

**THE EFFECT OF THERMOCYCLING
ON BIAXIAL FLEXURAL STRENGTH
OF DENTAL CERAMICS / DENTINE SYSTEMS**



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OF THE REQUIREMENTS FOR
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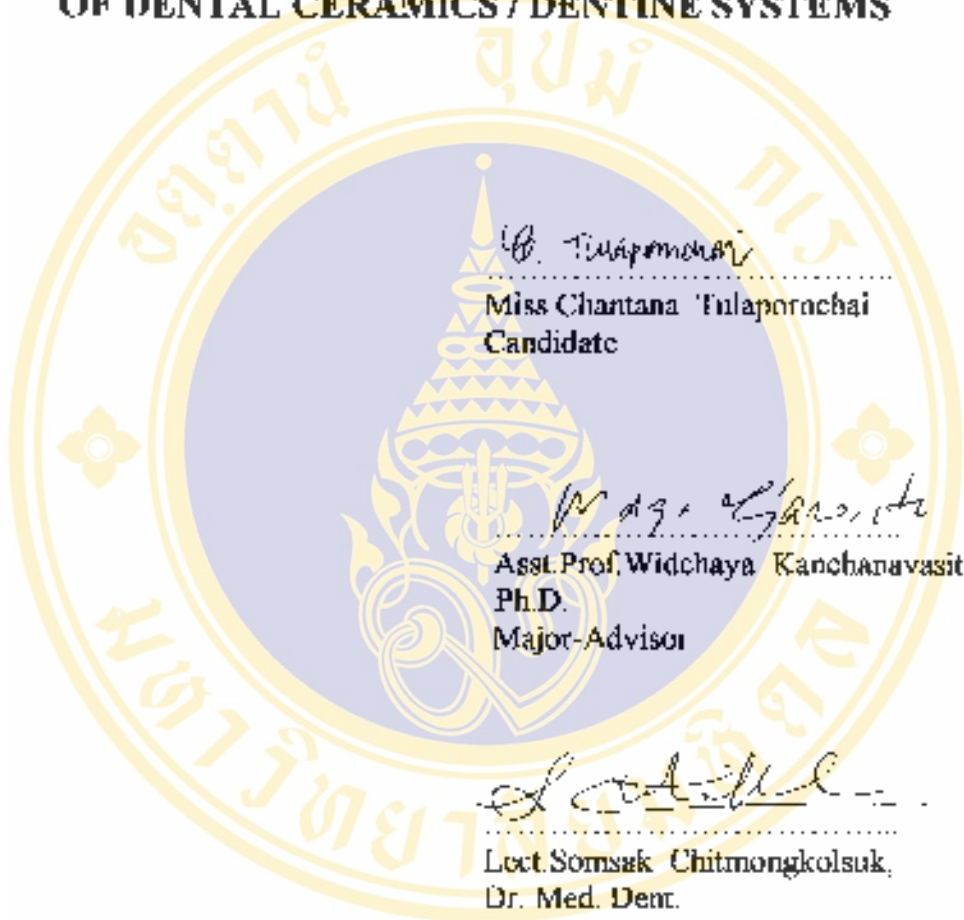
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Thesis
Entitled

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ON BIAXIAL FLEXURAL STRENGTH
OF DENTAL CERAMICS / DENTINE SYSTEMS**



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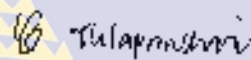
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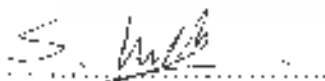
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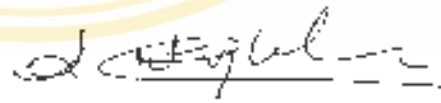
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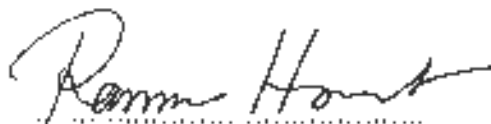
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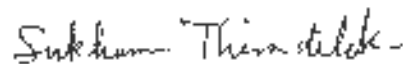
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THE EFFECT OF THERMOCYCLING ON BIAXIAL FLEXURAL STRENGTH OF DENTAL CERAMICS / DENTINE SYSTEMS.

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ABSTRACT

The purpose of this study was to evaluate the biaxial flexural strength of two dental ceramics, Feldspathic porcelain (VMK95, Vita Zahnfabrik, Germany) and Pressable ceramic (IPS Empress, Ivoclar, Liechtenstein) bonded to dentine with a resin cement (Variolink[®] II , Ivoclar, Liechtenstein), both before and after thermocycling. Thirteen disc-specimens were prepared for each test group. The biaxial flexural strengths (piston-on-3-ball) were determined with an universal testing machine at a crosshead speed of 1 mm./min. until broken.

The mean biaxial flexural strength of Vita VMK95, both before and after thermocycling, was not significantly different from that of IPS Empress ($p>0.05$).

The mean biaxial flexural strength of Vita VMK95 was not significantly different, when comparing results before and after thermocycling ($p>0.05$), while that of IPS Empress after thermocycling was significantly lower than before thermocycling ($p<0.05$).

Delamination at resin cement/dentine interface of the ceramics/dentine systems occurred in the 24 of 26 Vita VMK95 specimens and 22 of 26 IPS Empress specimens. After thermocycling, the number of delaminations increased by 2 of the 13 specimens in both Vita VMK95 and IPS Empress groups. Furthermore, the number of delaminations that occurred in Vita VMK95 and IPS Empress, both before and after thermocycling was not significantly different.

This study suggests that both Vita VMK 95 and IPS Empress for bonding to dentine with a resin cement may be the materials of choice for patients. However, IPS Empress was susceptible to thermocycling and showed a lower biaxial flexural strength after thermocycling, but it was not significantly different from Vita VMK 95.

KEY WORDS : DENTAL CERAMICS, BIAXIAL FLEXURAL STRENGTH

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ผลของเทอร์โมไซคลิกต่อกำลังดัดขวางในแนวสองแกนของเดนทัลเซรามิกที่ยึดติดกับเนื้อฟัน
(THE EFFECT OF THERMOCYCLING ON BIAXIAL FLEXURAL STRENGTH
OF DENTAL CERAMICS / DENTINE SYSTEMS)

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อประเมินผลของเทอร์โมไซคลิกต่อค่ากำลังดัดขวางในแนวสองแกนของเดนทัลเซรามิก 2 ชนิด ได้แก่ วี เอ็ม เค 95 และไอ พี เอส เอ็มเพรส ที่ยึดติดกับเนื้อฟัน ด้วยเรซิน ซีเมนต์ยี่ห้อเวริโอลิงค์ ทุ โดยเตรียมชิ้นตัวอย่าง 13 ตัวอย่าง สำหรับแต่ละกลุ่มทดลอง จากนั้นนำไปทดสอบหาค่ากำลังแรงดัดในแนวสองแกนด้วยเครื่องทดสอบสากลที่ความเร็วในการออกแรงกด 1 มิลลิเมตรต่อนาที จนกระทั่งชิ้นตัวอย่างแตกหัก

ค่ากำลังแรงดัดในแนวสองแกนของวี เอ็ม เค 95 และไอ พี เอส เอ็มเพรสมีค่าไม่แตกต่างกันอย่างมีนัยสำคัญ ($p > 0.05$) ทั้งก่อนและหลังเทอร์โมไซคลิก และค่ากำลังแรงดัดในแนวสองแกนของวี เอ็ม เค 95 ก่อนและหลังเทอร์โมไซคลิกไม่แตกต่างกันอย่างมีนัยสำคัญ ($p > 0.05$) ขณะที่ไอ พี เอส เอ็มเพรส มีค่ากำลังแรงดัดในแนวสองแกนหลังเทอร์โมไซคลิก ลดลงอย่างมีนัยสำคัญ ($p < 0.05$)

การแยกของเซรามิกจากเนื้อฟัน เป็นแบบดีลามิเนชันที่รอยต่อระหว่างเรซิน ซีเมนต์และเนื้อฟัน ซึ่งในวี เอ็ม เค 95 พบ 24 ใน 26 ตัวอย่าง และไอ พี เอส เอ็มเพรส พบ 22 ใน 26 ตัวอย่าง และหลังจากเทอร์โมไซคลิก พบมากขึ้น 2 ใน 13 ตัวอย่างทั้งสองกลุ่ม นอกจากนี้ วี เอ็ม เค 95 และไอ พี เอส เอ็มเพรส ยังเกิดดีลามิเนชันไม่แตกต่างกันอย่างมีนัยสำคัญทั้งก่อนและหลังเทอร์โมไซคลิก

จากผลการศึกษานี้แสดงให้เห็นว่าทั้ง วี เอ็ม เค 95 และ ไอ พี เอส เอ็มเพรส ที่ยึดติดกับเนื้อฟันด้วยเรซิน ซีเมนต์ เป็นทางเลือกหนึ่งสำหรับผู้ป่วยในแง่ของค่ากำลังดัดขวางในแนวสองแกน แม้ว่าไอ พี เอส เอ็มเพรส จะมีค่ากำลังแรงดัดในแนวสองแกนลดลงหลังจากเทอร์โมไซคลิก แต่ไม่แตกต่างจากวี เอ็ม เค 95 อย่างมีนัยสำคัญ

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LIST OF ABBREVIATIONS



µm.	micrometre
mm.	millimetre
mg.	milligram
g.	gram
ml.	millilitre
N	Newton
kN	kiloNewton
MPa	megaPascal
GPa	gigaPascal
min.	minute
Ltd.	Limited
Co.	Company
et al.	et alii
cont.	continue
MA	Massachusetts
Fig.	Figure
°C	degree celsius
SD	standard deviation

CHAPTER I

INTRODUCTION

All-ceramic dental restorations are popular because of their superior esthetics that closely resembles natural tooth structure. However, all-ceramic restorations are susceptible to fracture as a result of their brittle nature and stresses imparted to them during use.

