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Comparison Of Mechanical And Optical Properties Between Three Different CAD/CAM Materials

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COMPARISON OF MECHANICAL AND OPTICAL PROPERTIES BETWEEN THREE DIFFERENT CAD/CAM MATERIALS

A Thesis Presented
By
AASEM MUTLAQ ALHENAKI, B.D.S.

Submitted to the College of Dental Medicine of Nova Southeastern University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN DENTISTRY

June 2015

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Dedication

To my parents, Mr. Mutlaq Alhenaki and Mrs. Jamelah Aldhula’an, for all your support throughout my education. With your support and guidance I have been able to attain my goals. Additionally I would like to dedicate this thesis to my wife Dr. Nora Alamer, for all your encouragement and support throughout this process.

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ABSTRACT

COMPARISON OF MECHANICAL AND OPTICAL PROPERTIES BETWEEN THREE DIFFERENT CAD/CAM MATERIALS

DEGREE DATE: June 26, 2015

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Objective. This study aims to compare several mechanical and optical properties between three different CAD/CAM materials. The properties tested are: flexural strength, modulus of elasticity, hardness, translucency and surface gloss. **Background.** Typically, CAD/CAM restorations are either ceramic based or resin based. A new resin-ceramic hybrid material has recently been introduced and is thought to combine the advantages of both materials. **Methods.** Samples were divided into three groups, leucite-reinforced porcelain (IPS Empress CAD), lithium dicilicate (IPS e.max CAD) and resin-ceramic hybrid material (Vita Enamic). Twenty-six bar-shaped specimens were fabricated for each group by cutting standard CAD/CAM blocks. 3-point bending test and Vickers diamond pyramid indenters were used to test the flexural strength and microhardness respectively. Seven veneers were fabricated for each material with a thickness of 0.5 mm using a CAD/CAM milling machine. These veneers were used to test the optical properties via spectrophotometry and gloss-meter analysis. One-way ANOVA, and the Tukey HSD post hoc test were used for statistical analysis between the groups ($P<0.05$). **Results.** No significant difference was found between IPS Empress CAD and Enamic for flexural strength and surface gloss. However there was a significant difference when comparing IPS e.max CAD to the other materials. When comparing hardness and translucency of Enamic to the other materials there was a significant difference, however, no difference was found between IPS Empress CAD and IPS e.max CAD. **Conclusion.** Based on the result of this study, the current commercially available hybrid resin-ceramic material (VITA Enamic) showed, for the most part, similar properties to the machinable leucite-reinforced porcelain (IPS Empress CAD). Nevertheless, it does not appear to have any significant advantages over existing all ceramic materials, which may prove to be more esthetic with time. Therefore, the use of this class of material might be suitable for simple conservative indirect restorations. **Grants.** This study was funded by HPD grant.

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Chapter 1

Introduction

1.1 CAD/CAM in Dentistry

1.1.1 History of CAD/CAM

Computer-aided design (CAD) and computer-aided manufacturing (CAM) were developed in the 1960s. However, this technology was not introduced to the field of dentistry until the 1970s with the help of Dr. Francois Duret who developed the first dental CAD/CAM device. He used optical impressions of abutment teeth to fabricate prosthetic crowns using a numerically controlled milling machine. Later he presented his machine to the dental community at the French Dental Association International Congress in 1983.(1)

The first CAD/CAM machine used chair-side to fabricate an intra-coronal restoration (inlay) was developed in 1985 by Dr. Werner Mörmann and Dr. Marco Brandestini who had an electrical engineering background and suggested using optics to scan teeth. The machine was called CEREC, which stands for computer-assisted ceramic reconstruction.(2) Dr. Matts Andersson was the first person to use a CAD/CAM machine to fabricate a composite veneered restoration.(3) In 1983, he developed the Procera system (NobelProcera, Nobel Biocare, Zurich, Switzerland) which later became a processing center, connecting with satellite digitizers around the world, for fabrication of all ceramic restorations.(4) Originally, CAD/CAM was used merely to fabricate inlays, onlays, veneers and crowns. Presently, CAD/CAM includes the fabrication of fixed partial dentures and implant abutments. With the continuous development of CAD/CAM systems, there has been a corresponding increase in popularity of these machines in dental offices and laboratories.

1.1.2 Advantages of CAD/CAM

CAD/CAM technology provides several advantages to both patients and practitioners when compared to traditional techniques. Perhaps one of the main advantages of using CAD/CAM in dentistry is speed. Digital scanning and computer milling can be faster and easier than traditional impression making and laboratory fabrication. This is attributed to the fact that many steps of fabricating dental prosthesis such as pouring the impression, wax-ups, investing, casting, and firing are eliminated.(5) Various CAD/CAM manufacturing companies advertise that with the newest software and proper training, a full-arch scan should takes less than a minute to complete. Also, CAD/CAM provides to the patient the option of having the permanent prosthesis delivered the same day they come in, depending on the desired materials, and whether the milling machine is installed in the dental office instead of a dental laboratory.

Typically, a porcelain restoration is produced from a mixture of powder and liquid, condensed by vibration, and crystalized to decrease porosity. However, this process is subject to human error such as improper mixing, or entrapment of air causing an internal defect in the restoration that will negatively affect the life and performance of the final prosthesis. CAD/CAM restorations are made from prefabricated blocks manufactured in industrial conditions, producing fewer flaws and defects in the monolithic restoration, thus insuring more consistent and reliable results.(6)

Some of the common problems a dentist faces with traditional impression making are bubbles and tears of the impression material, gag reflex of the patient, especially with impression materials that require long setting time, and the expense of the impression material if a large volume of usage is considered. Digital scanning may over come some of these problems, given the speed of data acquisition and the ability to redo the impression with a press of a button. Also the ability to store the impression data and label it for every patient in the software will substitute the need for storing the patients' casts in the dental office or laboratory.(7)

1.1.3 Disadvantages of CAD/CAM

Although the advantages of CAD/CAM technology include speed of production, which reduces the time and labor needed for prosthesis fabrication and hence reduce the cost per patient, the initial cost of the software and equipment is extremely high. In addition, the dentist is required to spend time and money on training to be able to use the machine efficiently. Unless the dentist is planning to use the machine for a large volume of restorations in the office, making the investment pay off will be very difficult.(6)

Also, in order to fabricate a clinically acceptable prosthesis, digital scanning requires a precise scan. This means, just as with conventional impression, the tissues around the abutment tooth need to be retracted, the moisture needs to be controlled, and hemostasis needs to be achieved before the scanning procedure is done.

1.2 CAD/CAM Restorative Materials:

There are many categories of available restorative materials for chair-side CAD/CAM restorations (Table 1). These materials are manufactured as monolithic homogenous dense material in a solid block form that can be mounted in the milling machine (Figure 1).(8)

1.2.1 Feldspathic Porcelain Blocks:

Feldspathic porcelain is a material comprised of 15-20 volume % discrete leucite crystals in a glassy matrix. It possesses high translucency and moderate flexural strength. An example of this material is the Vitablocks Mark II (Vident, Brea, CA). This restorative material was introduced in 1991 and is available in different shades to match the patients' teeth color. Vitablocks Mark II blocks feature a smooth, high gloss milled surface and a minimum wear of the opposing enamel due to its small particle size, which make it a highly esthetic restoration.(9)

Since feldspathic porcelain blocks were one of the first CAD/CAM restorative materials, there are many studies that have evaluated the success and survival of this material in the clinical practice. Posselt and Kerschbaum treated 794 patients with 2328 ceramic inlays that were manufactured chair-side using CEREC technology in their private practice. They reported a survival rate after 9 years of 95.5%, with only 35 restorations failed.(10) Otto T, et al. published multiple studies evaluating the survival rate of 200 consecutively placed inlays and onlays, and reported a Kaplan-Meier survival probability of 90.4% after 10 years and 88.7% after a follow up of up to 17 years. They attributed the failure of the restoration mainly to porcelain fracture, tooth fracture and recurrent caries.(11,12)

1.2.2 Leucite-Reinforced Porcelain Blocks:

ProCAD was introduced from Ivoclar Vivadent (Lichtenstein) in 1998 as the first leucite-reinforced glass-ceramic CAD/CAM block. Later it was developed to become IPS Empress CAD (Ivoclar Vivadent) that contains 35% to 45% leucite crystals, and is referred to as a leucite-reinforced glass-ceramic. The addition of extra leucite particles to the glass matrix increases the physical properties of the material, such as flexural strength, flexural modulus, and fracture toughness.(13) It is available in different shades to match the patients' teeth color, as well as different levels of translucency, HT or high-translucency and LT referring to a low-translucency. Customization of the shade is also possible after milling using IPS Empress Universal Stains and try-in cement colors.(14)

Several studies reported on the performance of IPS Empress restorations for up to six years of follow up. Frankenberger and colleagues placed 96 ceramic restorations in 34 patients and reported a survival rate of 94%.(15) In 1998, a study evaluated 144 crowns over a period of 6 to 68 months and reported a success rate of 95.35%.(16) Another study reported a survival rate of 92% after 3.5 years.(17) All studies reported the major mode of failure is fracture of the restoration.

1.2.3 Lithium Disilicate Blocks:

Lithium disilicate restorations are known for their strength. The material's flexural strength is two to three times higher than other glass-ceramic materials. This increase in strength gives the clinician the opportunity to restore posterior teeth that are subject to high occlusal load with all-ceramic crowns, as well as the ability to fabricate three-unit fixed partial dentures.

In 2006, IPS e.max CAD was introduced as a lithium-disilicate CAD/CAM block. It contains lithium metasilicate crystals that range in size between 0.2 to 1 micrometers with approximately 40% crystals by volume. This makes the block look blue-violet in color. Therefore IPS e.max is commonly described as the "blue block". This state of partial crystallization allows the block to be milled easily without excessive wear and damage to the milling burs. After milling, the restoration undergoes a secondary crystallization process at 850℃. During this process the metasilicate crystals are dissolved, and lithium disilicate crystals formed.(18)

In a longitudinal study evaluating the clinical performance of IPS e.max CAD full contour crowns that were fabricated chair-side, there were no crown failures reported or porcelain chipping in any of the 62 samples after 2 years.(19) Another study also evaluated IPS e.max CAD restorations that were placed in 30 participants for two years. Two crowns needed endodontic treatment, however no technical complications, for example, cracks, chipping, or fractures, were detected.(20)

1.2.4 Nano-ceramic Hybrid Blocks:

A new material was recently developed using ceramic nanotechnology. The idea of this new material is to infiltrate a composite material into a roughly sintered, porous ceramic structure. Thus, combining the ease of handling of composite material with the retention of surface gloss and wear resistance as in porcelain. An example of this material is Vita Enamic (VITA Zahnfabrik; Bad Säckingen, Germany), which has been introduced to the market as a CAD/CAM block in 2013. Vita Enamic is characterized as an aluminum oxide-enriched, fine-structured feldspathic porcelain, combined with a polymer material containing urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEG-DMA). Manufacture testing reported a similar flexural strength to leucite-reinforced porcelain with significant reduction of the brittleness of the material that negatively impacts the mechanical durability of the material.(21) There have not been any long-term clinical studies reported on this material, due to its relatively short commercial availability.

1.2.5 Composite Resin Blocks:

Composite resin blocks have been used since 2000 as a long-term temporary restoration or in some cases as a final restoration. These materials are cross-linked micro-filled polymers that comprise zirconia-containing or other silicate glass filler particles. Examples of commercially available composite resin blocks include ParadigmTM MZlOO (3M ESPE, USA) and Vita CAD-Temp (Vident, CA, USA). The blocks are available in different shades and span length to accommodate multiple-unit fixed partial dentures.(22)

The use of composite resin block restorations allows for easy adjustments and intraoral polishing, as opposed to porcelain adjustments and repair, which are more difficult. The composite resin restorations fabricated using CAD/CAM have the advantage of low shrinkage and an air-inhibited layer found in conventional resin composite materials. The main drawback of composite block material is moisture absorption and the inability to retain a high-gloss surface finish over time, causing an inferior esthetic appearance.

1.3 Restorative Material Properties:

There are many meaningful properties of restorative materials that a clinician should know in order to determine the suitability of the material to a specific case given the clinical indication and limitation of each material. These properties may be divided into two categories: mechanical properties and optical properties.

1.3.1 Mechanical Properties:

1.3.1.1 Flexural Strength:

The flexural property (also known as bending property) of a material is measured by bending a beam-shaped specimen that is supported on two rollers with the load applied in the center on the topside of the beam. This test is called a 3-point bending test. The bending angel of the beam and the bending moment (force X distance) are recorded as the force applied on top of the beam is increased. The maximum stress measured at the point of fracture in the test is called flexural strength. This test determines the strength of the material as well as the amount of distortion expected. Flexural strength tests incorporate both tensile and compressive stresses, as well as the elastic behavior (modulus) of the material. This form of testing is commonly used to evaluate the strength of both ceramic and resin-based materials.(23,24)

1.3.1.2 Hardness:

Hardness of a material is defined as its resistance to permanent deformation. Hardness testing is done by applying a fixed load to an indenter, making a symmetrically shaped indentation in the surface of a specimen, which is then measured using a measuring microscope. Hardness values are then calculated using the indentation dimensions and the applied load. There are several methods for hardness testing. The Vickers hardness test is commonly used in the dental literature. It uses a 136-degree diamond pyramid-shaped indenter under a standardized force, to produce a square indentation, the diagonals of which are measured under a microscope.(23) Hardness is an important property when comparing restorative materials. The hardness of the restoration may indicate the level of abrasiveness of a material against the natural dentition.(25)

1.3.2 Optical Properties:

1.3.2.1 Translucency:

Translucency has been emphasized as one of the primary optical characteristics to achieve a good match to natural tooth structure.(26) Translucency occurs when light partially scatters or reflects while passing through an object. The greater the amount of impinging light that passes through the structure, the higher the translucency of the material.(27) The translucency of a natural tooth is evident when a noticeable amount of light passes through its incisal and/or proximal aspect due to the presence of a high proportion of enamel compared to the underlying dentin.

