วารสารวิชาการพระจอมเกล้าพระนครเหนือ ปีที่ 29 ฉบับที่ 4 ต.ค.–ธ.ค. 2562
The Journal of KMUTNB., Vol. 29, No. 4, Oct.–Dec. 2019

บทความวิจัย

การเข้ากันได้เชิงความร้อนระหว่างเซรามิกวีเนียร์และโครงเซรามิกชนิดความแข็งสูง

พรรณาภา สินธุประเสริฐ*
วิทยาลัยแพทยศาสตร์นานาชาติจุฬาภรณ์ มหาวิทยาลัยธรรมศาสตร์
Sarah Pollington และ Richard van Noort
School of Clinical Dentistry, The University of Sheffield, United Kingdom

* ผู้นิพนธ์ประสานงาน โทรศัพท์ 0 2564 4441 อีเมล: airpannapa@gmail.com DOI: 10.14416/j.kmutnb.2019.05.002
รับเมื่อ 11 กุมภาพันธ์ 2562 แก้ไขเมื่อ 9 เมษายน 2562 ตอบรับเมื่อ 24 เมษายน 2562 เผยแพร่ออนไลน์ 31 พฤษภาคม 2562

บทคัดย่อ

เพื่อศึกษาถึงความเข้ากันได้เชิงความร้อนระหว่างโครงเซรามิกชนิดแข็งสูงและเซรามิกวีเนียร์ โดยหาความสัมพันธ์ของค่าสัมประสิทธิ์การขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ในช่วงค่าต่างๆ กับค่าของโครงเซรามิกชนิดแข็งสูงหลากหลายแบบ ซึ่งมีผลต่อการแตกร้าวของวัสดุเมื่อให้มีการเปลี่ยนแปลงอุณหภูมิอย่างรวดเร็ว โดยทำการวัดค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ชนิดผสมกันระหว่างลูไซต์ และเฟลด์สปาร์แต่ละอัตราส่วนที่มีผลให้ค่าสัมประสิทธิ์การขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ แตกต่างกันแล้วทำการเคลือบผิวกับโครงเซรามิกชนิดแข็งสูง โดยค่าสัมประสิทธิ์การขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ที่นำมาทดลองอยู่ในช่วงอัตราส่วน ± 3 ppm/°C. โดยชิ้นงานถูกเตรียมในลักษณะชิ้นจานกลม จากนั้นดูผลจากความแตกร้าวเมื่อมีการทดสอบการทนต่อการเปลี่ยนแปลงอุณหภูมิอย่างรวดเร็ว ชิ้นตัวอย่างจะถูกนำไปวางในเตาอบเริ่มต้นที่อุณหภูมิ 90 องศาเซลเซียส จากนั้นนำออกมาใส่ในน้ำเย็นที่เตรียมไว้หน้าเตาอบอย่างรวดเร็ว หลังจากนั้นวัสดุตัวอย่างจะถูกทำให้แห้งและนำไปตรวจดูรอยการแตกร้าว ถ้าพบรอยแตกร้าวก็จะถือว่าวัสดุตัวอย่างนั้นล้มเหลวที่อุณหภูมิ 90 องศาเซลเซียส แต่หากยังไม่มีรอยแตกร้าวก็ให้นำวัสดุไปใส่ในเตาอบอีกครั้งโดยเพิ่มอุณหภูมิครั้งละ 10 องศาเซลเซียส ทำซ้ำขั้นตอนเดิมจนวัสดุตัวอย่างแตกร้าวจนหมด ค่าทางสถิติจะถูกคำนวณโดยใช้ ทูเวย์-อะโนวาร่วมกับการเปรียบเทียบความหลากหลายของทูคีย์โพส-ฮอก สำหรับค่าสัมประสิทธิ์การขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ชนิดผสมกันระหว่างลูไซต์ และเฟลด์สปาร์ที่นำมาทดลองในแต่ละช่วงอัตราส่วนในส่วนของการทดสอบการทนต่อการเปลี่ยนแปลงอุณหภูมิอย่างรวดเร็วค่าทางสถิติจะถูกคำนวณโดยใช้วันเวย์-อะโนวาร่วมกับการเปรียบเทียบความหลากหลายของทูคีย์ ผลของค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนของเซรามิกวีเนียร์ชนิดผสมกันระหว่างลูไซต์ และเฟลด์สปาร์แต่ละอัตราส่วน มีลักษณะสมการการถดถอยเชิงเส้นตรง และสำหรับโครงเซรามิกชนิดแข็งสูงแบบไอพีเอสอีแมกซ์แคด (IPS emax CAD) และแบบวีต้าอินซีแรมวายแซด (VITA In Ceram YZ) เมื่อเคลือบผิวด้วยเซรามิกวีเนียร์ที่บริษัทผู้ผลิตแนะนำแล้วพบว่ามีความแตกร้าวที่อุณหภูมิ 192 ± 12 องศาเซลเซียส และ 179 ± 18 องศาเซลเซียส ตามลำดับ โดยค่านัยสำคัญตั้งไว้ที่น้อยกว่า 5 เปอร์เซ็นต์ (p<0.05) ในขณะที่เมื่อเคลือบผิวด้วยเซรามิกวีเนียร์ที่มีค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนเท่ากันระหว่างเซรามิกวีเนียร์และโครงเซรามิกชนิดแข็งสูงทั้งแบบไอพีเอสอีแมกซ์แคด และแบบวีต้าอินซีแรมวายแซด พบว่ามีความแตกร้าวที่อุณหภูมิ 225 ±15 องศาเซลเซียส และ 218 ± 9 องศาเซลเซียส ตามลำดับ โดยค่านัยสำคัญตั้งไว้ที่น้อยกว่า 5 เปอร์เซ็นต์ (p<0.05) สำหรับโครงเซรามิกชนิดแข็งสูงแบบฟลูออคานาไซต์ (Fluorcanasite) เมื่อเคลือบผิวด้วยเซรามิกวีเนียร์ที่มีค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนเท่ากัน พบว่ามีความแตกร้าวที่อุณหภูมิ 232 ±25 องศาเซลเซียส ซึ่งมีค่ามากกว่าค่าความแตกร้าวของโครงเซรามิกชนิดแข็งสูงทั้งแบบไอพีเอสอีแมกซ์แคด และแบบวีต้าอินซีแรมวายแซด เมื่อเคลือบผิวด้วยเซรามิกวีเนียร์ที่มีค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนเท่ากัน อย่างมีนัยสำคัญ โดยค่านัยสำคัญตั้งไว้ที่น้อยกว่า 5 เปอร์เซ็นต์ (p<0.05) การเลือกเซรามิกวีเนียร์เพื่อเคลือบผิวของโครงเซรามิกชนิดแข็งสูงเพื่อให้ผลที่ดีที่สุดในการทนต่อการการเปลี่ยนแปลงอุณหภูมิอย่างรวดเร็วคือการเลือกเซรามิกวีเนียร์และโครงเซรามิกชนิดแข็งสูงให้มีค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อนเท่ากัน

