0.5 MPa, there was significant difference between heat-pressed specimens with 110 $\mu$m alumina at 0.5 MPa (P < 0.05) by one-way ANOVA analysis (Tables 3 and 4). The amount of remained veneer on zirconia in the control group was similar to that on blasted zirconia with 50 $\mu$m alumina in heat-pressed group. On the other hand, there was no significant difference (P > 0.05) between groups after cycling (Tables 3 and 5). Regarding he amounts of residual veneer ceramics on the zirconia surface before and after thermocycling, the one-way ANOVA analysis illustrated that the amounts of remained veneer after thermocycling were significant lower than those obtained before thermocycling for the groups basted with50 $\mu$m alumina at 0.3 MPa (P < 0.05). However, with 110 $\mu$m alumina groups, the amounts of remained veneer before and after cycling were not affected.

## Discussion

It is well known that blasting conditions were a major influential factor on surface properties of dental materials. Blasting conditions include blasting particle size, air pressure, working time, distance from framework, and impact angle. When compared to traditional dental ceramic materials such as feldspar- and leucite-ceramics, $Y_2O_3$-stablized zirconia can undergo phase transformation from tetragonal to monoclinic phase (t-m phase transformation) while external stress is applied. This transformation is accompanied by a volume expansion which leads to the formation of compressive stress layer on the loading zone and results in toughening and increases its crack propagation resistance.[19−22] The degree of t-m phase transformation[23−25] and surface roughness[16,23−26] of zirconia is increased with an increasing size of blasting particle (50−110, 120 and 250 $\mu$m), applied air pressure (0.1−0.2,

Veneer

Zirconia

L-A50-3

NCHU    Sb:80  LM    LEI    3.0kV    X50    WD 19.9mm    100μm

L-A50-3

NCHU    Sb:80  SEM    LEI    3.0kV    X300    WD 15.1mm    10μm

P-A50-3

NCHU    Sb:80  LM    LEI    3.0kV    X50    WD 15.6mm    100μm

P-A50-3

NCHU    Sb:80  SEM    LEI    3.0kV    X300    WD 7.9mm    10μm

P-A50-5

NCHU    Sb:80  LM    LEI    3.0kV    X50    WD 20.2mm    100μm

P-A50-5

NCHU    Sb:80  SEM    LEI    3.0kV    X300    WD 15.0mm    10μm

P-A110-5

NCHU    Sb:80  LM    LEI    3.0kV    X50    WD 15.2mm    100μm

P-A110-5

NCHU    Sb:80  SEM    LEI    3.0kV    X300    WD 7.9mm    10μm

P-A110-3

NCHU    Sb:80  LM    LEI    3.0kV    X50    WD 15.6mm    100μm

P-A110-3

NCHU    Sb:80  SEM    LEI    3.0kV    X300    WD 15.0mm    10μm

0.4 and 0.6 MPa), and treatment time (5, 10 and 30 s). In the present study, the different particle sizes of alumina did have a significant effect on surface roughness of zirconia. The surface roughness (Ra) values of zirconia blasted with 50 and 110 μm alumina at 0.5 MPa were 0.52 ± 0.02 μm and 0.82 ± 0.02 μm, respectively. We verified that zirconia surface could be roughened by increasing particle size of alumina, similar to the results of Hallmann et al. (0.55–0.7)[23] and Wang et al. (0.65–1.18).[26] However, our results did not agree with Curtis et al.[27] Their study reported that surface roughness of Lava ceramic (Y-TZP) remained unchanged from 0.19 to 0.18 μm using 25, 50 and 110 μm alumina at 0.48 MPa. The surface roughness was significant lower (0.18–0.19) than that of our results. In general, the ceramic framework is blasted with 50 and 110 μm alumina particles at 0.2–0.4 MPa and a distance of approximately 10 mm.[19,23] In the present study, the blasting parameters referred to the literature and dental laboratory process. Blasting carried out at 0.3–0.5 MPa for working time of 15 s and a distance of 10 mm. Thus, in the study of Curtis et al.,[27] lower surface roughness could be attribute to using shorter working time of 5 s and longer distance of 20 mm. Duration and particle size of blasting affect the roughness of zirconia.[24] The different surface roughness may be possibly related to the different ceramic brands used.[28]