Recently, a new glass-ceramic restorative system – IPS Empress – has been introduced. In contrast to the previous techniques, such as sintering and casting, this metal-free restorative system uses a thermoforming or heat-pressing procedure, where an investment mould is filled with heat-plasticized ceramics. Porosities and inhomogeneities that occur with sintering are avoided. In addition, the concept of dispersion strengthening is realized by guided leucite crystallization. Due to preceramming during production, the leucite crystals are already present in the delivered ceramic ingots, therefore no ceramming process is necessary to induce crystal growth as compared with cast glass-ceramics like Dicor.

Empress glass-ceramic material is basically a feldspathic ceramic with the following composition (in weight %): 63 SiO₂, 17.7 Al₂O₃, 11.2 K₂O, 4.2 Na₂O, 1.6 CaO, 0.7 BaO, 0.6 B₂O₃, 0.4 CeO₂, 0.2 TiO₂. The ceramic material is delivered in cylindrical ingots of 10 mm. height and 11 mm. diameter with different opacities and shades for a paint-on technique where the colour and characterization is mainly achieved by external shading and glazing. For a layering technique, a shaded crown coping is first pressed and final shape and colour are reconstructed by adding layered porcelain in a conventional sintering procedure. According to the manufacturer, IPS Empress ceramics are suitable for single crowns, inlays, onlays and veneers. (1,2)

Mechanical strength is one of the important factors that controls the clinical success of dental restorations. Complex stress distributions consisting of compressive, tensile, and shear stresses are present in most specimens under practical condition. The biaxial flexure test has been used for the determination of fracture characteristics of brittle materials, especially glasses and ceramics. The test has been recently included in ISO 6872 for dental ceramics. (3) The strength measurement of brittle materials under biaxial flexure conditions rather than uniaxial flexure is often considered more reliable, because the maximum tensile stresses occur within the central loading area and spurious edge failures are eliminated. (4) The stress conditions occurring in the materials are more representative of those occurring in the restorations.

The piston-on-three-ball test concerns the supporting of a disc specimen by three-ball bearing near its periphery but equi-distant from a load piston. The test fixture design compensates for the lack of perfectly plane and parallel surfaces and allows the testing of slightly warped specimens. (5) The use of disc specimens in biaxial flexure testing represents a surface to volume ratio closer to that of a crown or a veneer than that of a beam specimen, with the effects of specimen geometry and volume on strength value minimized. (6) In addition, the biaxial test models simulate the loading on a dental restoration during chewing more closely than the uniaxial test. (7)

Thermal cycling methods are used for accelerated testing in evaluating microleakage and stability of bonding between prosthetic appliances and the prepared tooth. Thermocycling is the *in vitro* process of subjecting a restoration and tooth to temperature extremes that conform to those found in the oral cavity. (8)

Previous studies concerning uniaxial and biaxial flexural strength of dental ceramics themselves have been reported in the literature, but literature concerning biaxial flexural strength of dental ceramics bonded to tooth structure is rare. (1,2,6,9-18) Thus, it is interesting to determine biaxial flexural strength of some dental ceramics, which are commonly used in dental practice, bonded to dentine with a resin cement, both before and after thermocycling for ceramics.

Objective of the study

To evaluate the biaxial flexural strength of some dental ceramics bonded to dentine with a resin cement, both before and after thermocycling.

Research hypothesis

1. There are no significant difference among the biaxial flexural strength of two types of dental ceramics when they were bonded to dentine.
2. There are no significant difference among the biaxial flexural strength of each ceramics/dentine system before and after thermocycling.

Statistical hypothesis

1. H_0 : Mean biaxial flexural strengths of two types of dental ceramics when they were bonded to dentine with a resin cement are equal at the 5% significance level.

H_1 : Mean biaxial flexural strengths of two types of dental ceramics when they were bonded to dentine with a resin cement are not equal at the 5% significance level.

$$H_0 : \mu_i = \mu_j$$

$$H_1 : \mu_i \neq \mu_j$$

where $i = \text{Vita VMK95}$, $j = \text{IPS Empress}$

2. H_0 : Mean biaxial flexural strengths of each ceramics/dentine system, both before and after thermocycling, are equal at the 5% significance level.

H_1 : Mean biaxial flexural strengths of each ceramics/dentine system, both before and after thermocycling, are not equal at the 5% significance level.

$$H_0 : \mu_{\text{before}} = \mu_{\text{after}}$$

$$H_1 : \mu_{\text{before}} \neq \mu_{\text{after}}$$

Clinical implications

1. Biaxial flexural strength of two types of dental ceramics when they were bonded to dentine with a resin cement, both before and after thermocycling, can be determined.
2. The results of this study will be beneficial to dentists for selecting dental ceramics which provide high biaxial flexural strength, when they are used clinically.



CHAPTER II

LITERATURE REVIEW

Dental ceramics play an important role in the fabrication of the most esthetic fixed restorations. Translucency, light transmission, and biocompatibility give dental ceramics highly desirable esthetic properties. In addition, they exhibit extreme chemical durability, and low thermal conductivity. However, the brittle nature of dental porcelains, which are basically noncrystalline glasses composing of structural units of silicon and oxygen (SiO_4 tetrahedra), limit the use of these materials. (19-21)

Dental porcelain is defined as a white, translucent ceramic that is fired to glazed state. Dental porcelains are classified according to fusion temperature as follows:

1. High fusion 1,290°C to 1,370°C
2. Medium fusion 1,090°C to 1,260°C
3. Low fusion 870°C to 1,070°C
4. Ultra-low fusion <850 °C (22)

The medium-fusion and high-fusion types are used for the production of the denture teeth. The low-fusion and ultra-low-fusion porcelains are used for crown and bridge construction.

Various ceramic restorative materials are widely used in dentistry and must fulfill the criteria of high strength, suitable fit, and acceptable esthetics. (14)

Feldspathic porcelain is one of the most commonly used dental ceramic materials. Feldspathic porcelain can be used for small restorations such as inlays, but generally requires metal reinforcement for fixed partial restorations. Conventional feldspathic porcelains are composed primarily of SiO_2 (silica, 64%) and Al_2O_3

(alumina, 18%), with various amounts of K_2O (potash) and Na_2O (soda, 8% to 10%) to control expansion. The flexural strength of feldspathic porcelain is quite low, generally in the range of 60 to 70 MPa, which is one of the primary reasons for the use of a metal substructure to reinforce the ceramic restoration. Unfortunately, metal prevents light transmission and decreases reproduction of the depth of color and vitality of natural teeth. (23)

McLean and Hughes (24) developed an aluminous porcelain specially for use as an all-ceramic crown material. A high-strength porcelain containing 50% by weight fused alumina crystals formed the core onto which a thermally matched veneer porcelain was baked. This resulted in a dental ceramic material having a range of flexural strength from 100 to 130 MPa. Although this was an improvement in strength, light transmission was limited because of the alumina crystals.

In recent years, IPS Empress systems have been introduced. This system is indicated for inlays, onlays, veneers and complete-coverage crowns. The system relies on a leucite-reinforced glass ceramic that is heat-pressed into a phosphate-bonded investment, forming either a core or a completed restoration. Unlike previous glass-ceramics, the IPS Empress system does not require a second heating cycle to initiate the crystalline phase of leucite crystals. Instead, they are formed within the glass matrix of feldspathic porcelain throughout various temperature cycles. (12,25)

Leucite ($K_2O-Al_2O_3-4SiO_2$) is a material formed by the incongruent melting of feldspar ($K_2O-Al_2O_3-6SiO_2$), and it is used in manufacturing of many dental porcelains. Leucite-based frits have been used since the early 1960s in the manufacture of materials for metal ceramic applications. The high-expanding leucite raises the thermal expansion of the bulk porcelain to a level where it is compatible with the metal substrate. More recently, leucite has been used in all-ceramic materials, not only for thermal compatibility, but also as a reinforcing material. (26) The IPS Empress ceramic material for the staining technique contains 40-45% by weight of leucite (26), which has a particle size of $1.9 \pm 1.8 \mu m^2$, evenly distributed in the glass matrix. (15) For the layering technique, leucite crystal size of $2.4 \pm 2.6 \mu m^2$, with

leucite crystal agglomerates interspersed with discrete leucite crystals, is distributed in the glass matrix 25.4% by weight. (15)

The advantages of this ceramic are the lack of metal or an opaque ceramic core, moderate flexural strength, excellent fit, excellent esthetics, chemical stability, thermal conductivity and coefficient of thermal expansion similar to enamel and dentine. The abrasion resistance is also similar to that of natural enamel. The disadvantages are its potential to fracture in posterior areas and the need for special laboratory equipment. (21) Due to relatively high leucite content and pressure forming process, the flexural strength of porcelain formed by this process is around 220 MPa. (21)

The IPS Empress uses the “lost wax technique” for producing the mould. The object is modeled in wax and then invested. After the muffle is preheated, the leucite-reinforced ceramic ingot is pressed automatically into the mould by means of the IPS Empress EP 500 pressing furnace at a temperature of 1,180°C for layering technique material and 1,050°C for paint-on material, with a pressure of 5 bar. After removal of the investment, the outer part of the restoration is finished to the required anatomical specifications in order to achieve good esthetics. The restoration is modified by layering it with incisal and transparent materials. The manufacturer claims that glazing increases the mechanical strength of the restorations. (12)

Fairhurst et al. (5) investigated the strengthening of feldspathic porcelain by analyzing the effect of polishing and self-glazing. They reported no difference in strength between glazed and as-ground specimens. Similarly, Sherrill and O'Brien (27), showed that the transverse strength of glazed porcelain and ground porcelain was not statistically significant different.

Cattel et al. (18) observed that the surface finish of the heat pressed specimen appeared to have little effect on the mean biaxial flexural strength, as no statistical difference between heat pressed polished group and sandblasted group was noted.

The properties of the IPS Empress pressed glass ceramic, which are summarized in Table 2-1 (25,28), fully satisfy the ISO standard 6872 for dental ceramics and have contributed to the success of this new metal-free materials system for dental applications.

