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BIAXIAL FLEXURAL STRENGTH OF ZIRCONIA-BASED CERAMIC CORE WITH VARIOUS VENEER MANUFACTURERS

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การวิจัยนี้เป็นการวิจัยในห้องปฏิบัติการเพื่อเปรียบเทียบความแข็งแรงดัดขวางสองแกนของเซอร์โคเนียคอร์ที่ใช้คู่กับวีเนียร์พอร์ซเลนในผู้ผลิตเดียวกันและต่างผู้ผลิต โดยใช้ คาตานะเซอร์โคเนียคอร์ คู่กับวีเนียร์พอร์ซเลนจาก 5 บริษัท ได้แก่ เซราเบียนซีอาร์ ลาวาซีแรม เซอร์คอนซีแรมคิส ไอพีเอสอีแมกซ์ซีแรม และวิต้าวีเอ็มไนน์ นำมาสร้างชิ้นตัวอย่างชนิดแผ่นกลมสองชั้นขนาดเส้นผ่านศูนย์กลาง 12.50 มิลลิเมตร และหนา 1.50 มิลลิเมตร ตามมาตรฐาน ISO 6872 ปี 2008 โดยให้ชั้นคอร์และชั้นวีเนียร์หนาชั้นละ 0.75 มิลลิเมตร แบ่งเป็น 5 กลุ่มตามบริษัทผู้ผลิตวีเนียร์พอร์ซเลน กลุ่มละ 12 ชิ้น ขึ้นรูปตามที่บริษัทกำหนด นำชิ้นตัวอย่างมาทำการเทอร์โมไซคลิง 20,000 รอบ จากนั้นนำมาทดสอบด้วยเครื่องยูนิเวอร์แซลเทสติงแมชชีนและคำนวณหาค่าความแข็งแรงดัดขวางสองแกนของแต่ละชิ้นตัวอย่าง นำค่าที่ได้มาหาค่าเฉลี่ยของแต่ละกลุ่ม จากนั้นเปรียบเทียบด้วย การวิเคราะห์ความแปรปรวนแบบทางเดียว ที่ระดับความเชื่อมั่นร้อยละ 95 และโพสท์ ฮอค ตูกี เอชเอสดี ที่ระดับความเชื่อมั่นร้อยละ 95 จากการทดลองและคำนวณทางสถิติได้ค่าเฉลี่ยความแข็งแรงดัดขวางสองแกน ± ค่าเบี่ยงเบนมาตรฐานของแต่ละกลุ่มดังต่อไปนี้ เซราเบียนซีอาร์ 489.56 ± 67.00 ลาวาซีแรม 602.55 ± 76.30 เซอร์คอนซีแรมคิส 705.94 ± 65.89 ไอพีเอสอีแมกซ์ซีแรม 496.94 ± 64.78 และวิต้าวีเอ็มไนน์ 483.72 ± 67.37 เมกะพาสคัล ซึ่งพบว่าเซอร์คอนซีแรมคิสให้ค่าความแข็งแรงดัดขวางสูงที่สุดอย่างมีนัยสำคัญ รองลงมาคือลาวาซีแรม โดยเซราเบียนซีอาร์ ไอพีเอสอีแมกซ์ซีแรม และวิต้าวีเอ็มไนน์แตกต่างกันอย่างไม่มีนัยสำคัญ แต่มีค่าที่ต่ำกว่าอีกสองกลุ่มข้างต้นอย่างมีนัยสำคัญ จากผลการศึกษาดังกล่าวสามารถสรุปได้ว่าในการที่จะเลือกใช้วัสดุเซอร์โคเนียคอร์คู่กับวีเนียร์พอร์ซเลนโดยให้ความแข็งแรงที่ดีนั้น ไม่จำเป็นต้องใช้คู่กันจากผู้ผลิตเดียวกันดั่งที่บริษัทผู้ผลิตแนะนำ แต่ควรพิจารณาสมบัติเชิงกลอื่นๆ เพื่อเลือกใช้วีเนียร์พอร์ซเลนให้เหมาะสมกับเซอร์โคเนียคอร์

ภาควิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต	....
สาขาวิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก	....
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KEYWORDS: BIAXIAL FLEXURAL STRENGTH / BILAYERED DISC SPECIMEN / THERMOCYCLING / VENEERING PORCELAIN / ZIRCONIA CORE

NATRAVEE CHANTRANIKUL: BIAXIAL FLEXURAL STRENGTH OF ZIRCONIA-BASED CERAMIC CORE WITH VARIOUS VENEER MANUFACTURERS. ADVISOR: ASST. PROF. PRAROM SALIMEE, Ph.D., 55 pp.

The aim of this study is to evaluate the biaxial flexural strength (BFS) of zirconia-based ceramic when used with veneering porcelains from the same and different manufacturers. Zirconia core material (Katana) and five veneering porcelains (Cerabien ZR, Lava Ceram, Cercon Ceram Kiss, IPS e.max Ceram and VITA VM9) were selected. The bilayered disc specimens (diameter: 12.50 mm, thickness: 1.50 mm) were prepared following ISO standard 6872:2008 by the same person for each pairing into five groups of veneering porcelains (n = 12), using the powder/liquid layering technique (core 0.75 mm, veneer 0.75 mm). After 20,000 cycles of thermocycling, BFS tests were conducted using a universal testing machine (Instron). The data were analyzed with one-way ANOVA and Tukey Post Hoc multiple comparison tests ($\alpha = 0.05$). The mean ± SD of BFS were as followed: Cerabien ZR = 489.56 ± 67.00 MPa, Lava Ceram = 602.55 ± 76.31 MPa, Cercon Ceram Kiss = 705.94 ± 65.89 MPa, IPS e.max Ceram = 496.94 ± 64.78 MPa and VITA VM9 = 483.72 ± 67.37 MPa. The statistical analysis showed that Cercon Ceram Kiss significantly had the highest BFS, followed by Lava Ceram. The BFS of Cerabien ZR, IPS e.max Ceram and VITA VM9 were not significantly different but were significantly lower than the other two groups above. Concluded from the result, to obtain for the strength, zirconia core might not be used to pair with veneering porcelain from the same manufacturer as recommended. The optimal compatibility of zirconia and veneering porcelain might result from many other physical factors of the material and needs further investigation.

Department:	Prosthodontics	Student's Signature	....
Field of Study:	Prosthodontics	Advisor's Signature	....
Academic Year:	2013		

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CHAPTER I
INTRODUCTION

Background and Rationale

The rising popularity of zirconia-based restoration is due to the potential for excellent esthetic, biocompatibility, non-cytotoxicity, long-term stability, lack of metal and reliable strength.[1-10] The widely used of dental zirconia is mostly in the form of yttria tetragonal zirconia polycrystal (Y-TZP). This is because of its transformation toughening property that tetragonal phase transforms to monoclinic phase in excellent proportion by adding certainly amount of stabilizing oxides, yttrium oxide (Y_2O_3).[5] However, the clinical studies have shown problems of veneering porcelain chipping to occur.[11] The study of Swain found that high rates of veneering porcelain chipping in all ceramic restorations might be due to residual stresses from a coefficient of thermal expansion (CTE) mismatch, tempering associated with rapid cooling and improper thickness of veneering porcelain. These parameters should be considered to prevent the chipping of the veneering porcelain.[12]

Most manufacturers recommend using zirconia core together with veneering porcelain from the same manufacturer for the best result. However, a survey conducted in Bangkok showed that most dental laboratories do not use zirconia core and veneering porcelain from the same manufacturer as recommended. Many studies about matching zirconia core with different veneering porcelains have found bond strength to be significantly different. Fazi et al. compared microtensile bond strength (MTBS) between groups of bilayered zirconia/veneer specimens. They found that Lava veneering with Lava Ceram from the same manufacturer had the lowest

MTBS which was significantly lower than veneering with VITA VM9 and Creation ZI from different manufacturers.[13] In 2006, Aboushelib et al. investigated MTBS between a zirconia material of Cercon base and seven various commercial veneer porcelains. They found that MTBS of Cercon base veneering with Cercon Ceram S from the same manufacturer was significantly lower than that with Nobel Rondo and Lava Ceram from others.[14] Furthermore, the study of Blatz et al. investigated the effect of thermocycling on the bond strength of different veneering porcelains to zirconia core material and found that thermocycling might affect the bond strengths of some veneering porcelain.[15] Ozkurt et al. investigated the shear bond strength (SBS) of three veneering porcelains to four types of zirconia cores (Zirkonzahn, Cercon, Lava and DC-Zirkon) and three types of veneering porcelains. It was found that the bonding of manufacturer-recommended veneering porcelain to zirconia core differed according to zirconia type and veneering porcelain.[16]

These controversial studies provided the rationale to question the necessity of pairing zirconia cores with veneering porcelains from the same manufacturers and investigate their effects on the strength of bilayered zirconia/veneering porcelain in dental restoration.

Objective

The aim of the study is to evaluate the BFS of zirconia-based ceramic (Y-TZP) when used with veneering porcelains from the same and different manufacturers.

Hypothesis

Null Hypothesis (H_0):

At the 95% confidence level, the BFS in the group that has zirconia core paired with the veneering porcelain of the same manufacturer will not be significantly different from the BFS in the group that has zirconia core paired with the veneering porcelains of a different manufacturer.

Alternative Hypothesis (H_1):

At the 95% confidence level, the BFS in the group that has zirconia core paired with the veneering porcelain of the same manufacturer will be significantly different from the BFS in the group that has zirconia core paired with the veneering porcelains of a different manufacturer.

Scope of the Research

This research was an experimental study that compared the BFS of a bilayered specimen made from zirconia core (Katana, Kuraray Noritake Dental Inc., Japan) paired with the veneering porcelain from the same manufacturer (Cerabien ZR, Kuraray Noritake Dental Inc., Japan) to the BFS of bilayered specimens from other groups those were made from the same zirconia core paired with four other commercial veneering porcelains: Lava Ceram (3M ESPE, USA), Cercon Ceram Kiss (Degudent GmbH, Hanau-Wolfgang, Germany), IPS e.max Ceram (Ivoclar Vivadent AG, Schaan, Liechtenstein) and VITA VM9 (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany). There were 12 specimens in each group.

Research Assumption

All of the specimens in this study were prepared by an expert ceramist using the recommendations provided by the manufacturers. The BFS tests were conducted by a trained professional and measured using the same equipment throughout the study.

Research Limitation

This research is a laboratory experimental study that cannot completely imitate certain factors of a true oral environment. Such factors include temperature, moisture, quantity and direction of the force in the BFS testing. In addition, due to the shape of zirconia core and veneering porcelain, the preparation, finishing and polishing procedures of the specimens differ from the procedures in fixed restoration.