Mechanical anchoring plays a vital role in the bond strength between zirconia and veneer ceramics. In this regard, from clinical dental technique it is considered that blasting technique is employed to increase the surface roughness for improvement of the ceramic sintered area and the formation of mechanical interlocking between zirconia and veneer ceramics,[28] although opposite arguments are mentioned by some manufacturers. In the present study, we demonstrated that zirconia substrates blasted with 50 μm alumina could provide suitable roughness (Ra = 0.4 or 0.5 μm) to promote the adhesion of veneer ceramics on zirconia, which was superior to that of 110 μm (Ra = 0.7 or 0.8 μm). For specimens blasted with 110 μm alumina, though the use of greater particle size resulted in a rougher surface, but the bond strength was not increased. Similarly, the strength might be decreased with an increasing blasting pressure. According to the literature,[20,23,24,29] surface treatments with larger particles and higher pressure as well as long working time may result in degradation of the mechanical properties of zirconia. A possible explanation was that higher roughness obtained by larger alumina particles and higher blasting pressure would lead to the formation of defects on the zirconia surface.[16,23,24,30] For example, Hallmann et al.[23] reported that when specimens were blasted with 110 μm alumina at pressure of 0.1, 0.25 and 0.35 MPa, some defects such as flaws, micro-cracks, pits, plastic deformations, melting of the ceramic surface and embedded alumina particles were observed on the surface. In addition, the blasting induced internal stress at the junction between veneer ceramics and zirconia framework could play an important role in the bond strength.[31]
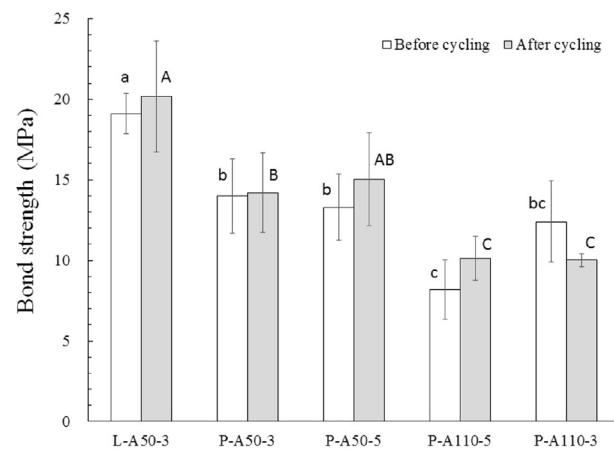


**Figure 4** Shear bond strength of the specimens with and without thermocycling. [ab] Different lowercase letters show significant differences (P < 0.05) between the shear bond strength among the groups before cycling; [AB] different capital letters show significant differences (P < 0.05) between the shear bond strength among the groups after cycling.

Until now some previous studies were mainly explored the bond strength between zirconia and heat pressed ceramics, but the relationship with the surface roughness was not discussed. Moon et al. investigated the effect of blasting conditions such as particle size, pressure, time and incidence angle on the surface characteristics of zirconia and shear bond strength of resin cement.[32] Their results confirmed that the surface roughness were proportional to the size, pressure, time and incidence angle, moreover, the specimen blasted with 50 μm particles exhibited higher bond strength on a similar surface roughness level compared with 25 or 125 μm. Our results agreed with them and had the same tendency, although the tested materials were not exactly the same. The bond strength value (14.0 MPa) of heat-pressed group in the present study was similar to the result of Harding et al.[33] However, the strength was significantly lower than the results (23.6 and 40.4 MPa) by Vidotti et al.[34] and Ishibe et al.,[35] possibly due to the different zirconia brands. Regarding the layered group, the strength (19.1 MPa) was higher than the results (11.5 MPa) proposed by Guess et al.,[36] however, lower than Vidotti's results of 22.5 MPa[33to34] and 30.0 MPa of Ishibe et al..[35] The differences could be resulted from the differences of shape of specimens, zirconia brands, and surface treatment with blasting conditions.[1,28,37]

The bond strength is affected by multiple factors, such as strength of the veneer ceramics or the zirconia framework and interface characterization between both ceramics. Zirconia and the veneer ceramics are considered the main factors affecting bond strength between both. On zirconia, the bond strength is not only determined by the surface roughness of zirconia, but also affected by fabrication methods such as milling or blasting that provokes a local tetragonal to monoclinic (t-m) transformation,[25,26]