คำสำคัญ: เซรามิก เซรามิกวีเนียร์ โครงเซรามิกชนิดแข็งสูง ค่าสัมประสิทธิ์ของการขยายตัวเหตุความร้อน การทนต่อการเปลี่ยนแปลงอุณหภูมิอย่างรวดเร็ว

การอ้างอิงบทความ: พรรณาภา สินธุประเสริฐ S. Pollington, และ R. van Noort, "การเข้ากันได้เชิงความร้อนระหว่างเซรามิกวีเนียร์และโครงเซรามิกชนิดความแข็งสูง," *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 29, ฉบับที่ 4, หน้า 630–640, ต.ค.–ธ.ค. 2562.

Research Article

Thermal Compatibility of Ceramic Veneers to a High Strength Core Material

Pannapa Sinthuprasirt*
Chulabhorn International College of Medicine, Thammasat University, Pathum Thani, Thailand
Sarah Pollington and Richard van Noort
School of Clinical Dentistry, The University of Sheffield, United Kingdom

* Corresponding Author, Tel. 0 2564 4441, E–mail: airpannapa@gmail.com
DOI: 10.14416/j.kmutnb.2019.05.002
Received 11 February 2019; Revised 9 April 2019; Accepted 24 April 2019; Published online: 31 May 2019