Conceptual Framework

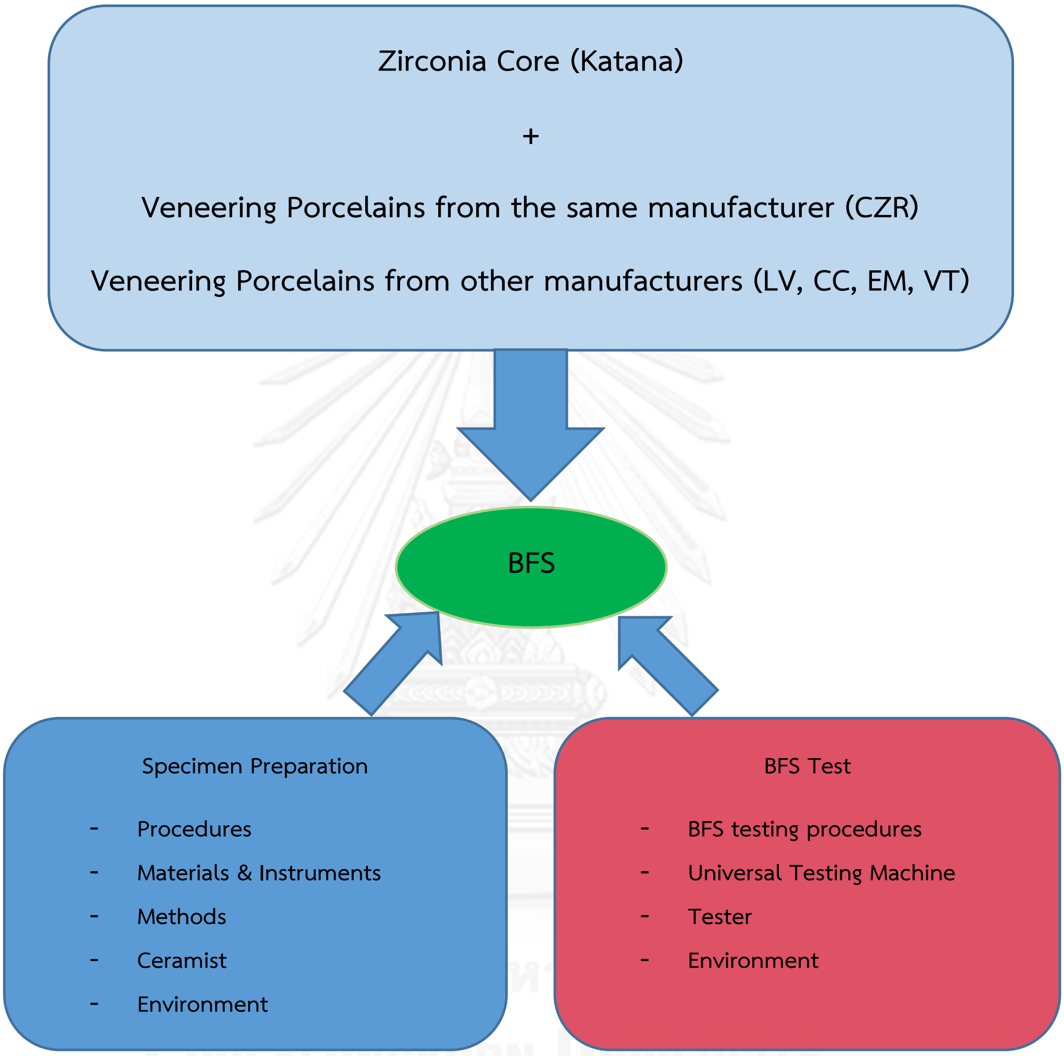

Figure 1. Conceptual framework

Key Words

Biaxial flexural strength

Bilayered disc specimen

Thermocycling

Veneering porcelain

Zirconia core

Expected Benefits and Applications

The research would support the decision to pair the zirconia core with the suitable veneering porcelain and plans for further study to support the results.

Duration

Table 1. Duration of the Study

	2013					2014						
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Review Literature	■	■										
Research design	■	■										
Write proposal	■	■										
Present proposal			■									
Prepare specimen			■	■	■	■						
Thermocycling					■	■	■					
BFS test						■	■	■				
Data collection						■	■	■				
Data analysis									■	■		
Data discussion									■	■		
Write full paper										■	■	
Thesis defense												■

CHAPTER II

LITERATURE REVIEW

Zirconia in Dentistry

Zirconia was identified as a metal dioxide in the reaction product obtained after heating some gems by Martin Heinrich Klaproth, the German chemist, in 1789. It was developed as a biomaterial in the late sixties and introduced to manufacture ball heads for Total Hip Replacement (THR). In the early stages of the development, several solid solutions (ZrO_2-MgO, ZrO_2-CaO, ZrO_2-Y_2O_3 and more) were tested for biomedical applications. But in the following years, the primary focus appeared to be on Y-TZP. Nowadays, Y-TZP is used widely as a promising dental ceramic due to its excellent biocompatibility and splendid mechanical properties.[17-20]

Zirconia or zirconium dioxide (ZrO_2), an inert white polycrystalline oxide of zirconium, is a transition metal with the highest mechanical properties ever reported for any dental ceramic; boiling point at 4,300 °C, melting point at 2,715 °C, high density (5.68 g/cm^3) and low in thermal conduction.[17, 18] Zirconia displays a different crystal structure at different temperatures without changing in chemistry, with three crystalline forms depending on the temperature: monoclinic at room temperature, tetragonal at the temperature in the range of 1,170 - 2,370 °C and cubic at 2,370 °C. While cooling down, a reversal transformation (T-M) occurs with a volume expansion of 4 – 5 % inducing high compressive stress in the material, rather like the martensitic transformation in stainless steel.[18, 19, 21-23]

Figure 2. Phase transformation of the zirconia

The compressive stress stops the formation of cracks in the zirconia when it occurs within a suitable extent by acting on the surfaces of the crack and hindering its propagation, called "Phase transformation toughening" that is responsible for its high mechanical properties. To stabilize the transformation, adding stabilizing oxide in a suitable proportion lets the zirconia has polymorphs at the room temperature, called "Partially stabilized zirconia" or "PSZ". When the whole material is constituted of tetragonal grains, it is called "Tetragonal zirconia polycrystal" or "TZP" which displayed as the best properties for dental applications if stabilized with yttrium oxide (Y_2O_3). Yttria tetragonal zirconia polycrystal, Y-TZP, is a fully tetragonal fine-grained zirconia ceramic material made of 100% small metastable tetragonal grains after adding approximately 2 – 3 mol% of Y_2O_3 as a stabilizer.[18]

The mechanical properties of zirconia were proved to be higher than all other dental ceramics. Fracture toughness is in the range of 5 – 6.27 $MPam^{1/2}$ [5, 17, 24-26] or 9 – 10 $MN/m^{3/2}$.[27] It has a flexural strength of 840 – 1,470 MPa [5, 17, 24-28] and a compressive strength of 2000 MPa.[18] It also has an average load-bearing capacity of 2,200 – 3,500 N in crowns[29] and 2,000 – 2,200 N in bridge restorations.[30] All studies demonstrated that zirconia yields higher fracture loads than other ceramics in dental restorations.[18, 28]

Biaxial Flexural Strength of Zirconia-based Ceramics

In 2004, Guazzato et al. investigated the uniaxial flexural strength, fracture toughness and microstructure of nine all-ceramic materials. They found that DC-Zirkon, fully sintered Y-TZP, had the highest flexural strength and fracture toughness (840 MPa, 7.4 MPam$^{1/2}$) compared to experimental Y-PSZ (680 MPa, 5.5 MPam$^{1/2}$), In-Ceram Zirconia slip (630 MPa, 4.8 MPam$^{1/2}$) and In-Ceram Zirconia dry-pressed (476 MPa, 4.9 MPam$^{1/2}$). Scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD) confirmed the correlation between phase transformation toughening and the higher strength of the zirconia.[31] It was similar to the finding from the study conducted by Papanagiotou et al. evaluating the effects of Low-temperature degradation (LTD) on the flexural strength of Y-TZP (Vita In-Ceram YZ blocks). They found that LTD within the limitations of the study had no significant negative effects on the flexural strength tested by the three-point bending method, ranging from 796.7 to 950.2 MPa.[25]

Zirconia copings for crown or bridge frameworks require the application of veneering porcelain for excellent esthetic. White studied on the strength of layered zirconia (Lava System Frame with Lava Ceram) and porcelain beams using three-point flexural testing. The specimens were prepared in five groups of various core-veneer ratios (1:0, 1:1, 1:3, 3:1 and 0:1), then tested by loading on the side of the zirconia core or veneering porcelain. The results of the study showed that the material on the tensile loaded side, lower layer, was responsible for the strength of the whole specimen. When the zirconia core was a loaded side, the modulus of rupture rose to 636 – 786 MPa. It was high compared to the strength when loaded on the side of veneering porcelain (77 – 85 MPa) and higher in the group that the zirconia core was thicker.[32] Similar to the study conducted by Salimee and Thammawasi, the flexural strength with BFS test (piston-on-three-ball) following ISO standard 6872:1995 and the mode of fracture on bilayered zirconia-based ceramics (Cercon system) were determined. There were five prepared groups of different core-veneer ratio such as 1:0, 2:1, 1:1, 1:2 and 0:1. From BFS testing, they reported that the core thickness should be more than a half of the whole thickness to strengthen the restoration, and the failures were found interfacially between the core and veneer.[5]

Piston-on-three-ball test has been selected by the International Organization for Standardization to establish ISO 6872 for the evaluation of the BFS of dental ceramics and it was claimed to be more reliable than the three-point flexure test and piston-on-ring test, because the forces used are not the direct loading and it is less sensitive to the undetectable defects in the material.[33] Consistent with Anusavice and Fischer, the flexural strength value obtained with a four-point flexural strength test is generally lower because the probability of having a surface crack between the two loading pistons is higher than in the small area beneath the loading pistons of a three-point flexure test. In the BFS test, the load is applied in the center of the specimen. Defects at the edges, which always lead to an early failure, are less effective. Anyways, the probability of finding a crack in the area of the loading piston is higher than in the three-point flexure test because the loaded area is larger.[34, 35] Huang and Hsueh performed finite element analyses (FEA), to simulate both piston-on-three-ball and piston-on-ring tests. Different degrees of the friction between the specimen supporting surface and the loading fixture were considered. The results of the FEA demonstrated how the friction between the specimen supporting surface and the loading fixture affects the BFS evaluation in piston-on-ring and piston-on-three-ball tests. It is critical to have frictionless contact between the disc and the supporting ring when evaluating the BFS by piston-on-ring tests. Otherwise, the application of the approximate formula, which was derived for piston-on-ring, to piston-on-three-ball is even better than piston-on-ring. This is true not only for monolayered discs but also multilayered discs.[36] It could be concluded that the BFS test is the most appropriate test for investigating the flexural strength because the specimen preparation is easy, but when a scientific approach is intended, the four-point flexure test should be preferred.