The color of a material is often measured using CIE L*a*b* coordinates.(28) These coordinates are measured using a spectrophotometer device that provides a numerical description of the color's position in a 3-dimensional color space to agree with Munsell color spacing. The L* color coordinate represents lightness and ranges from 0 to 100. The a* color coordinate represents the greenness and redness of the color and ranges from -90 to 70, while the b* color coordinate represents the yellowness and blueness and ranges from -80 to 100.(29) One of the most common methods of quantitatively measuring the translucency of dental materials is translucency parameter (TP). Translucency parameter measures the difference between the amount of light reflected through the specimen over a high reflectance backing (white background) and that of a high absorbent backing (black background). The translucency parameter is calculated using the following equation:

$$TP= [(L_B – L_W)^2 +(a_B – a_W)^2 +(b_B – b_W)^2]^{1/2}$$

where the subscripts “B” refers to the color coordinates on the black background and “W” to those on the white background. (30)

When the color of two specimens is expressed in L*a*b* coordinates, the color difference (ΔE) can be calculated using the following formula(31):

$$\Delta E = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$$

Delta E represents the numerical distance between two colors. When the color difference (ΔE) between two colors is less than 1 unit, then we can say that these two colors are symmetrical. If the color difference (ΔE) ranges in value from 1 to 2, then only a trained observer will be able to detect a color difference. Finally when the color difference (ΔE) between 2 colors is greater than 2 units, then the color difference will be apparent to all observers.(32,33) However, due to the multiple variables and the uncontrolled clinical conditions in the oral environment, studies have shown that a color difference (ΔE) of up to 3.7 is not noticeable and may be judged as match in color.(34,35) A study by Ruyter et al. in 1987 reported that 50% of the observers judged the color match between two veneers to be unacceptable when the color difference ΔE^*_{ab} was approximately 3.3. (36)

1.3.2.2 Surface Gloss:

Gloss is an optical property that indicates how well a surface reflects light in a specular direction. The gloss of a given material is affected by several factors such as the refractive index of the material, the angle of incident light and the surface topography i.e. surface roughness. The rougher the surface of the material, the more random is the reflection of the light that occurs, causing a decrease in surface gloss. Several polishing techniques have been advocated to achieve a smooth and glossy appearance. Surface gloss is one of the important properties when comparing different restorative materials.(37)

1.4 Purpose

The purpose of this study is to test the mechanical and optical properties of a newly introduced resin-ceramic hybrid material (Vita Enamic) and compare it to two existing, extensively used machinable dental ceramic materials (leucite-reinforced porcelain, and lithium disilicate glass ceramic).

1.5 Specific Aims

The aim of this study is threefold:

1. Compare the physical/mechanical properties (flexural strength, modulus of elasticity and microhardness) of three different CAD/CAM restorative materials (a resin-hybrid ceramic, a lithium disilicate glass ceramic, and a leucite-reinforced porcelain).
2. Compare the optical properties (translucency and surface gloss) of the same three CAD/CAM restorative materials.
3. Compare the marginal quality of the three different CAD/CAM restorative materials when milled to minimum thickness.

1.6 Hypotheses:

The new resin-hybrid CAD/CAM restorative material is purported to combine the advantages of both resin composite and ceramic materials. Therefore, several hypotheses are to be proposed in testing this new material. These hypotheses are the following:

1.6.1 Mechanical/Physical Properties Hypotheses:

- The resin-hybrid ceramic has significantly higher flexural strength when compared to a leucite-reinforced porcelain.
- The resin-hybrid ceramic has statistically equivalent flexural strength when compared to a lithium disilicate glass ceramic.
- The resin-hybrid ceramic has statistically equivalent modulus of elasticity and microhardness when compared to a leucite-reinforced porcelain.
- The resin-hybrid ceramic has significantly lower modulus of elasticity and microhardness when compared to a lithium disilicate glass ceramic.

1.6.2 Optical Properties Hypotheses:

- The resin-hybrid ceramic has significantly higher translucency and surface gloss when compared to a lithium disilicate glass ceramic.
- The resin-hybrid ceramic has statistically equivalent translucency and surface gloss when compared to a leucite-reinforced porcelain.

Chapter 2

Materials and Methods

The materials tested in this study are listed in (Table 2). The testing was divided into two parts, mechanical and optical. The following is a description of each test and the sample preparation necessary.

2.1 Mechanical and Physical Property Testing

The mechanical/physical properties tested for each material are: flexural strength, modulus of elasticity and microhardness.

2.1.1 Flexural Strength

In this study, 26 bar-shaped specimens (14 mm x 2 mm x 2 mm) were prepared by cutting standard commercially available CAD/CAM blocks using a low speed diamond wheel saw (Isomet, buehler, Lake Bluff, Illinois USA) (Figure 2). Then the specimens were ultrasonically cleaned in distilled water for 15 minutes. Afterwards, lithium metasilicate bars (that were partially crystalized) were mounted in a plate and placed in a porcelain oven for crystallization (Figure 3). A Programat CS oven (Ivoclar Vivadent, Schaan, Liechtenstein) was used for the crystallization and glazing process (Figure 4). After crystallization, the bars turned from their blue/violet color to the white porcelain color (Figure 5). The bars were then cleaned with distilled water.

One surface of each bar was finished to a uniform surface using 600, 800 and 1200-grit silicone carbide paper mounted in a grinder-polisher machine (MetaServ 2000, Buehler, Lake Bluff, Illinois USA) with tap water (Figure 6 and 7). The definitive thickness of the specimens was determined after polishing using a digital caliper (VWR

Digital Calipers, VWR International LLC, USA) with an accuracy of ± 0.05 mm (Figure 8).

The flexural strength was then determined for each material using a 3-point bending test in a universal testing machine (Instron, model 8841, USA) (Figure 9). The specimens were placed flat on the testing fixture with the polished surface facing down (away from the load direction) on rounded supporting rods 10 mm apart (Figure 10). The center of the each specimen was then loaded (load cell 1 KN) with a rounded chisel (radius 3 mm) at a crosshead speed of 0.5 mm/min until fracture occurs. The following equation was used for flexural strength (σ) calculation:

$$\sigma=3\ Pl/2wb^2$$

where P is the fracture load (N); l is the test span (10 mm); w is the width of the specimen (mm); and b is the thickness of the specimen (mm). The measurements of load and distance were calibrated to zero before every reading.

2.1.2 Modulus of Elasticity

The modulus of elasticity (Also referred to as the Young's modulus or elastic modulus) is a measure of stiffness of an elastic material. It can be calculated using the stress/strain curve, as stress is proportional to load and strain is proportional to deformation and it can be expressed as:

$$E = \sigma / \varepsilon$$

where "E" is Young's modulus; "σ" is the stress and "ε" is the strain. In this study, the modulus of elasticity was obtained directly from universal testing machine during the flexure strength testing.

2.1.3 Microhardness

The microhardness of each material was calculated using a Vickers hardness indenter (Model 1600-6125, Buehler, Lake Bluff, Illinois USA) (Figure 11). Ten of the bar-shaped specimens previously fabricated for flexural strength testing were used for the hardness test. A 136° pyramidal diamond indenter was placed on the highly polished surface center of each specimen at a low load of 0.5 N, a magnitude that prevented the formation of radial cracks as recommended by ASTM C 1327-99.(38) The load was maintained for a specific dwell time of 15 seconds (Figure 12) forming a symmetrical diamond indent. The indent size was determined by measuring the two diagonals of the diamond indent using an optical microscope. The average of the two diagonals was used in the following formula to calculate the Vickers hardness:

HV = Constant x test force / indent diagonal squared

where the constant is a function of the indenter geometry and the units of force and the indent diagonal.(39)

2.2 Optical Properties Tests

The optical properties tested for each material are: translucency and surface gloss

2.2.1 Veneer Samples Preparation

A cylindrical Teflon disk-mold with a 9.2mm diameter x 0.5mm thickness was used as a cast to make a digital impression (Figure 13). The computer-aided design system used in this study was CEREC® AC with Bluecam (Sirona Dental Systems GmbH Bensheim, Germany) and software version 4.0 (Figure 14). The process of capturing and designing the restoration using the CEREC® AC machine is comprise of four steps:

1. Administration: In this phase, a virtual patient was created and the restoration type was determined, defining the tooth numbers and the restorative materials that will be used. (Figure 15)
2. Acquisition: Prior to scanning a thin layer of Optispray (Sirona Dental Systems GmbH Bensheim, Germany) was sprayed over the Teflon disk-mold (Figure 16). Then CEREC camera was used for the optical scanning and the correlation was performed using a biogeneric copy. (Figure 17)
3. Model: The finish line was identified in this phase and the margins were drawn and edited, and the insertion axis of the virtual restoration was defined. The software automatically designs the porcelain veneer restoration. Alterations were made to the design as needed in order to ensure a thickness of 0.5 mm. (Figure 18)
4. Connect: In this phase, a connection was created between the CAD system and the CAM system. (Figure 19)

After the virtual design was completed, the milling process started using the MC XL Milling unit (Sirona Dental Systems GmbH Bensheim, Germany) (Figure 20). The filter of the SIRONA milling machine was changed prior to specimen fabrication in order to improve the function of the milling machine. In addition, Dentatec (Sirona Dental, Charlotte, NC) was added to the water in the filter tank as a manufactures recommendation. (Figure 21) Dentatec from Sirona® is used to clean and lubricate CEREC® and inLab® systems.

Seven disk-shaped veneer specimens were fabricated with a thickness of 0.5 ± 0.05mm by milling a standard leucite-reinforced glass-ceramic block (IPS Empress CAD, Ivoclar Vivadent, Schaan, Liechtenstein, Germany). The block size was C14 and the color selected was low translucency (LT) B1/1M-1 (Figure 22). The same specifications were used to fabricate seven veneer specimens from lithium disilicate glass ceramic (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) (Figure 23) and Resin-ceramic hybrid material (Vita Enamic, VITA Zahnfabrik; Bad Säckingen, Germany) (Figure 24). Due to the fact that lithium disilicate blocks are sold in a partially crystalized state, the veneer specimens were fully crystalized after milling using Programat CS oven (Ivoclar Vivadent, Schaan, Liechtenstein) and then cleaned with distill water before any optical testing was performed.

The machining process was carried out using a set of two different diamond burs, the "Step bur 12S" and the "Cylindrical bur 12S" (Figure 25). The manufacture recommends changing the burs after ten milling cycles. However, in this study each set of burs were used to mill seven samples only, as a new set of burs were used for each material (Figure 26).

2.2.2 Translucency

For each group, the color coordinates CIE L*a*b* were measured using a spectrophotometer (Color-Eye 7000A, Gretag Mecbeth, NY, USA) (Figure 27). The instrument was calibrated using a standard black light trap and a standard white calibration tile before any data acquisition, according to the manufacturer's recommendation (Figure 28). The CIE L*a*b* values of each specimen were measured against a standard white background (L* = 99.34, a* = 0.26, b* = –0.42) and a standard black background ($L^* = 2.34$, $a^* = -0.46$, $b^* = 0.57$) using D65 as the standard illumination source (as defined by the International Commission on Illumination) that corresponds to average daylight. The translucency parameter (TP) was then obtained by calculating the color difference between the two backgrounds using the following equation:

$$TP= [(L_B-L_W)^2 +(a_B-a_W)^2 +(b_B-b_W)^2]^{1/2}$$

where "L*" refers to the brightness, "a*" to redness to greenness, and "b*" to yellowness to blueness. The subscripts "B" refers to the color coordinates of the specimen aganist the black background and "W" to those against the white background. High translucency parameter (TP) means high translucency and less opacity of the restorative material. The color difference (ΔE) between the materials was also measured using the following equation:

$$\Delta E= [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

The data were entered in an Excel spread sheet.

2.2.2 Surface Gloss

The gloss between resin and ceramic varies significantly and may affect the choice of restorative material. The surface gloss of the three restorative materials was measured using a gloss meter (Novo- Curve, Imbotec group, USA) (Figure 29) .The seven milled veneer specimens of each group were rinsed with distilled water and air-dried, then placed on the specimen stage at the top level of the device. The gloss meter was calibrated before each measurement with a standard black board at 60° incidence angle. Afterward, three randomly selected veneers were polished using 600, 800 and

1200-grit silicone carbide paper under water irrigation. The surface gloss was measured again to compare the findings against the “as milled” surface.

2.3 Scanning Electro-Microscope (SEM) Evaluation

Two specimens from each group were randomly selected and evaluated under a scanning electro-microscope (SEM). SEM analysis was performed focusing on the thin margin of each material in order to evaluate qualitatively the effects of the machining process on the surface morphology of the restorations. The SEM illustrated the effect of the milling process on the thin section of the material and enabled us to detect any major irregularities or chipping that might indicate ease or difficulty of machining.

2.4 Statistical Method

Descriptive statistics were obtained and One-way ANOVA was used to look for differences between the study groups for all variables. Pairwise comparisons were conducted using a Tukey HSD adjustment. A p-value of less than 0.05 was set to be a criterion for statistical significance. SPSS was used for the data analysis.

Chapter 3

Results

3.1 Mechanical Properties

The measured mean and standard deviation of all the mechanical and physical properties (flexural strength, modulus of elasticity and hardness) for each material are shown in (Table 3). Enamic has the lowest flexural strength (139.50 MPa) when compared to IPS Empress CAD (145.27 MPa) and IPS e.max CAD (357.61 MPa). However, Tukey's Pairwise comparison (Table 4) shows no significant difference in mean strength between Enamic and IPS Empress CAD (p-value = 0.83) while the flexural strength of IPS e.max CAD is significantly higher than the other two materials (p-value < 0.00) (Figure 31).

