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Mechanical and optical properties of machined, printed, and conventional dental polymers

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HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

THESIS

MECHANICAL AND OPTICAL PROPERTIES OF MACHINED, PRINTED, AND CONVENTIONAL DENTAL POLYMERS

by

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BA, Boston University, 2011
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Master of Science in Dentistry
In the Department of Restorative Sciences and Biomaterials

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Dedication

(Allah is the Light of the heavens and the earth. His light is like a niche in which there is a lamp, the lamp is in a crystal, the crystal is like a shining star, lit from ˹the oil of˺ a blessed olive tree, ˹located˺ neither to the east nor the west, whose oil would almost glow, even without being touched by fire. Light upon light! Allah guides whoever He wills to His light. And Allah sets forth parables for humanity. For Allah has ˹perfect˺ knowledge of all things).

Dedicated to all who seek truth and knowledge.

And especially, dedicated to my parents and all parents who endlessly and passionately support their sons and daughters.

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"Your provisional should be blueprint of your final"

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Always there to help with knowledge, advise or friendly talk

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Dr. Peixi Liao
Digital Mastermind who thrives to digitalize our profession

Dr. Minglei Zhao

Always there. Always helping. Always reminding us that we are geniuses

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Abstract

Objective: This study aims to compare the flexural strength and color stability of conventional, machined, and printed dental polymers. Secondarily, the effects of aging, fatigue, coffee, distilled water, and UV light on the color stability and flexural strength of the different dental polymers will be evaluated.

Materials and Methods: Sixty disks 14mm in diameter and 2mm in thickness were fabricated from each of the following polymers: Jet Tooth Shade (Lang Dental), ProTemp (3M-ESPE), Telio CAD Temp (Ivoclar Vivadent), Vita CAD Temp (Vita), Temporary CB (FormLab), Dentca (Dentca), and Bego VarseoSmile Crown Plus (Bego). The sixty disks from each polymer were then divided into the six following groups: no treatment, thermocycling, fatigue, thermocycling and coffee, distilled water and finally UV Light. Prior to any treatment, the color coordinates CIE L*a*b*, were registered first. The non-treated groups were fractured using the Instron Universal Testing Machine to obtain flexural strength values. Thermocycling consisted of placing the specimens in 30 seconds 5°C water and then 30 seconds in 55°C water for 5,000 cycles. Fatigue testing consisted of cyclic loading the disk specimens by calculating 60% of the mean load to failure from the non-treated group and subjecting them to 50,000 cycles. The third group was placed under thermocycling for 1,500 cycles and then placed in coffee for 15 days. Another group was placed in distilled water for 15 days. Finally, the UV light treatment consisted of exposing the disk specimens to UV light for ten hours over the course of five days. After treatment, the color coordinates were recorded again and fractured using the Instron Universal Testing Machine. The data was analyzed for any statistically significant differences using ANOVA with $\alpha<0.05$.

Results: The flexural strength values were highest for Telio CAD Temp, that was affected only by UV light via a statistical analysis. ProTemp was second highest followed by Bego VarseoSmile Crown Plus, Dentca, Temporary CB, Vita CAD Temp and finally Jet Tooth Shade. Color differences were highest for Dentca followed by Jet Tooth Shade, ProTemp, Telio CAD Temp, Temporary CB and finally Vita CAD Temp. UV light and thermocycling/ coffee had the highest impact.

Conclusion: Telio CAD Temp had the highest overall flexural strength and was resistant to all post fabrication treatments except for UV light. ProTemp had the second highest overall flexural strength but was susceptible to multiple post fabrication treatments like distilled water, fatigue, and aging. The printed specimens had flexural strength values lower in the middle range of all tested materials. In terms of treatment, UV light and coffee/thermocycling had the biggest impact on the overall color stability values. Powder and Liquid based PMMA had the lowest overall flexural strengths.

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List of Abbreviations

ATSM- American Section of the International Association for Testing Materials

CAD/CAM - Computer Aided Design and Computer Aided Manufacturing

DLP- Digital Light Processing

MPa- Megapascals

RPM- Rotations Per Minute

SEM- Scanning Electron Microscope

STL- Standard Tessellation File

Chapter 1: Introduction

Dental provisional restorations serve the purpose of protecting teeth and the surrounding periodontal structures during the rehabilitation process. In addition, they help the patient maintain mastication, phonation, and esthetics. However, emphasis should also be placed on the importance of provisional restorations in providing a blueprint for the final restorations (1) (2). This is especially important in full mouth and esthetic reconstructions. It allows the patient to test a mock-up of the final prosthesis and allows the clinician to further evaluate the success of the treatment. If success with provisional restorations is attained, a physical or digital impression may be provided to the lab to convey the information of teeth shape and occlusal scheme to the technician. The lab technician can then use the provisional to fabricate the final prosthesis. Furthermore, a clinician is able to build repertoire and engagement with the patient using provisional restorations. Hence, exceptional, predictable, and reproducible provisional restorations should be key in a successful treatment outcome. Because provisional restorations confirm diagnosis and allow for further evaluation, they need to hold vertical dimension of occlusion and proper form during the rehabilitation process and withstand occlusal forces. Furthermore, the materials should be able to resist color change during the course of treatment.

Due to the digital revolution in the fields of medicine, novel ways of manufacturing dental materials have emerged. This has led to increased use of

CAD/CAM provisional restorations with a subsequent need to evaluate properties and their possible impact on clinical performance of those materials. The search for enhanced mechanical, physical, and optical properties continues. The search for standardization, reproducibility, and digital archiving also continues. A literature search was done to review the existing evidence regarding both methods of manufacturing: subtractive and additive in comparison with conventional methods of manufacturing. Conventional methods include both chairside and lab manufacturing.

Google Scholar, PubMed, and Embase have been searched for the following MeSH terms: (dental restoration, temporary); (tooth crown); and (denture partial, temporary). The databases were also searched for the following in the title or abstract: (provisional dental restorations) and (flexural strength); (provisional restorations) and (fracture resistance) ;); (provisional dental restorations) and (color stability).

1.1 Analog versus Digital Mode of Manufacturing

Traditionally, provisional dental polymers have been divided into the following categories: chemically activated auto-polymerizing resins, heat-activated acrylic resins, light-activated acrylic resins and dual light/chemical activated resins. The major advantage of these polymers is that they can be easily modified chairside to accommodate adjustments in occlusion and esthetics. Another big advantage is that these materials are readily available and are cost effective depending on the treatment.

Numerous materials are available in the market for conventional chairside fabrication and include polymethyl methacrylate resins and composites. An example of a polymethyl methacrylate is Jet Lang Tooth Shade (Lang Dental Manufacturing Co. Inc. Illinois, USA). This is a conventional two component self-curing acrylic. One component is a liquid and the second is a powder. The liquid consists of more than 95% methyl methacrylate and less than 5% N, N- dimethyl-p-toluidine, which acts as an accelerator for polymerization (3) (4). The powder component consists of:

1. 80% to 90% 2-propenoic acid, 2-methyl-, methyl ester
2. 10% to 20% diethyl phthalate which acts as a plasticizer
3. 5% to 10% benzoyl peroxide which acts as an activator

Other brands include Alike (GC America, Alsip, IL) and Coldpac (Yates Moltoid, Elmhurst, IL). Both of these materials are polymethyl methacrylates and are readily available in the market.

Composite resins are another popular option. An example of a composite resin is ProTemp Plus (3M-ESPE. Minnesota, USA). It is a bis-acryl that is chemically activated by mixing a base paste and a catalyst paste. The base paste consists of silane treated amorphous silica, polyurethane methacrylate and silane treated silica. The catalyst paste consists of ethanol, diacetate benzy-phenyl-barbituric acid and silane treated silica. Other bis-acryl composite materials include Luxatemp (DMG, Hamburg, Germany) and Integrity Temporary Crown and Bridge Material (Dentsply-Sirona, York, USA).

However, conventional chairside fabrication of provisional restorations has numerous limitations. These limitations are usually related to the mechanical and physical properties. The chairside fabrication is usually associated with a rough surface texture, voids and porosities leading to compromised mechanical properties and poor color stability (4). Heat generation from polymerization can lead to pulpal complications. In addition, chairside fabrication is not standardized and is difficult to reproduce. Polymerization shrinkage requires extensive adjustments and possible relining procedures. Residual monomer is another area of concern that also negatively affects biocompatibility and color stability. In addition, chairside manufacturing is done in the presence of water and humidity which in turn interferes with the radical polymerization leading to diminished mechanical and physical properties.

Currently, Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) is the norm for multiple prosthodontic treatment procedures. In addition to enhanced mechanical and physical properties, it has allowed reproducibility, standardization and digital archiving (5). CAD/CAM technology exists in both additive and subtractive form. Additive technology is a fairly novel approach and is rapidly evolving. Table 1 summarizes the main advantages of each mode of manufacturing.

Table 1: Advantages and Disadvantages of Different Modes of Manufacturing

Mode of Manufacturing	**Advantages**	**Disadvantages**
Conventional Manufacturing	• Low cost • Readily accessible	• Poor mechanical properties • No standardization • Residual Monomer • Polymerization Shrinkage
Subtractive Manufacturing	• High Accuracy • Standardization • Efficiency • High production capacity • Speed • Versatility of use of different materials	• High Entrance cost • More waste generation • Size of bur limiting factor

		• Inaccuracies from software and hardware
Additive Manufacturing	• Low cost materials • High density • High accuracy • Versatility	• High cost printer • Requires extensive post-processing • Material waste in post processing

1.1.1 Subtractive Manufacturing

Subtractive technology is when a pre-polymerized puck or block is cut into a final product by a computer-controlled drill or bur. A digital impression of the preparation is required to first design a digital proposal of a restoration. The restoration is then carved out of the block or puck. This process allows for standardization, efficiency, accuracy, speed, and digital archiving. The digital archiving allows for better control as well as predictability if a patient needs an emergency provisional restoration. Subtractive technology has also allowed for use of new materials. Since the restorations are fabricated from pre-polymerized machinable blocks, the mechanical properties are superior. They also possess improved color stability and residual monomer is of less concern (5). Subtractive technology does come with flaws. A major flaw is the high entrance cost due to expensive equipment and computers. Secondarily, there is the notion that milling and grinding generates a lot of waste do make a final product. A substantial portion of the block and puck is wasted as swarf. Another drawback in subtractive technology, is the notion that the size of bur and number of axes will determine feasibility of carving certain features and fine details. With subtractive technology, very fine features may be lacking and might require veneering by hand to achieve the most esthetic results. This holds true for both final and provisional restorations. Milled provisional restorations might require veneering and adjustments by hand to achieve highly detailed anatomy and translucent affects.

From the aforementioned studies, it is important to note that the superiority of subtractive technology materials stems from the idea that these are pre-polymerized under standardized conditions (5). This in turn translates to absence of polymerization shrinkage, voids, and porosities. The absence of residual monomer also translates to better color stability and optical properties.

The range and types of dental polymers used for provisional restorations is ubiquitous in the market. Telio CAD Temp from Ivoclar Vivadent is one such material. It is a crosslinked polymethyl methacrylate (PMMA) fabricated under standardized and pressurized conditions. It consists 99% of PMMA and 1% of pigments. There are other crosslinked polymethyl methacrylate blocks available in the market and these include ArtBlock Temp (Merz Dental GmBH, Lütjemburg, Germany).

Another machinable material is Vita CAD Temp which is also available in blocks or pucks as well. It is classified as a composite with a high molecular acrylate polymer network and inorganic filler materials. The inorganic filler material consists of silicon dioxide that provides additional crosslinking between the polymer chains.

Again, when it comes to evaluating physical, mechanical, and optical properties of dental polymers, both the mode of fabrication as well as the material itself should be taken into consideration. The software, hardware, and material are all contributing variables to the mechanical and optical properties for each polymer. Milling units for example can operate in 3-axis, 4-axis or 5-axis. The axes are basically the number of spatial directions the bur or drill can move into. The 3-

axis milling units can only move in the x, y and z directions. The 4-axis allows the block to rotate around the x-axis. The 5-axis milling units allows the block to rotate in both the x-axis and y-axis. The 5-axis compared to 3-axis is slower but is able to mill with higher accuracy and detail. On the other hand, 3-axis milling units are less expensive and bulky and can be used chairside. (6)(9)(10)(11). Furthermore, subtractive manufacturing can also happen under dry or wet conditions.

1.1.2 Additive Manufacturing

Recently, additive manufacturing is gaining momentum in the dental field. This has been due to the expiration of multiple patents making additive technology readily available and at lower costs than subtractive manufacturing units. Additive manufacturing is the process also known as 3D printing, rapid prototyping, or solid freeform fabrication. It builds the final product by layering until the desired geometrical shape is achieved.

Unlike subtractive manufacturing, additive technology can come in a larger variety of modes of fabrication. The American Section of the International Association for Testing Materials (ATSM) identifies seven categories for additive manufacturing. These include powder bed fusion, material extrusion, material jetting, stereolithography, binder jetting, powder bed fusion, direct energy deposition, and sheet lamination. The main differences between these categories is how the material is layered and cured to fabricate the final product. For the purposes of dental polymers used for provisional restorations, stereolithography is the mostly widely used method of fabrication. Stereolithography (SLA) utilizes the concept of photopolymerization where monomers are layered into a three-dimensional shape and exposed to a precise light or laser beam to polymerize layer by layer in the desired geometry. This requires a building platform to be immersed in a photosensitive liquid polymer monomer and a light source or laser. Figure 1 displays a schematic diagram of how a stereolithography printer works. (6)(12).