Table 2-1 Properties of the IPS Empress pressed glass ceramic (25,28)

Properties	IPS Empress
Mechanical : ─ Flexural strength ─ Fracture toughness ─ Abrasion behavior	120 MPa $1.3 \text{ MPa} \cdot \text{m}^{0.5}$ $21.8 \pm 8.8 \mu\text{m} / 5 \text{ years (29)}$
Optical : ─ Translucency	Contrast ratio 0.64-0.72 (30) (0.0 = transparent, 1.0 = opaque)
Thermal : ─ Coefficient of linear thermal expansion (α)	layering technique: $14.90 \pm 0.5 \cdot 10^{-6} / ^\circ\text{C}$ or paint-on technique: $18.25 \pm 0.5 \cdot 10^{-6} / ^\circ\text{C}$ enamel : $16.96 \pm 3.83 \cdot 10^{-6} / ^\circ\text{C}$ (31) dentine : $10.59 \pm 2.38 \cdot 10^{-6} / ^\circ\text{C}$ (31)
Chemical : ─ Solubility	$< 200 \mu\text{g}/\text{cm}^2$
Technical : ─ Pressing temperature ─ Application of the sintered glass ceramics (dentine and incisal materials)	$1,075 ^\circ\text{C}$ for paint-on technique, or $1,180 ^\circ\text{C}$ for layering technique $910 ^\circ\text{C}$

Previous studies showed variation in the biaxial flexural strength of IPS Empress (Table 2-2). (1,6,12-18) The variation in the biaxial flexural strength of IPS

Empress depended on disc dimension, dimension of loading piston, use of a load-distributing film, crosshead speed, surface finish, Poisson's ratio, and the biaxial flexural strength equation used.

Table 2-2 The biaxial flexural strength of IPS Empress (MPa)

Study	Uctasli et al. 1996 (12)	Zeng et al. 1996 (13)	Wagner et al. 1996 (14)	Cattel et al. 1997 (6)	Pröbster et al. 1997 (1)	Cattel et al. 1999 (15)	Wen et al. 1999 (16)	Gorman et al. 2000 (17)	Cattel et al. 2001 (18)
thickness of specimen (mm.)	2	2.00±0.01	2	2	-	2	1.2±0.2	1.5	2
diameter of support circle (mm.)	10	10	10	10	10	10	12	16	10
diameter of loaded area (mm.)	3	1.41	1.4	1.62	3.2	1.58	1.2	2.54	1.58
diameter of specimen (mm.)	16	16.18±0.10	16	14	-	14	13.0	20	14
Poisson's ratio	0.25	0.25	0.25	0.23	0.28	0.25	0.25	0.23	0.25
crosshead speed (mm./min.)	1	0.5	1	0.15	0.1	0.15	1	2	0.15
Biaxial flexural strength (MPa)									
: Layering technique (dentine shaded), Weibull modulus	99±16, 6.4	-	-	133.5 ± 21.5, 6.60	136.0± 19.8, -	120.1 ± 20.5, 6.1	-	134.4± 11.5,	120.1± 20.5, 6.1
: Paint-on technique (unshaded), Weibull modulus	160± 19, 9	104.0 ± 23.3, 5	-	-	160.2± 33.9, -	135.8 ± 16.0, 10.2	-	-	-
: IPS Empress, Weibull modulus	-	-	134± 22, 3.65	-	-	-	115± 24, 5.64± 0.27	-	-

All of these studies reported that the leucite-reinforced (pressable) ceramics provide superior mechanical properties over conventional feldspathic porcelain. Since the absolute values of material properties vary depending on the testing methods and conditions, a comparison of properties under similar conditions of testing is important.

Ban and Anusavice (4) reported that the biaxial flexural strength of zinc phosphate cement was insensitive to specimen size, diameter of the piston, use of a load-distributing film, and loading speed. The mean biaxial flexural strength of the brittle dental materials, such as zinc phosphate cement, feldspathic porcelain (Jelenko), and resin composite (Herculite XR), were higher than the mean four-point flexure strength. In addition, SEM images showed that the fracture surface of specimens produced by four-point flexure showed large pores, which were associated with the crack origin, while that for biaxial flexure test showed a homogeneous structure having small pores.

A range of Poisson's ratio values exists in the literature for dental ceramics. Anusavice and Hojjatie (32) analyzed this range of values and revealed that the influence of Poisson's ratio for the glass-ceramic material on the maximum tensile stress was small.

Drummond et al. (33) studied the modulus of rupture (four-point loading) of a magnesia alumina spinel (Cerestore™) at loading rates of 0.05, 0.5, and 5.0 mm./min. They found that the modulus of rupture was significantly lower for the specimens tested in air at 0.05 mm./min. when compare at 5.0 and 0.5 mm./min. This decrease is attributed the more time available for the microcracks present on the surface to grow and lead to catastrophic failure.

Dorsch et al. (34) investigated the influence of specimen thickness (1.0 mm., 1.5 mm., and 2.0 mm.), crosshead speed (0.2, 1.0, and 5.0 mm./min.) and surface treatment (ground and glazed) on biaxial strength of IPS Empress. They found that the biaxial flexural strength of IPS Empress were insensitive to crosshead speed and specimen thickness. In addition, glazing did not reduce the standard deviation.

Effect of thermocycling on bond strength

Kato et al. (35) showed the shear bond strength of feldspathic porcelain (G-Cera Cosmotech II Porcelain) bonded together with various luting cements decreased after thermocycling.

Mutsumura et al. (36) evaluated the shear bond strength of feldspathic porcelain (VMK68) bonded together with six combinations of three silane priming and two luting cements both before and after thermocycling. They noted that the shear bond strength reduced after thermocycling.

On the contrary, Kamada et al. (37) studied the effect of various ceramic surface treatments on the shear bond strengths of four resin luting agents to Cerec 2 Vitablocs Mark II, both before and after thermocycling. They reported that the strengths between before and after thermocycling were not significantly different for any of the four resin luting agents.

Wolf et al. (38) reported that the tensile bond strength of composite (Herculite XR) to porcelain (Ceramco II) using four porcelain bonding agents decreased after thermocycling.

Gemalmaz and Ergin (39) reported that the failure rate of 37 IPS Empress crowns luted with Variolink II was 2.7% after 21 to 41 months in clinical service. Fradeani and Aquilano (40) also reported a failure rate of 3.5% at 37 months of 144 IPS Empress crowns.

Grossman and Nelson (41) suggested that the use of a resin cement might reduce the percentage of the failure by changing the flaw geometry as a consequence of the acid-etching procedure or by reducing stress at the flaw tips by transferring stress to the bonding agent. A resin layer that is bonded to the flawed surface changes the ceramic material to a ceramic-resin composite. Under loading, a fraction of the stress at the original flaw tip that was adjacent to an air space is now transferred to the resin thereby reducing to susceptibility of the ceramic to crack initiation. Furthermore,

acid-etching reduces the stress concentrations at the flaw tips by changing the shape of the flaws. The ability of resin cement to transfer stresses across the tooth-crown interface was also reported by Grossman. (42)

The use of ceramic materials for esthetic dental restoration has increased substantially. This trend is attributed mainly to improvements in the properties of ceramics and porcelain bonding systems. Current ceramic bonding systems are based on mechanochemical bonding between the luting material and ceramic restorations. Porcelain surface preparation for mechanical retention are grinding, abrasion with a diamond rotary instrument, air-abrasion with alumina, and etching with acidulated phosphate fluoride or hydrofluoric acid. The application of silane couplers served as the chemical surface preparation for bonding porcelain. The use of silane primers considerably enhanced the bond strength of porcelain. (35) The combination of sandblasting and etching, therefore, are necessary in many clinical instances.

All-ceramic restorations also benefit from adhesive bonding to etched tooth structure, which is thought to increase their overall strength. The overall factors being associated with the reduction of ceramic surface flaws by the resin and the creation of surface compression by the polymerization shrinkage of composite luting cements and the ability of the composite lute to act as a shock absorber and transfer the occlusal load to the supporting tooth structure. (18)

The clinical survival of dental ceramic restorations is controlled by the density, severity and location of critical flaws. Initiating sites for the failure of dental ceramic restorations are small structure flaws, such as voids and cracks. Because of their stress-raising effects, such flaws have a strength-reducing effect that will adversely affect the durability of a ceramic restoration. Under the influence of cyclic loading, residual stresses, and the corrosive nature of oral fluids, crack growth is possible. Over time, the fracture resistance of the ceramic may decrease and the resulting can fracture under normal loads. (10)

Kelly et al. (43) reported that fractographic analysis of five Dicor glass-ceramic crowns that failed clinically revealed that the fractures were initiated at the internal surface, commonly at an internal line angle. The fracture stress calculated for a molar crown was 45 MPa. It is not known that which cement was used for these clinically failed crowns provided by local dentists.

Kelly et al. (44) observed that the majority of the crown failure were initiated at the internal surface, showing that this surface was placed under the greatest tensile stress or that it was probably the location of flaws and/or voids. Anusavice and Hojjatie (32) found that stress was concentrated at the internal crown surface.

Kelly et al. (45) studied finite element modeling and analysis and in vitro testing indicated the importance of the core-veneer interface, in terms of a site for defects, differences in elastic modulus and thermal differences between different ceramic media.

Summary of the literature review

1. Dental ceramic materials exhibit many desirable material properties, including biocompatibility, esthetics, diminished plaque accumulation, low thermal conductivity, abrasion resistance, and color stability. However, brittleness and low tensile strength are weak points of ceramic materials.
2. Dental porcelains are classified according to fusion temperature as follows: high fusion, medium fusion, low fusion and ultra-low fusion.
3. IPS Empress system have been introduced, which relies on a leucite-reinforced glass ceramic that is heat-pressed. It was claimed by its manufacturer to have higher flexural strength.
4. The variation in the biaxial flexural strength of IPS Empress depended on disc dimension, dimension of loading piston, use of a load-distributing film, crosshead speed, surface finish, Poisson's ratio, and the biaxial flexural strength equation used.
5. There have been relatively few studies of the effect of thermocycling on the bond strength of dental ceramics bonded to dentine.