Abstract

The purpose of this study is to determine the extent to which the coefficient of thermal expansion mismatch between a veneering and core ceramic affects the thermal shock resistance. This study is also to establish what is the ideal coefficient of thermal expansion for a veneering ceramic in relation to its core ceramic. Veneering ceramics matching the CTE of three ceramic core materials were manufactured by measuring the CTE of ceramics with a range feldspar/ high leucite ratios and using a linear regression equation. Discs of the core ceramics were veneered with varying wt% ratios of leucite/feldspar with CTE values ± 3 ppm/°C. The thermal shock resistance was determined by preheating the specimens to 90°C, quenching them in cold water, then reheating to 90°C. The specimens were allowed to cool to room temperature and was inspected for crazing. The specimens were then tested; the test was repeated in 10°C increments until a failure occurs. Statistical analysis was undertaken using two-way ANOVA and Tukey post-hoc tests for the CTE of the varying feldspar/ high leucite compositions; and one-way ANOVA with Tukey's multiple comparison tests for the thermal shock resistance. The CTE of the mixtures of feldspathic and leucite veneering ceramics was presented as a linear equation, obeying the rule of mixtures, thus enabling the development of matched CTE ceramic systems. For IPS emax CAD and VITA In Ceram YZ, when veneered with their recommended ceramic, the mean ΔT values were significantly lower (192 ± 12°C and 179 ± 18°C) than when veneered with a ceramic with a matched CTE (225 ±15°C and 218 ± 9°C) (p<0.05). However, for the fluorcanasite, the matched CTE ceramic produced a mean ΔT value of 232 ± 25°C, which was significantly higher than the two commercial systems (p<0.05). For high strength ceramic cores, the best thermal shock resistance is achieved with a veneering ceramic possessing a similar CTE to that of the core ceramic.

Keywords: Ceramic, Veneering Ceramic, High Strength Ceramic Core, The Coefficient of Thermal Expansion (CTE), Thermal Shock Resistance

Please cite this article as: P. Sinthuprasirt, S. Pollington, and R. van Noort, "Thermal compatibility of ceramic veneers to a high strength core material," *The Journal of KMUTNB*, vol. 29, no. 4, pp. 630–640, Oct.–Dec. 2019.

1. Introduction

Ceramic materials are among the most biocompatible materials developed for dental restorations. The interest in all-ceramic restorations has rapidly increased over the past decade as stronger, tougher and more aesthetic materials are developed, along with novel processing technologies such as hot pressing and CAD/CAM (Computer-Aided Design/ Computer-Assisted Manufacture) [1]. One such area is the core-veneered all-ceramic restoration. By combining the strength of ceramic cores with the aesthetics of veneering porcelains, a very natural cosmetic restoration can be created [2]. However, one concern that has been highlighted with these restorations is chipping of the veneering ceramic [3].

The high strength ceramic cores must be thermal compatible with the veneering ceramic in terms of the Coefficient of Thermal Expansion (CTE) in order to minimize stresses and crack formation within the material [3]. Permanent distortion of the ceramic structures can result from thermal stress [3], [4]. As ceramics are brittle materials, a deformity as low as 0.1% can result in fracture due to propagation of cracks from the surface through the bulk of the material [5]. Thermal stresses can be caused by a variety of factors including temperature change and differences in material's properties such as Coefficient of Thermal Expansion (CTE), glass transition temperature and viscosity [3], [6]. Methods available to assess the thermal compatibility of core and veneer ceramics include crack formation through thermal mismatch using CTE measurements, the influence of multiple firing and thermal shocking [3], [4], [7]–[9].

The common method of veneering a high strength core ceramic is by the process of sintering, which involves a number of high firing cycles. During the heating and cooling cycles, the ceramics will increase and reduce in length and volume as a function of their thermal expansion characteristics [10]. It is important that the core and veneering ceramic are thermally compatible to prevent thermal stress formation in restorations during the ceramic processing, which may lead to crazing, cracking, delamination or fracture and lead to the failure of restorations [3], [11]. Any mismatch would give rise to serious problems due to excessive differential shrinkage on cooling between core and ceramic veneer [7]. Transient stresses are created as the core and ceramic veneer cool at different contraction rates from the glass transition temperature to room temperature [12]. Residual stresses remain due to compatibility differences in the CTE between core and veneering ceramic. Residual stresses may be high enough to result in cracking or delaminating of the ceramic upon cooling to room temperature after a firing cycle or after a period of functional loading in the mouth, resulting in the phenomenon of chipping of the veneer.