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**Figure 3** Cross section through the interface: pores as structural defects observed in the veneer ceramics and at the interface to the zirconia ceramics. Original magnification × 50 (left) and × 300 (right). The arrow indicates the pore.
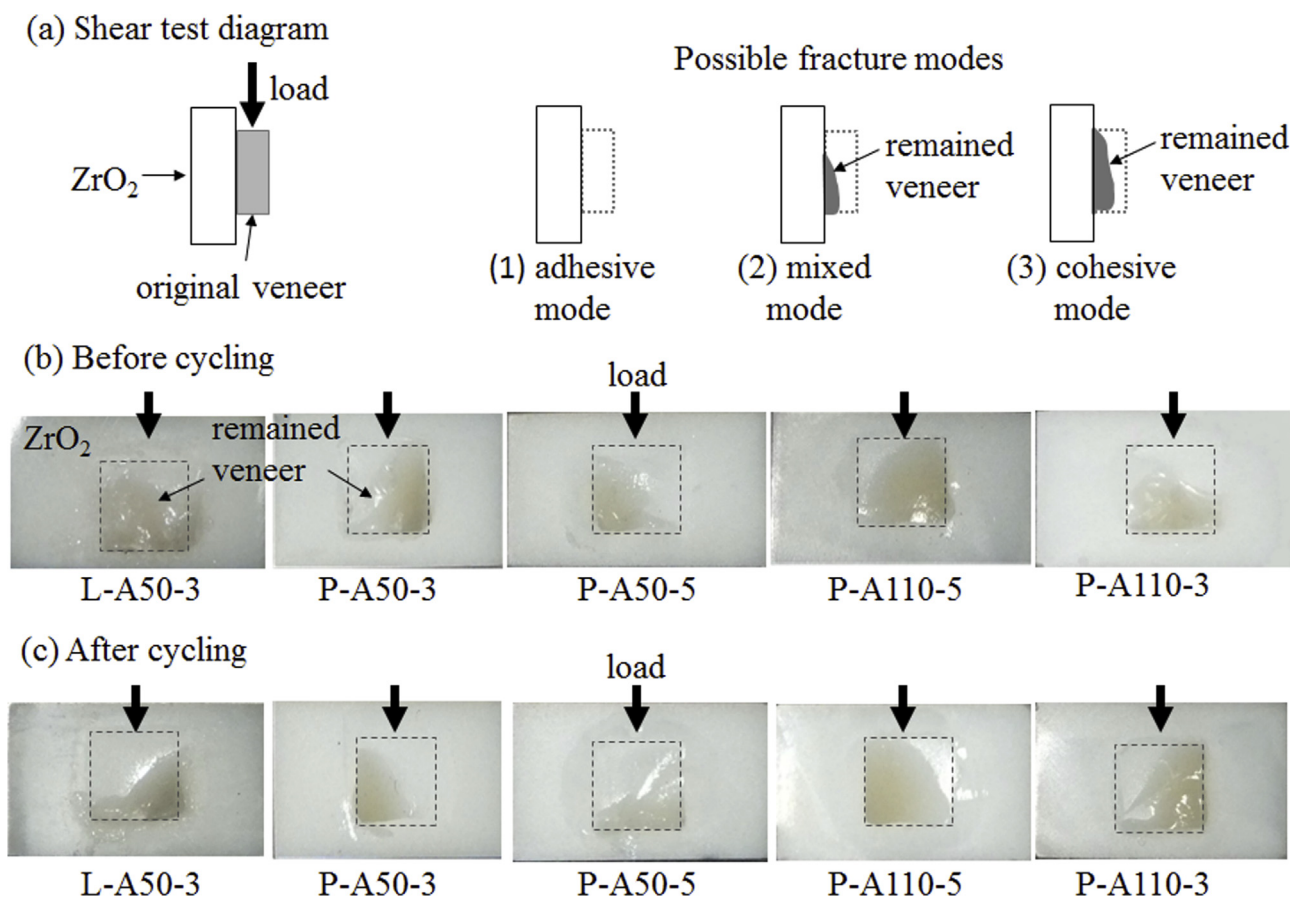
**Figure 5**    A schematic diagram of supposed possible fracture modes after shear test; (b) Before cycling, remained veneer ceramic on the substrate surfaces for each group after shear test; (c) After cycling.

**Table 3**    The amount of remained veneer ceramics on the zirconia surfaces after shear strength testing.

| Group | Remained area (%) | |
|---|---|---|
| | Before cycling | After cycling |
| L-A50-3 | $73.4 \pm 22.3^{A\ B}$ | $48.3 \pm 18.6^{\ C}$ |
| P-A50-3 | $67.6 \pm 13.0^{A\ B,a}$ | $42.5 \pm 3.8^{\ C,b}$ |
| P-A50-5 | $38.7 \pm 16.0^{\ B}$ | $51.1 \pm 23.4^{\ C}$ |
| P-A110-5 | $79.3 \pm 27.9^{A}$ | $75.9 \pm 18.7^{\ C}$ |
| P-A110-3 | $67.7 \pm 12.0^{A\ B}$ | $67.6 \pm 31.5^{\ C}$ |

$^{A\ B}$ Different capital letters show significant differences ($P < 0.05$) between the amounts of remained veneer ceramics among the groups before cycling; $^{ab}$ different small letters show significant differences ($P < 0.05$) between the amount of remained veneer ceramics before and after cycling in each group.