CHAPTER III

MATERIALS AND METHODS

MATERIALS

1. Lower anterior bovine teeth
2. Feldspathic porcelain (VMK 95, A3 Dentine Powder Lot No. 6064I, Modelling fluid Lot No. B74344, Vita Zahnfabrik, Germany)
3. Pressable ceramic (IPS Empress TC5 Lot No. C42678, Ivoclar, Liechtenstein)
4. Investment (IPS Empress 2 Special Investment: Powder Lot No. D97026, Liquid Lot No. E97112, Ivoclar Vivadent AG, Liechtenstein)
5. Resin cement (Variolink[®] II Professional set Lot No. E25000, Ivoclar, Liechtenstein) contains
 - Phosphoric acid 37% (Total Etch[™] etching gel, Lot No. E14480)
 - Monobond-S (Lot No. E24026)
 - Heliobond (Lot No. E10061)
 - Syntac[®] Primer (Lot No. E09369)
 - Syntac[®] Adhesive (Lot No. E14237)
 - Variolink[®] II Base paste A3 (Lot No. E18678)
6. Hydrofluoric acid 4.9% (IPS Ceramic etching gel Lot No. E52923, Ivoclar, Liechtenstein)
7. Bake porcelain kit
8. Ivory inlay casting wax (Kerr Corporation, USA)
9. 240-grit Silicon carbide paper (Swallow brand)
10. Diamond disc (EDENTA AG, Switzerland)
11. Blade
12. Distilled water

APPARATUS

1. Precision cutting machine (Accutom-50, Struers A/S, Denmark) with diamond cut-off wheel
2. Dental porcelain furnace (Vacumat 2500, Vita, Zahnfabrik.H.Ranter GmbH&Co., Germany)
3. EP 500 press furnace (Ivoclar Co., Schaan, Liechtenstein)
4. Electric burnout furnace
5. Weighing machine with the accuracy of ± 0.1 mg. (AB204, Mettler -Toledo Ltd., Thailand)
6. Electronic digital caliper with the accuracy of ± 0.01 mm.
7. Sand-blasting machine (ECO, Dentalfarm, Italy)
8. Curing light source (XL3000, 3M, model 5530 BF, Germany)
9. Temperature controlled bath TC400 (HB3030, HB2545, Faculty of Science, KMITL)
10. Universal testing machine (Instron model 5566, Instron Corporation, Canton, MA, USA)
11. Biaxial flexure testing jig (piston-on-3-ball)
12. Stainless steel mold with 16 millimeters in diameter and 1.6 millimeters in thickness
13. Micromotor (MF-PERFECTA 9975-E, W&H Dentalwerk, Austria)
14. Steel mass 1 kilogram with 59.5 millimeters in diameter and 45.5 millimeters in height
15. Temperature controlling container capable of maintaining temperature at $37^{\circ} \text{C} \pm 1$ temperature (SHEL LAB Model 1545, Sheldon Manufacturing, Inc., Oregon, USA)

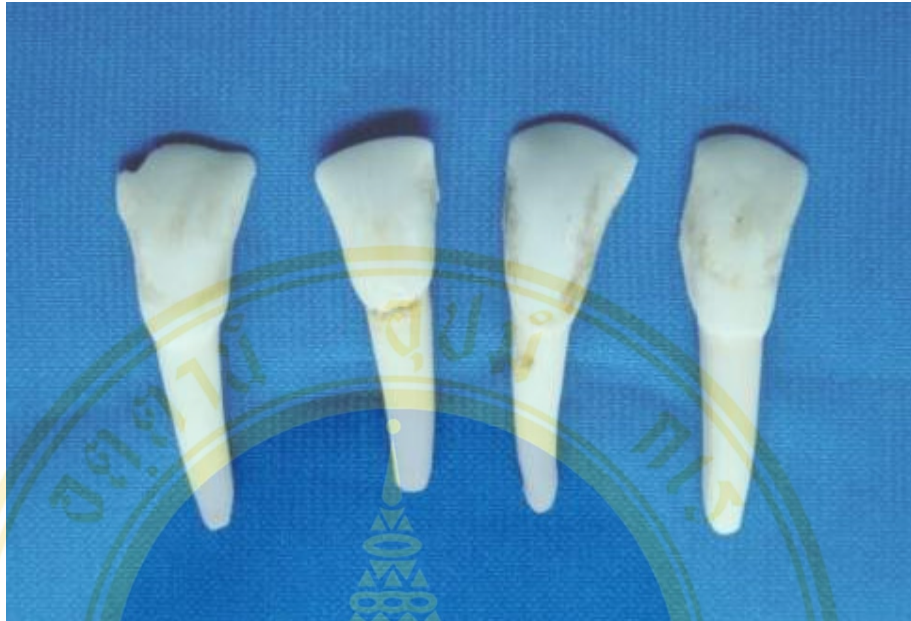


Fig 3-1 Lower anterior bovine teeth



Fig. 3-2 Feldspathic porcelain (VMK 95, Vita Zahnfabrik, Germany)



Fig. 3-3 Pressable ceramic (IPS Empress, Ivoclar, Liechtenstein)



Fig. 3-4 Investment (IPS Empress 2 Special Investment, Ivoclar Vivadent AG, Liechtenstein)



Fig. 3-5 Resin cement (Variolink[®] II Professional set, Ivoclar, Liechtenstein)



Fig. 3-6 Hydrofluoric acid 4.9% (IPS Ceramic etching gel, Ivoclar, Liechtenstein)



Fig. 3-7 Bake porcelain kit



Fig. 3-8 Ivory inlay casting wax (Kerr Corporation, USA)



Fig. 3-9 240-grit Silicon carbide paper

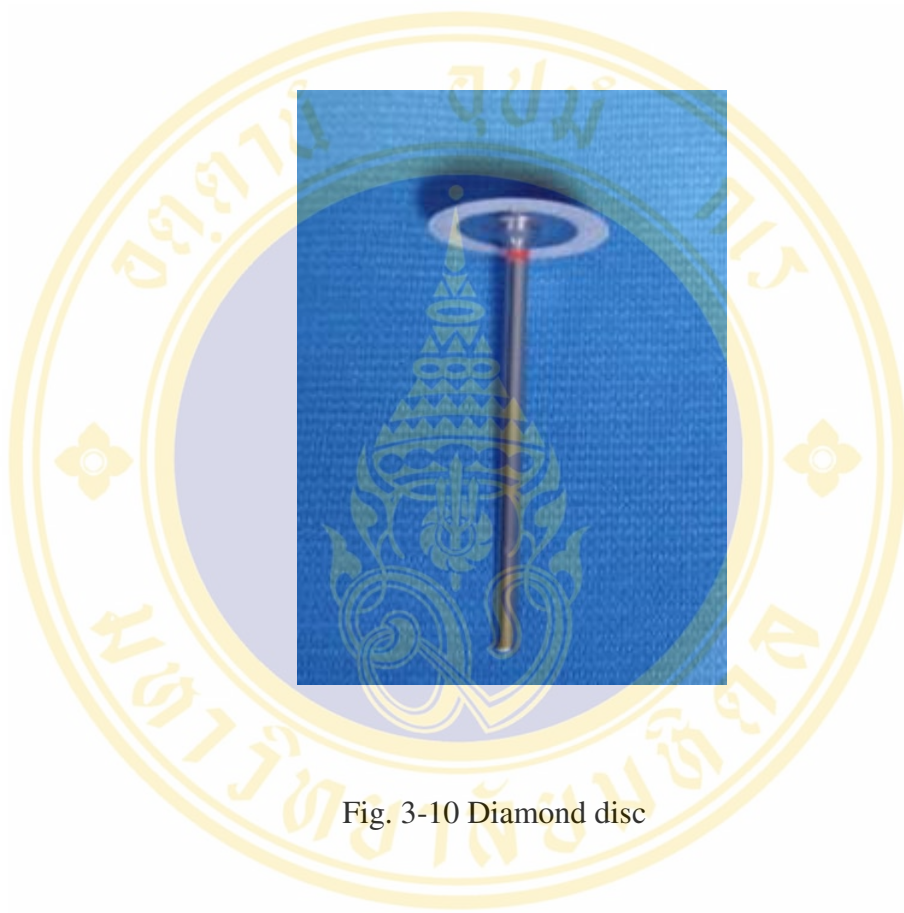


Fig. 3-10 Diamond disc



Fig. 3-11 Precision cutting machine (Accutom-50, Struers A/S, Denmark)
with diamond cut-off wheel



Fig. 3-12 Dental porcelain furnace (Vacumat 2500, Vita, Zahnfabrik.H.Ranter GmbH&Co., Germany)



Fig. 3-13 EP 500 press furnace (Ivoclar Co., Schaan, Liechtenstein)

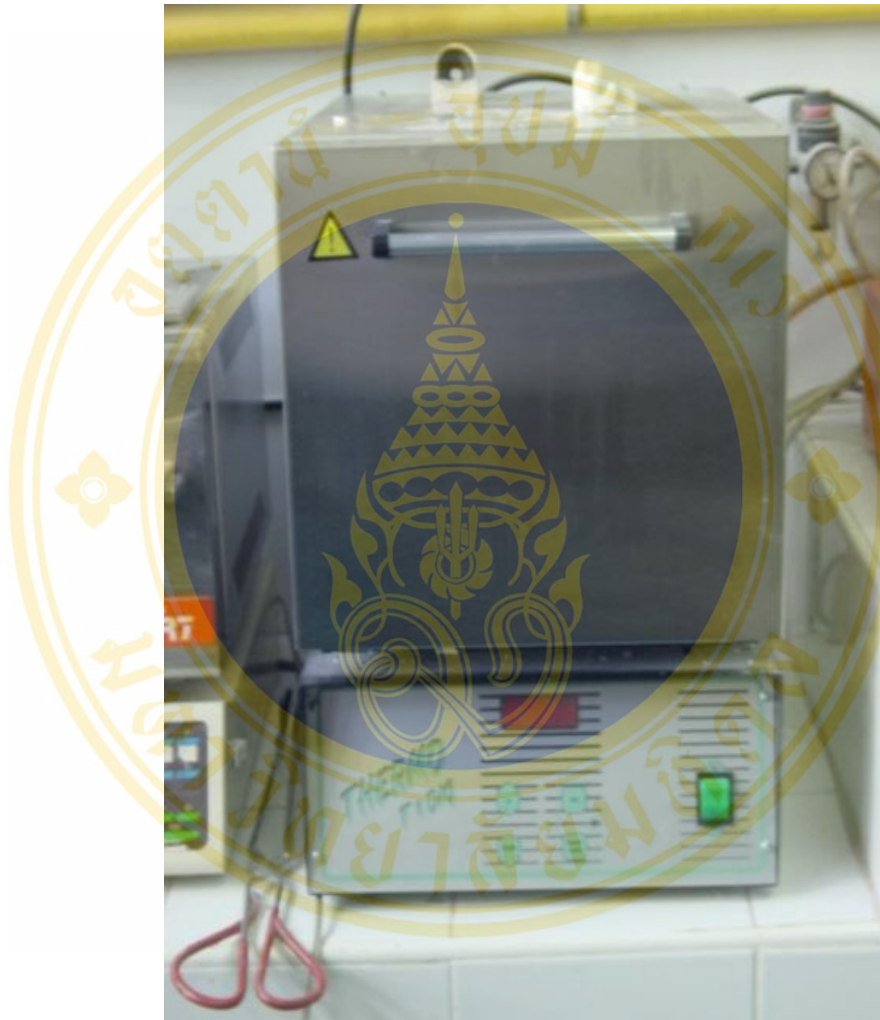


Fig. 3-14 Electric burnout furnace



Fig. 3-15 Weighing machine with the accuracy of ± 0.1 mg.
(AB204, Mettler -Toledo Ltd., Thailand)