Thermal shock testing is a way of assessing the thermal compatibility of all-ceramic systems and can identify systems where residual stresses are not enough to cause failure after the initial firing cycle but which may cause failure at a later stage [7]. CTE and thermal shock resistance was explored in this study to enable the development of a compatible veneering ceramic. The window of variation of the CTE of veneering ceramics with high strength ceramic cores were also investigated to determine

the range of CTEs of veneering ceramics that could be used without a thermal mismatch occurring. The objectives of this study were to: 1) determine a relationship between the coefficient of thermal expansion and the composition of high leucite and feldspathic veneering ceramics and 2) to evaluate the thermal compatibility in term of thermal shock resistance of the three high strength ceramic cores veneered with varying ratios of leucite/feldspathic veneering ceramics and two commercial veneering ceramics which are recommend by manufacturers in relation to their respective CTE. The hypothesis to be tested was that it is possible to predict the coefficient of thermal expansion of a mixture of two veneering ceramics from the CTE by using the rule of mixture and a perfect match in CTE of both the core and veneering ceramic would produce a thermally compatible system exhibiting good thermal shock resistance.

2. Materials and Methods

2.1 Glass preparation and blending process

Two separate glasses comprising of leucite and feldspar were prepared using reagent grade raw materials as shown in Table 1. Batches were mixed using a vacuum mixer (DeguDent, Dentsply USA) for 10 min. Both compositions were preheated in an alumina crucible and melted at 1,550°C for 2 hr in an electric air furnace (Vecstar furnace, UK) with a heating rate was 10°C/min.

The glass melts were rapidly cooled to form a glass frit and dried for 1 hr at 200°C, followed by cooling at 5°C/min to room temperature. The glass frits were ground using a planetary ball milling machine (PM 100, Retsch limited, Germany) with agate jar and balls at a grinding rate of 400 rpm for 5 min and then sieved to powder of particle size < 100 μm.

Table 1: The chemical compositions for a leucite and feldspathic forming glass

Oxides	Leucite (wt%)	Feldspathic (wt%)
K_2O	13	4
MgO	1	0.5
SiO_2	58	73
Al_2O_3	15	8
CaO	2	1.5
Na_2O	8	5.5
BaO	3	-
B_2O_3	-	7.5

These two glasses were blended together in varying leucite/feldspar ratios as follows: 100/0% leucite: 75/25%, 50/50% : 25/75% and 100% feldspar. The mixtures of leucite/feldspar specimens were compacted and fired in a IPS vacuum furnace (Programat P 300, Ivoclar Vivadent AG, Liechtenstein) at 930°C for 5 min.

The three ceramic cores used in this study were lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein), yttrium stabilised zirconia (VITA In-Ceram YZ, Vita Zahnfabrik, Germany) and a novel fluorcanasite (The University of Sheffield). As well as the above leucite/feldspar combinations, the veneering ceramics recommended by the manufacturer were also used for comparison: fluorapatite (IPS e.max ceram, Ivoclar Vivadent, Liechtenstein) for the lithium disilicate and leucite (VITA VM 9, Vita Zahnfabrik, Germany) for the yttrium stabilised zirconia. A summary of the core and veneering ceramics used is shown in Table 2.

Table 2: High strength ceramic cores and commercial veneering ceramics used in the study

Ceramic	Name and Batch Number	Indication	Manufacturer
Lithium disilicate	IPS e.max CAD JO8179	Core ceramic	Ivoclar Vivadent AG, Schaan, Liechtenstein
Yttrium stabilised zirconia	Vita In-Ceram YZ 2082	Core ceramic	VITA Zahnfabrik, Bad Sackingen, Germany
Fluorcanasite	Experimental	Core ceramic	University of Sheffield
Fluorapa-tite	IPS e.max Ceram J25801	Veneering ceramic	Ivoclar Vivadent AG, Schaan, Liechtenstein
Leucite	VITA VM 99053	Veneering ceramic	VITA Zahnfabrik, Bad Sackingen, Germany

2.2 Measurement of CTE of all core and veneering ceramics

Rod shaped specimens (n=3) were fabricated from the core and veneering ceramic materials with a length of 30 mm and diameter of 6 mm. The ceramic core samples were smoothed and square cut at both ends by trimming and paralleling with a rotary diamond cutting machine (LECO VC-50, LECO Corporation, USA) with a diamond wafering blade (Buehler, USA). The veneering ceramic samples were fabricated by sintering and the end of each rod was ground flat and parallel to the opposing end. The VITA VM 9 specimen rods were fired in a Vacumat 200 furnace (VITA Zahnfabrik, Germany) as per the manufacturers instructions and the IPS e.max ceram and the mixtures of leucite/feldspathic were fired in an IPS vacuum furnace (Programat P 300, Ivoclar Vivadent AG, Liechtenstein). The firing cycle of the mixtures of leucite/feldspar was 930°C for 5 min. The firing cycles of VITA VM 9 and IPS e.max Ceram used were those recommended by the manufacturers. All furnaces were calibrated prior to firing. The length of the rod was accurately measured using a digital micrometer (Mitutoyo Corporation, Japan).