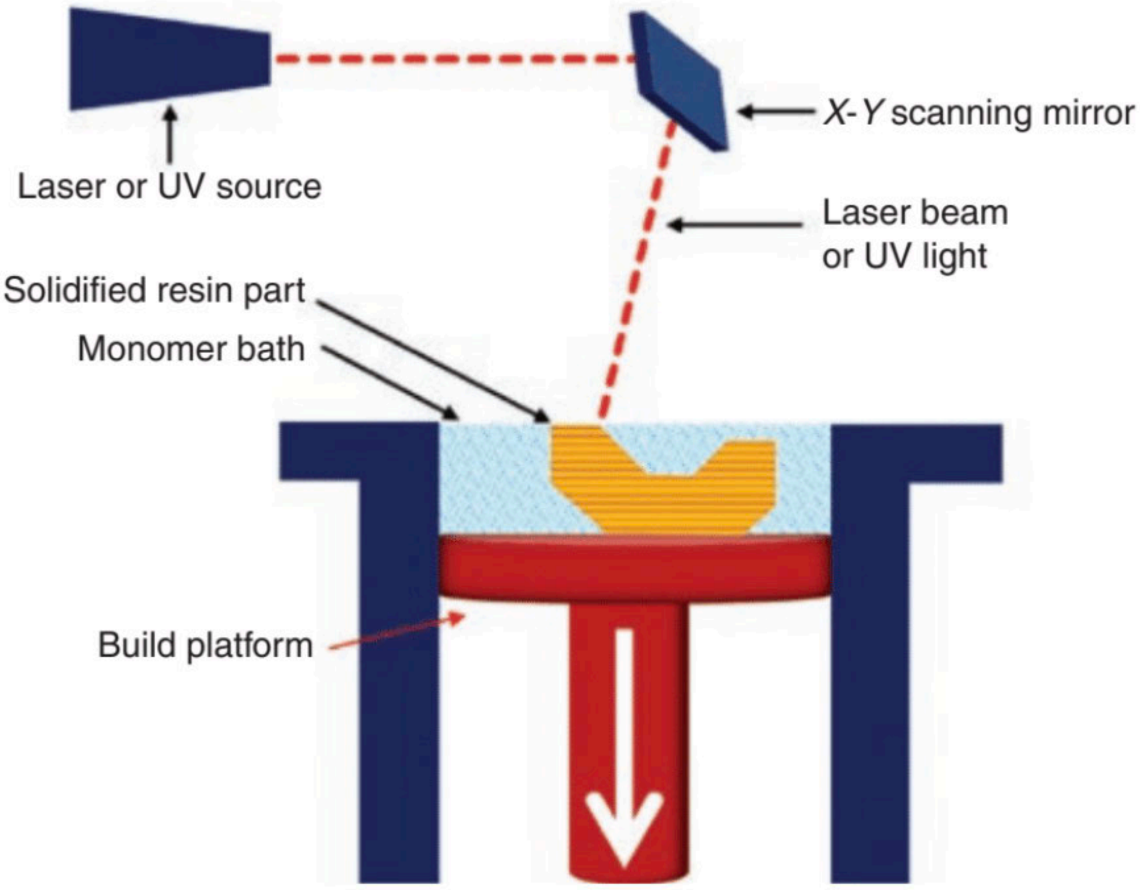


Figure 1: Stereolithography Printer Production Process (6)

Digital Light Projection (DLP) is a type of stereolithography. The main difference between DLP and stereolithography is the light source. The light source consists of microscopic mirrors that represent a pixel or several pixels. The pixels compromise a cross section of the desired product. The light is projected onto a vat of liquid resin and gradually the desired shape is fabricated from the liquid resin. Unlike stereolithography, DLP flash-cures an entire surface and hence translates to faster printing and lower costs. (6)(12)

Again, as with subtractive technology, data acquisition is the first step. An intra-oral or lab scanner acquires a 3D image of the prepared tooth. The second step is data processing where the provisional restoration is designed digitally. Additive technology does come with more variables that affect accuracy and mechanical properties. These variables include printing orientation, thicknesses, and the distribution of support structures.(6)(12)(13). After design and adjusting parameters according to the manufacturer's instructions, the final product can then be printed layer by layer. After printing, additive technology usually requires extensive post processing procedures. Post processing includes removal of support structures, and a workflow to remove and cure any residual monomer that can have an adverse effect on biocompatibility and mechanical properties of the provisional restoration.

There are numerous additive manufacturing units, printing resins, software, and post-processing units available in the dental market. Again, these are all variables that could have a potential role in the mechanical, physical, and optical properties of the polymer. One such material is VarseoSmile Temp (BEGO. Bremen, Germany) which is distributed as Temporary CB by FormLab. The resin can be utilized to make dental provisional restorations using either the Varseo 3D printers from Bego or the Form 2/3b from FormLab. These printers are all DLP 3D printers.

Temporary CB/ VarseoSmile Temp consists of a mixture of methacrylic acid esters, photo-initiators, proprietary pigments, and additives. It is the esterification products of 4,4'- isopropylidiphenol, ethoxylated and 2-methylprop-

2enoic acid. It also contains Silanized dental glass, methyl benzoylformate, diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide. It has a total content of inorganic fillers (particle size 0.7 μm) of 30–50% by mass.

Another photopolymer produced via additive technology is Dentca. It is printed by the Carbon 3D printer and is used for both denture teeth and provisional restorations. The Carbon 3D printer utilizes a technology called "Carbon Digital Light Synthesis (Carbon DLS)™. It utilizes photopolymerization and takes advantage of the oxygen rich layer to fabricate fully densified and homogenous resins. It cures resins via continuous production rather than cure layer by layer in increments as in a digital light processer 3D printer. The oxygen rich layer allows for crosslinking to happen across multiple layers. The Dentca resin consists of methacrylate monomer, diurethane dimethacrylate, trimehylopropane trimethacrylate as well as proprietary initiator, stabilizer and pigments.

1.1.2.1 3D Printed Permanent Restorations

One drawback of additive manufacturing is the inability to use any material as with subtractive technology. However, research and experimentation with permanent restorations still continues. Experimentation has been with printing ceramics in the green stage then sintering them.

One polymer available in the market for definitive restorations is VarseoSmile Crown Plus (BEGO. Bremen, Germany). The same resin is distributed by FormLab as Permanent Crown. The printed photopolymer is the esterification products of 4.4‘-isopropylidiphenol, ethoxylated and 2-methyl- prop-2enoic acid. Silanized dental glass, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide. Total content of inorganic fillers (particle size 0.7 µm) is 30–50 % by mass. This is different from Temporary CB/ VarseoSmile Temp as its classified as a ceramic filled hybrid, however, per manufacturer they both have the same filler content.

1.2 Biaxial Flexural Strength

Strength is defined as the amount of stress required to cause either breakage or plastic deformation. When breakage happens, this is defined as ultimate strength. On the other hand, when plastic deformation happens, this is defined as yield strength. For the purposes of this study, flexural strength will be evaluated and this is the ultimate strength in force per unit area required to cause breakage.

Flexural strength tests can be done on either bar or disk specimens. For disk specimens, this is referred to as biaxial flexural strength. Biaxial flexural strength testing is sometimes preferred over bend bar tests on bars to avoid edge effects such as fractures and defects. This is due to the fact that flexural strength tests on disks do not directly load the edges of the specimen. Additionally, the effects of geometry on strength tests have been identified and it is negligible in disk specimens. This was observed in the study by Anusavice and Ban in 1990 that concluded that biaxial strength values obtained from specimens with different dimensions were not different. (7).

The set up for one type of biaxial flexural strength tests includes applying a load by means of a piston onto the disk specimen. The disk specimen is supported by three steel balls which have a certain diameter and arranged at a 120-degree angle relative to one another. It is also assumed that the impact of specimen geometry on strength values is reduced when disk specimens are utilized.

Other studies have pursued clinical or semi-clinical set ups where flexural strength tests are conducted on anatomically shaped specimens. However, standardization and obtaining standardized units in terms of force per unit area is extremely difficult. For the purposes of simplification, standardization, as well as minimizing the number of variables, disk specimens were utilized in this study.

1.3 Color

In addition to mechanical properties, optical properties are also crucial in a successful treatment outcome. Polymers used for the purposes of provisionalization are exposed to extreme temperature changes, staining, and discoloration. This may become an issue of concern for both the patient and clinician and may ultimately need replacement due to color changes. Patients also need to be able to evaluate a certain shade of color prior to making any final decisions about color of the permanent restorations. This requires the color to be stable, predictable, and quantified. This allows the selected color to be communicated to the lab technician.

1.3.1 Color Models

There are multiple ways to represent color in terms of numbers or charts. One color model is the CIE 1931 XYZ which was created by the International Commission of Illumination in 1931. It was the first color model to define and quantify links between distributions of wavelengths in the visible light spectrum. (8). In 1973, the International Commission of Illumination, introduced another model called the CIELAB. It expresses color as three numerical values where L* is the lightness, a* is the green to red spectrum and b* is the blue to yellow spectrum. CIELAB is commonly found in multiple spectrophotometers in dentistry including the Vita Easyshade V.

1.4 Statement of the Problem

The purpose of the study is to compare the mechanical and optical properties of different polymers used for the purposes of provisional restorations produced both by digital and conventional methods. Digital methods include both additive and subtractive technology and is a fairly novel approach in the dental field. This necessitates the understanding of mechanical, physical, and optical properties of the different materials produced by different methods in order to aid in clinical selection and in predicting clinical performance.

1.5 Purpose

The purpose of the study is to investigate the performance of the different dental polymers fabricated via subtractive, additive or conventional methods. The effect of different treatments on color stability and flexural strengths of will be assessed.

1.6 Objectives

This in-vitro study aims to:

1) Compare the flexural strength and color stability of conventional, machinable and printed dental polymers.
2) Evaluate the effect of aging, fatigue, coffee, distilled water and UV light on the color stability and flexural strength of the different dental polymers.

1.7 Null Hypothesis

1) There is no significant difference in terms of flexural strength between conventional, machinable and printed dental polymers
2) There is no significant difference in terms of color stability between conventional, machinable and, printed dental polymers.

Chapter 2: Materials and Methods

2.1 Materials

Seven different polymers were used in this study. Six polymers are marketed for the purposes of dental provisional restorations and one polymer is marketed for the purpose of a definitive restoration.

The six polymers utilized for the purpose of provisional restorations are produced via subtractive technology, additive technology, and conventional methods and include the following:

1. Jet Tooth Shade (Lang Dental Manufacturing Co. Inc. Illinois, USA)
2. ProTemp (3M-ESPE. Minnesota, USA)
3. Telio CAD Temp (Ivoclar Vivadent AG. Schann, Liechtenstein)
4. Vita CAD Temp (Vita Zahnfabrik. Bad Sackingen, Germany)
5. Temporary CB (FormLabs, Inc. Massachusetts, USA)
6. Dentca (Dentca, Inc. California, USA)

The polymer from Bego is used for the purpose of definitive restoration and is produced via additive technology:

1. Bego VarseoSmile Crown Plus (BEGO. Bremen, Germany)

The materials along with modes of manufacturing and LOT numbers investigated in this study are listed in Table 2.

Table 2: Materials Investigated in this Study.