The mean modulus of elasticity of Enamic group (18.30 GPa) was significantly less than that of IPS Empress CAD (27.63 GPa) and IPS e.max CAD (39.37 GPa). A statistically significant difference was also found between the modulus of elasticity of IPS Empress CAD and IPS e.max CAD groups (p-value < 0.00) (Figure 32).

Enamic had a measured microhardness value (2.32 GPa) that was significantly less than the other two groups (p-value < 0.00). On the other hand, no statistically significant difference was found between IPS Empress CAD (5.18 GPa) and IPS e.max CAD (5.57 GPa) (p-value = 0.22) (Figure 33).

3.2 Optical Properties

The mean color coordinates (ΔL*, Δa* and Δb*), Translucency Parameters (TP) and gloss values of the samples was calculated and the values for individual samples are shown in Appendix B (RAW DATA). The descriptive statistics of all the variables for each material are shown in (Table 5).

Results of one-way ANOVA revealed a significant effect for the type of material on the translucency parameter ($p<0.001$). Post-hoc Tukey's test indicated that the mean translucency parameter for Enamic was significantly greater than that of the other materials. However, there is no statistical significant difference found between IPS Empress CAD and IPS e.max CAD (p-value = 0.77) (Table 6). The CIE Lab color coordinates were used to calculate the color difference (ΔE) between the three materials. The results are shown in (Table 7).

The mean surface gloss of the IPS e.max CAD veneers "as milled" (2.74 GU) showed a statistically significant difference (p-value < 0.00) when compared to the other two groups. No statistically significant difference was found between Enamic (1.46 GU) and IPS Empress CAD (1.50 GU). All the three materials showed significantly higher gloss values after polishing (The values ranged between 37.40 – 91.20 GU) when compared to the veneers as milled (1.3 – 2.9 GU) (Table 5).

3.3 Scanning Electro-Microscope (SEM) Evaluation

SEM pictures are illustrated in (Figures 34 – 36) and showing the margin of the veneer restorations of the three different materials after milling at a 50x magnification.

Chapter 4

Discussion

4.1 Overview

Typically, CAD/CAM restorations are either ceramic-based or resin-based. Each material has its advantages and disadvantages. Dental ceramics have been used for many years as a material of choice for final restorations due to their ability to fulfill both function and esthetic needs. Despite their excellent biocompatibility, low plaque retention, stain-resistant, translucency and high esthetics, the main drawback of ceramics is their brittleness, low tensile strength,(17,40) poor resistance to crack propagation (low fracture toughness), and low impact strength.(41) In addition, the high strength, which is often associated with high hardness, can negatively affect the milling process. Composite polymer materials, on the other hand, have the advantage of flexibility, which results in a material that can often withstand high flexural forces. These resin-based compositions are easy to repair and have low costs. Yet, resin can absorb moisture over time, compromising the esthetic appearance and the mechanical properties of the material.(42) Therefore, it would be extremely advantageous if we were able to use a material that combines the advantages of both. A new resin-ceramic hybrid material has recently been introduced. In this study we tested some of the mechanical, physical and optical properties of this resin-ceramic hybrid in order to evaluate if it is potentially better than the currently used CAD/CAM restorative materials.

4.2 Mechanical Properties

Several studies have used 3-point bending tests to determine the flexural strength of a given material.(24,43,44) In this study, the flexural strength of IPS e.max CAD was found to be significantly higher than that for IPS Empress CAD and Enamic. These finding were consistent with prior studies that compared these materials.(45-48) This is attributed to the size, shape, and distribution of the crystalline phases that have a great effect on the mechanical properties of the porcelain.

There was no significant difference found between IPS Empress CAD and Enamic. This suggests that the limitation of use of IPS Empress CAD in the oral cavity, such as posterior teeth and multiple units, should also apply to Enamic restorations. Due to the low flexural strength, their use should be limited to the anterior and premolar areas, where there is less occlusal loading.

The flexural strength values reported in this study are comparable with the data found in the literature and reported by manufacturers. For IPS Empress (145.27 MPa), Hooshmand et al. reported (118.6 ± 25.5)(49) and Vichi et al (125.1 ± 13),(50) while the manufacture reported a biaxial flexural strength of (160 MPa). As for IPS e.max CAD, in this study the mean was (357.6 MPa), and it has been reported in previous studies to be (230 – 380 MPa),(48,49) and by the manufacture to be (360 MPa). The flexural strength of Enamic in this study was approximately (140 MPa), which agrees with the values reported by Leung et al (48) and in house manufacturer testing.

Enamic showed the lowest modulus of elasticity when compared to the other groups. This is considered an advantage to the durability of Enamic, as it has very close stiffness values to natural dentin (about 18 GPa).(51,52) This property could be attributed to the polymer chains in the Enamic matrix that absorb much of the deformation related stress under the load, and hence potentially decrease crack growth.

Hardness is defined as the resistance of a material to permanent deformation. It can affect wear resistance and ease of milling. Restorative materials with high hardness values may also trigger wear of opposing natural teeth, while on the other hand, a material with low hardness may be subjected to excessive wear caused by the opposing dentition, hard food particles, or even aggressive tooth brushing abrasion. The microhardness of Enamic in this study was (2.3 GPa) while that of natural enamel reported in previous studies ranged between (2.7 - 6.4 GPa).(53-56) Therefore, Enamic may be more prone to wear by opposing dentition compared to IPS Empress CAD (5.2 GPa) and IPS e.max CAD (5.6 GPa). It should be noted, however, that wear is a complex process and is not determined merely by material hardness.

4.3 Optical Properties

Translucency of a material is defined as the ability to allow light to pass though it without scattering. In the field of dental restorative materials, translucency is considered an essential property, comparable in importance to tooth color.(57,58) In order to compare the translucency between different materials, translucency parameter (TP) values were calculated using CIE Lab color coordinates obtained from a spectrophotometer. A spectrophotometer has been used in several studies to measure the translucency of different restorative materials.(29,59,60)

There are several factors that affect the translucency of a restorative material. Some factors relate to the specimen itself, such as thickness, shade, surface texture, degree of porosity and amount of crystals within the porcelain matrix. While other factors relate to the measurement procedure such as illumination, edge-loss and the angle of observation.

Many studies in the literature found an indirect relationship between the thickness of the material and the degree of translucency.(61-64) That means the greater the thickness of the specimen the lower its translucency. In this study, all veneers were milled using the same virtual design and measurement made in the CAD/CAM software. The thickness of 0.5mm was chosen for all the specimens since it is considered the minimum thickness recommended for veneer preparation. The specimens were measured after milling using a dental crown gauge caliper (Figure 34). The standardization of the thickness ensures that any detectable difference in the translucency between the materials was not due to variable specimen thickness.

Porosity is another factor that may affect translucency.(65,66) During mixing and manipulation of ceramic powder, air-bubbles may be entrapped in the mixture causing voids, and therefore vary the degree of porosity. In our study however, the specimens were made from milling a prefabricated monolithic condensed CAD/CAM block. Thus eliminating porosity in all the specimens that may affect the measurement of translucency.

Since there are many variables that may affect the translucency parameter of restorative materials, it is difficult to compare the absolute value of translucency found in this study with values reported previously. In our study, the mean TP in decreasing order were Enamic (67.7), IPS Empress CAD (65.0) and IPS e.max CAD (64.6). These results do not agree with a recent study done by Awad et al.(67) who found Enamic to have the least TP (27.9) while IPS Empress CAD and IPS e.max CAD were (40.4) and (33.9) respectively. The thickness of the specimens differ between the two studies, as they used 1.0 and 2.0 mm disks that were cut using a low speed diamond saw rather than milled using a CAD/CAM machine, as in this study. Moreover, they used “A2” shade, which is a darker when compared to the shade used in this study “ B1”. Dark shades may affect the light passage though the specimen, and hence affect the translucency of the material.

For a restoration to be esthetically acceptable, the translucency of the veneering material needs to be similar to that of natural enamel. Because it is difficult to prepare specimens of pure enamel to measure translucency, there are few studies comparing the translucency of enamel and different restorative materials.(68) In addition, translucency of enamel differs significantly depending on the age, gender and tooth color of the individual teeth.(69) The translucency parameter for enamel reported in the literature varies from (40.4 – 69.1).(70) This means that the TP of all three materials tested in this study fall into the range of enamel translucency.

When it comes to color difference between restorative materials, it is not enough to rely on statistically significant differences. The human perception of detectable color difference should also be taken into consideration. According to Ishikawa-Nagai et al. the observer perceives color difference very subjectively, which results in an unpredictable color matching and evaluation among clinicians.(71) Previous studies came up with an acceptable color difference threshold (ΔE), beyond which, color differences are believed to be detectable clinically. Johnston & Kao (1989) reported that color difference (ΔE) between two colors should not exceed 3.7 to be judged as match,(34) while Ruyter et al. (1987) stated that the ΔE threshold was approximately 3.3.(35) For this study, the clinically detectable differences was considered to be a ΔE higher than 3.7. Based on the results shown in (Table 7) there were no clinically detectable differences between all tested restorative materials when evaluated immediately after milling.

Gloss unit is the number given to the reflectance value of a surface. It is commonly measured using a gloss-meter device.(37,72,73) In a study done by Lefever et al., dental enamel was reported to have a gloss unit of (113.2 ± 4.0).(73) The majority of restorative materials are categorized as "semi-gloss" because they fall into the range of 10 to 70 GU. When a surface has a GU less than 10 then it is considered a "dull surface" while a GU higher than 70 is "high-gloss".(74) In this study, veneers made from all three materials were determined to have dull surfaces after milling (GU < 10). However, after standard polishing procedures, the surface gloss of all tested materials significantly improved (GU > 50), and therefore became acceptable "semi-gloss" surfaces.

4.4 Scanning Electro-Microscope (SEM) Evaluation

When a thin section of a CAD/CAM restorative material is subject to high kinetic energy and vibrations during the milling procedure it tends to crack. Randomly selected specimens were evaluated under the SEM at the margin level for microcracks, or other defects. These evaluations were qualitative, with few measurements of observed defects performed. Due to the polymer content in Enamic, it showed the lowest surface defect content when compared to IPS Empress CAD and IPS e.max CAD. While microcracks may not affect the marginal integrity of a restoration clinically, they are considered a surface flaw that may potentially propagate as a larger crack, and compromise the integrity of the restoration.

4.5 Limitation of the Study

Some of the limitation of this study is that it is an in vitro study that does not replicate the oral cavity conditions. Also a disk-shaped veneer was fabricated due to ease of design and standardization as opposed to an accurate veneer preparation on a plastic tooth to mimic a clinical procedure.

4.6 Overall Evaluation of Hybrid Resin-Ceramic Material

The new class of hybrid resin-ceramic material uses a continuous porous ceramic network that is infiltrated with resin in order to theoretically improve its durability. However, based on the results of this study, the current commercially available variant of this type of material (Enamic) showed, for the most part, similar properties to the machinable leucite-reinforced porcelain (IPS Empress CAD). Nevertheless, it does not appear to have any significant advantages over existing all ceramic materials, which may prove to be more esthetic over time. Therefore, the use of this class of material might be suitable for simple conservative indirect restorations. While this new class of hybrid material looks promising when compared to resin composite, one must be cautious if deciding to use it for esthetic veneers, as there are no long-term clinical evaluations of its esthetic durability. Meanwhile, available all ceramic materials are well known for their superior stain resistance and retention of surface gloss. The major advantage of hybrid resin-ceramic material is its ease of repair intraorally in case of chipping as opposed to porcelain restorations that are impractical to repair and are commonly completely replaced. Additional short and long-term clinical data is needed to more completely assess the mechanical and esthetic efficacy of this new type of machinable composite material.

4.7 Future Research

One of the advantages of hybrid ceramic restorative materials is possible ease of repair. Perhaps an interesting study would be to evaluate the bond strength of repaired composite to the hybrid ceramic restoration.

Loss of surface gloss is one of the main disadvantages of indirect composite veneers. The retention of surface gloss in the hybrid ceramic however, is an area yet to be examined.

Chapter 5

Conclusion

Within the limitations of this study, the following conclusions were drawn:

- The strength of Enamic was found to be comparable to IPS Empress CAD but less than that of IPS e.max CAD. So it is not indicated for posterior or multiple unit restorations.
- Enamic has lower hardness values than IPS Empress CAD and IPS e.max CAD, which makes it potentially more prone to wear from opposing dentition.
- Enamic has clinically comparable translucency to both IPS Empress CAD and IPS e.max CAD, as well as that of natural teeth.
- All three tested materials have unacceptable surface gloss values “dull surface” after milling. However, after standard polishing procedure the gloss values were comparable to commonly used restorative material and tooth surface gloss.
- Long-term studies are needed to evaluate the esthetic durability of the hybrid resin-ceramic material. Until then it might be suitable for simple conservative indirect restorations.

Table 1. Categories of Materials tor Chair-side CAD/CAM Restorations

Category	Brand Name (Manufacturer)
Feldspathic Porcelain	Vitablocs Mark II (Vident)
Leucite-Reinforced Porcelain	IPS Empress CAD (Ivoclar Vivadent)
Lithium Disilicate	IPS e.max CAD (Ivoclar Vivadent)
Nano-ceramic	Enamic (VITA)
Composite resin	Paradigm MZlOO (3M ESPE)
Composite resin (temporary restorations)	Vita CAD-Temp (Vident)

Fasbinder DJ. Chairside CAD/CAM: An Overview of Restorative Material Options. Compend Contin Educ Dent. 2012 Jan;33(1):50, 52-8.