**Table 4**    Analysis of variances regarding the amounts of remained veneer ceramics among the groups before cycling.

| Source | Sum of Squares | DF | Mean Square | Prob > F |
|---|---|---|---|---|
| Group | 5248.73 | 4 | 1312.18 | 0.0251 |
| Error | 7471.66 | 20 | 373.58 | |
| C. Total | 12720.39 | 24 | | |

**Table 5**    Analysis of variances regarding the amounts of remained veneer ceramics among the groups after cycling.

| Source | Sum of Squares | DF | Mean Square | Prob > F |
|---|---|---|---|---|
| Group | 3944.15 | 4 | 986.038 | 0.1072 |
| Error | 9011.564 | 20 | 450.578 | |
| C. Total | 12955.714 | 24 | | |

and other surface treatment methods such as laser irradiation or powder coating[1,3]. In regard to the veneer ceramics, the factors affecting bond strength include coefficient of thermal expansion (CTE), the brand of veneer material, the times of firing, and the cooling rate after firing.[1] In our study, the CTE values ($9.75 \times 10^{-6}$/K) of the veneer ceramics was employed on the zirconia specimens (CTE $= 10.5 \times 10^{-6}$/K), and a simple square-shaped veneer

ceramics prepared by layered technique was repeatedly sintered for 3 times, which would not affect the bond strength. The bond strength of the heat-pressed group was lower than that of the layering group, possibly due to the lower porcelain sintering temperature adapted in the process. In addition, the types and composition of the used

veneer materials in the two groups also resulted in the differences on bond strength. The heat-softened veneer ingot was pressed onto the zirconia surface which showed lower bond strength compared with layering group by high temperature melting on the zirconia surface. In addition, the presence of defects in ceramics, microstructure, hole, and composition of materials also affect bond strength.[35,36,38]

In general, the amount of remained ceramics is used to illustrate the de-bonding mechanism between both ceramics, and also to analyze the degree of influence of different factors on the bond strength. In the present study, the fracture among all groups was almost ascribed to mixed fracture mode. Mixed fracture mode was regarded as cohesive in the veneer ceramics and adhesive at the interface with exposure of the zirconia ceramics. In heat-pressed group, zirconia blasted between 110 μm alumina and 50 μm alumina were compared, although zirconia blasted with 110 μm alumina had a greater surface roughness and lower bond strength, but more remained veneering ceramics was observed on zirconia surfaces. It seems that the present results established that amount of remained veneer did not relate to the bond strength examined in the two groups. The reason for this difference in the remaining amount of veneer ceramics could be possibly due to the defects in ceramics, microstructure, and porosity. Although well attached ceramics to zirconia were found, a number of holes were appeared at the junction between layered ceramics and zirconia. This could be attributed to the existence of air holes in the materials which were not excluded during the layering or heat-pressed process.[39] It has been reported that the clinical failure mode of all-ceramic crowns and FPDs is dependent upon the interfacial surface roughness and the modulus of the material in tension.[40] In the present study, the fracture mode was similar to a previous study,[31] but being not consistent with previous reports of cohesive fracture.[34,35] The discrepancy was emerged by the difference of shape of specimens, surface treatment with blasting conditions.[1,37] Therefore, evaluation of bond strength between veneer and zirconia could not solely depend on the amount of remained veneer, because the bond strength is caused by multiple factors. To date, no international standard, like ISO9693, could be utilized to evaluate the bond strength between zirconia and ceramics. Thus, the presence of defects in veneer ceramics and junction between ceramics might be one of the reasons which dominated the bond strength and fraction mode of the ceramics.

To simulate the effect of thermal change in oral environment on the durability and lifetime of ceramic restoratives, the ceramic specimens were underwent thermal cycles for 20,000 times, which was corresponding to that used in oral environment for 2 year.[41] The results indicated that fracture of specimens was not occurred during thermocycling. More importantly, the shear strength of ceramics remained constant before and after thermocycling treatment among all groups, in well agreement with previous study.[34] Thermocycling alone did not influence the bond strength of the interface between zirconia and veneer ceramics. In addition, the thermocycling treatment revealed negligible effects on the amount of remained heat-pressed veneer ceramics. The interfaces are stable in the presence of mechanical and thermal stresses in moisture.[34] In summary, bonding mechanism between zirconia and press veneer ceramics is still unclear in many respects, partly because this procedure is peculiar to dentistry. The basic research in this field will be necessary in the future.

In conclusion, our present findings suggested that the roughness of zirconia surface could be increased by blasting. The bond strength of specimens blasted with 50 μm alumina was higher than that with 110 μm at blasting pressure of 0.5 MPa. Alumina particle size had significant effect on shear strength, however, the blasting pressure did not influence the shear strength. The bond strength of heat-pressed veneer ceramics to zirconia was significantly lower than that of layered one. Amount of remained veneer was slightly increased with increasing alumina particle size. The fracture mode was mainly mixed mode among all groups. Thermocycling did not significantly affect the bond strength of all ceramic specimens.

## Conflicts of interest

The authors declare no conflict of interest.

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