Material	Manufacturer	Description	Mode of Fabrication	Shade	Lot No.	Expiration Date
Jet Lang Tooth Shade	Lang Dental	Two Component Powder and Liquid Methacrylate	Conventional	A2	Powder: 143020GE Liquid: 1404R.10	Powder: 2024-09 Liquid 2024-11
ProTemp Plus	3M-ESPE	Bis-Acryl	Conventional	A2	7093067	2022-03-13
Telio CAD Temp	Ivoclar Vivadent	PMMA machinable blocks	Subtractive	A2	ZOONG	-
Vita CAD Temp	Vita Zahnfabrik	Microfiller Reinforced Polyacrylic	Subtractive	0M1	27900	-
Temporary CB	FormLab, Inc.	Methyacrylate Based Photo-sensitive Resin	Additive	A2	600139	2022-08-17

Dentca	Dentca, Inc.	Methyacrylate Based Photo-sensitive Resin	Additive	A2	AF205A2	2022-06-16
Bego VarseoSmile Crown Plus	BEGO	Ceramic filled Hybrid	Additive	A2	NA	NA

Figure 1: Jet Tooth Shade (Lang Dental)

Figure 2: ProTemp (3M-ESPE)

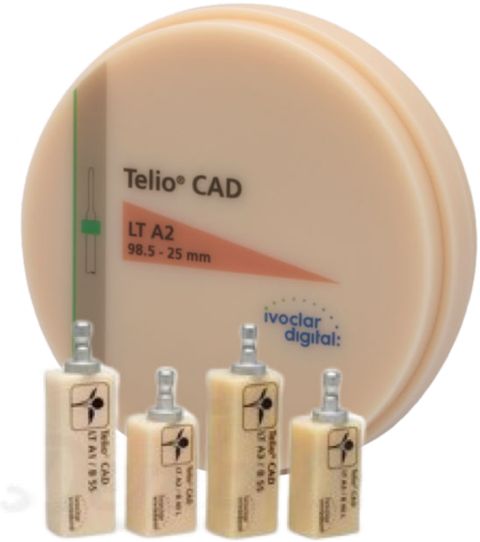
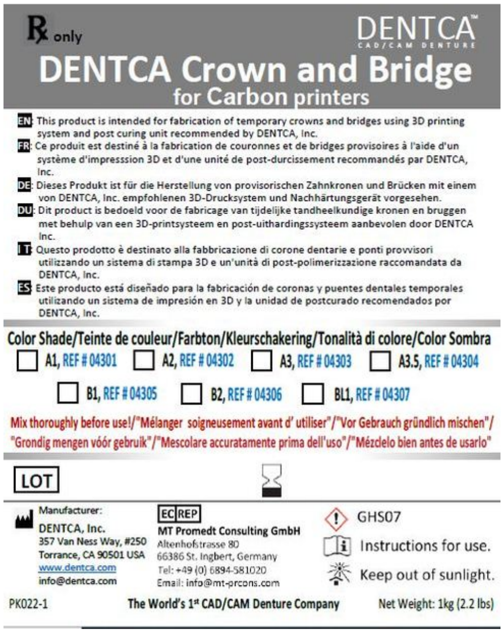


Figure 3: Telio CAD Temp (Ivoclar Vivadent)

Figure 4: Vita CAD Temp (Vita)

Figure 5: Temporary CB Resin (FormLab)



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EN: This product is intended for fabrication of temporary crowns and bridges using 3D printing system and post curing unit recommended by DENTCA, Inc.

FR: Ce produit est destiné à la fabrication de couronnes et de bridges provisoires à l'aide d'un système d'impresssion 3D et d'une unité de post-durcissement recommandés par DENTCA, Inc.

DE: Dieses Produkt ist für die Herstellung von provisorischen Zahnkronen und Brücken mit einem von DENTCA, Inc. empfohlenen 3D-Drucksystem und Nachhärtungsgerät vorgesehen.

DU: Dit product is bedoeld voor de fabricage van tijdelijke tandheelkundige kronen en bruggen met behulp van een 3D-printsysteem en post-uithardingssysteem aanbevolen door DENTCA Inc.

IT: Questo prodotto è destinato alla fabbricazione di corone dentarie e ponti provvisori utilizzando un sistema di stampa 3D e un'unità di post-polimerizzazione raccomandata da DENTCA, Inc.

ES: Este producto está diseñado para la fabricación de coronas y puentes dentales temporales utilizando un sistema de impresión en 3D y la unidad de postcurado recomendados por DENTCA, Inc.

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☐ A1, REF # 04301 ☐ A2, REF # 04302 ☐ A3, REF # 04303 ☐ A3.5, REF # 04304

☐ B1, REF # 04305 ☐ B2, REF # 04306 ☐ BL1, REF # 04307

Mix thoroughly before use!/"Mélanger soigneusement avant d' utiliser"/"Vor Gebrauch gründlich mischen"/"Grondig mengen vóór gebruik"/"Mescolare accuratamente prima dell'uso"/"Mézdelo bien antes de usarlo"

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GHS07
Instructions for use.
Keep out of sunlight.

PK022-1 The World's 1st CAD/CAM Denture Company Net Weight: 1kg (2.2 lbs)

Figure 6: Dentca Resin

Figure 7: Bego VarseoSmile Crown Plus Printing Resin

2.2 Methods

2.2.1 Specimen Preparation

Disk specimens from each material were prepared with dimensions of 14mm in diameter and 2mm in thickness.

2.2.1.1 Conventional Specimen Preparation

Jet Tooth Shade specimens were made per manufacturer's instructions. A glass pipette, a stainless-steel spatula and a silicone dappen dish were all cleaned with 70% isopropyl alcohol and dried. 30ml of powder was added to 10ml of liquid in a silicone dappen dish and rigorously hand mixed. The mixture was then added to a prepared custom silicone mold (Figure 8) and pressed between two glass slabs and a constant load of 10N on the material was maintained throughout auto-polymerization. The specimens were left to auto-polymerize at room temperature for ten minutes. Any disk specimen with visible voids was discarded. All flash was removed using a low speed handpiece with a H251EF.11.060 HP EF Cutter Carbide (Brasseler USA, Savannah, GA) bur at 30,000 rotations per minutes.

ProTemp disk specimens were fabricated in the same manner as Jet Tooth Shade disk specimens. The cartridges containing the ProTemp material were first examined and dispensed onto a mixing pad without an auto-mixing tip. The auto-mixing tip was then placed and the resin was dispensed into a custom-made silicone mold and pressed between two glass slabs again. A constant load of 10N was maintained for five minutes to ensure minimum excess material. All flash was removed using a low speed handpiece with an H251EF.11.060 HP EF Cutter Carbide (Brasseler USA, Savannah, GA) bur at 30,000 rotations per minutes.

2.2.1.2 Machinable Materials Specimen Preparation

Both Telio CAD Temp and Vita CAD Temp specimens were prepared in the same manner. The machinable blocks were core drilled into cylinders of the desired diameter using the Palmgren 12” Drill Press with a 5/8-inch diamond core drill (Starlite Industries, Rosemont, PA), shown in Figure 9. Figure 10 shows the core drilled Vita CAD Temp cylinders after core drilling. The cylinders were then prepared for sectioning. A mandrel was attached by using epoxy glue and left to set under a load of 1000 grams for 24 hours (Figure 11).

Figure 8: Custom Silicone mold utilized to fabricate conventionally prepared disk specimens

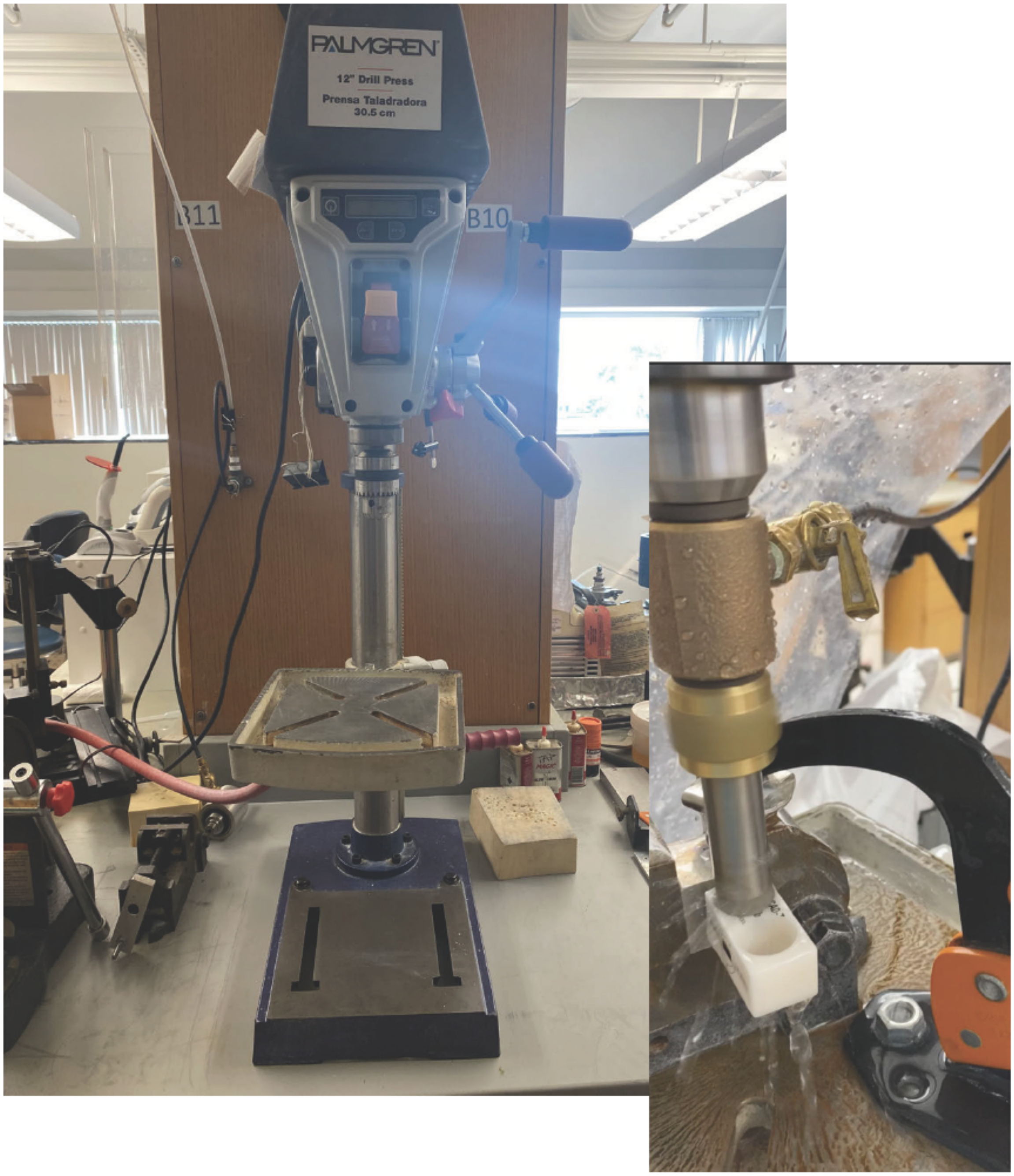


Figure 9: Core Drill (Palmgren 12" Drill Press)

The cylinders attached to the mandrels were then fixed into a holder of a precision saw machine (Isomet 5000, Buehler, Lake Bluff, IL) and finally sectioned into the desired thicknesses of 2 mm using a diamond blade with 0.15mm thickness and 76mm in diameter. The saw machine was operated at 700 rotations per minute and a feed rate of 8.0mm per minute.

Figure 10: Vita CAD Temp Core Drilled Cylinders

Figure 11: Vita CAD Temp Cylinders attached to mandrels with epoxy resin and placed under weight

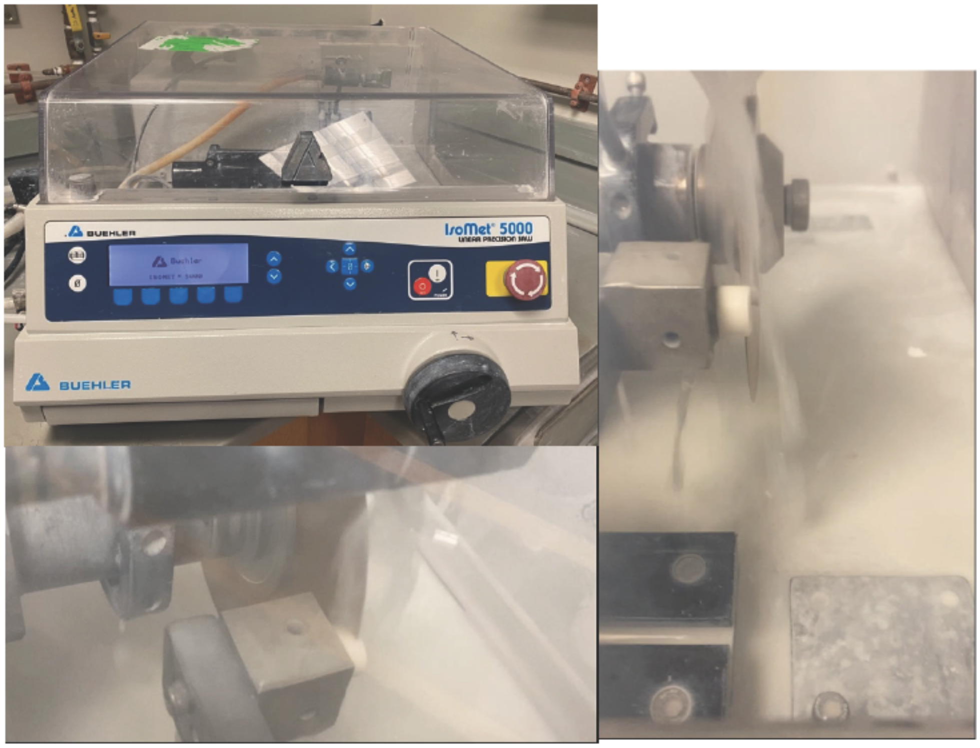
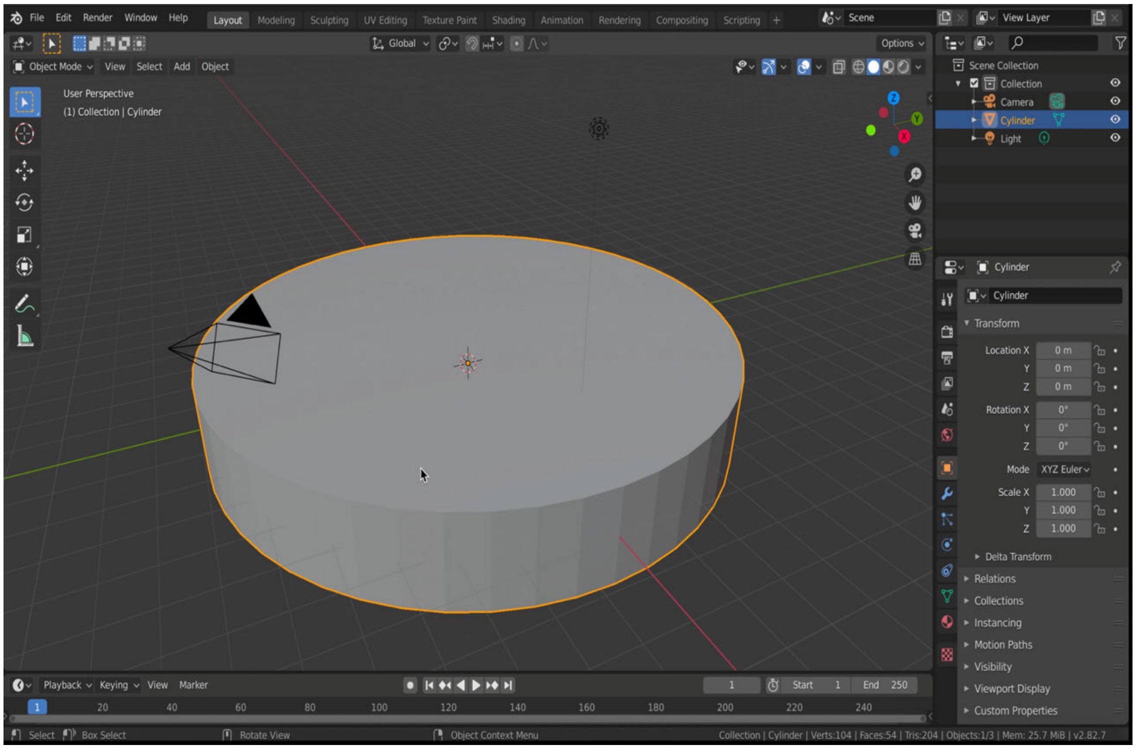