Table 2. Material Tested

Material	Manufactures
Leucite-reinforced porcelain	IPS Empress CAD; Ivoclar Vivadent, Schaan, Liechtenstein
Lithium disilicate glass ceramic	IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein
Resin-ceramic hybrid material	VITA Enamic, VITA Zahnfabrik; Bad Säckingen, Germany

Table 3. Descriptive Statistic of Mechanical Properties

		N	Mean	Std. Dev.	Min	Max
Enamic	Strength (MPa)	26	139.50	8.97	118.09	153.12
	Modulus (GPa)	26	18.30	2.00	15.28	21.37
	Hardness	10	236.04	28.55	194.50	280.40
		N	Mean	Std. Dev.	Min	Max
IPS Empress CAD	Strength (MPa)	26	145.27	20.15	98.42	178.17
	Modulus (GPa)	26	27.63	1.87	23.65	32.90
	Hardness	10	528.25	79.38	473.50	725.50
		N	Mean	Std. Dev.	Min	Max
IPS e.max CAD	Strength (MPa)	26	357.61	57.13	248.58	440.68
	Modulus (GPa)	26	39.37	2.54	35.67	44.55
	Hardness	10	568.06	30.56	524.40	615.90

Table 4. Tukey’s Pairwise Comparison for Mechanical Properties

				Difference	Lower 95% CI	Upper 95% CI	P-Value
Strength	IPS Empress CAD	Vs.	Enamic	5.76	-17.98	29.51	0.83
	IPS e.max CAD	Vs.	Enamic	218.11	194.36	241.85	0.00
	IPS e.max CAD	Vs.	IPS Empress CAD	212.34	187.88	236.80	0.00
				Difference	Lower 95% CI	Upper 95% CI	P-Value
Modulus	IPS Empress CAD	Vs.	Enamic	9.33	7.86	10.81	0.00
	IPS e.max CAD	Vs.	Enamic	21.07	19.60	22.55	0.00
	IPS e.max CAD	Vs.	IPS Empress CAD	11.74	10.22	13.26	0.00
				Difference	Lower 95% CI	Upper 95% CI	P-Value
Hardness	IPS Empress CAD	Vs.	Enamic	292.21	234.77	349.65	0.00
	IPS e.max CAD	Vs.	Enamic	332.02	274.58	389.46	0.00
	IPS e.max CAD	Vs.	IPS Empress CAD	39.81	-17.63	97.25	0.22

Table 5. Descriptive Statistic of Optical Properties

		N	Mean	Std. Dev.	Min	Max
Enamic	ΔL*	7	67.58	0.86	66.56	69.13
	Δa*	7	-0.77	0.03	-0.81	-0.74
	Δb*	7	0.39	0.32	0.00	0.93
	Translucency Parameters (TP)	7	67.58	0.86	66.57	69.13
	Gloss meter	7	1.46	0.08	1.30	1.50
	Gloss meter Polished	3	70.57	10.54	61.90	82.30
		N	Mean	Std. Dev.	Min	Max
IPS Empress CAD	ΔL*	7	64.97	1.30	62.62	66.42
	Δa*	7	-1.00	0.02	-1.03	-0.98
	Δb*	7	0.10	0.27	-0.27	0.49
	Translucency Parameters (TP)	7	64.98	1.30	62.63	66.43
	Gloss meter	7	1.50	0.08	1.40	1.60
	Gloss meter Polished	3	50.93	13.26	37.40	63.90
		N	Mean	Std. Dev.	Min	Max
IPS e.max CAD	ΔL*	7	64.48	1.61	62.20	67.18
	Δa*	7	-1.63	0.09	-1.75	-1.54
	Δb*	7	-0.03	0.27	-0.45	0.27
	Translucency Parameters (TP)	7	64.50	1.61	62.22	67.20
	Gloss meter	7	2.74	0.22	2.30	2.90
	Gloss meter Polished	3	91.20	0.79	90.60	92.10

Table 6. Tukey's Pairwise Comparison for Optical Properties

				Difference	Lower 95% CI	Upper 95% CI	P-Value
Translucency Parameter (TP)	IPS Empress CAD	Vs.	Enamic	-2.60	-4.36	-0.84	.004
	IPS e.max CAD	Vs.	Enamic	-3.09	-4.85	-1.32	0.01
	IPS e.max CAD	Vs.	IPS Empress CAD	-0.48	-2.25	1.28	0.77
				Difference	Lower 95% CI	Upper 95% CI	P-Value
Gloss meter	IPS Empress CAD	Vs.	Enamic	0.04	-0.14	0.23	0.83
	IPS e.max CAD	Vs.	Enamic	1.29	1.10	1.48	0.00
	IPS e.max CAD	Vs.	IPS Empress CAD	1.24	1.06	1.43	0.00
				Difference	Lower 95% CI	Upper 95% CI	P-Value
Gloss meter Polished	IPS Empress Polished	Vs.	Enamic Polished	-19.63	-44.16	4.89	0.11
	e.max CAD Polished	Vs.	Enamic Polished	20.63	-3.89	45.16	0.09
	e.max CAD Polished	Vs.	IPS Empress Polished	40.27	15.74	64.79	0.01

Table 7. Color Difference (ΔE) Between Materials

$\Delta E = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{\frac{1}{2}}$	
ΔE IPS Empress CAD vs. IPS e.max CAD	**0.800**
ΔE IPS Empress CAD vs. Enamic	**2.783**
ΔE IPS e.max CAD vs. Enamic	**3.293**

Figure 1. Ceramic mill blocks for the CAD/CAM machine

Fasbinder DJ. Chairside CAD/CAM: An Overview of Restorative Material Options. Compend Contin Educ Dent. 2012 Jan;33(1):50, 52-8.

Figure 2. Low speed diamond wheel saw (Isomet, buehler, Lake Bluff, Illinois USA)

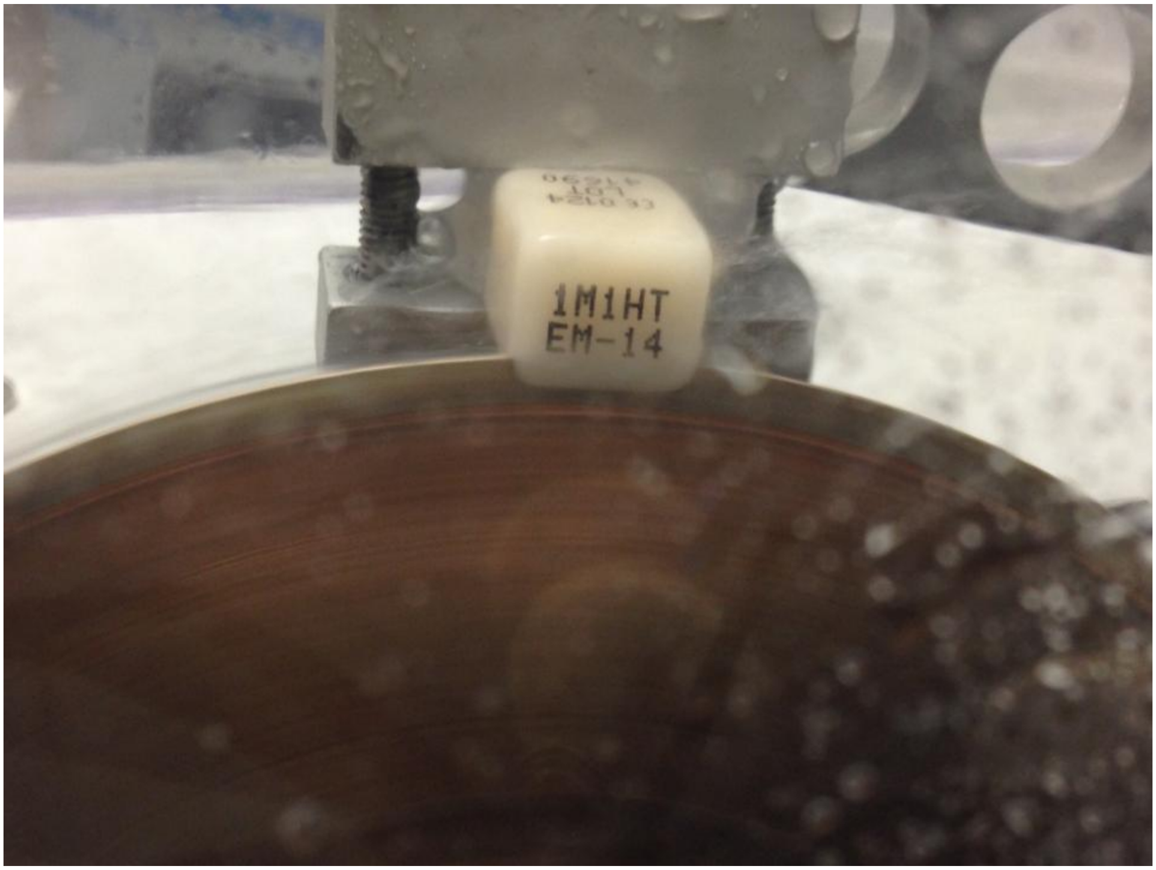

Figure 3. Lithium metasilicate bars mounted in a plate for crystallization

Figure 4. Programat CS oven (Ivoclar Vivadent, Schaan, Liechtenstein)

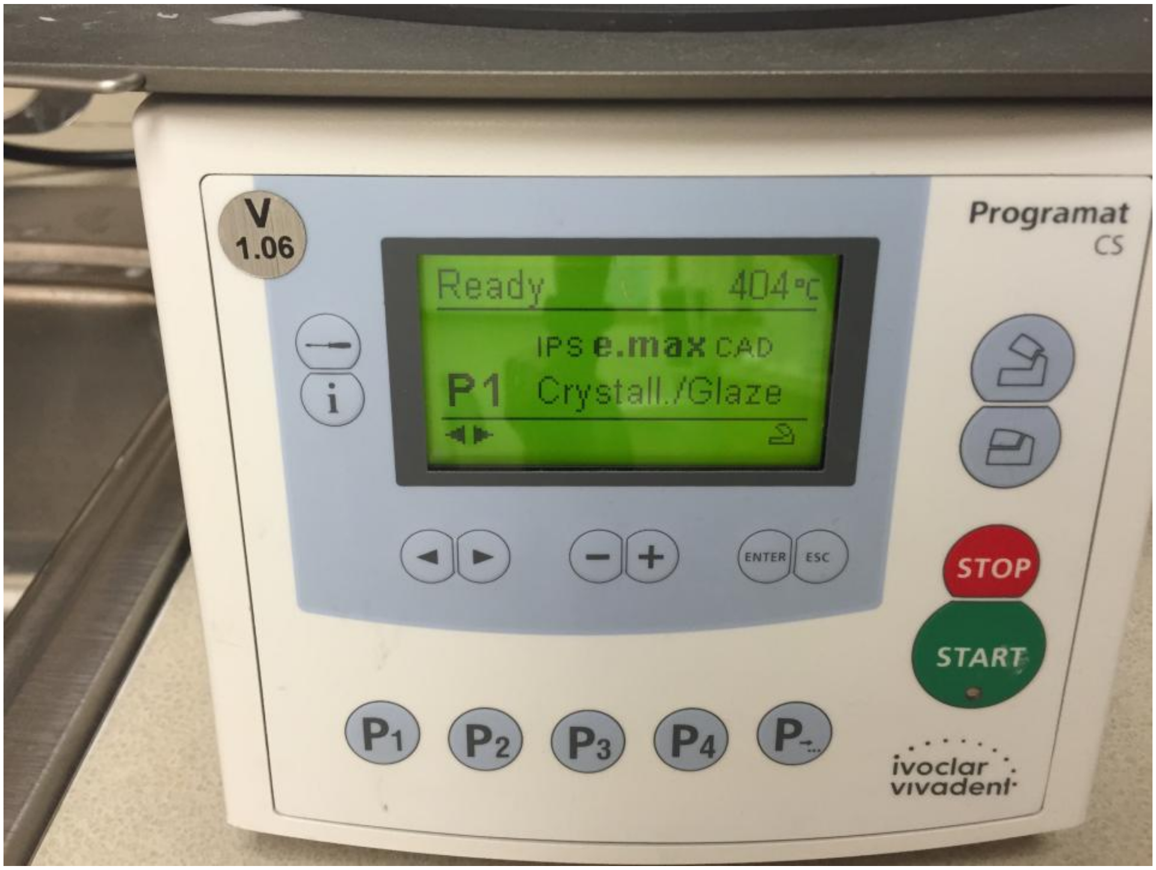

Figure 5. Lithium disilicate bars after crystallization

Figure 6. Grinder-polisher machine (MetaServ 2000, Buehler, Lake Bluff, Illinois USA)