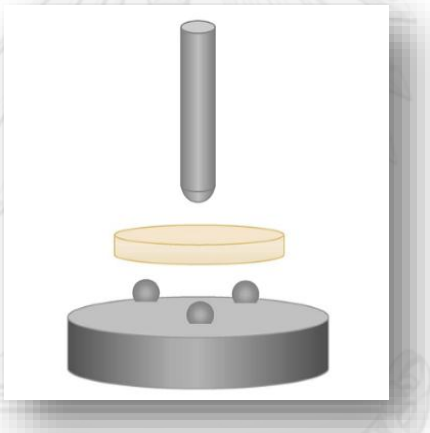

Figure 3. Biaxial flexural strength test (piston on three ball) [37]

Guazzato and Swain compared the BFS, reliability, and the fracture modes of bilayered discs made of two core materials (In-Ceram Alumina and In-Ceram Zirconia), both veneered with conventional feldspathic porcelain (Vita Alpha). FEA was used to estimate the maximum tensile stress at fracture and SEM was used to identify the initial crack and characterize the fracture mode. The test showed that all specimens with the core material on the bottom surface were significantly stronger and more reliable than those with the veneering porcelain on the bottom. The material that underwent tensile stress dictated the strength, reliability, and fracture mode of the specimens.[38] In the same year, they investigated the BFS, reliability and the mode of fracture of bilayered zirconia/veneer discs. Eighty specimens were prepared into four groups by Y-TZP core and conventional dental porcelain as follows: monolithic porcelains, monolithic core material, bilayered specimens with the porcelain on top and bilayered specimens with core material on top. The BFS test and FEA were used to estimate the maximum tensile stress at fracture. SEM was used to identify the initial crack and characterize the fracture mode. Monolithic cores and bilayered specimens with the core material on the bottom were statistically significantly stronger than monolithic porcelains and bilayered specimens with the porcelain on the bottom. The study indicated that the material on the bottom surface dictated the strength, reliability and fracture mode of the specimens.[24] This corresponded to the study by Lawn et al. in 2001. They used Hertzian contact tests on flat models of monolayer, bilayer, and trilayer ceramic-based structures to represent important aspects of crown response in oral functions, providing useful relationships for predicting critical occlusal loads to induce lifetime-threatening fracture. It was demonstrated that radial cracking from the lower core is the dominant failure mode of the layered ceramic-based restoration. For strengthening whole all ceramic restorations, a strong core material such as Y-TZP should be the first choice.[39]

Veneering Porcelains for Zirconia

In 2008, Fischer compared the flexural strengths of veneering porcelains for zirconia with veneering porcelains for metal using three flexure tests: three-point flexure test, biaxial flexural strength test and four-point flexure test. Ten veneering porcelains for zirconia and three veneering porcelains for metal were tested. Three-point flexural strength values of veneering porcelains for zirconia were similar to those of veneering porcelains for metal. The four-point flexure test showed the highest discrimination among all three tests between the different ceramic materials.[35]

The Matching of Zirconia with Veneering Porcelain and the Associated Problems

Zirconia coping for crowns and bridges requires the application of veneering porcelain to achieve the favorable esthetics. The high rates of clinical failures of zirconia-based restorations are attributed to debonding and veneering porcelain chipping.[18] Swain found the three major factors influencing the chipping of veneering porcelains on all ceramic dental restorations. There were CTE mismatch, tempering associated with rapid cooling and the thickness of the veneering porcelains which might raise the residual stress.[12]

De Kler et al. investigated the influence of CTE mismatch and fatigue loading on phase changes in porcelain veneered Y-TZP zirconia discs. They hypothesized that a mismatch in CTE between the veneering porcelain and the zirconia core causing phase transformation of tetragonal to monoclinic in the zirconia core at the interface boundary when exposed to fatigue loading, resulting in fracture at the interface boundary. Zirconia discs were veneered with three veneering porcelains differing in CTE. BFS test, FEA and XRD were used to measure and found that the sintered tetragonal structures were converted to monoclinic phase up to a depth of 27 μm after airborne abrasion, and reversed back to tetragonal phase after veneering with porcelain. Fatigue loading did not cause any conversion from tetragonal phase to monoclinic phase even with the highest possible CTE mismatch stress.[40] In accordance with Saito study that investigated the relationship between CTE and SBS of veneering porcelain to zirconia cores. Three core materials: Katana zirconia, casting gold alloy (Degudent U) and feldspathic porcelain (Cerabien ZR) were chosen as the bonding substrates. Five veneering porcelains (Cerabien ZR, Cercon Ceram Kiss, IPS e.max Ceram, Vintage ZR and VITA VM9) were fired to Katana zirconia, and Super Porcelain AAA was veneered on Degudent U. Cerabien ZR was veneered on Cerabien ZR discs to evaluate the strength of the veneering porcelain. Super Porcelain AAA and Cerabien ZR were applied to Katana zirconia and Degudent U, respectively, to investigate the effect of CTE mismatch on the bond strength of the veneer to zirconia core material. SBS tests were done after 24 hours of water storage. They found that strong discrepancies in CTE between veneering porcelains and zirconia cores significantly affect their bond strength. The SBS of feldspathic porcelain to the Katana zirconia was comparable to feldspathic porcelain to gold alloy and depends on the strength of the veneering porcelain.[41]

Aktas et al. evaluated the adhesion of zirconia cores with their corresponding veneering porcelains, having different CTE, when zirconia cores were colored at green stage. Two zirconia cores (ICE Zirconia and Prettau Zirconia) were randomly divided into two groups in their green stage, half of them were colored with coloring liquid.

Three different veneering porcelains (ICE ceramics, GC Initial and IPS e.max Ceram) with different CTE were fired on both groups of zirconia cores. Specimens of high noble alloys (Esteticor Plus) veneered with veneering porcelain (VM13) acted as the control group. SBS test was conducted. From the results of the study, neither the zirconia core material nor coloring significantly affected the results, but the veneering porcelains with different CTE. The control groups, metal-ceramic, exhibited significantly higher SBS values than all other tested groups, zirconia-veneer.[42]

Komine et al.[43] investigated the effect of cooling rate on SBS of veneering porcelains to a zirconia core material and found that mechanical retention and bonding of the veneering porcelain to the core material are the key factors in the successful performance of bilayered zirconia/veneer restorations. Initial cracks were generated by mismatches of CTE between the core materials and veneering porcelains, firing shrinkage of the porcelain, improper fabrication during grinding or other machining, undesirable heating and cooling rates. They referred to Tuccillo and Neilsen's study[44] suggesting that the rate of firing temperature of the veneering porcelain might be related to the shear stresses that are sufficient to affect the bond strength between the core and veneer. They fabricated forty-eight pre-sintered Katana zirconia discs and then divided them into three groups, veneered by Cerabien ZR, IPS e.max Ceram and Super Porcelain AAA (veneering porcelain for gold alloy used as a control for this study). Every group was separated into two subgroups according to cooling rate (0°C or 4°C). The results showed that the SBS significantly differed by cooling time in Katana zirconia with Super Porcelain AAA and Katana zirconia with IPS e.max Ceram. However, SBS values of Katana zirconia with Cerabien ZR did not significantly differ by cooling time. After SBS was tested, the failure mode of Katana with Super Porcelain AAA with rapid cooling was defined combined between adhesive and cohesive failure, and the failure mode of Katana with Super Porcelain AAA with slow cooling was spontaneous debonding. The findings of the study suggested that when applying IPS e.max Ceram to the Katana zirconia, slow cooling was recommended. The cooling rate may affect the shear bond strength differently on each veneering porcelain from different manufacturers.

The zirconia/veneer interfacial bond strength is influenced by many factors. The mechanisms include chemical bonding, mechanical fitting, and shear stress based on the difference in the CTE between the Y-TZP core and the veneering porcelain. The factors which influence the bond strength include surface roughness, heat treatment of the Y-TZP and the use of the liner. The veneering porcelain should have a CTE lower than the core material. The zirconia cores have a CTE ranging from 9 to 11 µm/mK while veneering porcelains can have CTE values ranging from 7 to 13 µm/mK.[18]

Zirconia Core and Veneering Porcelain from the Different Manufacturers

Fazi et al. compared MTBS between groups of bilayered zirconia/veneer specimens. The disc specimens were prepared from Lava, the only selected zirconia core, and veneered with veneering porcelains from three different manufacturers (Lava Ceram, VITA VM9 and Creation ZI) using conventional layering techniques. After cutting the disc into microbars, MTBS were measured. The lowest MTBS was Lava with Lava Ceram (14.76 MPa) from the same manufacturer and it was significantly lower than the other two (Lava with VITA VM9 obtained 23.52 MPa and Lava with

Creation ZI obtained 18.35 MPa). Failures were found to be mainly interfacial between the zirconia cores and veneering porcelains in all tested groups.[13] In 2006, Aboushelib et al. investigated MTBS in a zirconia substrate (Cercon base) veneering with seven various commercial veneer ceramics, and also evaluated the effect of optionally applying liner material between the core and veneer. The chosen veneering porcelains were Cercon Ceram S, Cercon Ceram Express, Nobel Rondo Dentine, Nobel Rondo Shoulder, Lava Ceram Dentin, Sakura Interaction and Experimental Pressable. The MTBS tests were done and it was found that liner application for Nobel Rondo Dentin and Cercon Ceram Express significantly weakened the bond strength of zirconia/veneer, but significantly improved the bond strength for Sakura Interaction. For the others, there were no significant differences between the groups with or without the liner application. These described results lead to the recommendation of the application of liner for some materials only. From the test, MTBS of Cercon base with Cercon Ceram S were significantly lower than Cercon base with Nobel Rondo and Lava Ceram.[14]

Blatz et al. evaluated and investigated the effect of thermocycling on the bond strength of different veneering porcelains (Cerabien ZR, GC Initial and Lava Ceram) to zirconia core material (Lava). It was found that significantly different SBS values (Cerabien ZR > GC Initial > Lava Ceram). Bond strength were not affected by thermocycling, except for Cerabien ZR, which had significantly higher SBS after thermocycling.[15]

Ozkurt et al. investigated the SBS of veneering porcelains to zirconia, four types of zirconia cores (Zirkonzahn, Cercon, Lava and DC-Zirkon) and three types of veneering porcelains (IPS e.max Ceram, VITA VM9 and manufacturer-recommended veneering porcelains) were selected. SBS test was conducted and fracture surface analysis was performed to determine the failure modes. DC-Zirkon showed the highest SBS (40.49 ± 8.43 MPa), followed by Lava (27.11 ± 2.72 MPa), Zirkonzahn (24.46 ± 3.72 MPa) and Cercon (20.19 ± 5.12 MPa). DC-Zirkon and Lava with manufacturer-recommended veneering porcelains had significantly higher SBS, as compared to IPS e.max Ceram and VITA VM9. On the other hand, Cercon and Zirconzahn did not show any significant differences in bond strength among three veneering porcelains. Surface analysis of the fracture surfaces revealed that the predominant failure modes between zirconia core and the veneering porcelain were combined and adhesive failures. No cohesive failures were observed. Concluded from the results, the bonding of manufacturer-recommended veneering porcelain to the zirconia core differed according to zirconia type, but it was not a decisive factor. Since VITA VM9 veneering porcelain resulted in combined failures with three types of zirconia materials. Zirconia/veneer bond strength is sensitive to the type of veneering porcelain used and zirconia core. It was due to the different structural characteristics of the veneering porcelains tested, in terms of composition, strength, CTE or firing shrinkage. On the other hand, the different surface characteristics of the zirconia core materials, in terms of grain size, shape, composition, density and hardness, also affected the bond strength of the final structure.[16] Aboushelib et al. studied on the effect of zirconia type on its bond strength with different veneering porcelains. Five zirconia cores (Cercon white and yellow, Lava white and yellow, and Procera zirconia) were treated on their surfaces with three techniques (CAD/CAM milled surface, airborne-particle abrasion and liner application), and then veneered with two veneering porcelains (Noble Rondo and Cercon Ceram Express). After disc-shaped specimens were cut into microbar, the MTBS test was conducted and they found that the type of the zirconia core had a significant effect on the bond strength. Pigmented zirconia cores were statistical significantly weaker compared to the white ones. SEM confirmed the changed structure of the pigmented that reduced their bond to veneering porcelains. Suitable surface treatment was conducted on a veneering surface of the zirconia core, airborne-particle abrasion for white zirconia core and liner application for pigmented zirconia core, before veneering with the veneering porcelains.[45]

The results of the reviewed studies raised the question about the necessity of matching the zirconia core with the same manufacturer’s veneering porcelain.