Fig. 3-16 Electronic digital caliper with the accuracy of ± 0.01 mm.



Fig. 3-17 Sand-blasting machine (ECO, Dentalfarm, Italy)



Fig. 3-18 Curing light source (XL3000, 3M, model 5530 BF, Germany)

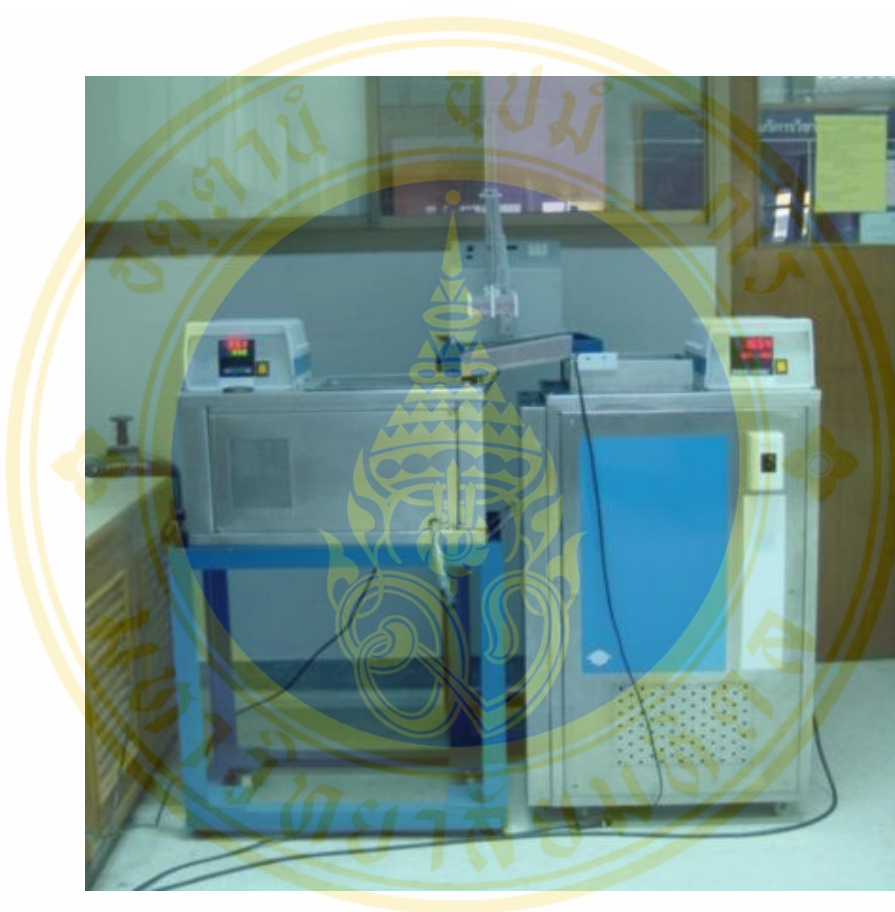


Fig. 3-19 Temperature controlled bath TC400 (HB3030, HB2545, Faculty of Science, KMITL)



Fig. 3-20 Universal testing machine (Instron model 5566,
Instron Corporation, Canton, MA, USA)



Fig. 3-21 Biaxial flexure testing jig (piston-on-3-ball)

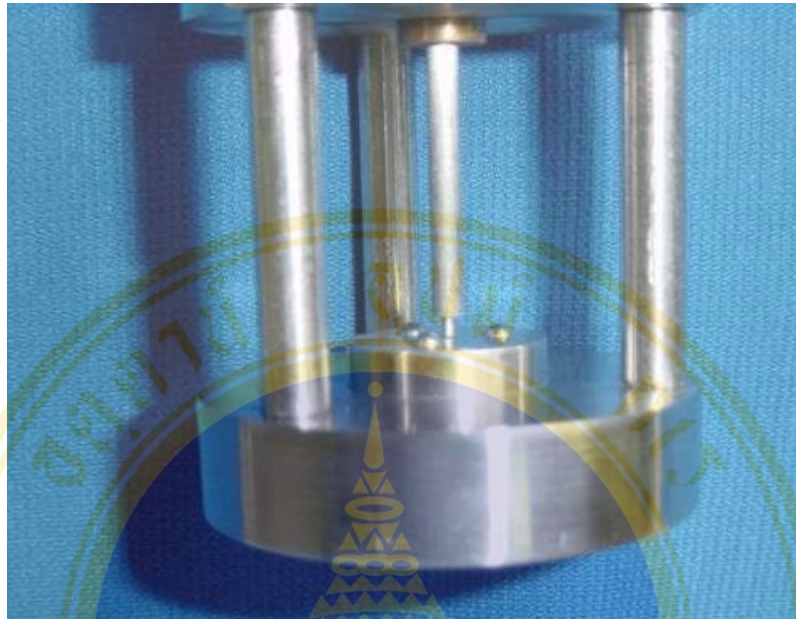


Fig.3-22 Biaxial flexure testing jig (piston-on-3-ball)



Fig.3-23 Micromotor (MF-PERFECTA 9975-E, W&H Dentalwerk, Austria)



Fig. 3-24 Stainless steel mold for preparation of feldspathic porcelain specimen
(top view)



Fig. 3-25 Stainless steel mold for preparation of feldspathic porcelain specimen
(lateral view)



Fig. 3-26 Steel mass 1 kilogram



Fig. 3-27 Temperature controlling container capable of maintaining temperature at $37^{\circ}\text{C} \pm 1$ temperature

(SHEL LAB Model 1545, Sheldon Manufacturing, Inc., Oregon, USA)

METHODS

1. Preparation of bovine teeth specimens

Fifty-four disc-shaped dentine specimens, 1 mm. in thickness and 12 mm. in diameter, were prepared from bovine teeth. Two specimens were used to determine the elastic modulus.

Lower anterior bovine teeth, aged one month but less than six months after extraction, were used. Prior to storage, the teeth were thoroughly washed in running water and all blood and adherent tissue were removed. Teeth were stored in distilled water in a refrigerator at 4°C. Teeth were prepared with Precision cutting machine and a diamond disc. All specimens were ground with 240-grit SiC abrasives.

2. Preparation of porcelain specimens

Twenty-eight disc-shaped specimens of each ceramic material were prepared to the same dimensions as the bovine teeth. Two specimens were used to determine the elastic modulus. The preparation procedure was as follows:

2.1 Vita VMK95

Approximately 1 g. of a feldspathic porcelain powder were placed in a stainless steel mold as shown in Fig. 3-24 & Fig.3-25. The wet powder were packed into the mold, then compressed while applying a light tapping force with the hammer. Excess moisture were removed with an absorbent tissue. A blade was used to level the specimen by removing excess material from the overfilled mould. The porcelain samples were removed en bloc by tapping on firing tray. All specimens were fired in a programmable vacuum furnace (Vacumat2500). The firing schedule consisted of 1) drying at 600°C outside the muffle, 2) drying at 600°C inside the muffle for 6 min., 3) increasing the temperature from 600°C to 930°C under pressure for 6 min. The specimens were then held at 930°C for 1 min. and bench-cooled. All specimens were ground with 240-grit SiC abrasive paper on both side. The one surface was sand-blasted with 50 µm SiO₂. This side was boned to dentine.

2.2 *IPS Empress*

For the heat-press procedure, a special furnace (EP 500; Ivoclar Co., Schaan, Liechtenstein) was used. This furnace consists of a microprocessor-controlled heated chamber and pressure unit accepting the system's muffles.

The specimens were modeled in casting wax measuring 12 mm. in diameter and 1 mm. in thickness and embedded in IPS Empress 2 phosphate-bonded investment using the system's cylindrical muffle formers. A total of 200 g. investment powder and 44 ml. of liquid (special liquid : distilled water = 31 : 13) were mixed under vacuum, poured and allowed to set for 1 hour. The wax was eliminated from the moulds in a burn-out furnace at 250°C for 30 min. and at 850°C for 90 min. The ceramic ingots, as well as the alumina pistons, were also heated to 850°C. The muffles were then placed in the preheated EP 500 furnace. The ceramic ingot was placed in the muffle crucible. The alumina piston was placed on top of the ingot. The furnace was closed, and the pressing procedure will start. The mould-filling process was completely controlled by the microcomputer in the furnace. The ceramic was plasticized at 1050°C and pressed at a pressure of 5 bar into the mould in a 1 hour process. The muffle was removed from the furnace and allowed to cool to room temperature. The specimens were de-vested by blasting with 50 µm. glass beads at 2 bar. The sprues were cut off with a diamond wheel in a handpiece and the specimens were ground with 240-grit SiC abrasive paper on the both side. The one surface was sand-blasted with 50 µm. SiO₂. This side was boned to dentine.