Figure 12: Sectioning Machine Isomet 5000.

2.2.1.3 Printed Specimen Preparation

For all printed specimens, the same standard tessellation (STL) file was used. The disk was digitally designed on Blender™ (Blender Foundation, Amsterdam, Netherlands) in the desired dimensions then uploaded to each material's corresponding software and finally printed. Figure 13 displays the disk specimen design on Blender™.



Location X 0 m
Y 0 m
Z 0 m
Rotation X 0°
Y 0°
Z 0°
Mode XYZ Euler
Scale X 1.000
Y 1.000
Z 1.000

1 Start 1 End 250

Collection | Cylinder | Verts:104 | Faces:54 | Tris:204 | Objects:1/3 | Mem: 25.7 MiB | v2.82.7

Figure 13: Disk Specimen Digital Design on Blender™

2.2.1.3.1 Temporary CB Disk Specimen Preparation

The STL file of the disk specimen was uploaded to Preform™ (version 2.19.2) software and printed using the FormLab 2 (SN: MelodiousSkunk). After printing, the specimens were then washed with >99% isopropyl alcohol (LOT L018-29, Lab Chem Zellenpole, PA) and placed in the Form Wash (SN: IcterineSphinx) for 3 minutes with >99% isopropyl alcohol. The printed specimens were then placed in the post-processing unit Form Cure (SN: KiwiWarthog) and post cured in 405nm wavelength light and 60 degrees Celsius for 20 minutes. The sprues and support structures were then removed, sandblasted and cured in the Form Cure again unit for 20 more minutes. This step is done to ensure removal of residual uncured resin to ensure biocompatibility and optimum mechanical properties.

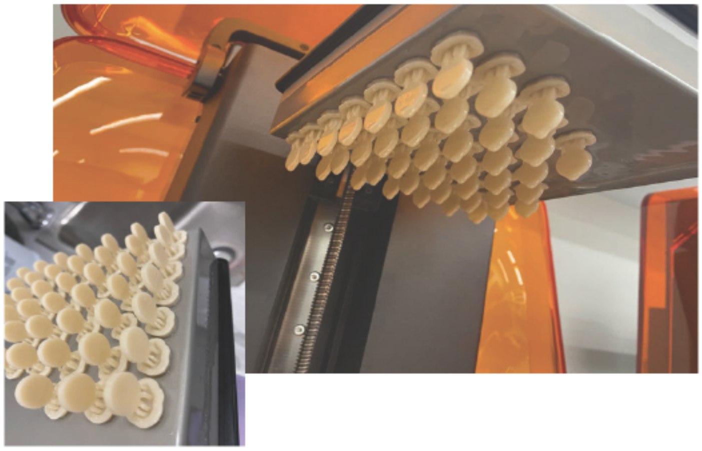


Figure 14: Temporary CB Disk Specimens on the Stainless-Steel Build Platform of FormLab 2

2.2.1.3.2 Dentca Disk Specimen Preparation

The STL file of the disk specimen was uploaded to the Carbon 3D software and printed using the M1 printer (Model 102750). The printed specimens were then placed in an orbital shaker with >99% Isopropyl Alcohol (LOT L018-29, Lab Chem Zellenpole, PA) for 5 minutes at a speed of 140 rotations per minute. The isopropyl alcohol solution was changed again and the specimens were left in the orbital shaker for five more minutes at 140 rotations per minute.

The specimens were then allowed to air dry for 15 minutes and then immersed in a vegetable glycerin solution (LOT 111620g01, Glycerin Supplier, Houston, TX) and placed in the Dreve PCU LED post processing unit. The Dreve PCU LED unit was connected to nitrogen gas (N_2). The specimens were allowed to cure for 30 minutes at 90% intensity. The Dreve PCU LED is a post curing unit that creates a vacuum for printed products to cure in the absence of an oxygen inhibited layer with a light intensity of 410nm. This ensures biocompatibility and enhanced mechanical properties by removing and curing any residual resin. The manufacturer did not recommend to flip the printed products since both sides cure simultaneously.

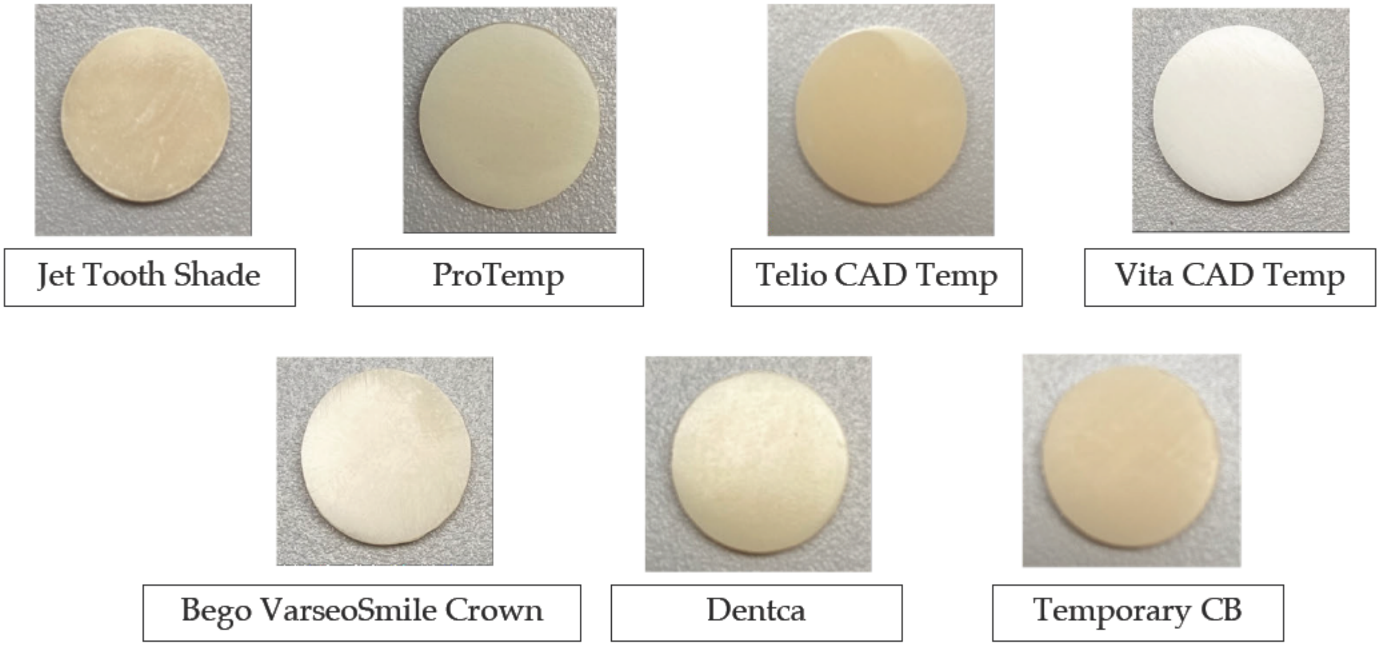
2.2.1.3.2 Bego VarseoSmile Crown Plus Disk Specimen Preparation

The Bego VarseoSmile Crown Plus disk specimens were also designed using the same software (Blender ™) and were printed by Alien Milling Technologies, Glendora, CA. (Figure 15)

Figure 15: Bego VarseoSmile Crown Plus Specimens Provided by Alien Milling

2.2.1.4 Finishing and Polishing

All specimens were then finished and polished using the Buehler grinding-polishing system (Buehler Ecomet 250, Buehler Ltd, IL, USA). They were polished starting with graded diamond grits 45 μm and 15 μm to ensure that thicknesses were 2mm and remove any surface scratches and irregularities. The specimens were then further polished with 6 μm polycrystalline diamond suspensions applied to special pads using the Buehler grinding-polishing system. Finally, specimens were further polished with 1 μm alumina suspension applied to another set of pads. The thicknesses and diameters were confirmed with a digital caliper. A disk specimen from each material is shown in Figure 16.



Jet Tooth Shade

ProTemp

Telio CAD Temp

Vita CAD Temp

Bego VarseoSmile Crown

Dentca

Temporary CB

Figure 16: Disk Specimens

2.2.2 Biaxial Flexural Strength

All flexural strength values were obtained by a three-point flexural strength test using the Instron Universal Testing Machine (5566A; Instron, Canton, MA). The disks were placed on three symmetrically spaced rounded-tip steel rods with diameters of 9mm. The crosshead speed was set at 1.0mm/min. The tip radius was 0.8mm and support radius was 5.0mm (18). These parameters were the same for all the flexural strength tests done in this study for static flexural strength tests as well as after the various treatments. All flexural strength values were determined in Megapascals (MPa). The Universal Testing Machine was set to calculate biaxial flexural strength values in megapascals from the mean load to failure in Newtons. Maximum flexural strength (σ) in MPa was calculated with the following equation:

$$\sigma = \frac{-0.2387 \times F \times (X - Y)}{d^2}$$

Where F is the failure load in Newtons and d is the thickness of the specimen. X and Y are calculated via the following equations:

$$X = (1 + \upsilon)\ln\left(\frac{c}{R}\right)^2 + \left(\frac{1 - \nu}{2}\right) \times \left(\frac{c}{R}\right)^2$$

$$Y = (1 + \nu)\left[1 + ln\left(\frac{a}{R}\right)^2\right] + (1 - \nu) \times \left(\frac{a}{R}\right)^2$$

Where ν is Poisson’s Ratio, R is the radius of the sample in millimeters, c is the radius of the piston and support balls, and a is the radius of the loading circle.

Poisson’s ratio is the elastic ratio between lateral strain and longitudinal strain. It is used to quantify a specific material’s deformation perpendicular to the direction of load. For example, in the case of compression, the material will get thicker in the lateral direction. As a general rule, stiffer materials will have lower Poisson’s ratios than softer materials. In this case, 0.3 was used as Poisson’s ratio.

2.2.3 Color Difference (ΔE*)

All color values were recorded using the spectrophotometer, X-Rite Ci7600 (X- Rite Inc., Grand Rapids, MI). The L*, a*, and b* for each specimen was recorded. Before recording color values, the spectrophotometer was calibrated per manufacturer’s instructions. The parameters for the spectrophotometer were set according to the following: corrected standard temperature, 6 mm viewport opening and a D65 standard illumination source (as defined by the International Commission on Illumination) that corresponds to average daylight.

All disk specimens that underwent the treatments of thermocycling, immersion in distilled water, thermocycling and coffee, and finally UV light had pre-treatment and post treatment CIE L*a*b* values recorded. ΔE* or change in color will be calculated with the following formula:

$$\Delta E^* = \sqrt{(L^*2 \quad L^*1)^2 + (a^*2 \quad a^*1)^2 + (b^*2 \quad b^*1)^2}$$

Where L*2, a*2, and b*2 are the color coordinates post treatment and L*1, a*1, and b*1 are pre-treatment color coordinates. As mentioned earlier, L* is the lightness, a* is the green to red spectrum and b* is the blue to yellow spectrum.

2.2.4 Treatments

A total of 60 disk specimens were made from each material. Ten disk specimens were fabricated for each of the following groups:

1) Static flexural strength
2) Flexural strength after fatigue
3) Flexural strength and color stability after thermocycling
4) Flexural strength and color stability after immersion in distilled water
5) Flexural strength and color stability after thermocycling plus immersion in coffee
6) Flexural strength and color stability after exposure to UV light.