CHAPTER III

MATERIALS AND METHODS

Target Population

Zirconia-based ceramics with veneer porcelain

Sample Group

Bilayered disc specimens with diameter 12.50 ± 0.05 mm, core thickness 0.075 ± 0.005 mm and veneer thickness 0.075± 0.005 mm

Materials

1. Zirconia core (Katana, Kuraray Noritake Dental Inc., Japan)
2. Veneering porcelains and modeling liquids
    a. Cerabien ZR and CZR forming liquid (Kuraray Noritake Dental Inc., Japan)
    b. Lava Ceram and Lava modeling liquid (3M ESPE, USA)
    c. Cercon Ceram Kiss and Ducera liquid form (Degudent GmbH, Hanau-Wolfgang, Germany)
    d. IPS e.max Ceram and IPS e.max Ceram Build-up allround (Ivoclar Vivadent AG, Schaan, Liechtenstein)

e. VITA VM9 and VITA modeling liquid (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany)

3. Crack finder (VITA In-ceram testing liquid, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany)

Table 2. Materials used in this study

Materials	Products	Manufacturers	Lot	Type
Zirconia core	Katana zirconia	Kuraray Noritake Dental Inc., Japan	DDMDG	non-sintered zirconia
Veneering porcelains and Modeling liquids	Cerabien ZR and CZR forming liquid	Kuraray Noritake Dental Inc., Japan	054260, DDYSA	feldspatic
	Lava Ceram and Lava modeling liquid	3M ESPE, USA	8646A, 1184E	feldspatic
	Cercon Ceram Kiss and Ducera liquid form	Degudent GmbH, Hanau-Wolfgang, Germany	112882, 77677	feldspatic
	IPS e.max Ceram and IPS e.max Ceram Build-up allround	Ivoclar Vivadent AG, Schaan, Liechtenstein	S28033, S19195	nano-fluorapatite
	VITA VM9 and VITA modeling liquid	VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany	20370, 33851	feldspatic
Crack finder	VITA In-ceram testing liquid	VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany	63523	-

Equipment

1. Low speed cutting machine (IsoMet® 1000 Precision Saw, Buehler, USA)
2. Porcelain furnace (Programat P300, Ivoclar Vivadent AG, Schaan, Liechtenstein)
3. Ultrasonic cleaner (Bransonic model 5210, Branson, USA)
4. Sand blasting machine (Vario basic 230 V, Renfert GmbH, Germany)
5. Thermo cycling unit (King Mongkut's University of Technology Thonburi, Thailand)
6. Universal testing machine (Servo hydraulic system model 8872, Instron, England)
7. Piston on three balls; Ball 3 mm diameter, Support circle 10 mm diameter
8. Vibrator (Wassermann KV-36, Wassermann, Germany)
9. 3D milling machine (S3 Master, Schick GmbH, Germany)
10. Digital vernier caliper; least count 0.01 mm (Digimatic Vernier, Mitutoyo, Japan)
11. Wet abrasive papers no. 360, 600, 800 and 1,000
12. Porcelain kit; glass slab, brush
13. Weight pendulum; 5 kg

Specimen Preparation

Katana zirconia core and five veneering porcelains; Cerabien ZR, Lava Ceram, Cercon Ceram Kiss, IPS e.max Ceram and VITA VM9 were selected in this study. The specimens were designed for bilayered zirconia/veneer discs (diameter 12.50 mm, core thickness 0.75 mm and veneer thickness 0.75 mm), as shown in Figure 4 and prepared into five groups according to the manufacturers' recommendations (n = 12).

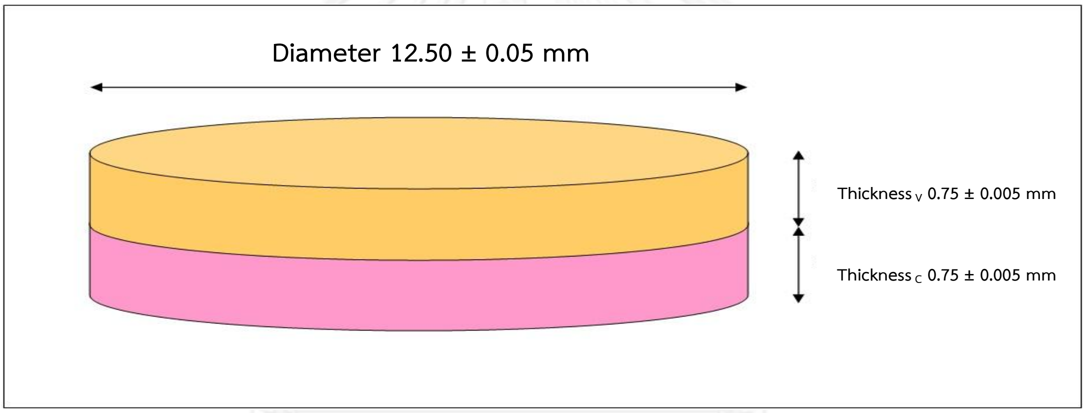

Figure 4. The design of the bilayered disc specimen

Core Preparation

The Katana zirconia block was cut into an oversize disc shape. Raw cores were sintered according to the manufacturer's program, then finished and polished with wet abrasive papers Nos. 360, 600, 800 and 1,000 respectively. The digital vernier caliper was used to measure the diameter (12.50 ± 0.05 mm) and thickness of the cores for 0.75 ± 0.005 mm. The VITA In-ceram testing liquid was used to find the crack line. Any core that had a crack line must be excluded. Sandblasting with aluminum oxide powder (110µm at 3.5 psi) was done at a distance of 10 mm from the tip to the side that was in contact with the veneer porcelain, at 45 ° to the flat surface. Then the cores were ultrasonically cleaned in acetone solution for 15 minutes to clean and remove residual greasy substance.

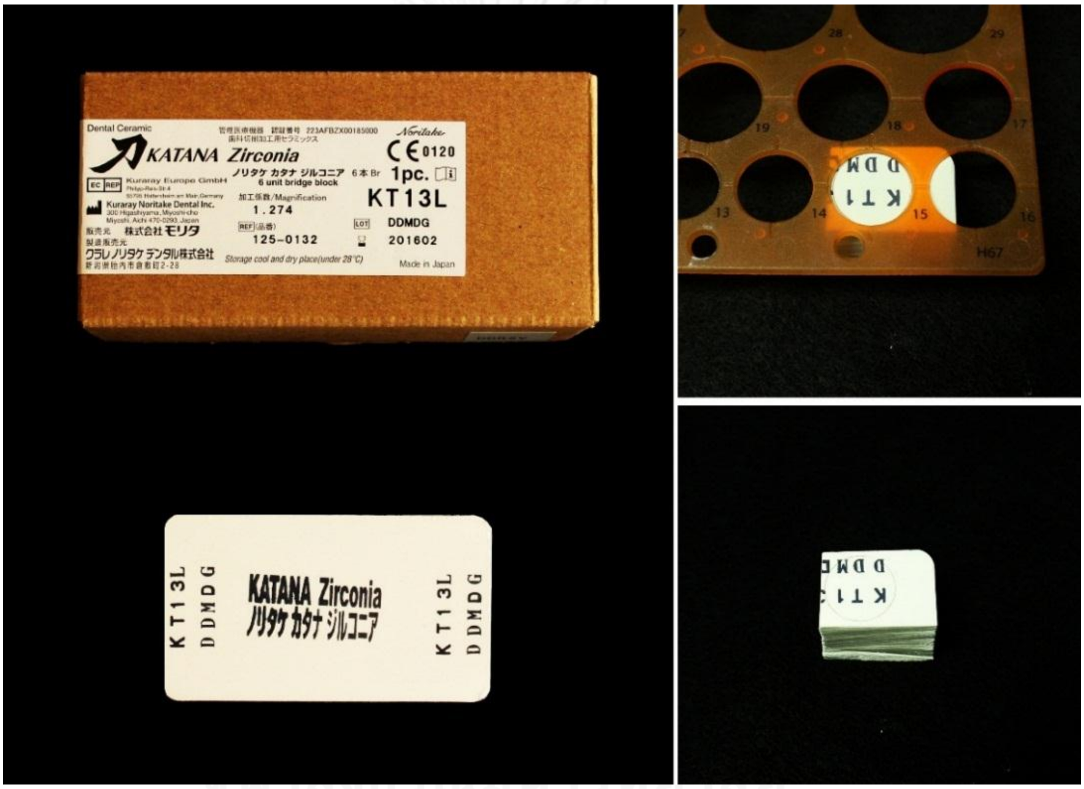

Figure 5. Katana zirconia block was cut and a circle of 16 mm diameter was drawn on the block.

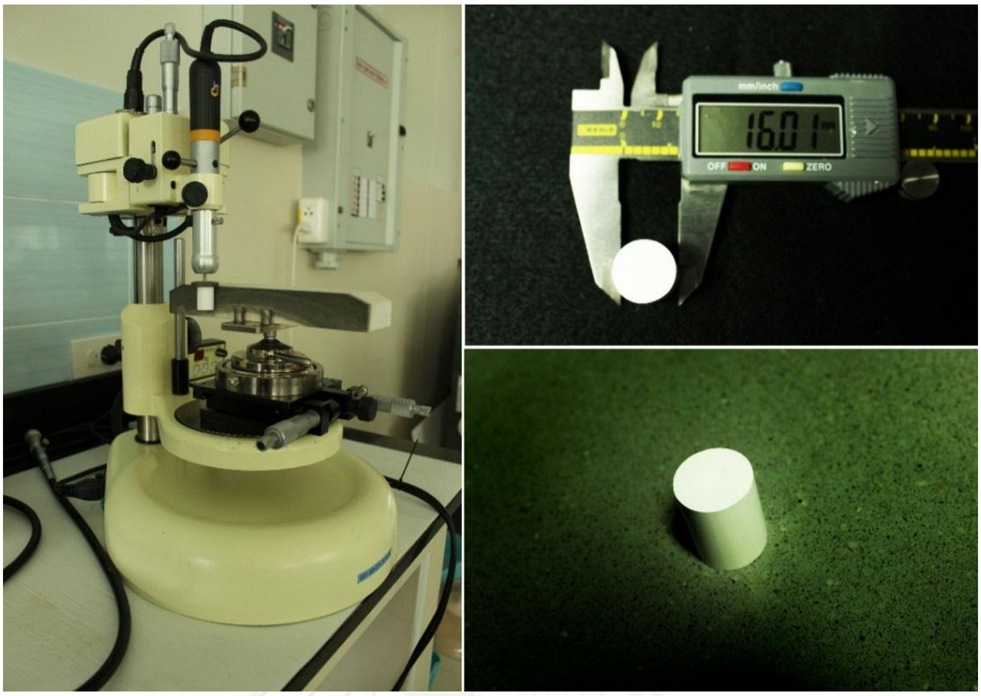

Figure 6. The zirconia block was trimmed into a cylindrical-shape using the 3D milling machine.