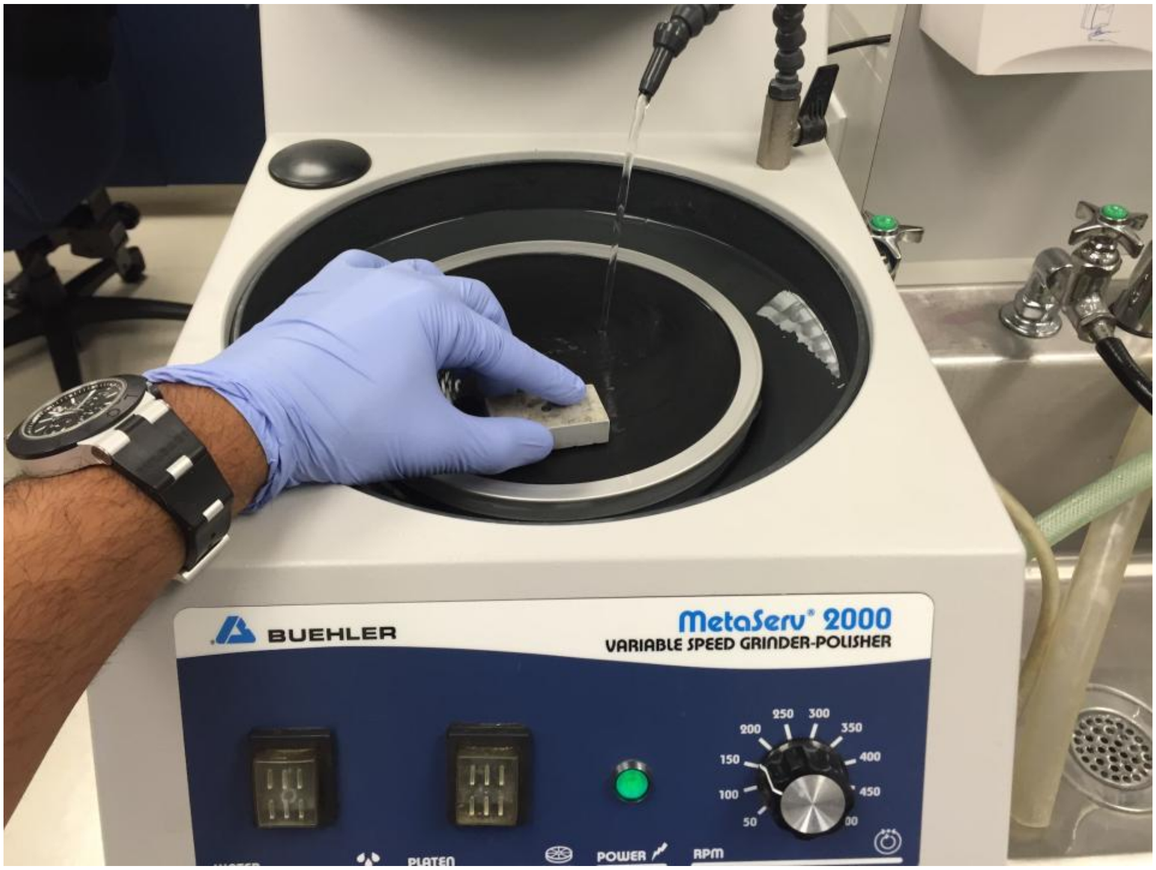

Figure 7. Polishing specimens

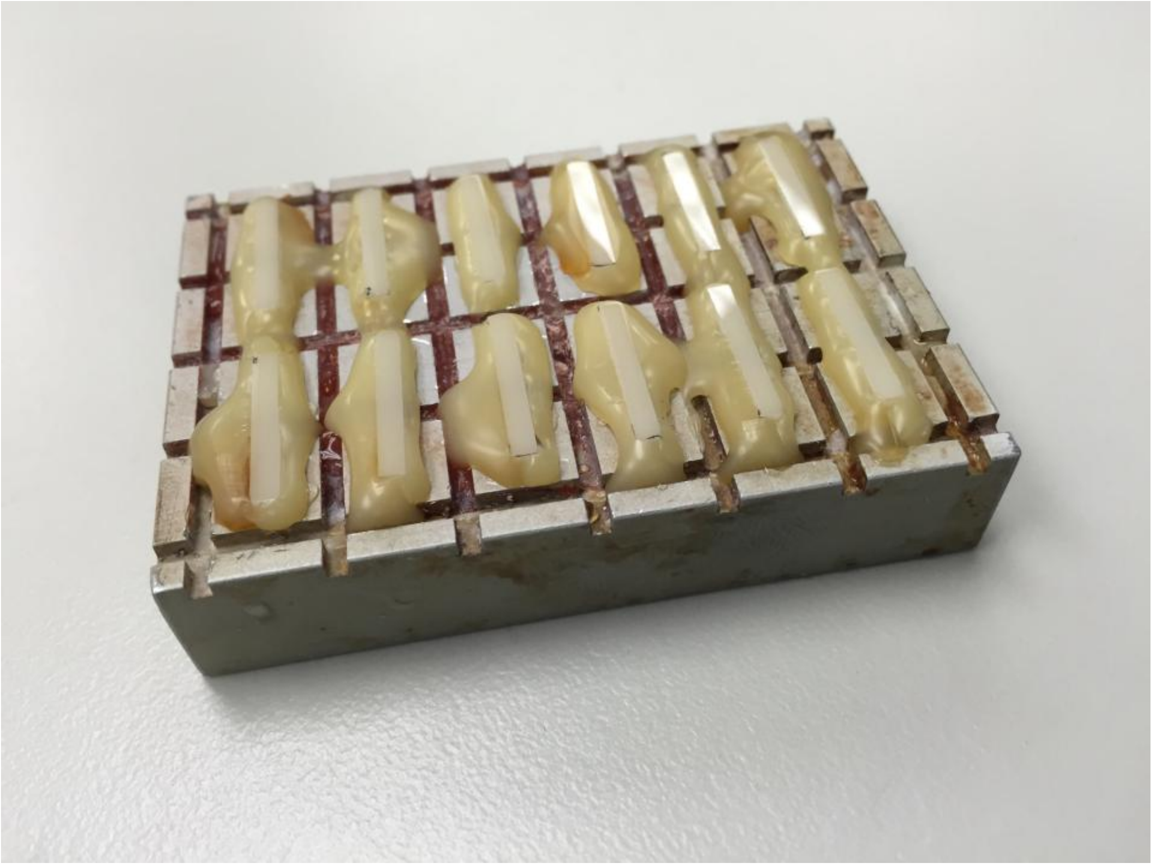

Figure 8. Measurement of the specimen using digital caliper

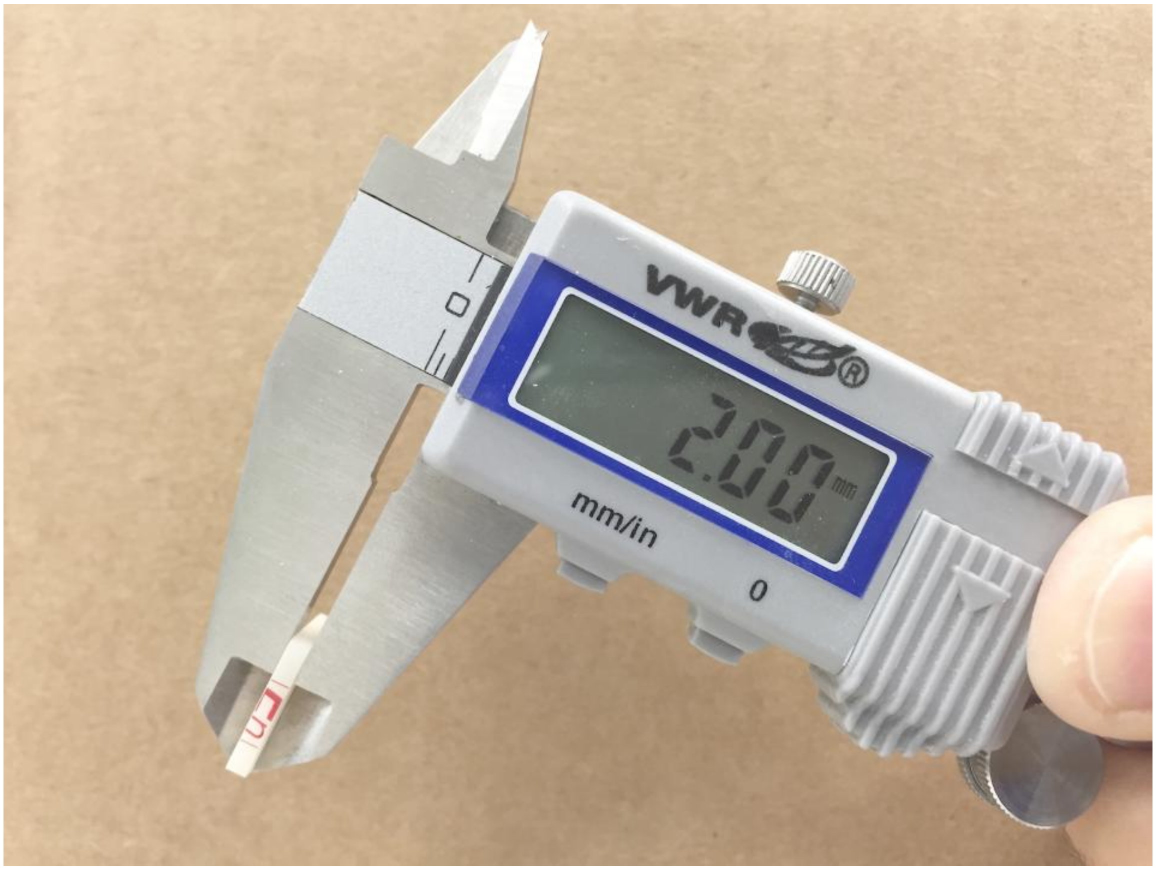

Figure 9. Three-point bending test in a universal testing machine (Instron, model 8841, USA)

Figure 10. Mountain jig with the rounded supporting rods 10 mm apart

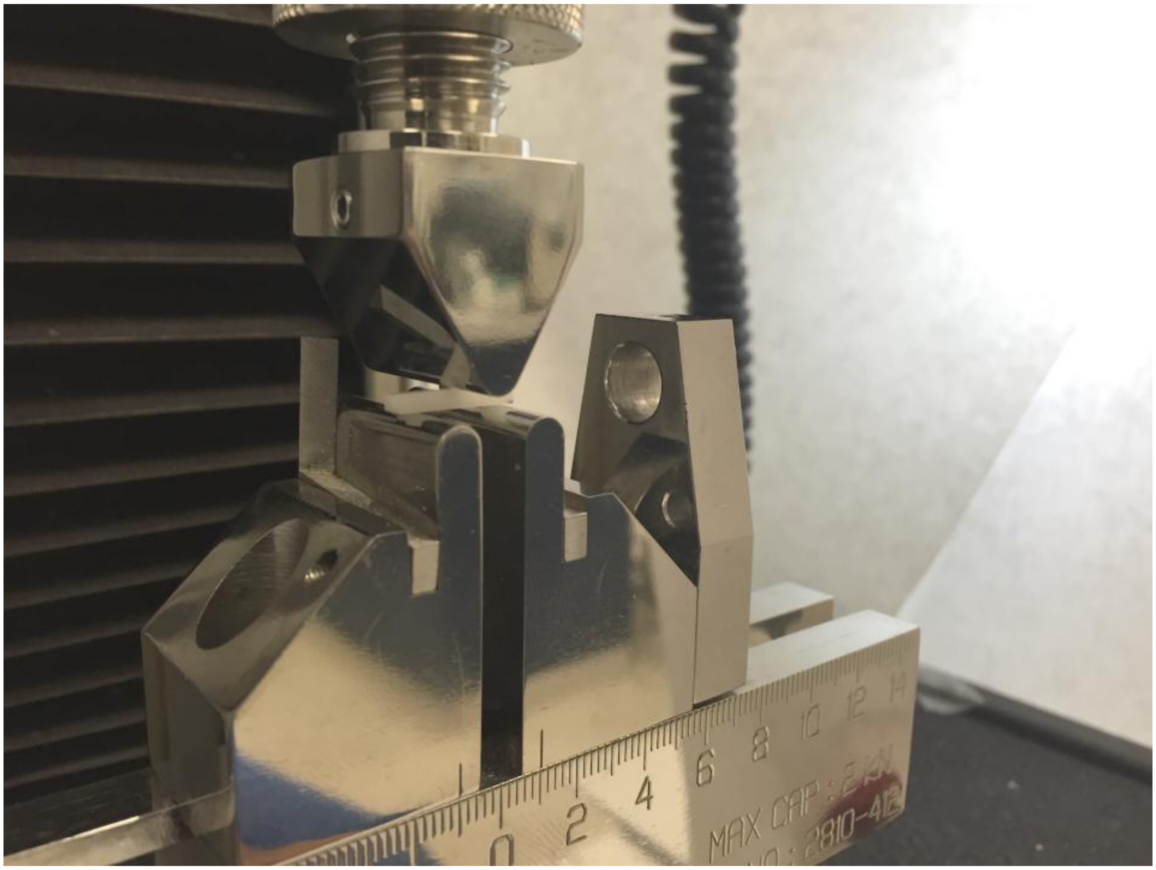

Figure 11. Vickers hardness indenter (Model 1600-6125, Buehler, Lake Bluff, Illinois USA)