2.2.4.1 Static Flexural Strength

Ten disk specimens from each material were immediately fractured after fabrication without any treatment. Instron Universal Testing Machine (5566A; Instron, Canton, MA) was utilized to register flexural strength values. The flexural strength values were determined in Megapascals and used as a baseline for later comparisons and statistical analyses.

2.2.4.2 Fatigue

For fatigue testing, specimens from each group per each material were subjected to cyclic loading by a powered cylinder and an electronic control device (Pober

Industries, Waban MA). The cyclic loading machine is shown in Figure 18. The cyclic loading machine consists of pistons with different sizes. For this test, the size piston utilized was 7/8 inches and it applied a load factor of 2.67 Newtons per pounds per square inch (N/psi). The peak load in Newtons applied on each specimen represented 60% of the mean fracture load of each material for 50,000 cycles at a frequency of 1 Hz. The fatigue peak value in Newtons for each material was converted to psi:

1) Jet Tooth Shade: 109 N ÷ 2.67 N/psi = 40.8 psi
2) ProTemp: 230 N ÷ 2.67 N/psi = 86.2 psi
3) Telio CAD Temp: 275 N ÷ 2.67 N/psi = 103 psi
4) Vita CAD Temp: 145 N ÷ 2.67 N/psi= 54.3 psi
5) Temporay CB: 185 N ÷ 2.67 N/psi = 69.3 psi
6) Dentca: 175 N ÷ 2.67 N/psi = 65.6 psi
7) Bego VarseoSmile Crown Plus: 163 N ÷ 2.67 N/psi = 61 psi

The cyclic loading was applied perpendicular to and at the center of the specimen. A washer was fabricated to keep the disk specimen in place and ensure that the load was applied at the center. In the cylinder, the specimen was supported by 6 mm stainless steel balls. After cyclic loading, the disk specimens were then removed from the cyclic loading apparatus and fractured using the Instron Universal Testing Machine (5566A; Instron, Canton, MA). The parameters were maintained the same as the static flexural strength tests. Flexural strength values in MPa were determined.

2.2.4.3 Thermocycling

For thermocycling, ten specimens from each material were first stored in distilled water for 24 hours. The L*, a*, and b* values were recorded first using the spectrophotometer, X-Rite Ci7600 (X- Rite Inc., Grand Rapids, MI). The specimens were then placed in a meshwork and stabilized so that all disk specimens were equally exposed to the thermocycling solution on the both sides. To mimic aging, the disk specimens were then placed in a thermocycling machine. The thermocycling machine alternates the specimens in 5°C water and 55°C water with a 30 second dwell time. This is done for 5000 cycles. The thermocycling machine is shown in Figure 19. After 5000 thermal cycles the specimens were rinsed with distilled water and color was immediately recorded using the same spectrophotometer in the form of L*, a* and b* values. Once color was recorded, the disk specimens were loaded in the Instron Universal Testing Machine with the same parameters and flexural strength values were obtained in Megapascals.

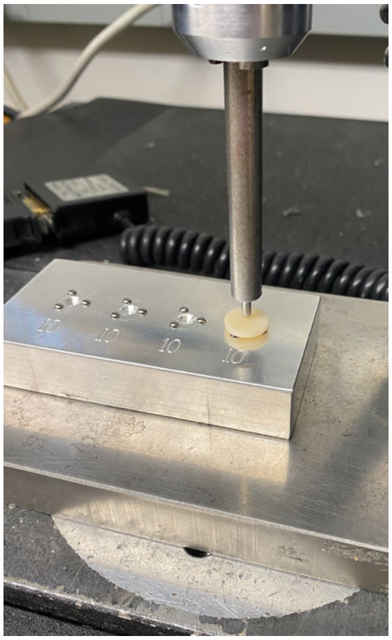


Figure 17: Disk Specimen Set-Up on the Universal Testing Machine

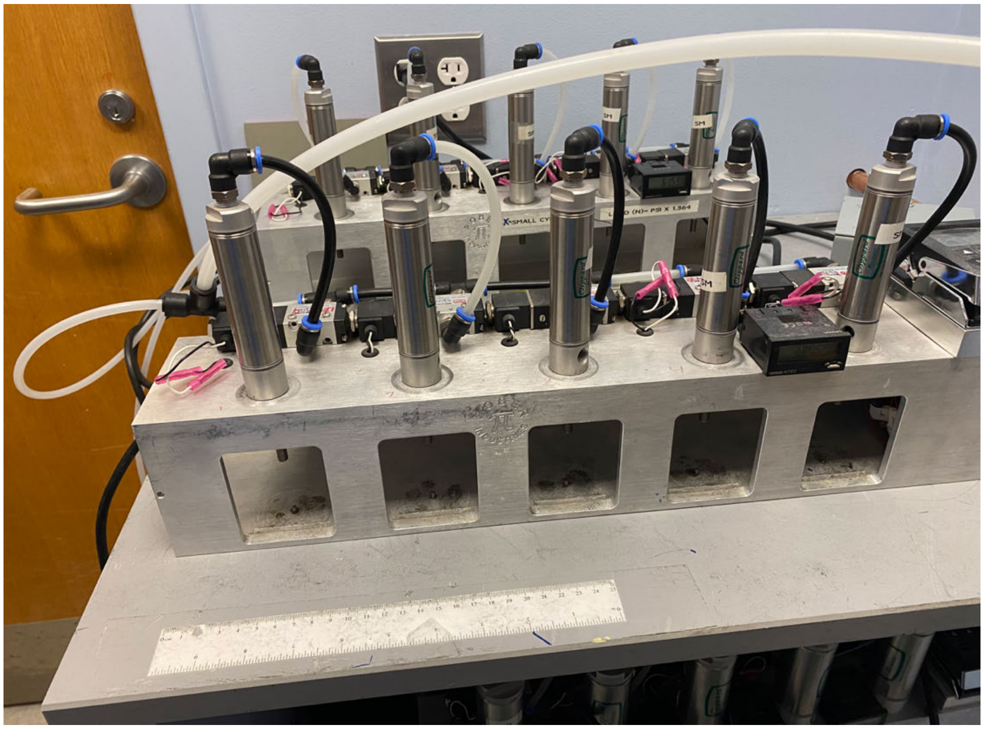


Figure 18: Cyclic Loading Machine, Pober Industries, Waban, MA

Figure 19: Thermocycling Machine

2.2.2.4 Distilled Water

Ten disk specimens from each material were immersed in distilled water for a total of 24 hours. The L*, b*, and a* values were then recorded using the X-Rite Ci7600 Spectrophotometer (X- Rite Inc., Grand Rapids, MI). The disk specimens were then placed back in distilled water for a total of 15 days. The specimens were kept in an incubator with a temperature of 37°C. After 15 days, the disk specimens were removed and the L*a*b* values were again recorded. After recording post treatment color, the specimens were finally loaded with the Instron Universal Testing Machine.

2.2.4.5 Thermocycling and Coffee

Ten disk specimens from each material also were stored in distilled water for 24 hours. The L*a*b* values were then recorded using the spectrophotometer, X-Rite Ci7600 (X- Rite Inc., Grand Rapids, MI). The specimens were then placed in the thermocycling apparatus (Figure 19) for a total of 1500 cycles. The specimens were then removed and placed in coffee for 15 days. The specimens in the coffee solutions were kept in an incubator with a temperature of 37°C. The coffee was replaced on a daily basis. After 15 days has elapsed, the specimens were rinsed with distilled water and the L*a*b* values were recorded again. Once post treatment color was recorded, the specimens were loaded in the Instron Universal Testing Machine. The color values before and after treatment in addition to flexural strength values were recorded.

2.2.4.6 UVC Light

Finally, the last treatment was done on an additional ten specimens from each material group. The L*a*b* values were recorded after immersion in distilled water for 24 hours using the spectrophotometer, X-Rite Ci7600 (X- Rite Inc., Grand Rapids, MI). The specimens were then adhered to the sides of a cardboard box by double-sided tape. A UVC bulb with ozone E26-25 W, 253.7nm ± 185nm. (Coospider, Aopu Lighting, Guangzhou, China)(Figure 20) was then placed in the cardboard box. The whole apparatus, shown in Figure 21, was placed under a black covering. The UVC light was turned on for 15-minute intervals and allowed to rest for an additional 15 minutes. All disk specimens were exposed for a total of 2 hours a day for five days totaling to ten hours of UVC light exposure. The L*a*b* values were then recorded again using the spectrophotometer as post treatment color values. The disk specimens were then loaded in the Instron Universal Testing Machine with the same parameters. The pre-treatment and post treatment L*a*b* color values were recorded as well as flexural strength values in terms of megapascals.

Figure 20: UVC Light Source

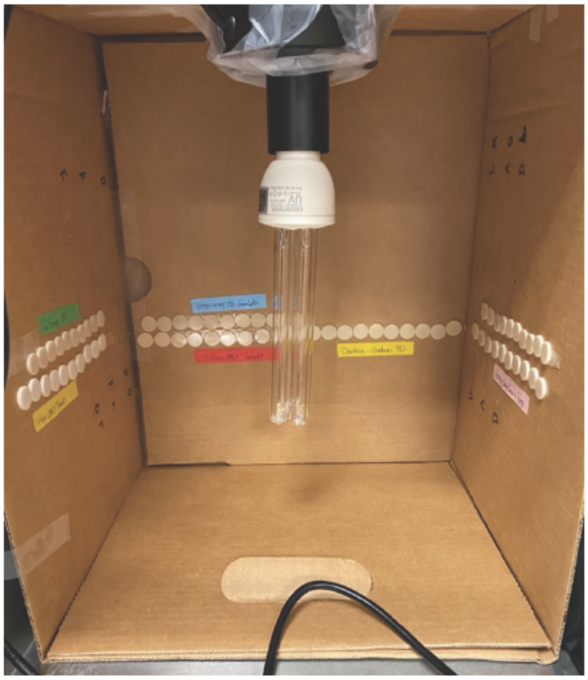


Figure 21: UVC Light Treatment Apparatus and Set-Up

2.2.5 Statistical Analysis

A statistical analysis was performed to measure the outcomes of flexural strength and color differences. The independent variables were the different treatments of fatigue, thermocycling, distilled water, thermocycling and coffee, and finally UVC light exposure. Multi-way analysis of variance (ANOVA) mode was utilized to derive the presence of any statistically significant differences. Pairwise comparisons among the groups was also conducted using the Tukey-Kramer HSD test with an alpha equal to 0.05. Microsoft Excel and JMP Pro 15 (JMP, SAS, Cary, NC) were used to record data and conduct statistical tests.

2.2.6 Microstructure Analysis

Some specimens were selected for observation under a scanning electron microscope (Field Emission Variable Pressure Analytic Scanning Electron Microscope FESEM-VP- Hitachi SU6600 with Oxford Instrument AZtec X-Max 50 SDD Energy Dispersive Spectrometer, Hitachi High Tech, Oxford Instruments). The specimens were observed for fracture patterns, and presence of any voids or defects that may have been the source of failure. The specimens were cleaned with ethanol and left to dry. The specimens were then placed in a vacuum sputter for gold-palladium coating. The specimens were then evaluated under the SEM at the fracture cross-section. SEM images were imported as images using the ImageJ software (ImageJ 1.52K, National Institute of Health, USA).

Chapter 3: Results

3.1 Biaxial Flexural Strength

Different polymers used for the purposes of provisional restorations were assessed for biaxial flexural strength. The aim was to primarily compare the durability of all materials when subjected to different treatments and evaluate the performances after various treatments. Also, strength values were used to determine if aging, cyclic loading, coffee, UV light, and distilled water adversely affected the dental polymers. The means and standard deviations of the seven materials with different treatments are summarized in Table 3, Table 4, and Figure 22. The highest overall flexural strength across all treatment groups was recorded for Telio CAD Temp static value, demonstrating an average value of 156.66 Megapascals. The lowest overall flexural strength across all treatments was recorded by Jet Tooth Shade with an average value of 72.88 MPa.

Two-way analysis of variance demonstrated in Table 5 shows that a statistically significant difference exists between the overall flexural strength values of the different materials and treatments with a p-value of less than 0.0001. Both, the effects of material type and treatment procedure were significant as shown in the effects test summarized in Table 6 where the interactions are also significant. Table 7 shows the variables that had a significant effect on flexural strength. Variables were analyzed according to p-values, and LogWorth, which is the -log(p-value). Highly significant p-values have large LogWorths. The material variable showed the most significant effect with a p-value LogWorth of 54.117, which indicated the material type was the dominant effect on the flexural strength.