The specimens were heated using the Electronic Dilatometer 402 EP (Netzsch, Germany) at a heating rate of 3°C /min from 20°C to 580°C, followed by cooling to room temperature. Calibration of the dilatometer was performed by measurement of the CTE of a standard quartz specimen. The CTE of all specimens was calculated in the temperature range from 300°C to 400°C using the software programme (EP programme SW/DIL/421.85) connected to the dilatometer.

2.3 Thermal compatibility of ceramic veneers to a high strength core material

For each core ceramic the CAD/CAM blocks as provided by the manufacturers were core drilled and sectioned using a rotary diamond cutting machine (LECO VC-50, LECO Corporation, Michigan, USA) with a diamond wafering blade (Buehler, Illinois, USA). Seventy discs (12.0 mm × 1.2 mm) were produced for each core material, which were then cerammed as per the manufacturer's recommendations. Varying wt% ratios of the leucite/feldspar veneering ceramics were prepared to create CTE values 1, 2 and 3 ppm/°C lower and 1, 2, and 3 ppm/°C higher than the CTE of the core as well as a perfectly matched CTE. The powders were

carefully weighed using an electronic digital microbalance (Mettler AJ100L Mettler-Toledo, UK) with an accuracy of 0.0001g. The resulting compositions were evenly mixed to ensure a homogenous distribution of the feldspar and high leucite components. The veneering ceramic was subsequently combined with feldspar modelling fluid (Vitadur Alpha, VITA Zahnfabrik, Germany) into slurry and carefully applied to the core ceramics. Excess liquid was blotted using absorbent paper. The IPS e.max ceram veneering ceramic was used for veneering IPS e.max CAD and VITA VM 9 was used for veneering VITA In-Ceram YZ. Before applying the veneering ceramics to ceramic cores, a wash firing was done according to the manufacturers' recommendation.

An even layer of the veneering ceramic (0.7 mm) was applied to each disc using a silicone mould and digital calipers. The bilayered discs were then fired as described previously. The bilayered discs were observed using light microscopy (Wild M3Z, Heerbrugg, Switzerland) at 10x magnification with fibre-optic transillumination (Intralux 4000, Switzerland) for signs of thermal mismatch, such as fracture, cracking, crazing or separation between the veneer and core ceramic.

Ten specimens of each group were placed inside an oven (Vecstar ECF2, UK), which had been preheated to 90°C. After a 30 min hold to allow the samples to reach thermal equilibrium, they were removed from the oven and quenched in ice cold water for 20 seconds then dry it immediately. The samples were then dried, returned to the oven, reheated to 90°C for 30 min and subsequently cooled to room temperature to allow for inspection. The specimens were inspected for crazing using light microscopy (Wild M3Z, Switzerland) at 40x magnification with fiber optic transillumination (Intralux 4000, Switzerland). If crazing was observed, this would constitute a failure at ΔT = 90°C. If no failure was observed, the specimens were tested again at increasing temperature increments of 10°C until failure

2.4 Statistical analysis

Statistical analysis was undertaken using two-way ANOVA and Tukey post-hoc tests (SPSS for Windows, version 14.0, SPSS Inc, Chicago, Ill) for the CTE of the varying feldspar/high leucite compositions; and one-way ANOVA with Tukey's multiple comparison tests for the thermal shock resistance. The results were considered significant for $p<0.05$.