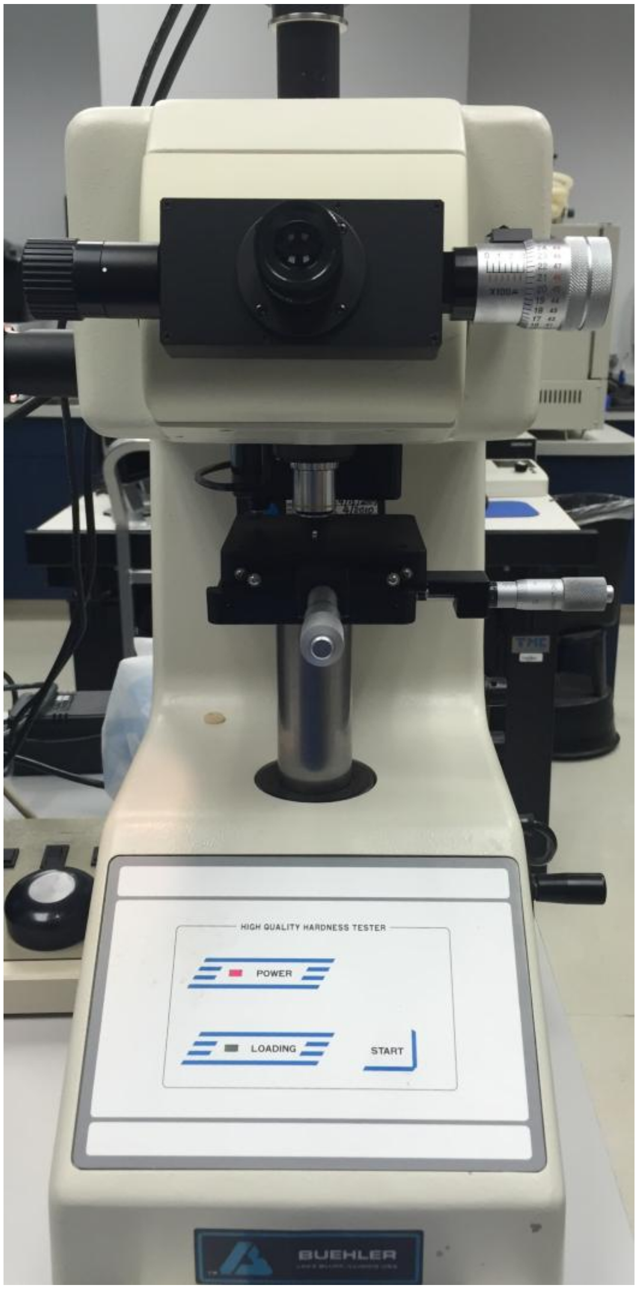

Figure 12. The load was maintained for a specific dwell time of 15 seconds

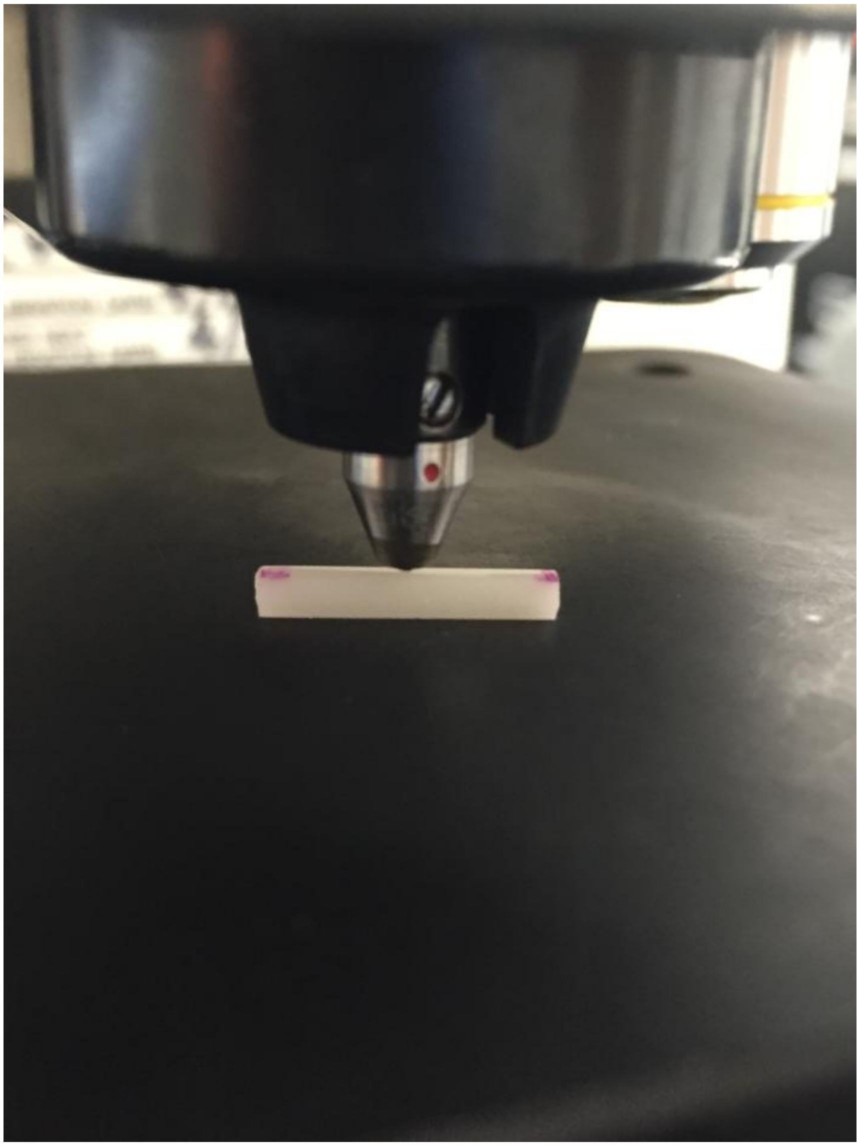

Figure 13. Cast Model/ Teflon Disk-Shape

Figure 14. CEREC AC (Sirona) 4th Generation

Figure 15. CAD/ Administration

Figure 16. Teflon disk-shape model prior to scanning

Figure 17. CAD/ Acquisition

Figure 18. CAD/ Model

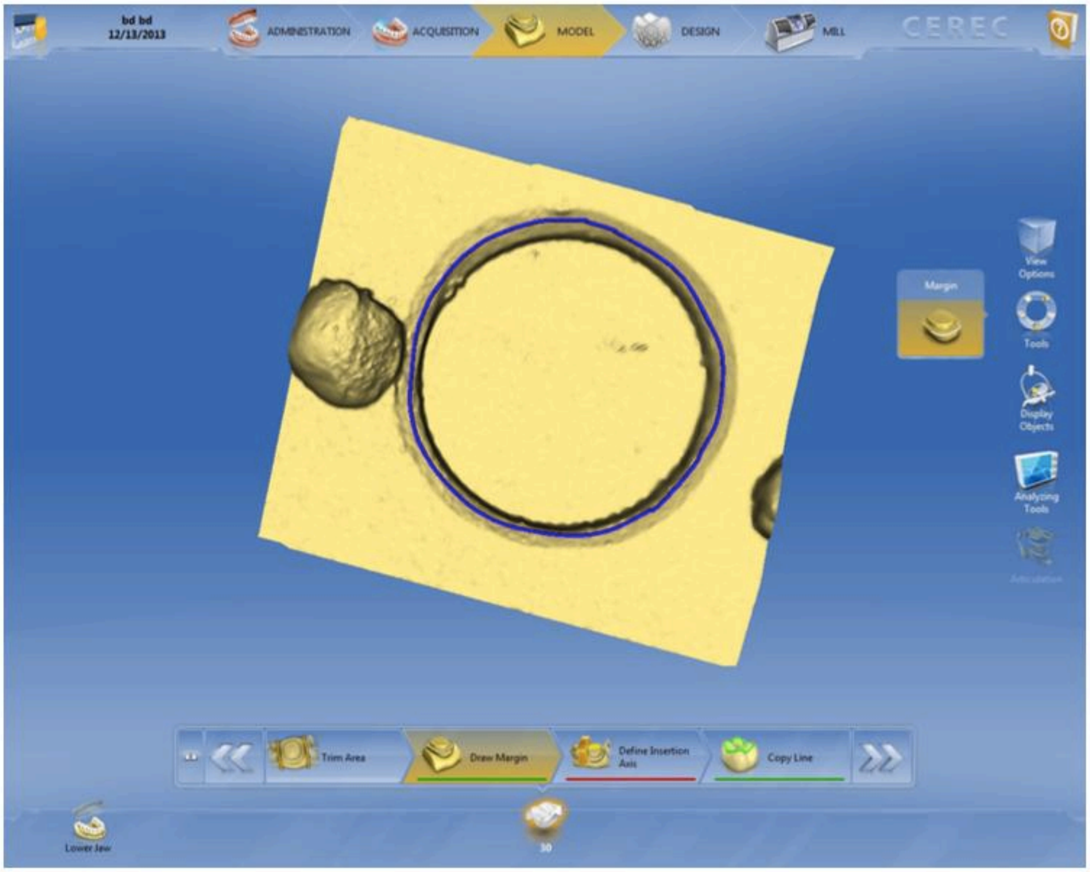

Figure 19. CAD/ Connection

Figure 20. CEREC MC XL (Sirona)

Figure 21. Water filter (left) and Dentatec (right) for MC XL Milling Unit CEREC.

Figure 22. IPS Empress CAD block mounted in the CAM machine

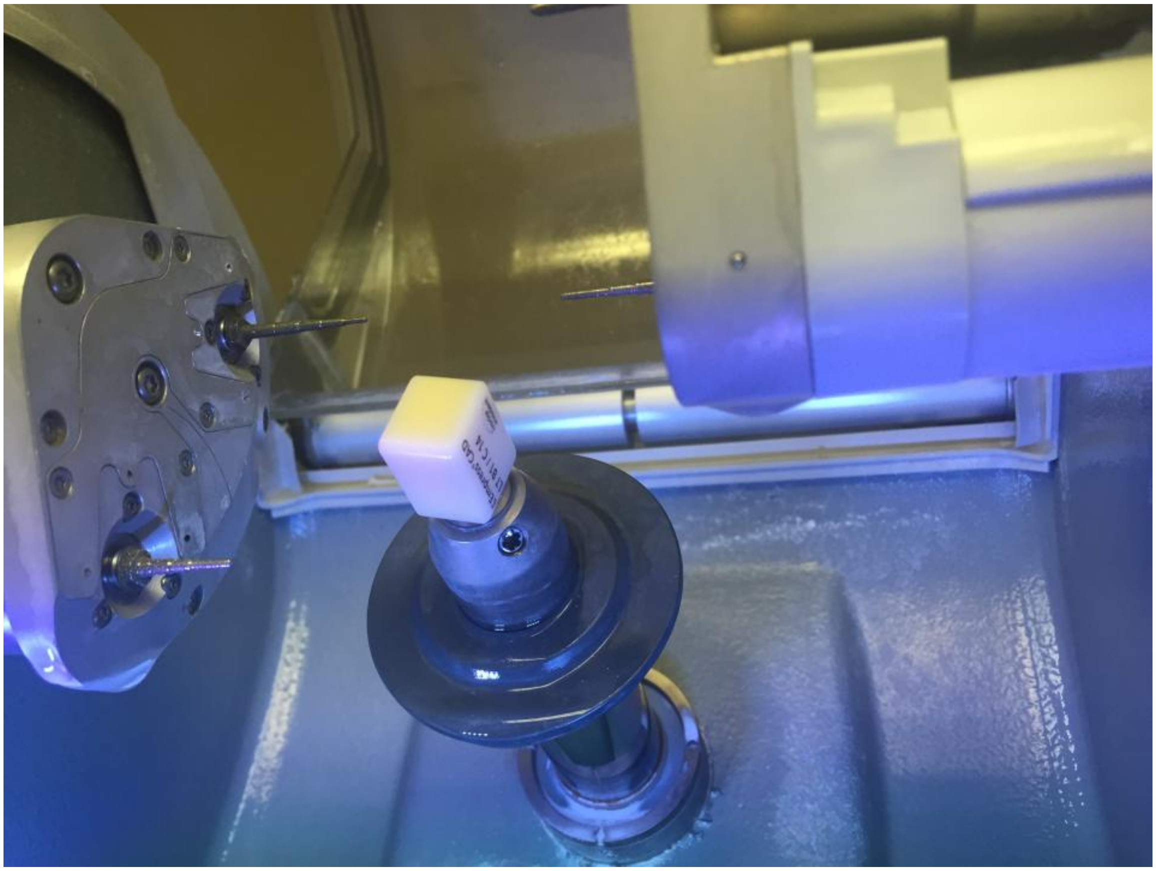

Figure 23. IPS e.max CAD block mounted in the CAM machine

Figure 24. VITA Enamic block mounted in the CAM machine

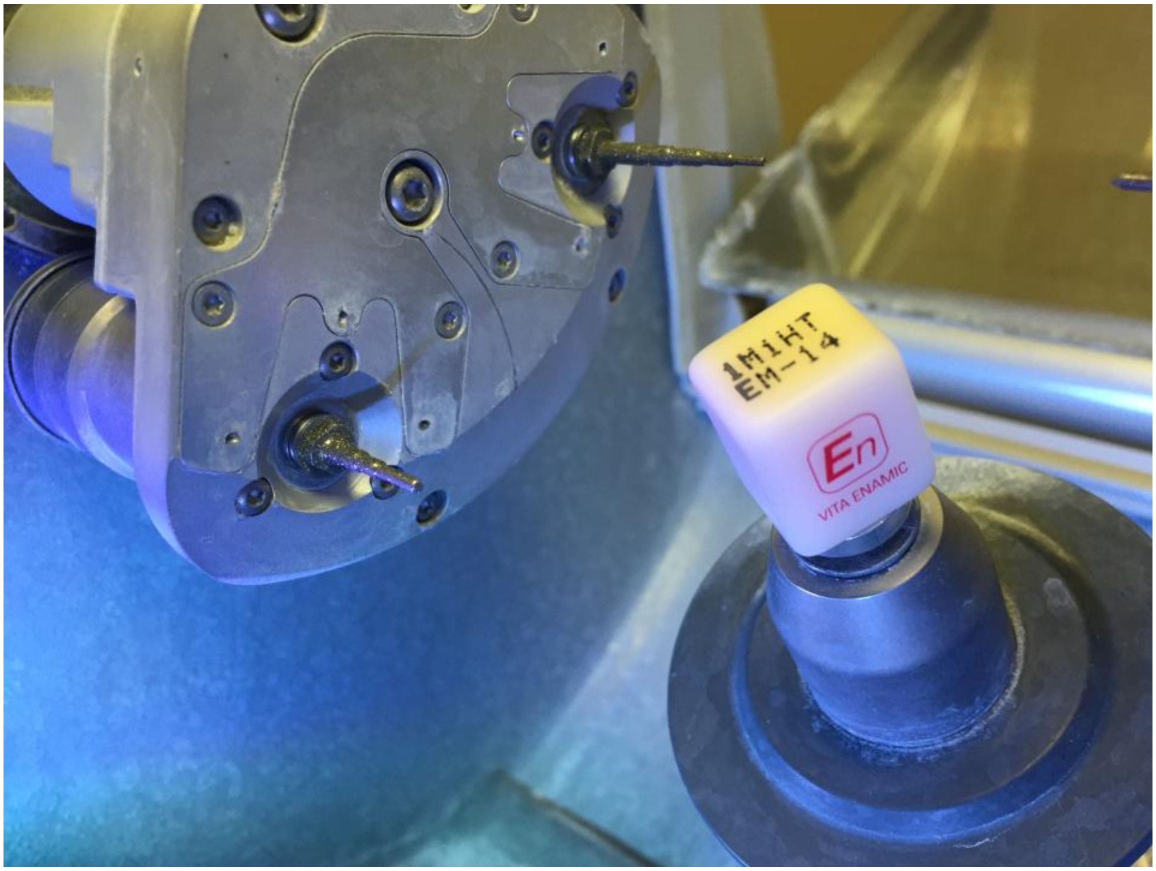

Figure 25. Cylindrical bur 12S (left) and step bur 12S (right)