Table 3: Means and Standard Deviations (Megapascals) of Different Materials in Each Treatment Group

Material	**Static**	**Fatigue** (50,000 cycles at 60% of mean load to failure)	**Aging** (5000 Thermal Cycles)	**Distilled Water** (15 Days)	**Coffee** (1500 Thermal Cycles and 15 Days Coffee)	**UV Light** (10 hours, 15-minute intervals)
Temporary CB (FormLab)	127.94 ± 15.33	143.71 ± 25.37	96.76 ± 24.88	115.29 ± 31.29	112.97 ± 21.38	123.90 ± 15.98
Dentca (Carbon 3D)	131.59 ± 40.96	149.80 ± 70.99	116.07 ± 54.49	105.62 ± 64.03	105.57 ± 56.62	127.93 ± 59.83

Bego VarseoSmile Crown Plus	143.39 ± 36.38	152.69 ± 12.05	122.36 ± 34.86	129.24 ± 29.16	145.49 ± 23.95	130.63 ± 38.64
Telio CAD Temp (Ivoclar Vivadent)	187.43 ± 17.89	163.63 ± 30.68	167.80 ± 13.40	165.60 ± 17.80	158.57 ± 13.30	96.92 ± 22.84
Vita CAD Temp (Vita)	105.26 ± 3.57	103.41 ± 4.17	95.52 ± 5.50	91.94 ± 3.56	86.00 ± 7.99	75.06 ± 7.13
ProTemp (3M)	161.12 ± 16.37	135.41 ± 11.94	120.43 ± 19.21	141.18 ± 11.59	151.09 ± 12.42	151.55 ± 11.51
Jet Tooth Shade (Lang Dental)	76.57 ± 6.48	74.24 ± 7.75	65.96 ± 6.75	79.38 ± 9.71	68.46 ± 9.84	72.66 ± 8.49

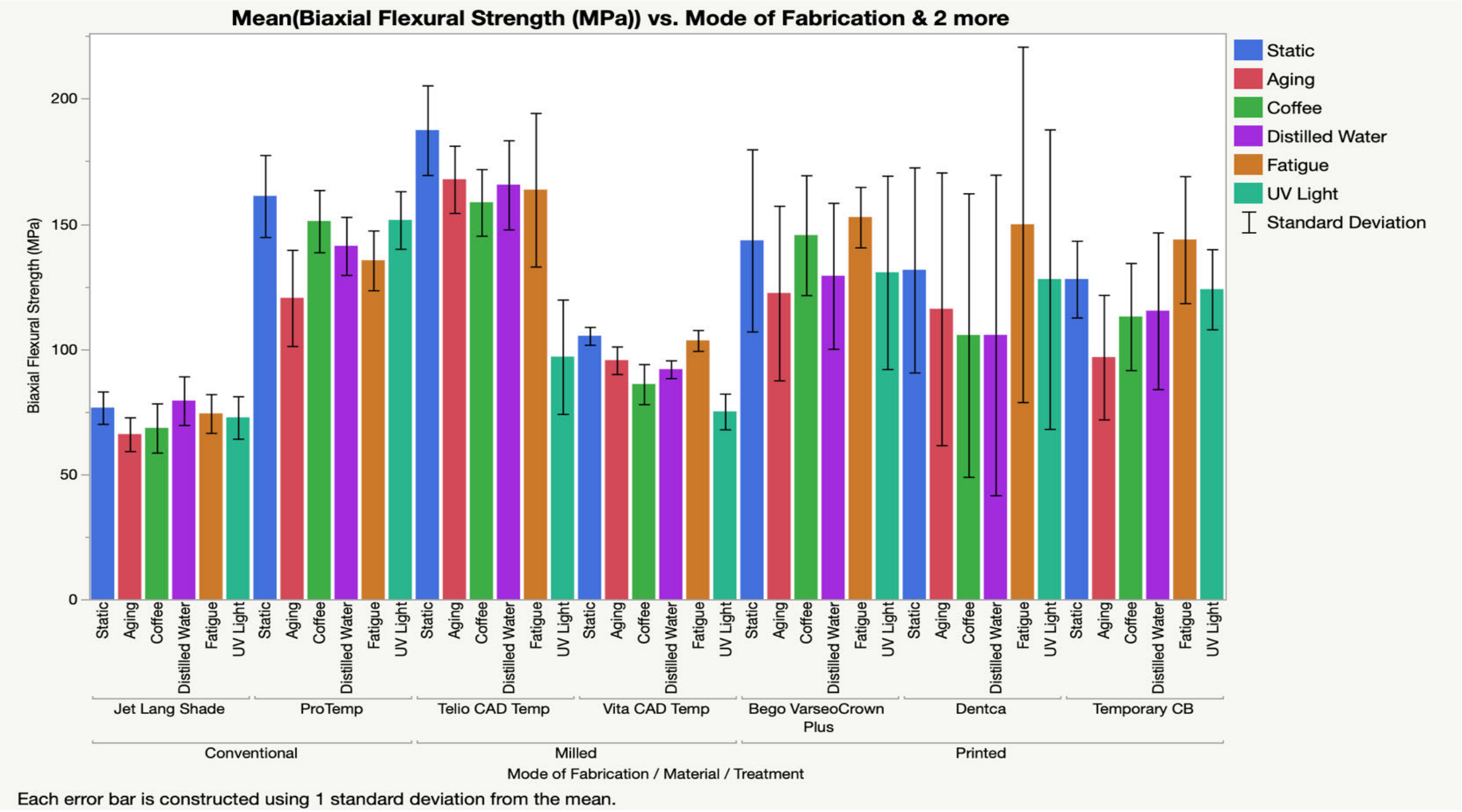


Figure 22: Bar Graph of Means and Standard Deviations of Flexural Strength Values of Different Materials under Various Treatments

Table 4: Means, Standard Deviations, Coefficients of Variation of all Materials and Treatments in Megapascals

		Biaxial Flexural Strength (MPa)			
Material	**Treatment**	**N**	**Mean**	**Std Dev**	**CV**
Bego VarseoSmile Crown Plus	Static	10	143.39	36.38	25.37
	Aging	10	122.36	34.86	28.49
	Coffee	10	145.49	23.94	16.45
	Distilled Water	10	129.24	29.16	22.56
	Fatigue	10	152.69	12.05	7.89
	UV Light	10	130.63	38.64	29.58
Dentca	Static	10	131.59	40.96	31.13
	Aging	10	116.07	54.49	46.94
	Coffee	10	105.57	56.62	53.64
	Distilled Water	10	105.62	64.03	60.62
	Fatigue	10	149.80	70.99	47.39
	UV Light	10	127.93	59.83	46.77
Jet Tooth Shade	Static	10	76.57	6.48	8.47
	Aging	10	65.96	6.75	10.24
	Coffee	10	68.46	9.84	14.37
	Distilled Water	10	79.38	9.71	12.23
	Fatigue	10	74.24	7.75	10.44
	UV Light	10	72.66	8.49	11.69
ProTemp	Static	10	161.12	16.37	10.16
	Aging	10	120.43	19.21	15.95
	Coffee	10	151.09	12.42	8.22

	Distilled Water	10	141.18	11.59	8.21
	Fatigue	10	135.41	11.94	8.82
	UV Light	10	151.55	11.51	7.60
Telio CAD Temp	Static	10	187.43	17.89	9.54
	Aging	10	167.80	13.43	8.00
	Coffee	10	158.57	13.30	8.39
	Distilled Water	10	165.60	17.80	10.75
	Fatigue	10	163.63	30.68	18.75
	UV Light	10	96.92	22.84	23.56
Temporary CB	Static	10	127.94	15.33	11.98
	Aging	10	96.76	24.88	25.71
	Coffee	10	112.97	21.38	18.93
	Distilled Water	10	115.29	31.29	27.14
	Fatigue	10	143.71	25.37	17.65
	UV Light	10	123.90	15.98	12.90
Vita CAD Temp	Static	10	105.26	3.57	3.40
	Aging	10	95.52	5.50	5.75
	Coffee	10	86.00	7.99	9.30
	Distilled Water	10	91.94	3.56	3.87
	Fatigue	10	103.41	4.17	4.03
	UV Light	10	75.06	7.13	9.50

Table 5: Analysis of Variance for Overall Flexural Strength Tests

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	41	408843.33	9971.79	12.4579	<0.0001
Error	378	302565.23	800.44		
C.Total	419	711408.56			

Table 6: Effects Tests for Overall Flexural Strength that displays both material and treatment as significant interactions

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Material	6	6	309183.04	64.3780	<0.0001
Treatment	5	5	32051.84	8.0086	<0.0001
Material*Treatment	30	30	67608.45	2.8155	<0.0001

Table 7: Variables Effects on Overall Biaxial Flexural Strength Values

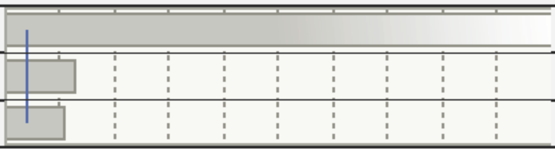
Source	LogWorth		p-Value
Material	54.117		0.00000
Treatment	6.466		0.00000
Material*Treatment	5.560		0.00000

Table 8: Static Flexural Strength Values of Dentca Disk Specimens and number of fractured pieces

Specimen No.	**Load (N)**	**Strength (MPa)**	**Fractured Pieces**
1	216.28	104.42	3
2	316.02	130.60	3
3	372.40	171.73	5
4	523.42	222.11	8
5	222.30	94.21	2
6	220.66	98.30	3
7	263.86	120.03	5
8	256.93	118.39	6
9	199.21	98.72	3
10	330.92	157.36	6

3.1.1 Effect of Material Type on Biaxial Flexural Strength

Statistical analysis was done to detect the presence of any significant differences in terms of overall flexural strength between the material types. Table 9 shows the least square means values of the overall flexural strength values with standard deviations of each material in megapascals.

The values were analyzed by an ANOVA test and a Tukey Kramer Honest Significant Difference Test. The statistical tests were conducted to detect the presence of any significant differences between the materials in the overall flexural strength tests.

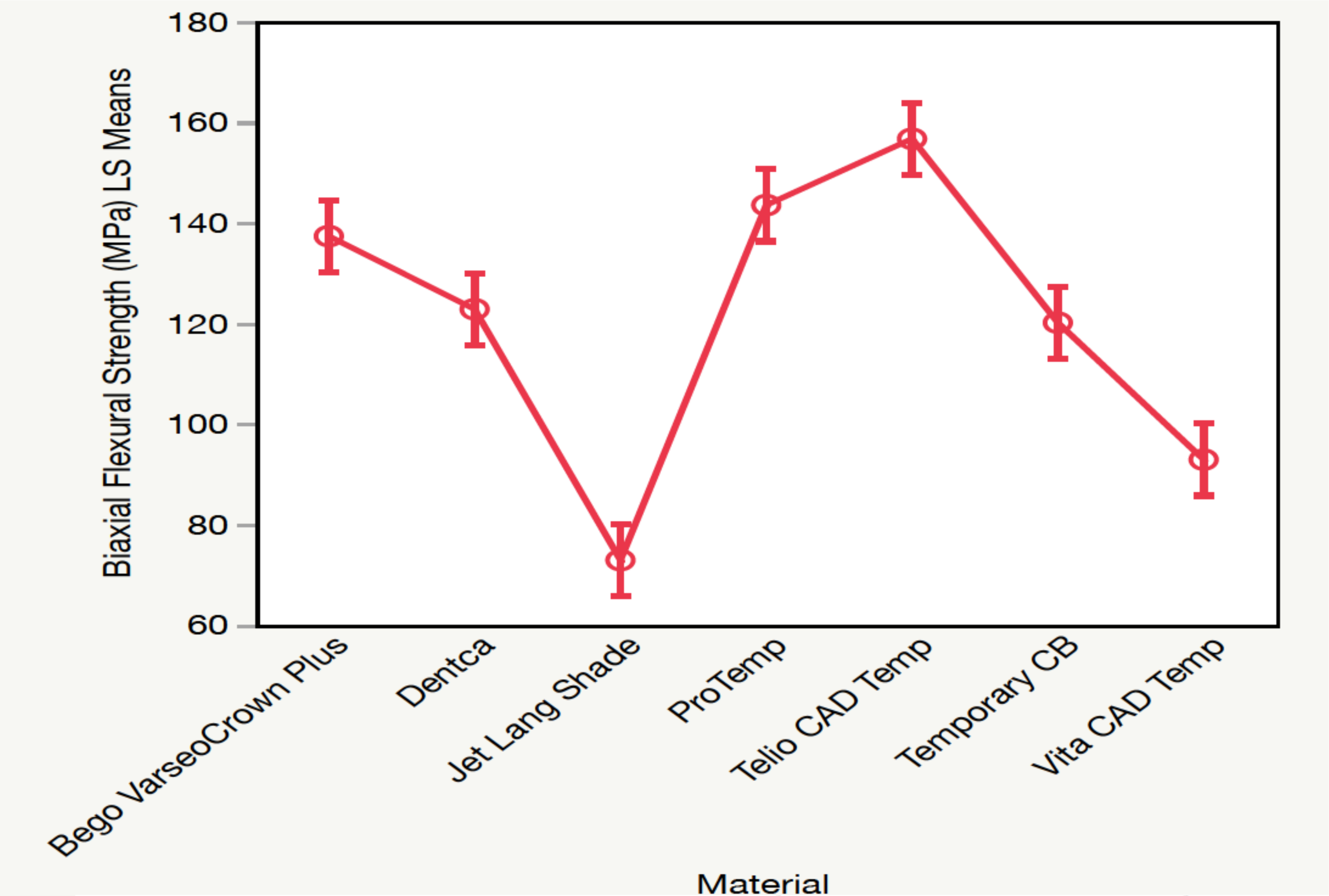


Figure 23: Least Square Means Plot of Flexural Strength Values for All Treatments with material as variable

When the materials are set as a variable, we can infer from Table 10 the performance of each material relative to one another. The p-values are listed in Table 11. The statistical analysis demonstrated that Telio CAD had a significantly higher flexural strength than Jet Tooth Shade (p-value < 0.001), Vita CAD Temp (p-value <0.0001), Temporary CB (p-value < 0.0001), Dentca (p-value < 0.0001), and Bego VarseoSmile Crown plus (p-value = 0.0039). The only material that Telio CAD Temp was not significantly higher than was ProTemp (p-value = 0.1434).