3. Results

The CTE data for the various ceramics used in the study are presented in Table 3. The results for the CTEs for the mixtures of feldspar an leucite are

Table 3: Experimental results of the CTE of the ceramics used in this study in the temperature range of 300°C to 400°C (n=3)

Batch	Mean CTE ±SD (ppm/°C)
IPS e.max CAD	10.51 ± 0.18
VITA In-Ceram YZ	10.01 ± 0.13
Fluorcanasite ceramic core	9.70 ± 0.07
IPS e.max Ceram	9.31 ± 0.12
VITA VM 9	8.75 ± 0.20
100% feldspathic	6.14 ± 0.11
75% feldspathic: 25% leucite	7.67 ± 0.35
50% feldspathic: 50% leucite	9.72 ± 0.28
25% feldspathic: 75% leucite	11.35 ± 0.10
100% leucite	13.54 ± 0.43

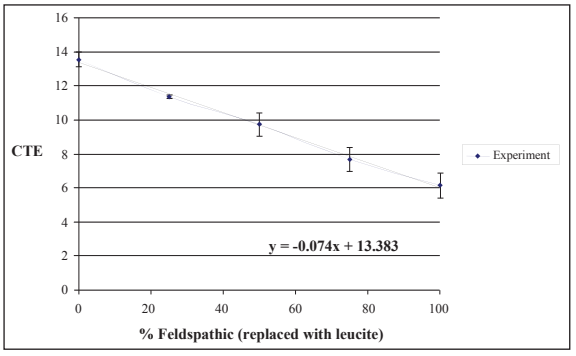

Figure 1: The experimental data of coefficient of thermal expansion and regression equation.

presented in Figure 1. Linear regression revealed a significant positive correlation between percentage of feldspar and leucite with r^2=0.99. The relationship between composition and CTE can be presented by the equation y = –0.074x+13.38, where y is the CTE of the mixture and x is the percentage of feldspathic glass replacing the leucite).

For the thermal shock resistance of each ceramic system, the mean ΔT value, standard deviation and ΔT range are presented in Table 4. With IPS emax CAD, when veneered with its manufacturer recommended ceramic, the mean ΔT value was significantly lower (192 ± 12 ppm/°C) than when veneered with an experimental ceramic with a matched CTE (225 ±15 ppm/°C) (p<0.05). Any deviation of as little as 1 ppm/°C either side of the matched CTE resulted in a significant reduction in ΔT. Similarly for the VITA In-Ceram YZ, when veneered with the manufacturer's recommended veneering

Table 4: Mean ΔT and ΔT range of the core ceramics with range of veneering ceramics of varying CTE

Ceramic Core	CTE of veneering ceramic (300–400°C)	n	Mean ΔT ± SD (°C)	ΔT range (°C)
IPS e.max CAD	13.5	10	Failure (room temp)	-
	12.5	10	188 ± 10	170–200
	11.5	10	204 ± 11	180–220
	10.5(Perfect match)	10	225 ± 15	200–240
	9.5	10	194 ± 13	170–210
	8.5	10	161 ± 12	150–180
	7.5	10	Failure (room temp)	-
	IPS e.max ceram (CTE=9.3)	10	192 ± 12	170–210
Fluorcanasite	12.7	10	Failure (room temp)	-
	11.7	10	149 ± 44	120–230
	10.7	10	194 ± 21	170–230
	9.7 (Perfect match)	10	232 ± 25	210–280
	8.7	10	185 ± 6	130–230
	7.7	10	121 ± 15	110–150
	6.7	10	Failure (room temp)	-
VITA In-Ceram YZ	13	10	Failure (room temp)	-
	12	10	170 ± 17	150–200
	11	10	197 ± 9	180–210
	10 (Perfect match)	10	218 ± 9	210–230
	9	10	181 ± 16	160–200
	8	10	167 ± 16	150–200
	7	10	Failure (room temp)	-
	VITA VM 9 (CTE=8.7)	10	179 ± 18	150–200

ceramic, the mean ΔT value was lower (179 ± 18) than when veneered with the experimental ceramic with a matched CTE (218 ± 9 ppm/°C) (p<0.05), although still the lowest value for ΔT recorded among the three core/veneer combinations. As previously noted above for the IPS emax CAD, similarly for the VITA in-Ceram YZ any deviation of as little as 1 ppm/°C either side of the matched CTE resulted in a significant reduction in ΔT. For the fluorcanasite, the matched CTE ceramic produced a mean ΔT value of 232 ± 25 ppm/°C, which was significantly higher than the mean ΔT value for the two commercial ceramic systems (p<0.05).