The specimen dimensions were measured using an electronic digital caliper. The thickness of each specimen was calculated as the mean of three measurements taken at random sites. The diameter of each specimen was calculated as the mean of the major and minor axes.

Cementation with a resin cement

Pre-treatment of ceramic specimens

All specimens were rinsed with water and dried. The sand-blasted surface was etched with hydrofluoric acid 4.9% (IPS Ceramic etching gel) for 60 seconds. The acid was rinsed off the surface and dried again. Monobond-S was applied to the

specimen surface for 60 seconds and then dried. Heliobond was applied to the etched and silanized ceramic surface to a thin layer.

Pre-treatment of tooth surface

All specimens were rinsed with water spray and dried. The tooth surface was etched with phosphoric acid 37% (Total Etch™ etching gel) for 30 seconds. The acid was removed with water spray for 15 seconds and dried. Syntac® Primer was applied to the etched tooth surface for 15 seconds and dried. Syntac® Adhesive was then applied for 10 seconds and dried. Heliobond was applied to the bonded tooth surface.

Cementation of dental ceramics to tooth surface

Variolink® II Base paste was applied on tooth surface with a spatula. Ceramic specimen was placed with slight pressure and excess cement was removed with a brush. A load of 10 N was applied to the ceramic sample and maintained for 15 seconds. Excess Variolink® II was removed with a brush. Variolink® II was polymerized for 40 seconds per segment overlapping as shown in Fig. 3-28.

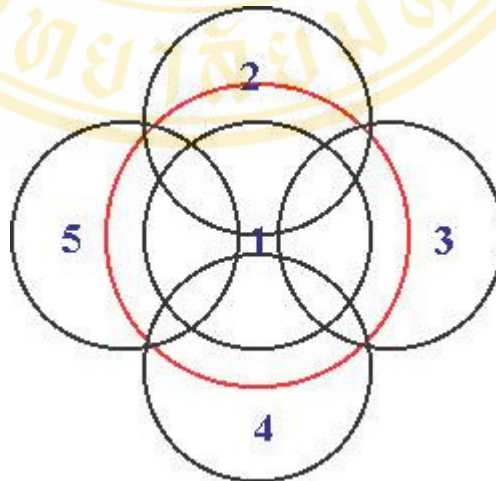


Fig. 3-28 Schematic diagram of overlapping polymerization zones for cementation

Testing conditions (as shown in Fig. 3-29)

All specimens were cleaned with distilled water and stored in water at 37°C. After storage for 24 hours, the biaxial flexural strength of thirteen specimens of each ceramics/dentine system were determined (thermocycle 0). The remaining 13 of each system were placed in 5°C and 55°C water baths, with a 1-minute dwell time in each bath, for 1,000 cycles using a thermocycling apparatus. After that, the biaxial flexural strength of each system were determined.

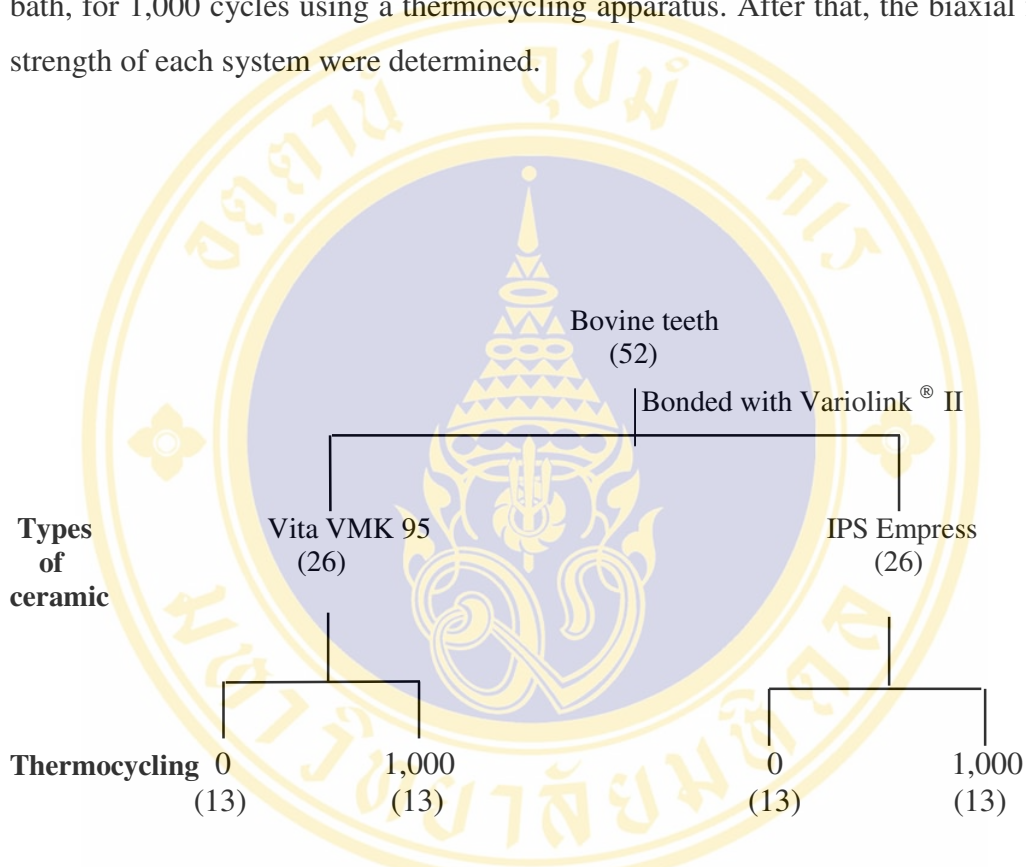


Fig. 3-29 The experimental design of test specimens

Biaxial flexural strength testing

The specimens were loaded on a device described in International Standard Organization (ISO) standard 6872 for dental ceramics (Fig. 3-21 & Fig. 3-22). For the support of the test specimen, three steel balls with a diameter of 3.2 mm., positioned 120° apart on a support circle with a diameter of 10 mm. was provided. Each specimen was placed concentrically on the supporting balls of the testing device (Fig 3-30). The specimen was loaded with a flat punch with a diameter of 1.2 mm. with an universal testing machine at a crosshead speed of 1 mm./min. until broken. A 10 kN load cell

was used (Fig. 3-31). The load required to fracture the specimen was recorded for each specimen to the nearest 0.01 N. The biaxial flexural strength of each specimen was calculated using the equation (7,46-48) :

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

where,

$$M = \frac{P}{4\pi} \left[(1 + \nu_e) \ln \frac{r}{r_0} + 1 \right]$$

$$\nu_e = \nu_a \frac{K_{3p}}{K_{2p}}$$

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

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

$$r_0 = \sqrt{1.6b^2 + t^2} - 0.675t$$

where,

P = load, in Newtons

t_a = the specimen thickness of ceramic, in millimeters

t_b = the specimen thickness of dentine, in millimeters

a = the radius of support circle, in millimeters (5 mm.)

b = the radius of loaded area, in millimeters (0.6 mm.)

r = the radius of specimen, in millimeters

r₀ = the equivalent radius of loaded area, in millimeters

ν_a = Poisson's ratio of ceramic (0.25) (12-16,18,46)

ν_b = Poisson's ratio of dentine (0.31) (49,50)

ν_e = the equivalent value of Poisson's ratio

E_a = Young's modulus of ceramic

and E_b = Young's modulus of dentine

Determination of the elastic modulus from biaxial flexural test

The elastic modulus of dentine and dental ceramics were calculated using the equation (51,52) :

$$\gamma = \beta' \frac{Pa^2}{Et^3} \quad \text{where} \quad \beta' = \beta + \alpha$$

$$\beta = -0.0642 - 2.1900m^{-3} + (0.5687 + 3.2542m^{-3})(1 - \nu^2) + [-0.3793 + 11.0513m^{-3} + (0.5223 - 7.8535m^{-3})(1 - \nu^2)] \left[\frac{a}{r} \right]^3$$

and
$$\alpha = \frac{3(1 - \nu^2)}{4\pi} \frac{b^2}{a^2} \left[\frac{(\nu - 1)}{(\nu + 1)} \frac{a}{2r^2} + \ln \frac{b - 5}{a} \right]$$

for $0.25 \leq \nu \leq 0.33$; $0.50 \leq \frac{a}{r} \leq 1.00$; $m = 3, 4, 5, 6$ and ∞

where, γ = the center deflection, in millimeters

m = number of supports ($m=3$)

The biaxial modulus for each material was the average of two specimens reported to the nearest GPa.

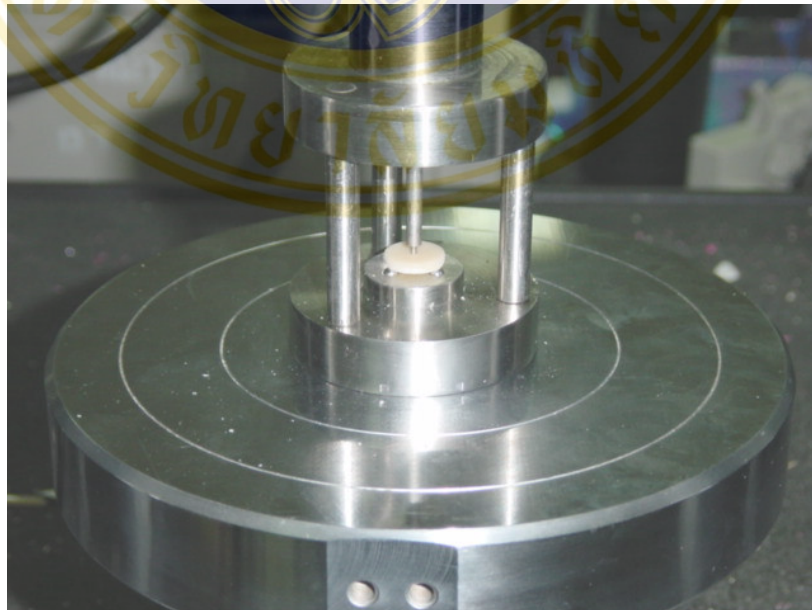


Fig. 3-30 The specimens held in the biaxial flexure testing jig (piston-on-3-ball)