Figure 26. Replacement of CAD/CAM burs

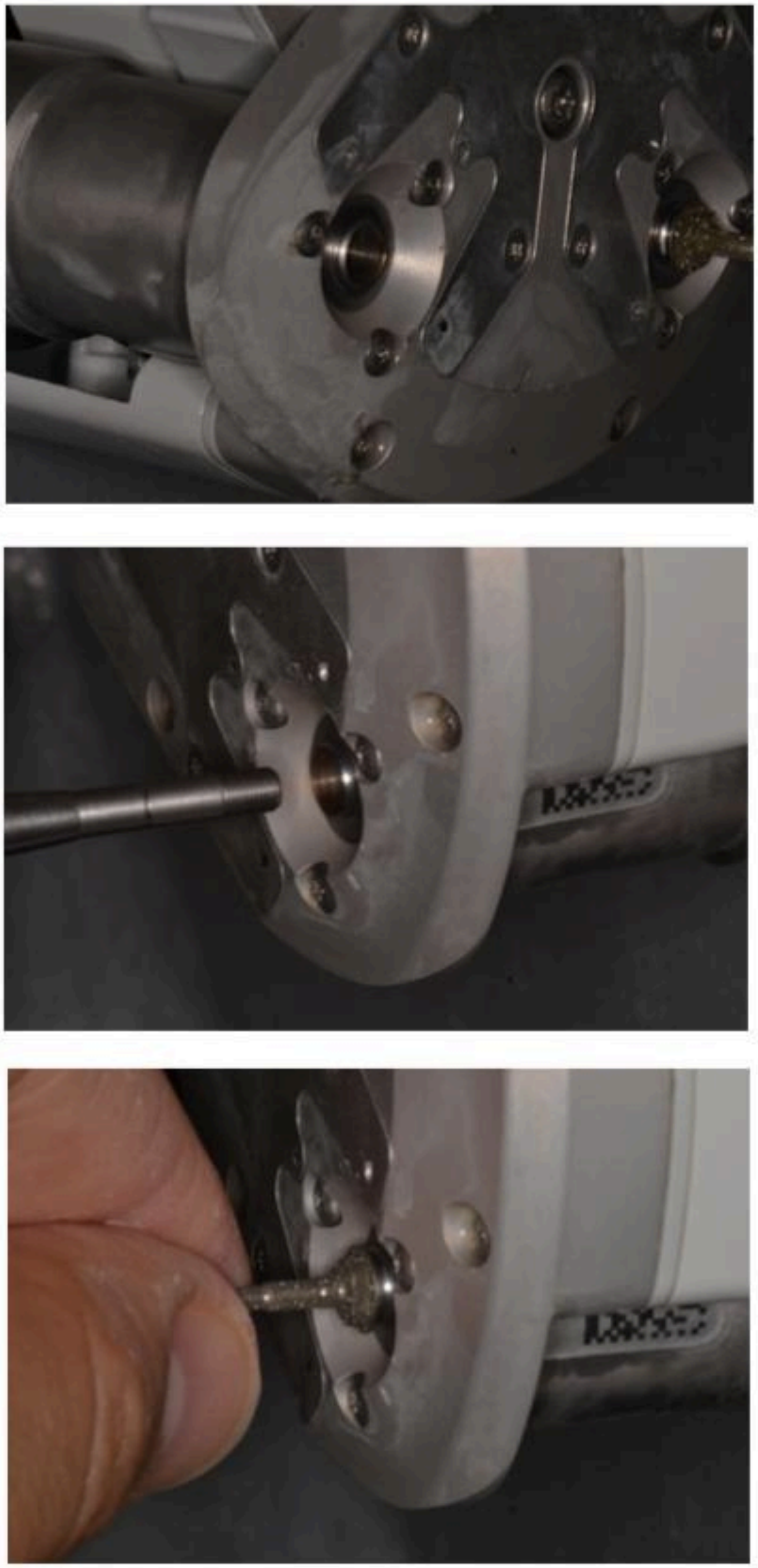

Figure 27. Spectrophotometer (Color-Eye 7000A, Gretag Mecbeth, NY, USA)

Figure 28. Calibration of spectrophotometer

A) Black Calibrator

B) White Calibrator

Figure 29. Gloss meter (Novo- Curve, Imbotec group, USA)