4. Discussion

Differences in CTE of the core and veneer ceramic may result in thermally induced stresses, which may subsequently lead to crazing, cracking, delamination and fracture of the all-ceramic system [3], [11]. Differences in expansion and contraction between the core and veneer can produce transient or residual tensile stresses in the ceramic [7]. Transient stresses are created as the core and veneer cool at different rates from the glass transition temperature to room temperature, while residual stresses remain due to differences in CTE [12]. With the metal-ceramic system, it is well known that a small positive mismatch in CTE results in a beneficial compressive stress on the veneering ceramic, which increases the strength of the whole restoration [13], [14]. However, with all-ceramic systems, this is not the case as ceramics are very strong under compressive stresses but weak under tensile stresses [6], [15]. When the CTE of the veneer is less than the core, the core will attempt to shrink more than the veneer, thus placing the veneer in a state of compression [16]. The core is subjected to a tensile stress while the veneer is still subjected to compressive stress [4]. This may have a negative effect on the core, as the tensile strength of the brittle ceramic is much lower than its compressive strength and may weaken not only the core but the whole all-ceramic restoration [4], [15]. On the other hand, if the CTE of the veneer is greater than the core, the veneer will attempt to contract more than the core. This will place the veneer under tension during cooling and the core will be in a state of compression [16]. The surface tensile stresses could be sufficient to cause the formation of surface cracks and a crazed surface. Hence it would be reasonable to presume that the ceramic core and veneer systems have to be developed with a similar thermal expansion behaviour so that the materials will shrink at the same rate with no generation of differential stresses.

In this study, the CTE as a function of percentage feldspar and leucite showed a linear relationship. This allowed the CTE of a mixture of the two ceramics to be predicted by using the rule of mixture and provided a convenient way for the correct mixing ratio of veneering ceramic with the same CTE as the ceramic core.

The thermal shock test was used a simple and practical method for testing the thermal compatibility of the all ceramic systems. It can identify systems where residual stresses are not enough to cause failure after initial firing but may cause failure at a later stage and is critical for long term success of restorations [7]. The thermal shock resistance method used in this study observed failure after reheating at the same temperature because thermal shock

is caused by uneven or rapid heating or cooling during the firing of the restoration. A specimen surface may expand or contract more quickly than its interior and so differential thermal expansion stresses will occur. All ceramics are stronger when placed under compression rather than under tension. When a specimen is removed from the furnace and cooled in air, the surface loses heat more rapidly than the interior. The specimen surface will contract faster than the interior but generally will be placed in compression by the balancing tensile stresses developed either within the ceramic core or ceramic veneer due to their different thermal expansions. It is often possible to induce thermal cracks which might disappear on cooling but can reappear later upon re-heating.

The thermal shock testing results from this study support the concept that the thermal compatibility in ceramic systems requires the CTE of the ceramic core and veneer to be similar (CTEceramic core = CTEceramic veneer) so that the materials will shrink at the same rate with no generation of differential stresses.

As anticipated for all the ceramic systems tested, the further the CTE mismatch was away from a perfectly matched CTE, the lower the resultant thermal shock resistance. The different ceramic systems were tested for a range of compatibility values for CTE of ceramic cores and ceramic veneers up to a mismatch of –3 and +3 ppm/°C. For the highest mismatch in CTE some specimens showed failure even at room temperature. These results suggest the CTE mismatch must be less than 1 ppm/°C, which is supported by the study of Steiner *et al*. [17] who reported that a mismatch value between a ceramic core and veneering porcelain of less than 1 ppm/°C does not produce visible cracks in a layered all ceramic restoration.

It is interesting to see that with the IPS e.max CAD, where the materials are designed by the manufacturer to be thermally compatible with e.max Ceram, had a mismatch of 1.2 ppm/°C while VITA In-Ceram YZ and VITA VM 9 had a mismatch of 1.3 ppm/°C. This means that the CTE of both the ceramic veneers was lower than ceramic cores as has been recommended by Anusavice [12]. Both of these systems showed no significant different in thermal shock resistance to each other. However, the thermal shock resistance results of both of these commercial ceramic systems was significantly lower than those of the exerimental feldspar glass and leucite veneering ceramics, which had been formulated to achieve a perfect match with ceramic cores. This can be explained because the veneer is placed in radial tension while the hoop stresses will be compressive following cooling after firing [7]. These residual stresses will be greatest at the core /veneer interface and act as a crack propagates inward by deflecting in the direction of higher tensile stress along a surface tangential to the interface [7].

Therefore, based on the thermal shock resistance data presented in this study, developing veneering ceramics with a CTE more closely matched to that of the core ceramic may contribute to a reduction in chipping as has been observed clinically. For a novel fluorcanasite can be appropriate choice as a high strength ceramic core when using with the perfect match CTE veneering ceramic as the result showed a high thermal shock resistance. However, the further works are needed as it is a new material.