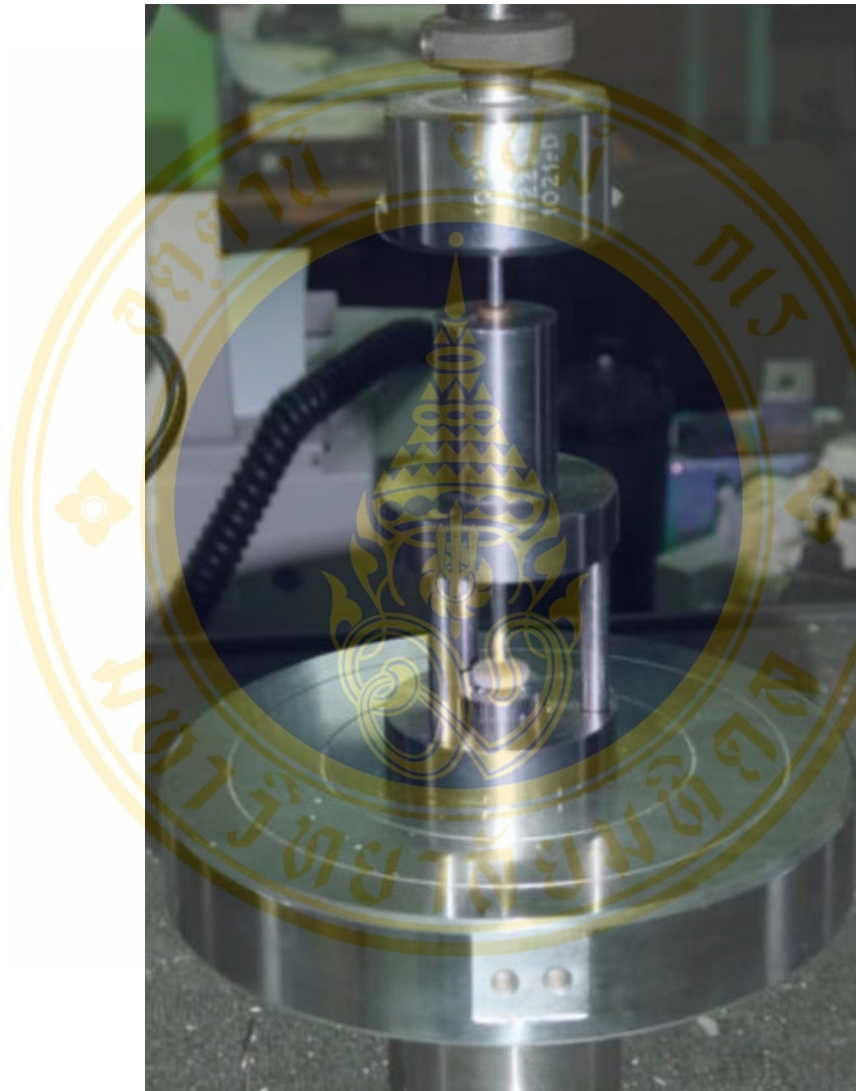


Fig. 3-31 The specimens mounted into the universal testing machine for biaxial flexural strength testing

CHAPTER IV RESULTS

The elastic moduli of each material are summarized in Table 4-1.

Table 4-1 The elastic modulus of each material (GPa)

Vita VMK95	30.19
IPS Empress	30.60
Dentine	9.13

The mean biaxial flexural strength data of the ceramics / dentine systems are shown in Table 4-2.

Table 4-2 The mean biaxial flexural strength of dental ceramics /dentine systems (MPa)

Types of ceramics Thermocycling (cycle)	Vita VMK95	IPS Empress
0	73.69±20.47 ^{a,b}	84.59±16.11 ^b
1000	69.19±12.12 ^{a,c}	68.17±13.44 ^c

Mean ± SD superscribed with the same letter (a, b, or c) are not statistically significant different from each other.

The biaxial flexural strength data were analyzed using SPSS 11.0 for windows (SPSS Inc., Chicago, Illinois, USA). Kolmogorov-Smirnov test with Lilliefors significance correction was used to determine normality and Levene’s test to determine homogeneity of variance of the data in each test group.

The data of each group illustrated normal distribution and homogeneity of variance at a significance level of 0.05. (Table 4-3 and 4-4)

The mean biaxial flexural strength data were analyzed using t-test at a significance level of 0.05. (Table 4-5)

Table 4-3 Tests of normality

Types of dental ceramics (thermocycling)	Kolmogorov-Smirnov ^a	
	df	p
Vita VMK95 (0)	13	.056
Vita VMK95 (1000)	13	.132
IPS Empress (0)	13	.152
IPS Empress (1000)	13	.200*

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

Table 4-4 Tests of homogeneity of variance

	Levene's test	
	F	p
Thermocycling 0	.970	.335
Thermocycling 1000	.002	.966
Vita VMK95	3.913	.060
IPS Empress	.709	.408

Table 4-5 t-test

	t-test		
	t	df	p
Thermocycling 0	-1.509	24	.144
Thermocycling 1000	.205	24	.840
Vita VMK95	.681	24	.502
IPS Empress	2.823	24	.009

Statistical analysis showed that

1. The biaxial flexural strength of Vita VMK95 was not significantly different from that of IPS Empress either before or after thermocycling ($p>0.05$).
2. The biaxial flexural strength of Vita VMK95 was not statistically reduced after thermocycling ($p>0.05$). On the contrary, the strength of IPS Empress significantly lower after thermocycling ($p<0.05$).

Delamination

Delamination of the ceramics / dentine systems are shown in Table 4-6 and Fig. 4-1 to 4-4. Delamination occurred in the majority of specimens in each test group. Delamination occurred more frequently after thermocycling in both Vita VMK95 and IPS Empress groups. In addition, a larger number of delaminated specimens were found in Vita VMK95 group than in IPS Empress group, both before and after thermocycling.

Table 4-6 Delamination of the ceramics / dentine systems

Types of ceramics Thermocycling (cycle)	Vita VMK95	IPS Empress
0	11/13 Delaminated	10/13 Delaminated
1000	13/13 Delaminated	12/13 Delaminated

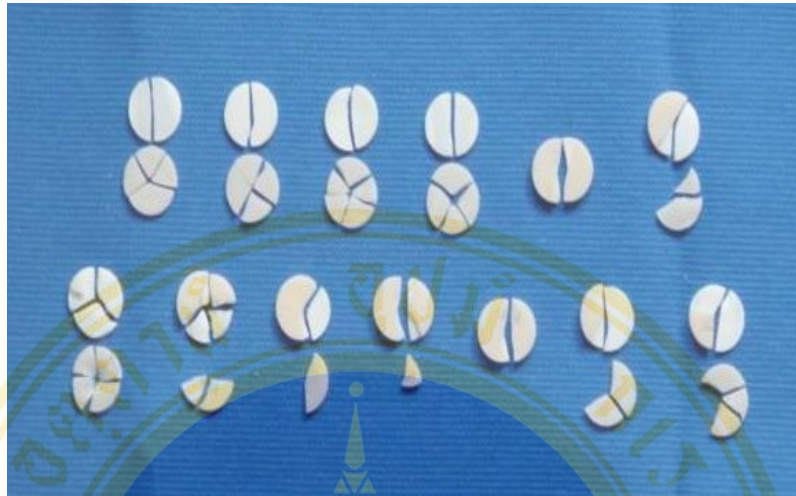


Fig. 4-1 The specimens of Vita VMK95 after biaxial flexural strength testing
(before commencement of thermocycling)



Fig. 4-2 The specimens of Vita VMK95 after biaxial flexural strength testing
(after thermocycling)

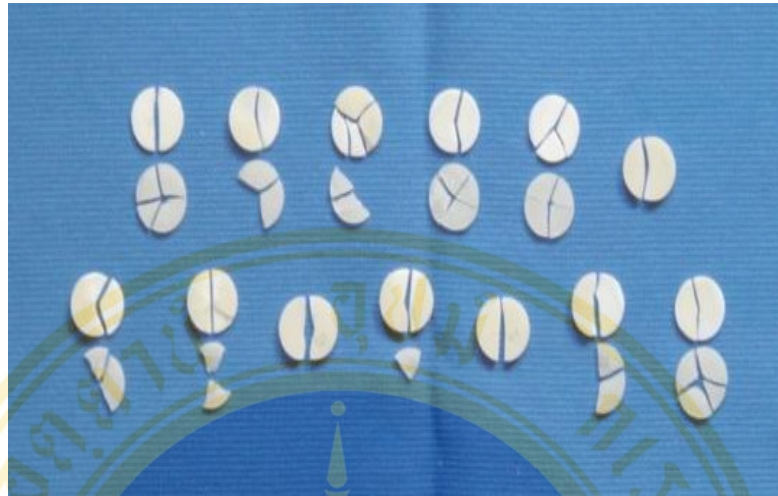


Fig. 4-3 The specimens of IPS Empress after biaxial flexural strength testing
(before commencement of thermocycling)

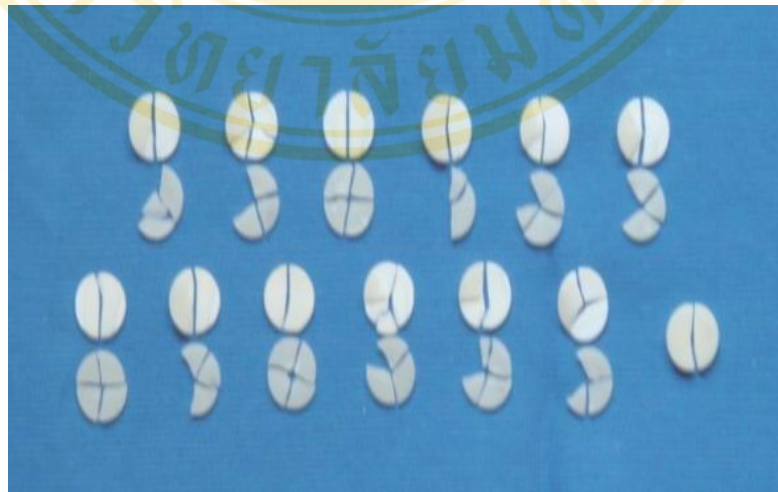


Fig. 4-4 The specimens of IPS Empress after biaxial flexural strength testing
(after thermocycling)

CHAPTER V

DISCUSSION

The number of sample size were calculated from the result of the pilot study. Thus, in the study sample size in each test group was thirteen.