Figure 30. Flexural strength

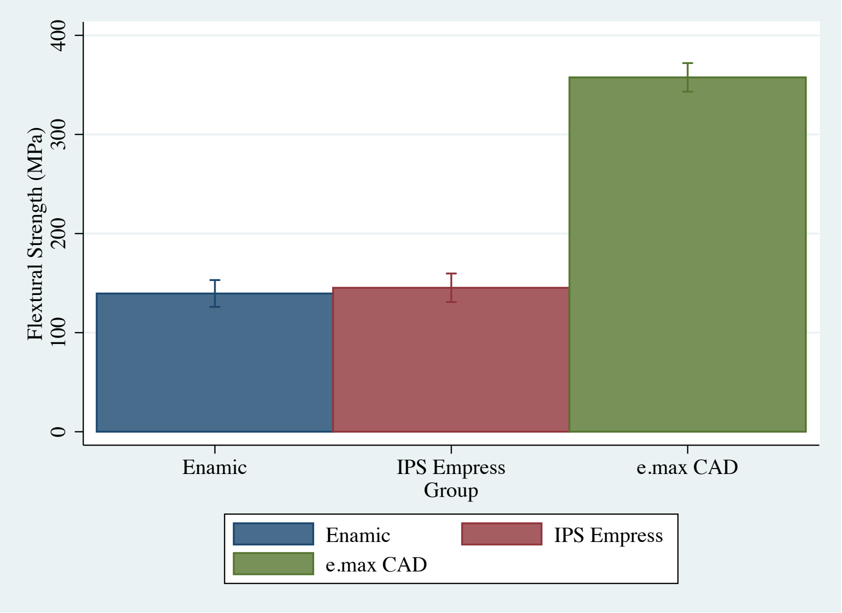

Figure 31. Modulus of Elasticity

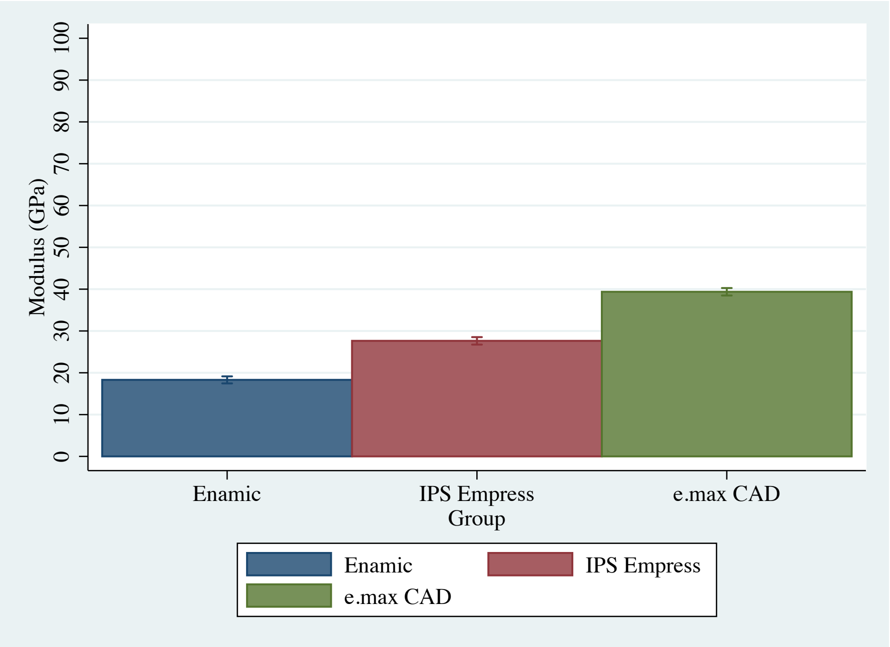

Figure 32. Hardness values

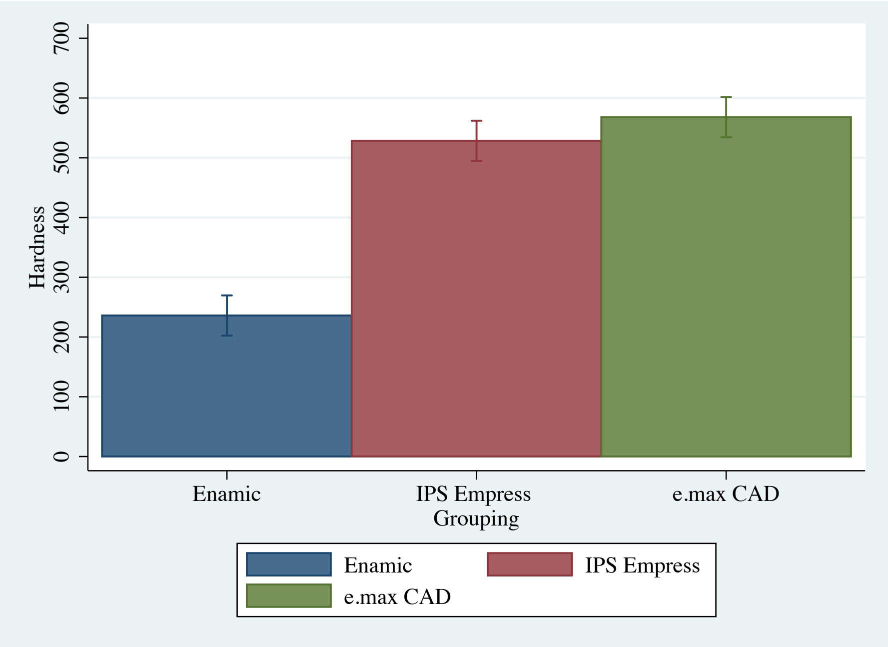

Figure 33. SEM view of IPS Empress CAD

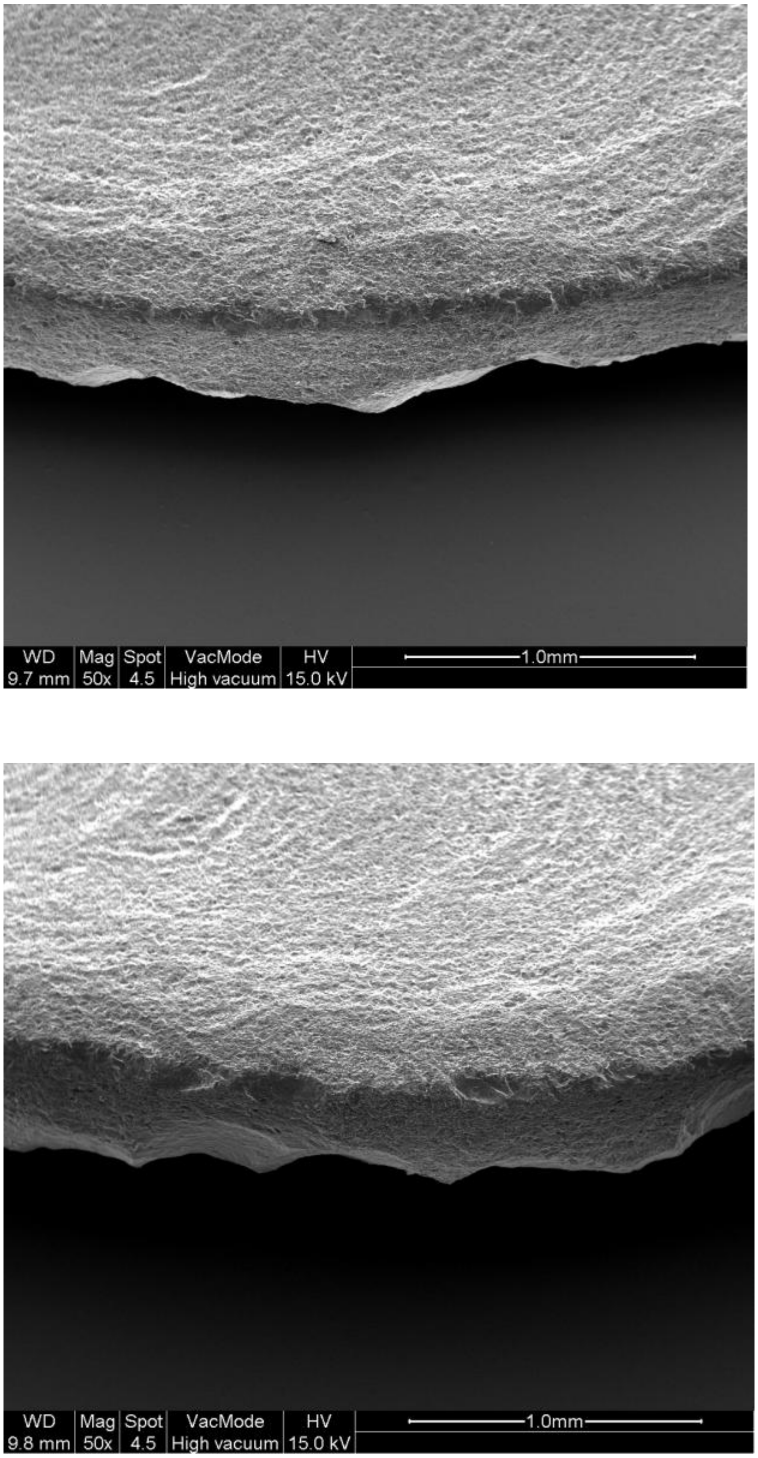

Figure 34. SEM view of IPS e.max CAD

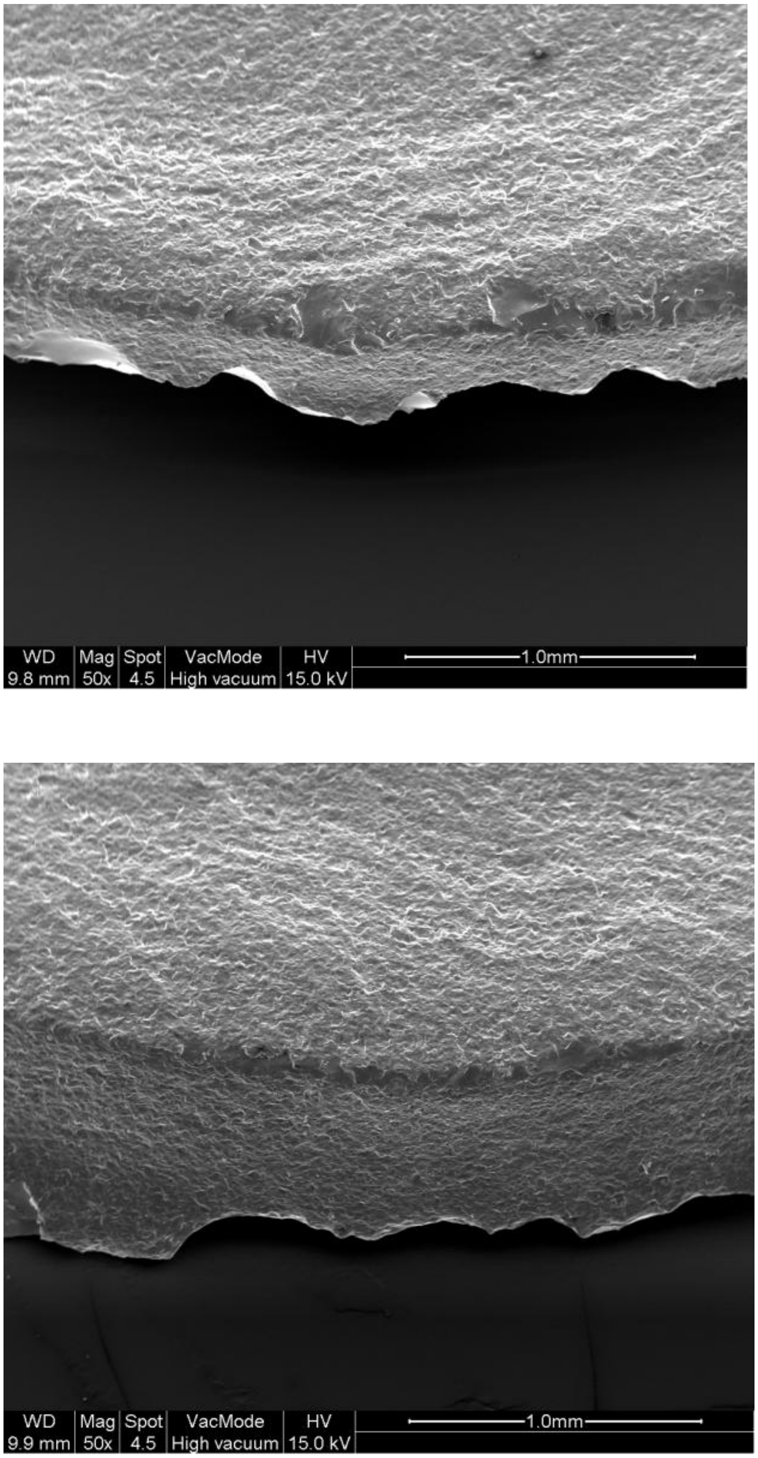

Figure 35. SEM view of VITA Enamic CAD

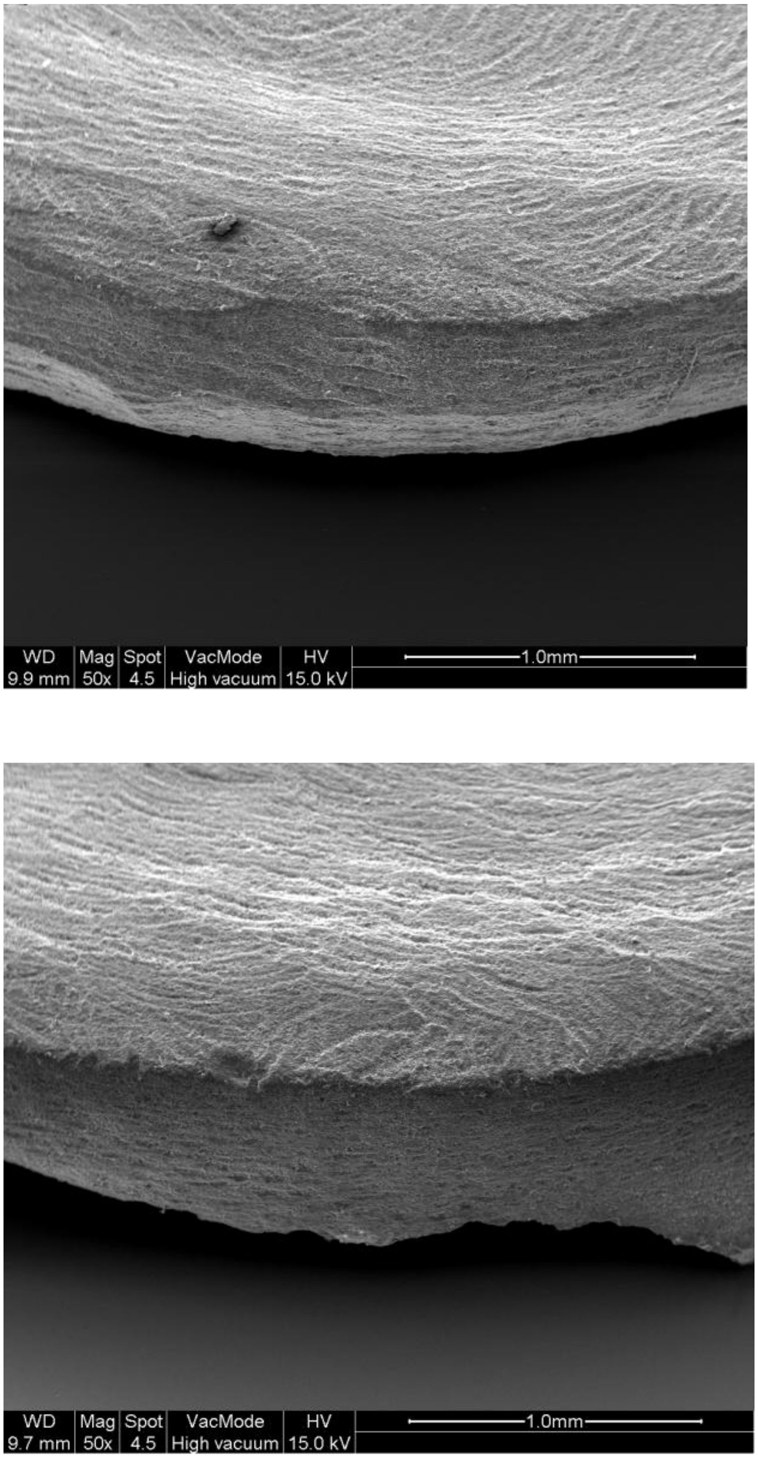

Figure 36. Measurement of the veneer specimen after milling

Appendix A: Raw Data for Mechanical Properties

IPS Empress CAD

	Maximum Load (N)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Hardness Values (HV)
Sample 1	95.03	178.17	30.53	725.50
Sample 2	82.37	154.45	26.94	481.10
Sample 3	69.79	130.85	24.52	501.50
Sample 4	52.49	98.42	25.82	503.80
Sample 5	90.02	168.79	32.90	520.70
Sample 6	87.50	164.06	26.73	475.70
Sample 7	55.82	104.66	23.65	606.50
Sample 8	72.56	136.05	27.54	483.30
Sample 9	71.19	133.48	28.33	473.50
Sample 10	78.84	147.82	26.65	510.90
Sample 11	82.55	154.78	26.74	
Sample 12	75.63	141.80	29.10	
Sample 13	62.48	117.15	28.53	
Sample 14	85.02	159.41	26.26	
Sample 15	79.83	149.68	27.92	
Sample 16	85.82	160.91	27.23	
Sample 17	75.26	141.12	28.74	
Sample 18	71.64	134.33	28.90	
Sample 19	92.77	173.94	27.69	
Sample 20	83.33	156.24	28.47	
Sample 21	72.18	135.34	27.38	

Sample 22	79.93	149.86	27.43
Sample 23	79.93	149.86	27.57

IPS e.max CAD

	Maximum Load (N)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Hardness Values (HV)
Sample 1	181.45	340.23	37.24	524.40
Sample 2	220.10	412.70	38.47	550.20
Sample 3	168.33	315.63	39.61	544.90
Sample 4	220.02	412.54	35.67	601.90
Sample 5	230.22	431.65	37.25	615.90
Sample 6	132.57	248.58	36.76	600.30
Sample 7	194.79	365.23	37.74	582.40
Sample 8	235.03	440.68	42.17	565.30
Sample 9	222.59	417.36	37.87	539.70
Sample 10	226.10	423.93	40.39	555.60
Sample 11	213.31	399.96	42.76	
Sample 12	167.29	313.67	43.84	
Sample 13	138.75	260.15	43.53	
Sample 14	166.83	312.81	40.25	
Sample 15	144.79	271.47	38.69	
Sample 16	210.18	394.08	37.23	
Sample 17	209.45	392.72	40.85	
Sample 18	187.58	351.70	38.07	
Sample 19	169.92	318.59	44.55	

Sample 20	212.47	398.37	38.18
Sample 21	188.82	354.04	39.80
Sample 22	183.39	343.85	36.19
Sample 23	162.70	305.06	38.44

VITA Enamic

	Maximum Load (N)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Hardness Values (HV)
Sample 1	69.86	130.99	21.03	277.50
Sample 2	76.94	144.27	16.81	205.00
Sample 3	63.14	118.39	16.10	218.40
Sample 4	73.18	137.21	19.96	240.00
Sample 5	73.28	137.39	18.28	194.50
Sample 6	76.15	142.78	20.22	280.40
Sample 7	73.66	138.11	18.84	238.50
Sample 8	81.52	152.85	20.21	230.30
Sample 9	80.02	150.04	16.92	220.80
Sample 10	75.15	140.90	17.55	255.00
Sample 11	67.78	127.08	17.41	
Sample 12	73.09	137.04	20.85	
Sample 13	71.54	134.13	16.57	
Sample 14	77.43	145.18	17.05	
Sample 15	74.99	140.60	16.37	
Sample 16	74.69	140.04	21.20	
Sample 17	74.41	139.52	20.01	

Sample 18	62.98	118.09	15.28
Sample 19	78.29	146.79	20.81
Sample 20	78.10	146.43	20.17
Sample 21	78.96	148.05	17.48
Sample 22	72.99	136.85	15.64
Sample 23	77.24	144.82	21.37
Sample 24	70.36	131.92	16.10
Sample 25	81.66	153.12	17.11
Sample 26	77.07	144.50	16.48

Appendix B: Raw Data for Optical Properties

IPS Empress CAD

	ΔL*	Δa*	Δb*	TP
Sample 1	66.42	-1.02	-0.01	66.43
Sample 2	64.71	-1	0.26	64.72
Sample 3	65.93	-1.03	-0.27	65.94
Sample 4	64.03	-0.99	0.15	64.04
Sample 5	62.62	-0.98	0.49	62.63
Sample 6	65.62	-0.98	0.27	65.63
Sample 7	65.46	-1.02	-0.16	65.47

IPS e.max CAD

	ΔL*	Δa*	Δb*	TP
Sample 1	63.86	-1.73	-0.19	63.88
Sample 2	65.37	-1.75	-0.45	65.39
Sample 3	62.2	-1.69	-0.12	62.22
Sample 4	67.18	-1.61	-0.14	67.2
Sample 5	64.4	-1.55	0.15	64.42
Sample 6	63.26	-1.54	0.25	63.28
Sample 7	65.07	-1.54	0.27	65.09

VITA Enamic

	ΔL*	Δa*	Δb*	TP
Sample 1	69.13	-0.81	0	69.13
Sample 2	66.97	-0.76	0.15	66.97
Sample 3	67.96	-0.77	0.37	67.97
Sample 4	67.69	-0.74	0.49	67.7
Sample 5	66.92	-0.76	0.62	66.93
Sample 6	67.81	-0.8	0.2	67.82
Sample 7	66.56	-0.74	0.93	66.57

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