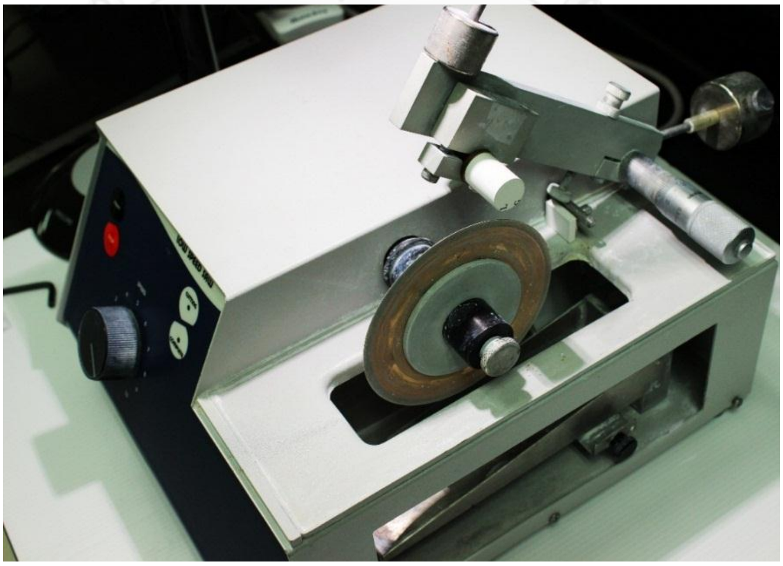

Figure 7. The core was cut into 1 mm-thick disc using the Isomet cutting machine.

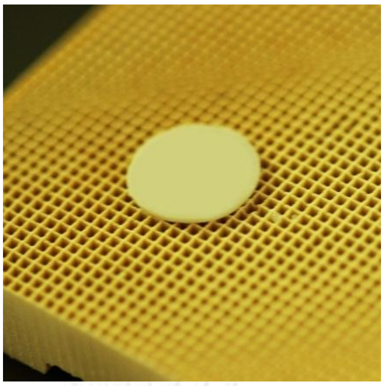

Figure 8. The core was sintered following the manufacturer instruction.

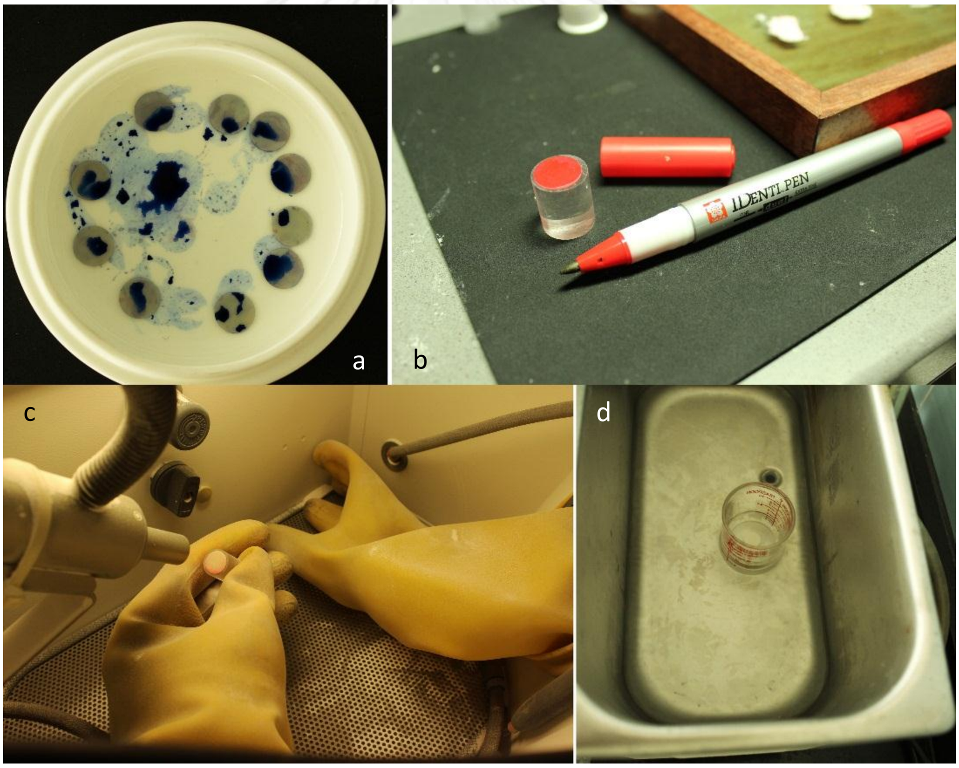

Figure 9. (a) Cracks were detected using VITA In-ceram Testing Liquid. (b) The zirconia disc was painted with permanent marker on the veneering side. (c) The painted side of the disc was sandblasted until color was disappeared. (d) The disc was ultrasonically cleaned in acetone solution for 15 minutes.

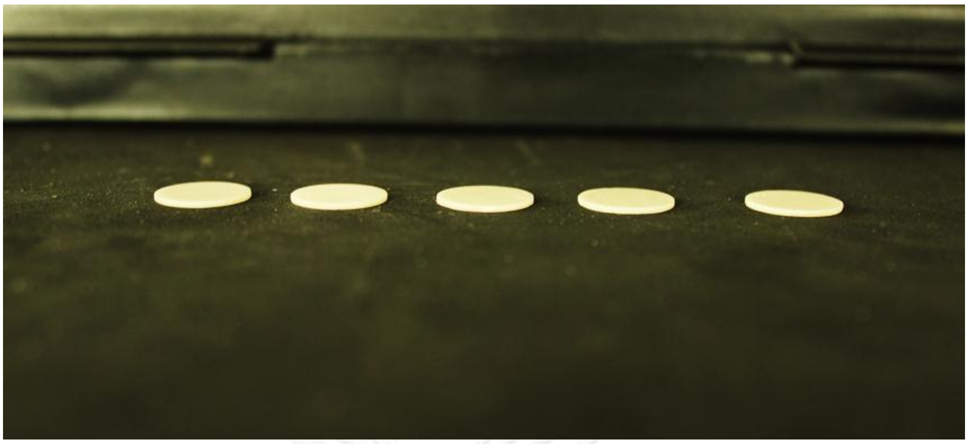

Figure 10. The prepared Katana zirconia cores

Veneer Preparation

After blotted, veneering porcelains were prepared on the cores with powder/liquid layering technique in the enlarged silicone mold to compensate the shrinkage and sintered according to manufacturer’s program. Sintered specimens were finished, polished and measured for the final thickness of 12.50 ± 0.05 mm. Crack test was done again to confirm crack after veneer sintering. Then, the specimens were thermocycled for 20,000 cycles of alternating temperature between 55 °C for 30 seconds and 5 °C for 30 seconds.

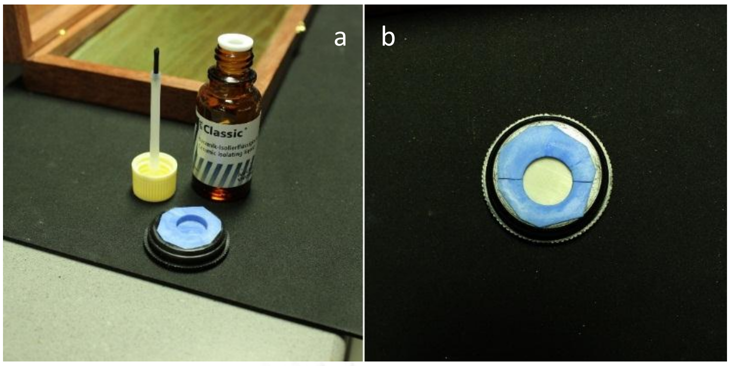

Figure 11. (a) The silicone mold was applied with the separating media. (b) The core was put into the mold.

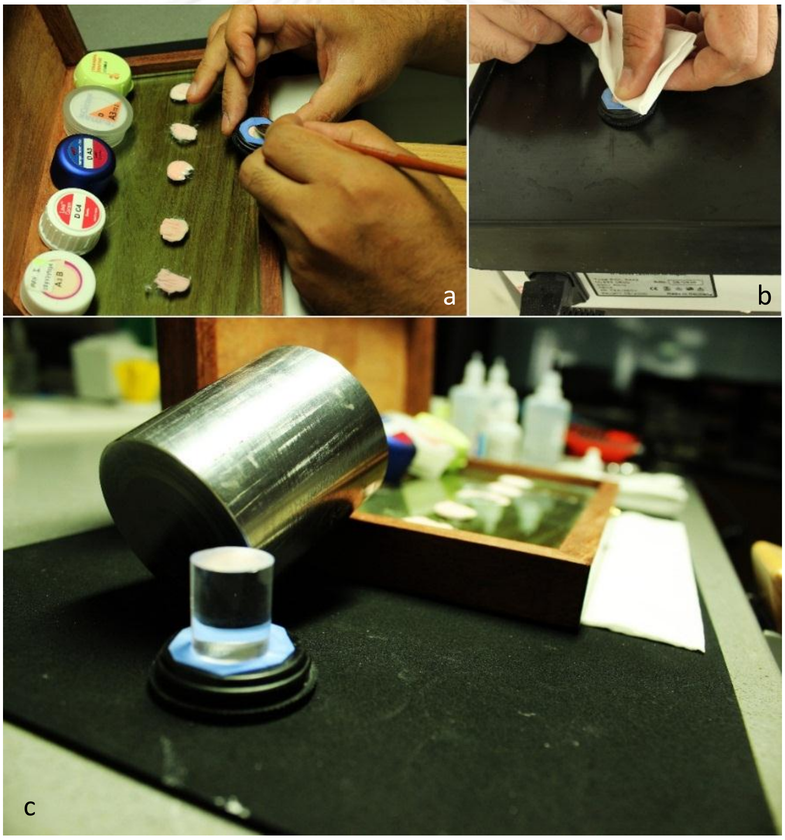

Figure 12. (a) The core was veneered with each veneering porcelain using powder/liquid layering technique. (b) The veneer-core was gently vibrated and blotted dry to remove excess liquid. (c) A 5 kg weight pendulum loaded on the veneering porcelain.