Watanabe and Nakabayashi (8) and Sano et al. (53) noted that the composition of bovine dentine was similar to human dentine. Furthermore, Schilke et al. (54) and Nakamichi et al. (55) demonstrated that shear bond strength and tensile bond strength of human permanent dentine and bovine coronal dentine were not significantly different. Thus, bovine dentine specimens were used in this study as an alternative to human dentine specimens because the bovine teeth covered the size of the disc specimens used in this study (12 mm. in diameter, 1 mm. in thickness).

The biaxial modulus of elasticity of bovine dentine, determined from this study, was 9.13 GPa. Previous studies reported that elastic modulus of human dentine was 13.7-20 GPa (53,56-58), and that of bovine dentine was 14.7 GPa.(53) The lower value reported here may be attributed to different condition of testing, such as measuring methods (Ultra-Micro-Indentation System, Nano-indentation technique, or Berkovitch indenter), and specimen preparation.

The biaxial moduli of elasticity of Vita VMK95 and IPS Empress were 30.19 and 30.60 GPa, respectively. Seghi et al. (59) reported that the modulus of elasticity of IPS Empress was 69.8 GPa., and that of Vita VMK95 was 91 GPa.(60) The moduli of elasticity of ceramics in this study were also less than those in previous studies. This may be the influence of testing method and specimen preparation. Seghi et al. (59) determined the elastic modulus of IPS Empress with a nondestructive dynamic method by impulse excitation of vibration from the rectangular specimen dimensions of approximately 2 mm.x 5 mm.x 30 mm. In this study, the elastic moduli

determined from biaxial flexural strength testing of disc specimens.

IPS Empress was claimed by its manufacturer to have higher flexural strength than Vita VMK95. The previous published article using bending test of beam specimens revealed that the flexural strength of IPS Empress was 120 MPa compared to 85 MPa of Vita VMK95 porcelain. (60) The factors that influenced the flexural strength of the material include testing method, specimen preparation, flaw size, flaw number, and flaw distribution especially in are of high tensile stress, and strength equation used.

Zeng et al. (13) evaluated the failure stresses in flexural tests of IPS Empress, In-Ceram, and Procera AllCeram using ring-on-ring and piston-on-three-ball tests and using different methods of calculation. They found that the flexural strengths from the different test methods are significantly different. The piston-on-three-ball test gave the flexural strengths of In-Ceram and Procera AllCeram higher than the ring-on-ring test, whereas the piston-on-three-ball test gave the flexural strengths of IPS Empress lower than the ring-on-ring test. In addition, when the Timoshenko's equation was used to calculate the strength for the ring-on-ring test, the failure stress value was higher than the Shetty's equation.

All-ceramic restorations also benefit from adhesive bonding to etched tooth structure, which is thought to increase their overall strength. The overall factors being associated with the reduction of ceramic surface flaws by the resin and the creation of surface compression by the polymerization shrinkage of composite luting cements and the ability of the composite lute to act as a shock absorber and transfer the occlusal load to the supporting tooth structure. (18)

Matos et al. (61) reported that no statistical difference was found between the tensile bond strengths of resin-based composite (Tetric Ceram) to dentine and to a leucite-reinforced ceramic (SONICsys, similar in composition to IPS Empress). In addition, re-treatment of leucite-reinforced ceramics with hydrofluoric acid and silane did not affect on the bond strength to resin-based composite.

In this study, the ceramic specimens were bonded to dentine using a resin cement. The biaxial flexural strength before thermocycling of the IPS Empress/dentine system were higher than that of the Vita VMK95/dentine system (84.59 ± 16.11 and 73.69 ± 20.47 MPa, respectively) but the difference was not significant ($p > 0.05$). In the Vita VMK95 porcelain/dentine group, the mean biaxial flexural strength after thermocycling was decreased but the reduction was not statistically significant ($p > 0.05$). In the IPS Empress/dentine group, the mean flexural strength was significantly reduced after the samples have been through the thermocycling process ($p < 0.05$). It seems that the Vita VMK95/dentine system is superior than the IPS Empress/dentine system in term of the reduction of the flexural strength after the thermocycling process. However, the biaxial flexural strengths of Vita VMK95/dentine and IPS Empress/dentine system were not statistically different after thermocycling. Therefore, both Vita VMK95 and IPS Empress can be the material of choice.

Dentine has a highly oriented microstructure that has tubules arranged in a radial form running from the pulp chamber outward to the dentine-enamel junction in the crown. This arrangement of oriented tubules might logically have an effect on the strength of the dentine. (62,63)

On the other hand, Phrukkanon et al. (64) indicated that the micro-tensile bond strength between resin and dentine was not influenced by tubule orientation and dentine location. Thus, the effect of dentine tubules orientation might be excluded from the present study.

Polymerization shrinkage of light-cured composite resins and differences in coefficient of thermal expansion between tooth structure and composite resin will lead to compression and tensile forces on the margins of restoration during curing and thermocycling. These forces will cause a flow of oral fluids into any gaps between the restoration and the tooth. (65) Lower bond strength is expected to result from thermocycling conditions because of differences in the coefficient of thermal expansion between porcelain and resin composite and between resin composite and

dentine. This study showed all groups to have lower bond strength after thermocycling, similar to the report of Wolf et al. (38)

The failure loads for ceramic bilayer bars are controlled by both the elastic modulus difference between the ceramics and the strength of the material on the tensile surface. (66) In this study, the elastic moduli of ceramics and dentine are different, so they may affect to the biaxial flexural strength of dental ceramics/dentine systems.

According to the bending theory of bimetallic circular plates, the top surface of plates is subjected to the compressive stress and the bottom surface of plates is subjected to the tensile stress. Thus, in this study, the compressive stress is on the top surface of the ceramic and dentine plates and the tensile stress is on the bottom surface of the ceramic and dentine plates, simulates the loading on a dental restoration during chewing.

Delamination at the resin/dentine interface of the ceramics/dentine systems occurred in the majority of specimens. After thermocycling, both Vita VMK 95 and IPS Empress, delamination occurred greater than before thermocycling. Furthermore, the biaxial flexural strengths of Vita VMK 95 and IPS Empress were reduced after thermocycling but the difference was not significant for Vita VMK95. In order for delamination to occur, the load necessary for tensile failure must be greater than that required for delamination. Conversely, for specimens that do not delamination, fracture occurs before the higher load required for delamination. (67)

In this study, the number of fragments in each specimen are varied, which depended on loaded stress. The higher the stress, the more number of fragments.

In one test of tri-layer laminate bars (ceramic-cement-dentine; dentine on the tensile surface), failure originated predominantly from the ceramic at its interface with the cement. (68,69)

CHAPTER VI

CONCLUSION

Within the parameters of the present study, designs and material tests, the following conclusions were made:

1. The biaxial moduli of dentine, Vita VMK 95, and IPS Empress were 9.13, 30.19, and 30.60 GPa, respectively.
2. The biaxial flexural strength of Vita VMK95 / dentine system was not significantly different from that of IPS Empress / dentine system either before or after thermocycling ($p>0.05$).
3. The biaxial flexural strength of Vita VMK95 / dentine system was not statistically reduced after thermocycling ($p>0.05$). On the contrary, the strength of IPS Empress / dentine system significantly lower after thermocycling ($p<0.05$).
4. After thermocycling, both Vita VMK 95 and IPS Empress, delamination occurred greater than before thermocycling. Furthermore, delamination occurred in Vita VMK95 closer to IPS Empress, both before and after thermocycling.

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Table A-1 The data of fracture load (N) and elastic modulus (GPa) of dentine and dental ceramics

n	Dentine		Vita VMK 95		IPS Empress	
	Load	E	Load	E	Load	E
1	125.90	9.57	62.46	31.94	76.69	30.36
2	115.19	8.69	60.45	28.44	96.05	30.84
Mean	120.55	9.13	61.46	30.19	86.37	30.60



Table A-2 The data of fracture load of dental ceramics / dentine systems (N)

Dental ceramics	Vita VMK 95		IPS Empress	
Luting cement	Variolink® II			
Thermocycling (cycle) n=13	0	1000	0	1000
1	149.38	246.58	225.68	215.89
2	201.61	207.64	237.15	216.57
3	200.41	192.13	345.55	256.21
4	211.07	181.40	316.56	246.24
5	246.50	186.94	175.27	147.70
6	346.01	150.21	259.45	173.34
7	325.48	241.63	336.13	153.74
8	315.14	273.74	298.44	272.25
9	200.49	265.27	290.25	214.29
10	286.59	246.42	289.22	186.47
11	270.01	273.18	300.71	271.30
12	129.97	240.63	201.49	222.15
13	200.14	187.71	304.48	282.05
Mean	237.14	222.58	275.41	219.86
SD	67.42	40.21	51.97	44.90

Table A-3 The data of biaxial flexural strength of dental ceramics / dentine systems (MPa)

Dental ceramics	Vita VMK 95		IPS Empress	
Luting cement	Variolink® II			
Thermocycling (cycle) n=13	0	1000	0	1000
1	47.99	76.94	69.00	67.29
2	63.39	64.55	71.57	66.73
3	63.16	59.28	104.16	77.97
4	63.35	56.55	94.82	76.70
5	76.72	59.87	53.08	45.33
6	108.63	48.67	80.85	54.32
7	99.88	74.48	102.36	48.36
8	99.20	81.36	95.56	82.02
9	63.26	83.78	91.38	67.34
10	86.42	75.76	86.37	57.68
11	81.52	86.33	94.86	81.90
12	41.64	75.13	61.65	72.97
13	62.82	56.82	94.07	87.59
Mean	73.69	69.19	84.59	68.17
SD	20.47	12.12	16.11	13.44

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