Furthermore, ProTemp recorded significantly higher values than Dentca (p-value = 0.0014), Vita CAD Temp (p-value < 0.0001), Temporary CB (p-value = 0.0002), and Jet Tooth Shade (p-value<0.0001). However, ProTemp was not statistically significantly higher than Bego VarseoSmile Crown Plus (p-value = 0.8964). As mentioned earlier, ProTemp was not statistically significantly weaker from Telio CAD Temp either (p-value = 0.1434).

Bego VarseoSmile Crown Plus registered statistically significantly weaker values than Telio CAD Temp only (p-value = 0.0039). On the other hand, Bego VarseoSmile Crown Plus was not significantly different than ProTemp (p-value=0.8964) or Dentca (p-value = 0.0753). However, Bego VarseoSmile Crown Plus did register significantly stronger flexural strengths than Temporary CB (p-value= 0.0164), Vita CAD Temp (p-value < 0.0001), and Jet Tooth Shade (p-value < 0.0001).

Dentca was not statistically significantly lower than Bego VarseoSmile Crown Plus p-value = 0.0753) or Temporary CB (p-value = 0.9986). However, Dentca was significantly weaker than ProTemp (p-value = 0.0014) and Telio CAD

Temp (p-value < 0.0001). Dentca registered significantly higher flexural strength values than both Jet Tooth Shade (p-value < 0.0001) as well as Vita CAD Temp (p-value < 0.0001).

Vita CAD Temp was statistically significantly weaker than all materials (all p-values <0.0001) and statistically stronger than Jet Tooth Shade (p-value = 0.0024). Jet Tooth Shade was the statistically significant weakest material. It registered p-values less than 0.001 when compared to all materials except for Vita CAD Temp where the p-value = 0.0024.

The differences of least squares mean of each material can be visualized in Figure 23. Again, Telio CAD Temp registered the highest flexural strength values when compared to other materials. Jet Tooth Shade registered the lowest flexural strength values.

Table 9: Least Squares Means Table of Overall Flexural Strength Values with Material as Variable.

Level	Least Sq Mean (MPa)	Std Error	Mean (MPa)
Bego VarseoSmile Crown Plus	137.29943	3.6524811	137.299
Dentca	122.76216	3.6524811	122.762
Jet Tooth Shade	72.87821	3.6524811	72.878
ProTemp	143.46475	3.6524811	143.465
Telio CAD Temp	156.65894	3.6524811	156.659
Temporary CB	120.09250	3.6524811	120.092
Vita CAD Temp	92.86362	3.6524811	92.864

Table 10: Flexural Strength Least Square Means Differences Tukey HSD with Materials as Variable

Level							Least Sq Mean (MPa)
Telio CAD Temp	A						156.65894
ProTemp	A	B					143.46475
Bego VarseoSmile Crown Plus		B	C				137.29943
Dentca			C	D			122.76216
Temporary CB				D			120.09250
Vita CAD Temp					E		92.86362
Jet Tooth Shade						F	72.87821

*Letters not connected by the same letter are significantly different.

Table 11: Differences, Standard Error Differences, Confidence Intervals, and p-Values with Material as Variable

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Telio CAD Temp	Jet Tooth Shade	83.78073	5.165388	68.4690	99.09249	<.0001*
ProTemp	Jet Tooth Shade	70.58654	5.165388	55.2748	85.89830	<.0001*
Bego VarseoSmile Crown Plus	Jet Tooth Shade	64.42122	5.165388	49.1095	79.73298	<.0001*
Telio CAD Temp	Vita CAD Temp	63.79532	5.165388	48.4836	79.10708	<.0001*
ProTemp	Vita CAD Temp	50.60113	5.165388	35.2894	65.91289	<.0001*
Dentca	Jet Tooth Shade	49.88395	5.165388	34.5722	65.19571	<.0001*
Temporary CB	Jet Tooth Shade	47.21429	5.165388	31.9025	62.52605	<.0001*
Bego VarseoSmile Crown Plus	Vita CAD Temp	44.43581	5.165388	29.1241	59.74757	<.0001*
Telio CAD Temp	Temporary CB	36.56645	5.165388	21.2547	51.87821	<.0001*
Telio CAD Temp	Dentca	33.89679	5.165388	18.5850	49.20855	<.0001*
Dentca	Vita CAD Temp	29.89854	5.165388	14.5868	45.21029	<.0001*
Temporary CB	Vita CAD Temp	27.22887	5.165388	11.9171	42.54063	<.0001*
ProTemp	Temporary CB	23.37225	5.165388	8.0605	38.68401	0.0002*
ProTemp	Dentca	20.70259	5.165388	5.3908	36.01435	0.0014*
Vita CAD Temp	Jet Lang Shade	19.98541	5.165388	4.6737	35.29717	0.0024*
Telio CAD Temp	Bego VarseoSmile Crown Plus	19.35951	5.165388	4.0478	34.67127	0.0039*

Bego VarseoSmile Crown Plus	Temporary CB	17.20694	5.165388	1.8952	32.51870	0.0164*
Bego VarseoCrown Plus	Dentca	14.53728	5.165388	-0.7745	29.84904	0.0753
Telio CAD Temp	ProTemp	13.19419	5.165388	-2.1176	28.50595	0.1434
ProTemp	Bego VarseoSmile Crown Plus	6.16532	5.165388	-9.1464	21.47708	0.8964
Dentca	Temporary CB	2.66966	5.165388	-12.6421	17.98142	0.9986

3.1.2 Effect of Treatment on Biaxial Flexural Strength

A statistical analysis was done to evaluate which treatment had a significant effect on the flexural strength values of all materials collectively. The different treatments along with least square means, standard errors and means are listed in Table 12. A Tukey test was done as well to assess any significant differences in the values of flexural strength tests with treatment as variable. It was assessed to evaluate the effect of each treatment on flexural strength on all materials collectively. Table 13 shows the Lowest Squares Means Differences Tukey HSD test.

When evaluating the effects of the various treatments on all polymers, a statistically significant difference has to be established between each treatment and the static flexural strength values. From Table 13 and

Table *14*, it can be assessed that only fatigue had no statistically significant difference from the static flexural strength values of all polymers. Distilled water, coffee, aging, and UV light all seem to have a statistically significant effect on the flexural strength of the polymers analyzed in this study. All these treatments have a statistically significant impact on flexural strength. This can also be visualized in Figure 24.

Table 12: Least Squares Means Table with Treatment as Variable

Level	Least Sq. Mean (MPa)	Std Error	Mean (MPa)
Static	133.32664	3.3815404	133.327
Aging	112.12819	3.3815404	112.128
Coffee	118.30604	3.3815404	118.306
Distilled Water	118.32096	3.3815404	118.321
Fatigue	131.84257	3.3815404	131.843
UV Light	111.23527	3.3815404	111.235

Table 13: Least Squares Means Differences Tukey Test with Treatments as Variable for all Materials

Level				Least Sq Mean (MPa)
Static	A			133.32664
Fatigue	A	B		131.84257
Distilled Water		B	C	118.32096
Coffee		B	C	118.30604
Aging			C	112.12819
UV Light			C	111.23527

*Letters not connected by the same letter are significantly different.

Table 14: Differences, Standard Error Differences, Confidence Intervals, and p-Values of Different the Different Treatment Groups Compared with Static Flexural Strength Values

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Static	UV Light	22.09138	4.782220	8.3932	35.78960	<.0001*
Static	Aging	21.19846	4.782220	7.5002	34.89667	0.0002*
Static	Coffee	15.02060	4.782220	1.3224	28.71882	0.0222*
Static	Distilled Water	15.00568	4.782220	1.3075	28.70390	0.0225*
Static	Fatigue	1.48408	4.782220	-12.2141	15.18230	0.9996

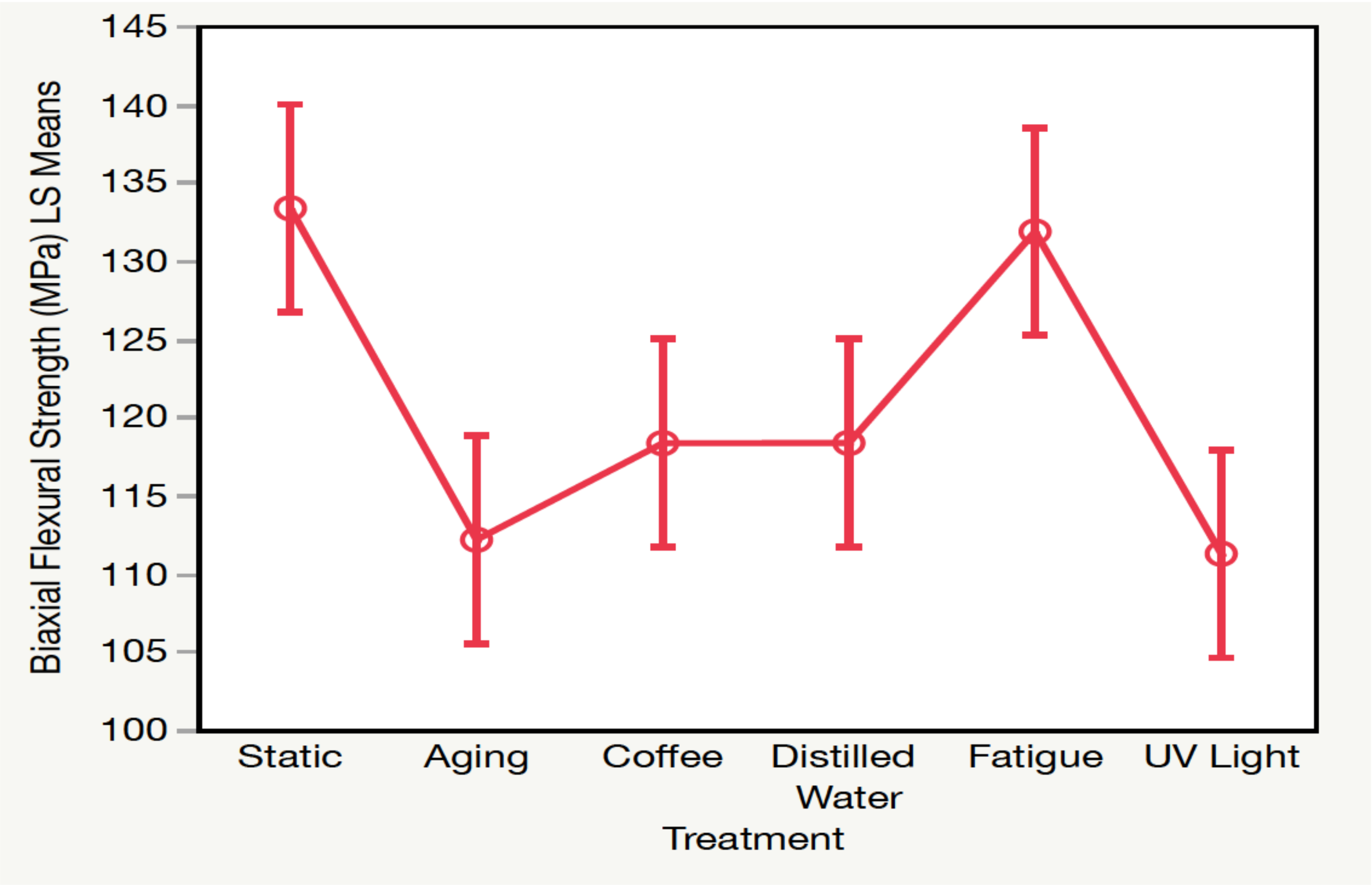


Figure 24: Lowest Squares Means of Flexural Strength (MPa) Plot for All Materials with Treatment as Varia

3.1.3 Effect of Material and Treatment on Biaxial Flexural Strength

A two-way ANOVA was done to demonstrate a significantly different pattern of the effect by post-treatment for the different materials. Figure 25 exhibits the least square means plot with both material and treatment as variables. Table 15 displays the Least Squares means differences Tukey test for material and treatment interactions.