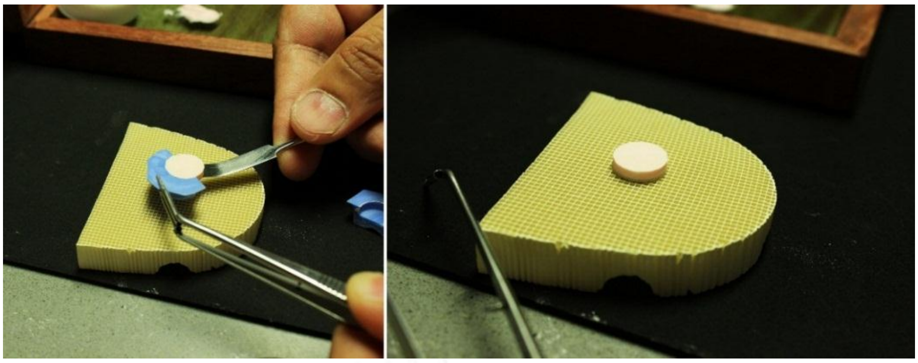

Figure 13. The veneering core was removed from the silicone mold.

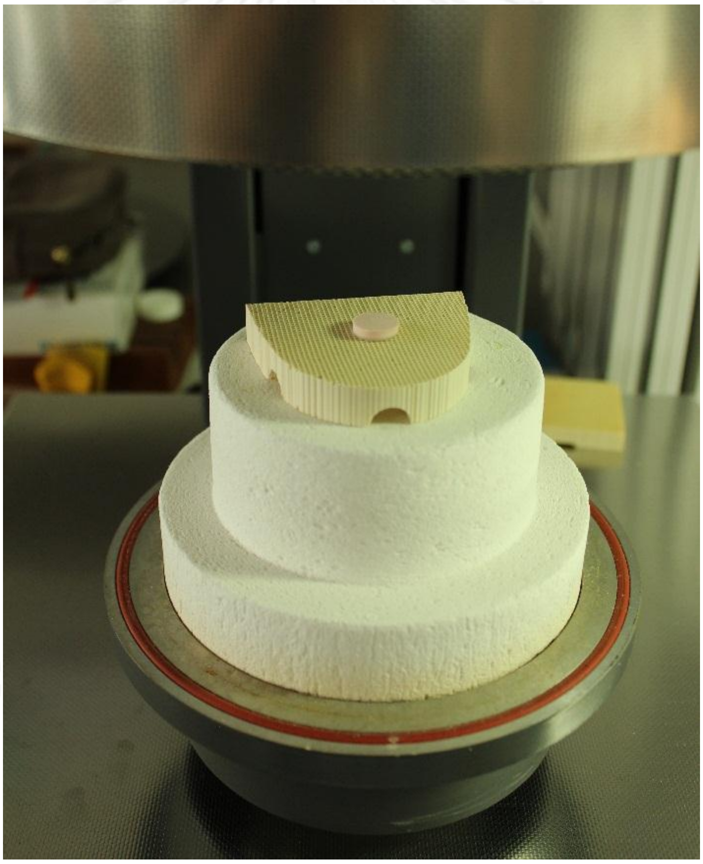

Figure 14. The veneering porcelain was sintered following the manufacturer guideline.

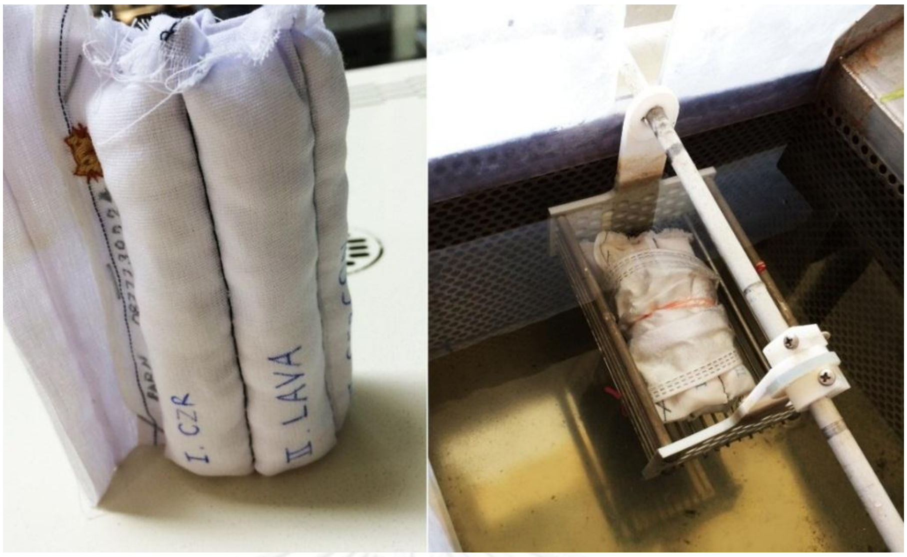

Figure 15. The bilayered zirconia/veneer specimens were thermocycled for 20,000 cycles at 5 °C for 30 seconds and 55 °C for 30 seconds.

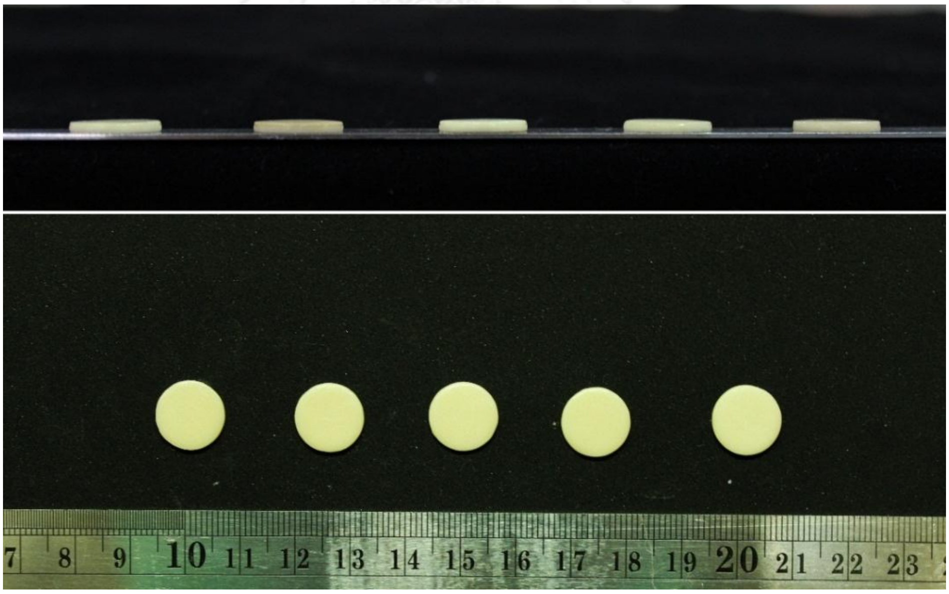

Figure 16. The bilayered zirconia/veneer specimens

Biaxial Flexural Strength Test

The BFS were measured using the piston on three balls, tested on a universal testing machine (Servo hydraulic system model 8872, Instron, England) following ISO standard 6872:2008[46] as shown in Figure 17. The test was carried out at a 0.5 mm/min crosshead speed until failure by placing a thin plastic sheet (thickness 0.05 mm) in between to distribute the load and minimize the stress concentration. The load at fracture was recorded and then calculated for BFS by the formula for two layer discs.[47, 48] Shown in Figure 18.

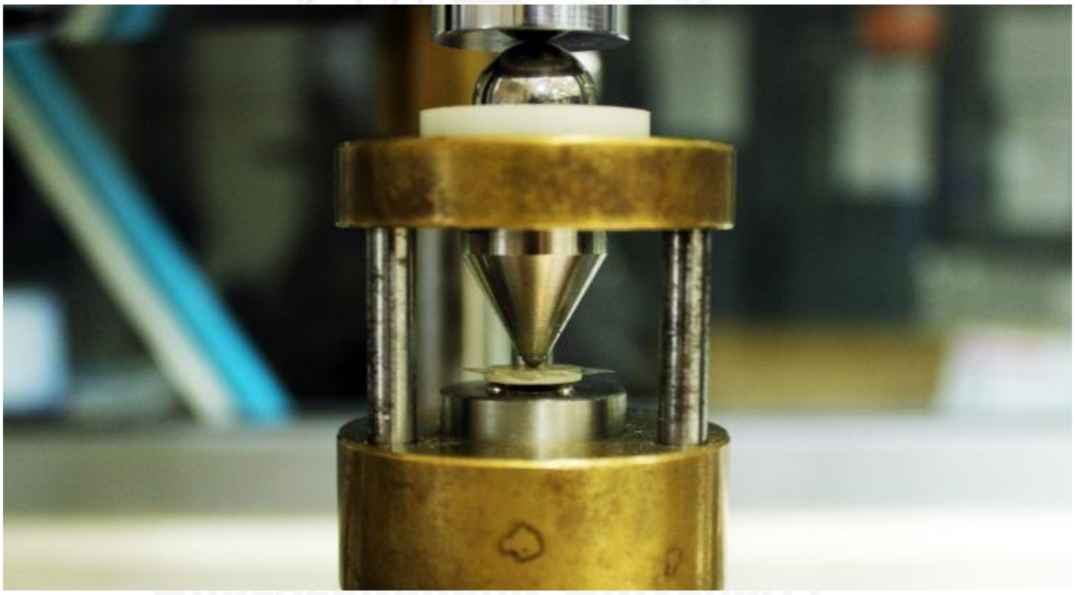

Figure 17. Biaxial flexural strength test was conducted on the bilayered zirconia/veneer specimen using the universal testing machine following ISO standard 6872:2008.

$$\mathrm{BFS} = \frac{6M}{t_a^2 K_{2p}}\left[\frac{E_b t_b (1-\nu_a^2)}{E_a t_a (1-\nu_b^2)} + \frac{t_a(1-\nu_a^2)\left(1+\left(\frac{t_b}{t_a}\right)\left(1+\frac{E_a t_a}{E_b t_b}\right)\right)}{t_a\left(1+\frac{E_a t_a}{E_b t_b}\right)^2 - \left(\nu_a \frac{\nu_b E_a t_a}{E_b t_b}\right)^2}\right]$$

$$R = \sqrt{1.6B^2 + d^2} - 0.675d$$

$$M = \frac{W}{4\pi}\left[(1+\nu)\log\frac{A}{R} + 1\right]$$

$$K_{2p} = 1 + \frac{E_b t_b^3 (1-\nu_a^2)}{E_a t_a^3 (1-\nu_b^2)} + \frac{3(1-\nu_a^2)\left(1+\frac{t_b}{t_a}\right)^2\left(1+\frac{E_a t_a}{E_b t_b}\right)}{\left(1+\frac{E_a t_a}{E_b t_b}\right)^2 - \left(\nu_a + \frac{\nu_b E_a t_a}{E_b t_b}\right)^2}$$

R = equivalent radius of loading

M = maximum bending moment (N)

W = work load (N)

P = maximum work load (N)

ν = Poisson's ratio (0.25)

A = support circle's radius (5 mm)

B = piston's radius (0.75 mm)

C = specimen's radius (6.25 mm)

d = specimen's thickness (1.50 mm)

t_a = upper layer's thickness (0.75 mm)

t_b = lower layer's thickness (0.75 mm)

E_a = Young's modulus of upper layer, veneering porcelain

(CZR 76, Lava Ceram 80, Cercon Ceram Kiss 65, IPS e.max Ceram 95 GPa)

E_b = Young's modulus of lower layer, Katana zirconia core (205 GPa)

Figure 18. The formulation of biaxial flexural strength for two layer disc

Data Collection and Statistical Analysis

The mean and SD of BFS data were collected for each group. The statistical analysis was performed using one-way ANOVA and Tukey post hoc multiple comparison tests (α = 0.05) using SPSS version 17.0 (SPSS Inc., Chicago, USA).