5. Conclusion

1. The CTE of varying ratios of feldspathic and leucite veneering ceramics can be presented as a linear equation, obeying the rule of mixtures.

2. From the perspective of thermal shock resistance the CTE of the veneer and core ceramic need to be exactly matched.

Under thermal shock conditions, the best resistance of the ceramic veneer is a perfect match in CTE of both the core and veneering ceramic and it decreases with increasing window of variation.

References

[1] M. Guazzato, M. Albakry , SP. Ringer, and MV. Swain MV, "Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics," *Dent Mater*, vol. 20, no. 5, pp. 449–456, 2004.

[2] MN. Aboushelib, M. Kler, JM. van Zel, and AJ. Feilzer, "Effect of veneering method on the fracture and bond strength of bilayered zirconia restorations," *International Journal of Prosthodontics*, vol. 21, no. 3, pp. 237–240, 2008.

[3] G. Isgro, H. Wang, CJ. Kleverlaan, and AJ. Feilzer, "The effects of thermal mismatch and fabrication procedures on the deflection of layered all-ceramic disc," *Dent Mater*, vol. 21, no. 7, pp. 649–655, 2005.

[4] G. Isgro, CJ. Kleverlaan, H. Wang, and AJ. Feilzer, "The influence of multiple firing on thermal contraction of ceramic materials used for the fabrication of layered all-ceramic dental restorations," *Dent Mater*, vol. 21, no. 6, pp. 557–564, 2005.

[5] DW. Jones and PA. Jones, "Modulus of elasticity of dental ceramics," *Dent Pract Dent Rec*, vol. 22, no. 5, pp. 170–173, 1972.

[6] WD. Kingery, HK. Bowen, and DR. Uhlmann, *Introduction to Ceramics*, 2nd ed. New York : Wiley, 1976, pp. 50–56.

[7] GP. Mora and WJ. O'Brien, "Thermal shock resistance of core reinforced all-ceramic crown systems," *Journal of Biomedical Materials Research Banner*, vol. 28, no. 2, pp. 189–194, 1994.

[8] AA. Barrett, NJ. Grimaudo, KJ. Anusavice, and MC. Yang, "Influence of tab and disk design on shade matching of dental porcelain," *Journal of Prosthetic Dentistry*, vol. 88, no. 6, pp. 591–597, 2002.

[9] KJ. Anusavice, RD. Ringle, PK. Morse, CW. Fairhurst, and GE. King, "A thermal shock test for porcelain-metal systems," *Journal of Dental Research*, vol. 60, no. 9, pp. 1686–1691, 1981.

[10] KJ. Anusavice, "Dental ceramics," in *Philip's Science of Dental Materials*, 11th ed. Missouri, Elsevier Saunders, 2003, pp. 441–447.

[11] K. Asaoka and JA. Tesk, "Transient and residual stress in a porcelain-metal strip," *Journal of Dental Research*, vol. 69, no. 2, pp. 463–469, 1990.

[12] KJ. Anusavice, PH. DeHoff, SW. Twiggs, and PC. Lockwood, "Thermal shock resistance of porcelain discs," *Journal of Dental Research*, vol. 62, no. 10, pp. 1082–1085, 1983.

[13] JP. Coffey, KJ. Anusavice, PH. DeHoff, RB. Lee, and B. Hojjatie, "Influence of contraction mismatch and cooling rate on flexural failure

of PFM systems," *Journal of Dental Research*, vol. 67, no. 1, pp. 61–65, 1988.

[14] JP. Nielsen and JJ.Tuccillo, "Calculation of interfacial stress in dental porcelain bonded to gold alloy substrate," *Journal of Dental Research*, vol. 51, no. 4, pp. 1043–1047, 1972.

[15] G. Isgro, CJ. Kleverlaan, H. Wang, and AJ. Feilzer, "Thermal dimensional behavior of dental ceramics," *Biomaterials*, vol. 25, no. 12, pp. 2447–2453, 2004.

[16] R. van Noort, "Dental ceramic," in *Introduction to Dental Materials*, 2nd ed. Mosby Ltd., 2002, pp. 231–256.

[17] PJ. Steiner, JR. Kelly, and AA. Giuseppetti, "Compatibility of ceramic-ceramic systems for fixed prosthodontics," *International Journal of Prosthodontics*, vol. 10, no. 4, pp. 375–380, 1997.