CHAPTER IV

RESULTS

The results of the BFS test were shown in Table 3, 4 and Figure 19. The statistical analysis showed that Katana with Cercon Ceram Kiss had significantly the highest BFS, followed by Katana with Lava Ceram. The BFS results of Katana with Cerabien ZR, IPS e.max Ceram and VITA VM9 were not significantly different but they were significantly lower than the previous two groups.

Table 3. Recorded maximum load (N) and biaxial flexural strength (MPa)

Specimen	Group I (CZR)		Group II (LV)		Group III (CC)		Group IV (EM)		Group V (VT)	
	Max. Load (N)	BFS (MPa)	Max. Load (N)	BFS (MPa)	Max. Load (N)	BFS (MPa)	Max. Load (N)	BFS (MPa)	Max. Load (N)	BFS (MPa)
1	1073.72	586.87	1148.57	615.25	1202.06	699.04	775.61	387.61	749.10	434.25
2	874.39	477.92	1273.78	682.32	1276.71	742.45	975.26	487.38	823.74	477.51
3	850.36	464.79	1150.32	616.18	1312.28	763.14	1025.03	512.25	932.13	540.35
4	999.06	546.06	1223.61	655.44	1176.03	683.90	849.81	424.69	795.74	461.28
5	924.51	505.31	1074.24	575.43	1076.91	626.26	924.24	461.88	649.78	376.67
6	1024.22	559.81	1200.40	643.01	1299.99	755.99	1124.53	561.98	722.73	418.96
7	999.90	546.52	1050.36	562.64	1125.83	654.71	1025.44	512.46	714.48	414.18
8	673.02	367.86	975.48	522.53	1101.80	640.73	1149.17	574.29	1031.67	598.05
9	924.17	505.13	1223.05	655.14	1450.90	843.75	949.21	474.36	835.00	484.04
10	775.40	423.81	1223.61	655.44	1076.60	626.08	872.83	436.19	980.19	568.21
11	730.48	399.26	764.06	409.28	1276.96	742.60	1214.23	606.80	928.10	538.01
12	899.08	491.42	1190.95	637.95	1190.95	692.58	1047.37	523.42	850.78	493.19
Max.	1073.72	586.87	1273.78	682.32	1450.90	843.75	1214.23	606.80	1031.67	598.05
Min.	673.02	367.86	764.06	409.28	1076.60	626.08	775.61	387.61	649.78	376.67
Mean	895.69	489.56	1124.87	602.55	1213.92	705.94	994.39	496.94	834.45	483.72
SD	122.57	67.00	142.45	76.30	113.31	65.89	129.62	64.78	116.22	67.37

Table 4. Mean ± SD and statistical analysis of biaxial flexural strength

a, b and c showed the homogeneous subsets of group with Tukey HSD.

Groups of BFS test in the study	n	BFS (Mean ± SD, MPa)
1. Katana with Cerabien ZR : (CZR) (Kuraray Noritake Dental Inc., Japan)	12	489.56 ± 67.00 [a]
2. Katana with Lava Ceram : (LV) (3M ESPE, USA)	12	602.55 ± 76.31 [b]
3. Katana with Cercon Ceram Kiss : (CC) (Degudent GmbH, Hanau-Wolfgang, Germany)	12	705.94 ± 65.89 [c]
4. Katana with IPS e.max Ceram : (EM) (Ivoclar Vivadent AG, Schaan, Liechtenstein)	12	496.94 ± 64.78 [a]
5. Katana with VITA VM9 : (VT) (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany)	12	483.72 ± 67.37 [a]

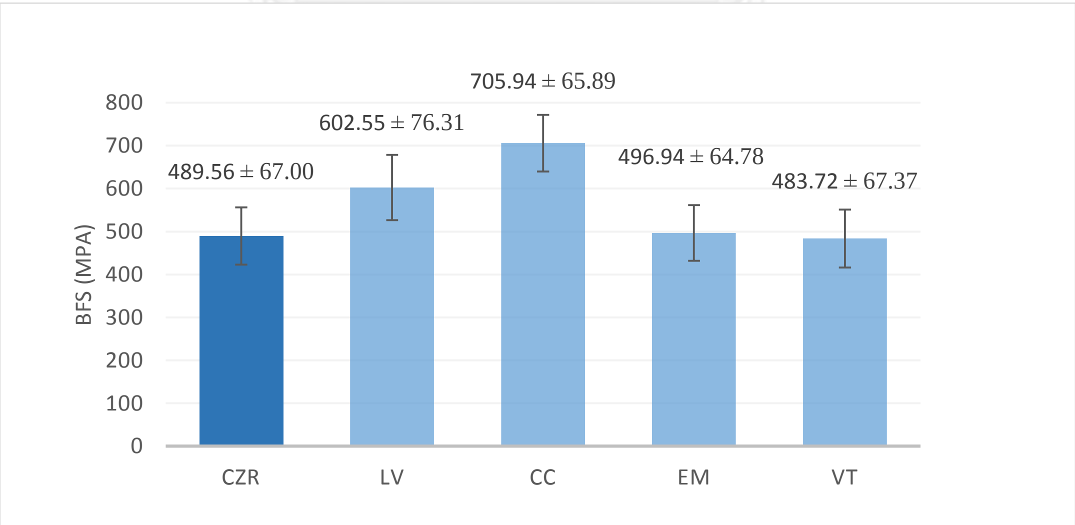

Figure 19. The results of the study, mean ± SD of biaxial flexural strength (MPa)

CHAPTER V

DISCUSSION AND CONCLUSION

Discussion

The BFS test, piston-on-three-ball, was used in this study because it is more reliable to reduce the sensitivity to undetectable defects in the material at the loaded position.[33] In the BFS test, the load is applied in the center of the specimen indirectly, so defects at the edges which always generate early failure are less likely to influence the outcome.[34] In addition, the BFS test is the most appropriate because of its ease of use, so the errors would be fewer than for other tests involving greater difficulty.[35]

In this study, we specified the core-veneer ratio as 1:1 (core thickness: 0.75 mm / veneer thickness: 0.75 mm), and put the side of the core material down as the lower side while conducting the test. In the BFS test of zirconia-based ceramic, Salimee and Thammawasi found that the zirconia core should be at least a half of the whole thickness of the restorations and the fractures mostly start at the zirconia/veneer interface.[5] In addition, many studies showed that the bottom layer of bilayered all-ceramic restorations were tensile stress zones and determined the overall strength of the restoration.[24, 32, 39]

The result of this study showed that the BFS could be significantly divided into three groups. Cercon Ceram Kiss provided the highest BFS, followed by Lava Ceram, while the lowest BFS was found in Cerabien ZR, IPS e.max Ceram and VITA VM9. Notably, Cerabien ZR, which was recommended for use with Katana zirconia from the same manufacturer, showed the lowest BFS. Concerning the the strength calculated by Young modulus as shown in the Table 5, Young modulus of IPS e.max Ceram is the closest to the Katana zirconia's, followed by Lava Ceram, Cerabien ZR, VITA VM9 and Cercon Ceram Kiss. This was not correlate to the results of our study that the strength from Cercon Ceram Kiss group was the highest, followed by Lava Ceram group and the lowest strengths were from the groups of Cerabien ZR, IPS e.max Ceram and VITA VM9. It could be assumed that the unpredictable results may cause by CTE, the ability of bonding between zirconia core and veneering porcelains, etc.

Table 5. Young modulus of the materials used in our study

(Based on the manufacturer' scientific data)

Materials	Young modulus (GPa)
Katana zirconia	205
Cerabien ZR	76
Lava Ceram	80
Cercon Ceram Kiss	65
IPS e.max Ceram	95
VITA VM9	65.52

According to the study of Swain, the high rates of veneering porcelain chipping on all-ceramic restorations might be due to residual stress from a CTE mismatch.[8] We found that among the veneering porcelain used in this study, the

CTE of Cerabien ZR and VITA VM9 were the most different from the Katana zirconia core. This might be one of the reasons explaining the obtained result.

Table 6. Coefficient of thermal expansion of materials used in this study (Based on the manufacturer scientific data)

Materials	Coefficient of thermal expansion (50-500°C$10^{-6}K^{-1}$)
Katana zirconia	10.1
Cerabien ZR	9.1
Lava Ceram	10.0
Cercon Ceram Kiss	9.6
IPS e.max Ceram	9.5 ± 0.25
VITA VM9	9.1 ± 0.1

Saito et al. also found that strong discrepancies in CTE between veneering porcelains and zirconia cores significantly affect their bond strength.[41] Aktas et al. evaluated the adhesion of zirconia cores with their corresponding veneering porcelains, having different CTE, when zirconia cores were colored at green stage. From the finding, neither the zirconia core material nor coloring significantly affected the results, but the veneering porcelains with different CTE significantly affected.[42] From these study, CTE mismatch should be considered as an important factor causing the porcelain chipping in zirconia-based restoration. However, the study of De Kler et al. investigated the CTE mismatch and fatigue loading, they found that a mismatch in CTE between the veneer and the zirconia core caused a conversion from tetragonal to monoclinic phase up to a depth of 27μm after airborne abrasion, and reversed back to tetragonal phase after veneering with veneering porcelain. The results showed the changes of the zirconia after airborne abrasion.[40]

Surface treatments of the zirconia core, such as airborne abrasion or liner application, were proved to have effects on the bond strength between the zirconia core and veneering porcelain. From the study of Aboushelib et al., they evaluated the effect of liner application and found that applying the liner material might affected the bond strength and failure modes depended on materials used. Moreover, sandblasting was recommended to improve the bond of the veneering porcelain to zirconia with liner.[14] From the other study of Aboushelib et al on the effect of zirconia type on the bond strength with different veneering porcelains, they found the controversial results about the effect of liner application and airborne abrasion on the bond strength between zirconia and veneer, depending on zirconia type. They suggested to apply the liner for the pigmented zirconia type, while the airborne abrasion was recommended for non-pigmented zirconia.[45] This is the reason for using airborne abrasion as a surface treatment on veneering side of the zirconia core in our study, instead of liner application. Moreover, sandblasting is conducted as a routine in the laboratory process for increasing the surface roughness and removing the deposits on the zirconia surface before veneering with the veneering porcelain. However, the studies on the surface treatment of the zirconia core were not in the same way. Many studies claimed that sandblasting or liner applying on the zirconia core decreased the bond strength to the veneering porcelain[49-51] while the results from other studies showed that sandblasting[51, 52] or liner application[45] improved the bond strength of the zirconia/veneer specimens. Furthermore, some studies resulted in no significant difference on the zirconia/veneer bond strength of the liner application[50] or sandblasting.[53] From these results, more studies about the suitable surface treatment of the zirconia core before veneering with the porcelain should be further investigate.

Moreover, there might have been other factors influencing these findings such as the sintering frequency, sintering temperature, tempering associated with rapid cooling of the veneering porcelains[12] and other factors affecting the bond between the zirconia core and the veneering porcelain. Mechanical retention and bonding of the veneering porcelain to the core material are the key factors in the successful performance of bilayered core-veneer restorations. Initial cracks were generated by mismatches of CTE between the core materials and veneering porcelains, firing shrinkage of the porcelain, improper fabrication during grinding or other machining, undesirable heating and cooling rates.[43] Komine et al. investigated the effect of cooling rate (0 s and 4 s) on SBS of three veneering porcelains (Cerabien ZR, IPS e.max Ceram and Super Porcelain AAA) to Katana zirconia. They found that the cooling rate may affect the SBS differently on each veneering porcelain from different manufacturers. The SBS significantly differed by cooling time in Katana zirconia with Super Porcelain AAA and with IPS e.max Ceram, but not with Cerabien ZR. They suggested that when applying IPS e.max Ceram to a Katana zirconia, slow cooling was recommended.[43] The study of Tuccillo and Neilsen suggesting that the rate of firing temperature of the veneering porcelain might be related to shear stresses that are sufficient to affect the bond strength between the core and veneer.[44] In addition, Saito et al. also studied about the relationship between CTE and SBS of various veneering porcelains to Katana zirconia and Degudent U casting gold alloy. They found that Cercon Ceram Kiss and IPS e.max Ceram had significantly lower SBS than the Cerabien ZR group, and no significant differences were found between Vintage ZR, VITA VM9 and Cerabien ZR. The SBS of veneering porcelains to the zirconia core depended on their strength.[41]

Ozkurt et al. investigated the SBS of veneering porcelains to zirconia and found that the bonding of manufacturer-recommended veneering porcelain to zirconia core differed according to zirconia type, but it was not a decisive factor. It seem to indicate that core-veneer bond strength is sensitive to a multitude of interacting variable, type of veneering porcelain used and the type of the zirconia core. It was due to the different structural characteristics of the veneers tested, in terms of composition, strength, CTE or firing shrinkage. On the other hand, the different surface characteristics of the zirconia core materials, in terms of grain size, shape, composition, density and hardness, also affected the bond strength of the final structure.[16] Moreover, Aboushelib et al. also investigated the effect of zirconia type on its bond strength with different veneer porcelain. They found that the type of zirconia core had a significant effect on the bond strength. Pigmented zirconia cores were significantly weaker compared to the white ones. SEM confirmed the changed structure of the pigmented that reduced their bond to veneer porcelains.[45]

In this study, we performed thermocycling 20,000 cycles to imitate the condition of oral function for 2 years.[54] Since the effects of mechanical and thermal environment in oral cavity were concerned.[55, 56] The rapid variations of thermal, chemical and physical in the oral cavity may stimulate growth of the cracks within and eventually fail the dental ceramics.[37, 54, 57-60] Therefore, Thermocycling is important for investigating the mechanical properties of ceramics as same as the mechanical tests that are tended to simulating the conditions of the masticatory function by inducing alternate tensile or compressive stresses in the specimens.[37, 61, 62] Thermocycling was designed for producing alternative stresses at the interface between different materials based on temperature changes.[63] The CTE mismatch of the used materials causes an adhesive failures under temperature variations.[64, 65] From these studies, the thermocycling might reduce the strength of the dental porcelains. However, Blatz et al. investigated the effect of thermocycling on the bond strength of different veneering porcelains (Cerabien ZR, GC Initial and Lava Ceram) to Lava zirconia. It was found that SBS were significantly different (Cerabien ZR > GC Initial > Lava Ceram). Bond strength were not affects by thermocycling, except for Cerabien ZR, which had significantly higher SBS after thermocycling.[15]

Concerning the pattern of failure, most of the specimen failed from adhesive failure between core and veneering porcelain. From the observation during the BFS test, we found that the veneering porcelain was crushed into pieces before the failure of zirconia core, as shown in Figure 20. We also found that the greater the number of specimen fragments counted, the higher the BFS value that was recorded which consistent with the study of Salimee and Thammawasi.[5]

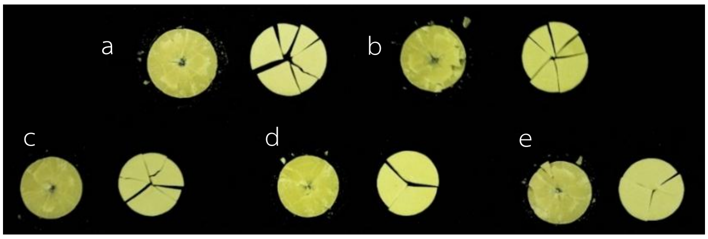

Figure 20. The biaxial flexural strength tested specimens from each group.

(a) CC (b) LV (c) EM (d) CZR (e) VT

Conclusion

Katana with Cercon Ceram Kiss had the highest BFS, followed by Katana with Lava Ceram while the BFS of Katana with Cerabien ZR, IPS e.max Ceram and VITA VM9 were not significantly different but they were lower than the previous two groups.

Zirconia core and veneering porcelain from the same manufacturer did not show good results in terms of BFS. It might not be necessary to match the zirconia core with the same manufacturer’s veneering porcelain as recommended. Matching of veneering porcelain to zirconia core should take into consideration many other influential factors, such as CTE, firing temperature, tempering associated with rapid cooling, the thickness of the veneering porcelain, etc., all of which differ individually from each manufacturer. The dental laboratories should concern the factors above to choose the proper veneering porcelain for the zirconia core material and trial matching would be beneficial.

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APPENDIX

Table 7. Mechanical properties of material used in the study

(Based on manufacturer's recommendation)

Materials	Flexural strength (MPa)	Young modulus (GPa)	Firing temperature (ºC)
Katana zirconia	1,200	205	1,350
Cerabien ZR	69	76	930
Lava Ceram	85	80	810
Cercon Ceram Kiss	84	65	830
IPS e.max Ceram	73.2	95	750
VITA VM9	~100	65.52	910

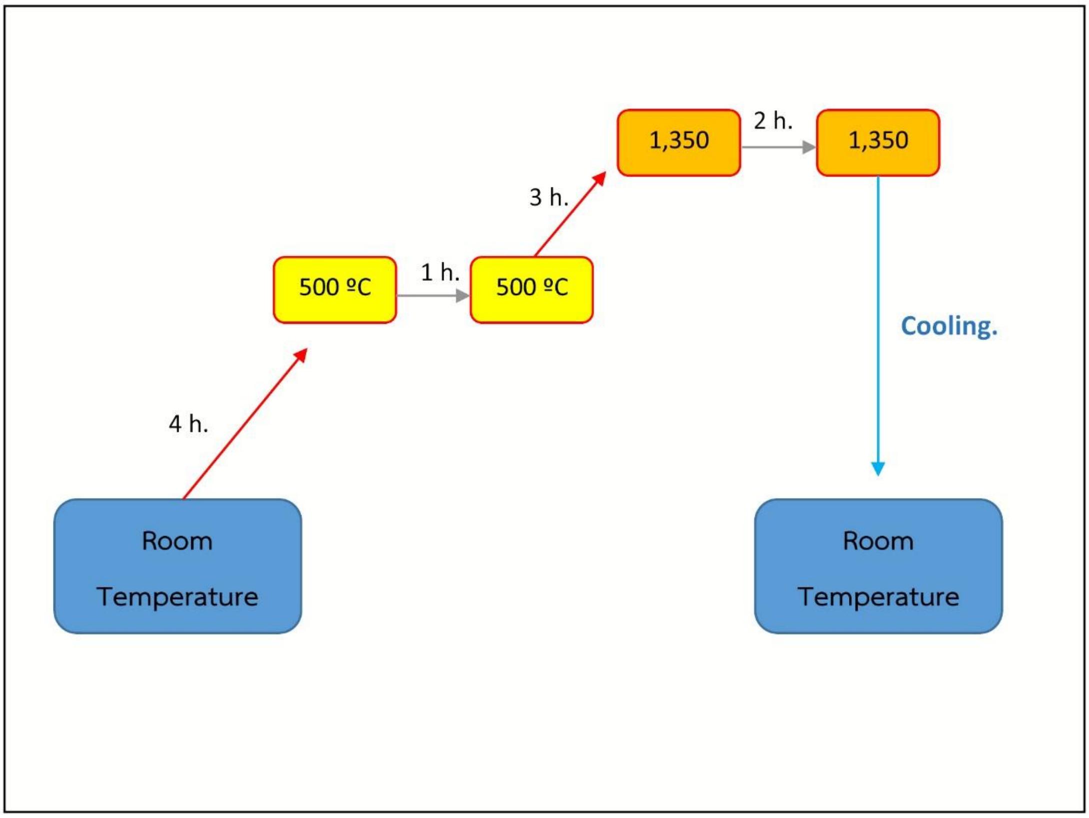

Figure 21. Katana zirconia firing program

(Based on manufacturer's recommendation)

Table 8. Firing schedules for all veneering porcelains

(Based on manufacturers' recommendations)

Veneering porcelains (Dentin)	Dry out time (min.)	Low temperature (ºC)	Heat rate (ºC/min.)	Hold time (min.)	High temperature (ºC)	Cool time (min.)
Cerabien ZR	7	600	45	1	940	4
Lava Ceram	6	450	45	1	810	0
Cercon Ceram Kiss	6	300	55	1 - 2	830	0
IPS e.max Ceram	4	403	40	1	750	0
VITA VM9	6	500	55	1	910	0

VITA

Natravee Chantranikul was born on May 12 1985 in Bangkok, Thailand, where she studied pre-school (Wannabul Kindergarten), primary school (Santa Cruz Convent School) and secondary school (Suksanari School). When she was 16 years old, she went to study in Mahidolwitthayanusorn Science School in Nakorn Pathom province, where science became her interest. After high school, she studied Engineering at Kasetsart University for 1 year but found that she was better suited to becoming a dentist. Then, she took the 2nd entrance examination and moved to study in the Faculty of Dentistry, Chiang Mai University. When she studied as an undergraduate student, she and her research companies carried out research about dental material titled “Anatomical study of spaces under contact areas in periodontal patients” to study the anatomy of the areas under contact in periodontal patients who lived in the north of Thailand for further study about wedge design for developing low-cost wedge that would be appropriate for Thai people. The experience brought her to the world of dental material for first time. After 6 years, she graduated with the bachelor's degree of Doctor of Dental Surgery (DDS.) from the Faculty of Dentistry, Chiang Mai University in 2011 and started her career as a dentist. She worked at a private clinic in Bangkok for 1 year in 2012, then decided to become a prosthodontist and passed the examination for Chulalongkorn University in 2013. Now, she is studying as a master's student in the Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University. Her interest in dental material and her advisor who specialized in dental ceramics brought her to this research.