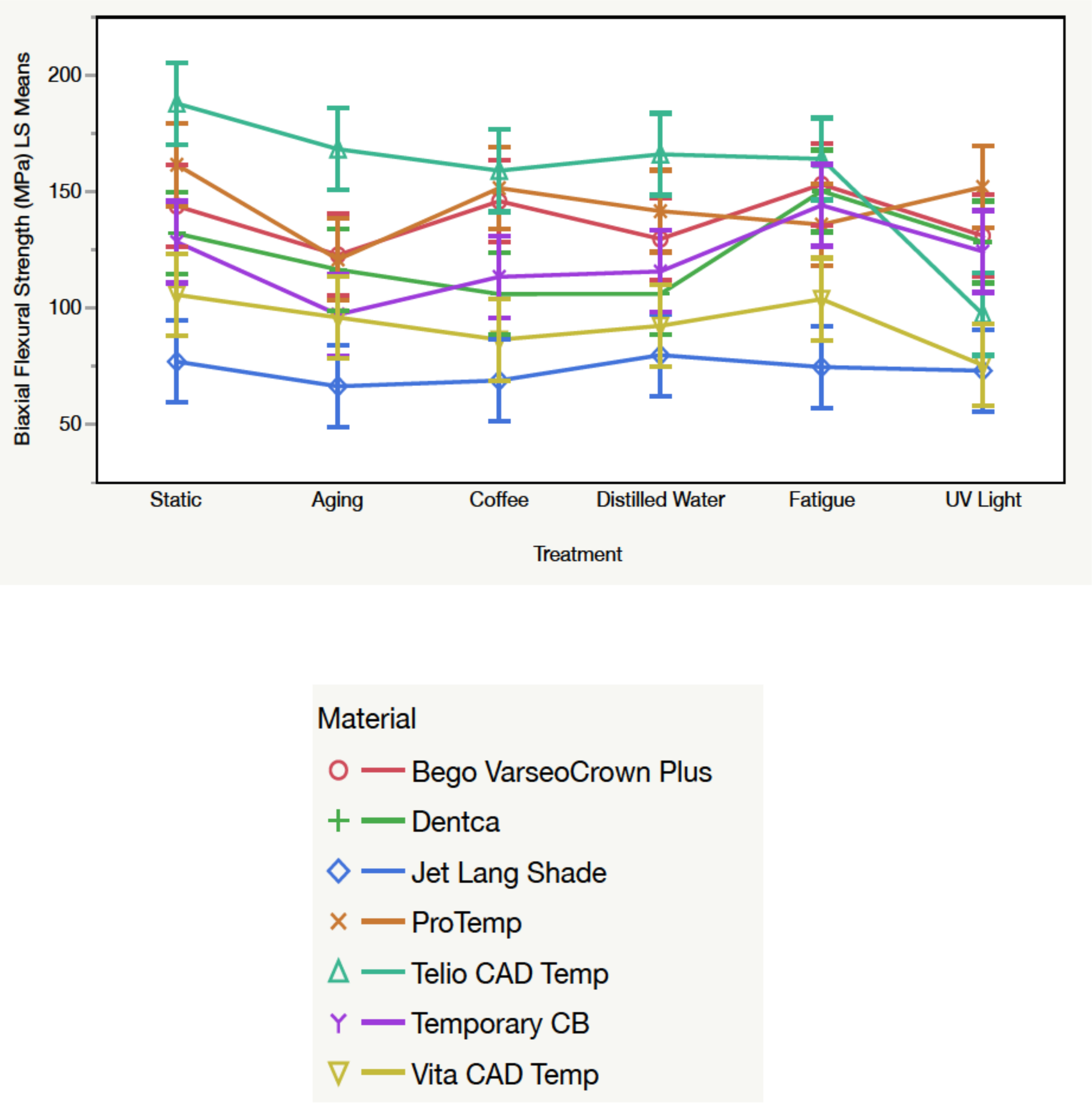


Figure 25: Plot Graph of Biaxial Flexural Strength Values with Both Material and Treatment as Variables

Table 15: Least Squares Means Differences Tukey Test for Material and Treatment Interaction

Level																**Least Sq Mean**
Telio CAD Temp,Static	A															187.43277
Telio CAD Temp,Aging	A	B														167.80012
Telio CAD Temp,Distilled Water	A	B	C													165.59821
Telio CAD Temp,Fatigue	A	B	C	D												163.63429
ProTemp,Static	A	B	C	D	E											161.11900
Telio CAD Temp,Coffee	A	B	C	D	E											158.56812
Bego VarseoCrown Plus,Fatigue	A	B	C	D	E	F										152.68959
ProTemp,UV Light	A	B	C	D	E	F										151.55346
ProTemp,Coffee	A	B	C	D	E	F										151.09475
Dentca,Fatigue	A	B	C	D	E	F										149.80098
Bego VarseoCrown Plus,Coffee	A	B	C	D	E	F	G									145.48765
Temporary CB,Fatigue	A	B	C	D	E	F	G	H								143.70807
Bego VarseoCrown Plus,Static	A	B	C	D	E	F	G	H								143.38778
ProTemp,Distilled Water	A	B	C	D	E	F	G	H	I							141.18381

ProTemp,Fatigue		B	C	D	E	F	G	H	I	J						135.41082
Dentca,Static		B	C	D	E	F	G	H	I	J						131.58788
Bego VarseoCrown Plus,UV Light		B	C	D	E	F	G	H	I	J						130.63111
Bego VarseoCrown Plus,Distilled Water		B	C	D	E	F	G	H	I	J	K					129.24450
Temporary CB,Static		B	C	D	E	F	G	H	I	J	K					127.93551
Dentca,UV Light		B	C	D	E	F	G	H	I	J	K					127.92908
Temporary CB,UV Light		B	C	D	E	F	G	H	I	J	K	L				123.89518
Bego VarseoCrown Plus,Aging		B	C	D	E	F	G	H	I	J	K	L	M			122.35597
ProTemp,Aging		B	C	D	E	F	G	H	I	J	K	L	M			120.42666
Dentca,Aging			C	D	E	F	G	H	I	J	K	L	M	N		116.07249
Temporary CB,Distilled Water				D	E	F	G	H	I	J	K	L	M	N	O	115.28821
Temporary CB,Coffee					E	F	G	H	I	J	K	L	M	N	O	112.96766
Dentca,Distilled Water						F	G	H	I	J	K	L	M	N	O	105.61563
Dentca,Coffee						F	G	H	I	J	K	L	M	N	O	105.56688
Vita CAD Temp,Static						F	G	H	I	J	K	L	M	N	O	105.25607
Vita CAD Temp,Fatigue						F	G	H	I	J	K	L	M	N	O	103.41207

Telio CAD Temp,UV Light							G	H	I	J	K	L	M	N	O	96.92015
Temporary CB,Aging							G	H	I	J	K	L	M	N	O	96.76035
Vita CAD Temp,Aging								H	I	J	K	L	M	N	O	95.52267
Vita CAD Temp,Distilled Water									I	J	K	L	M	N	O	91.93838
Vita CAD Temp,Coffee										J	K	L	M	N	O	85.99522
Jet Lang Shade,Distilled Water											K	L	M	N	O	79.37799
Jet Lang Shade,Static												L	M	N	O	76.56750
Vita CAD Temp,UV Light												L	M	N	O	75.05732
Jet Lang Shade,Fatigue												L	M	N	O	74.24215
Jet Lang Shade,UV Light													M	N	O	72.66056
Jet Lang Shade,Coffee														N	O	68.46200
Jet Lang Shade,Aging															O	65.95906

3.1.4 One-Way Analysis by Treatment for Each Material

From Table 7, material type was found to be the dominant effect on the flexural strength values. Therefore, each material was statistically analyzed using one-way ANOVA to conclude whether any of the various treatments had a statistically significant effect on the biaxial flexural strength values. The flexural strength of each treatment level was compared against the static group.

Bego VarseoSmile Crown Plus demonstrated its resistance to any treatment as there were no statistically significant differences between the static flexural strength values or any of the treatment groups. This can be seen in Table 16 where the analysis of variance showed an F value of 0.2238, indicating the absence of any statistically significant differences.

As with Bego VarseoSmile Crown Plus, Dentca also had no statistically significant differences between any of the treatment groups. The ANOVA (Analysis of Variance) result is displayed in Table 17.

Jet Tooth Shade demonstrated only one significant difference and that occurred between the distilled water and aging with a difference of 12.42 and a p value of 0.0080. Static flexural strength averages demonstrated no statistically significant differences with any of the treatment groups. This can be seen in Table 18.

ProTemp seemed to be affected by more than one treatment. There was a statistically significant difference between static flexural strength values and each of the following groups: distilled water (p-value = 0.0302), fatigue (p-value = 0.0021) and aging (p-value < 0.001). UV light (p-value = 0.6582) and coffee (p-value

= 0.6121) showed no significant effect on ProTemp. The ANOVA (Analysis of Variance) result is displayed in Table 19. Table 20 shows the differences between static flexural strength and the rest of treatments that had significant and nonsignificant effects, along with the p values. Table 21 displays the Tukey Test for ProTemp with Treatment as Variable.

As for Telio CAD Temp, static flexural strength average values showed a statistically significant difference with UV light (p-value < 0.0001) and to a lesser extent, coffee (p-value = 0.0272). The ANOVA (Analysis of Variance) result is displayed in Table 22. The differences and p-values are shown in Table 23. Table 24 displays least square means differences Tukey Test for Telio CAD Temp with Treatment as Variable

Compared with static flexural strength values, Temporary CB had a significant difference only with aging (p-value =0.0420) as a treatment variable. No other significant differences are detected between the static flexural strength group and the remaining treatment groups. Table 25 displays the results of one-way ANOVA (Analysis of Variance). Table 26 and Table 27 highlights the statistical differences, confidence intervals and p-values between static flexural strength values and the rest of the treatments.

Static flexural strength values of Vita CAD Temp were statistically significantly different from the flexural strength values after the following treatments: aging (p-value = 0.0036), distilled water (p-value < 0.0001), coffee (p-value < 0.0001) and UV light (p-value < 0.0001). Only fatigue had no impact on the flexural strength of Vita CAD Temp with a p-value of 0.9764. An ANOVA

(Analysis of Variance) was conducted and is listed in Table 28. Table 29 lists the statistical differences by treatment for Vita CAD Temp compared with the static flexural strength values along with the confidence intervals and p-Values. Table 30 displays the least square mean differences Tukey Test.

Table 16: Analysis of Variance for Bego VarseoSmile Crown Plus with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	6736.274	1347.25	1.4434	0.2238
Error	54	50404.205	933.41		
C.Total	59	57140.479			

Table 17: Analysis of Variance for Dentca with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	14701.21	2940.24	0.8575	0.5156
Error	54	185156.72	3428.83		
C.Total	59	199857.93			

Table 18: Analysis of Variance for Jet Tooth Shade with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	1251.4325	250.287	3.6551	0.00064
Error	54	3697.6836	68.476		
C.Total	59	4949.1162			

Table 19:Analysis of Variance for ProTemp with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	10361.387	2071.28	10.3552	<0.0001
Error	54	10806.54	200.12		
C.Total	59	21167.841			

Table 20: ProTemp Differences, Standard Error Differences, Confidence Intervals and p-Values with Treatment as Variable.

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Static	Aging	40.69234	6.326445	22.0010	59.38372	<.0001*
Static	Fatigue	25.70818	6.326445	7.0168	44.39956	0.0021*
Static	Distilled Water	19.93519	6.326445	1.2438	38.62657	0.0302*
Static	Coffee	10.02425	6.326445	-8.6671	28.71563	0.6121
Static	UV Light	9.56554	6.326445	-9.1258	28.25692	0.6582

Table 21: Lowest Squares Means Differences Tukey Test for ProTemp with Treatment as Variable

Level				Mean
Static	A			161.11900
UV Light	A	B		151.55346
Coffee	A	B		151.09475
Distilled Water		B		141.18381
Fatigue		B	C	135.41082
Aging			C	120.42666

Table 22: Analysis of Variance for Telio CAD Temp with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	47720.886	9544.18	23.3060	<0.0001
Error	54	22113.830	409.52		
C.Total	59	69834.715			

Table 23: Telio CAD Temp Differences, Standard Error Differences, Confidence Intervals, and p-Values with Treatment as Variable.

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Static	UV Light	90.51262	9.050032	63.7745	117.2508	<.0001*
Static	Coffee	28.86465	9.050032	2.1265	55.6028	0.0272*
Static	Fatigue	23.79848	9.050032	-2.9397	50.5366	0.1076
Static	Distilled Water	21.83456	9.050032	-4.9036	48.5727	0.1702
Static	Aging	19.63265	9.050032	-7.1055	46.3708	0.2689

Table 24: Least Squares Means Differences Tukey Test for Telio CAD Temp with Treatment as Variable

Level				Mean
Static	A			187.43277
Aging	A	B		167.80012
Distilled Water	A	B		165.59821
Fatigue	A	B		163.63429
Coffee		B		158.56812
UV Light			C	96.92015

Table 25: Analysis of Variance for Temporary CB with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	12519.021	2503.80	23.3060	0.0012
Error	54	28695.948	531.41		
C.Total	59	41214.969			

Table 26: Temporary CB Differences, Standard Error Differences, Confidence Intervals, and p-Values with Treatment as Variable.

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Static	Aging	31.17516	10.30928	0.7166	61.63376	0.0420*
Fatigue	Static	15.77256	10.30928	-14.6860	46.23116	0.6469
Static	Coffee	14.96785	10.30928	-15.4908	45.42645	0.6955
Static	UV Light	4.04033	10.30928	-26.4183	34.49893	0.9987

Table 27: Least Squares Means Differences Tukey Test for Temporary CB with Treatment as Variable

Level				Mean
Fatigue	A			143.70807
Static	A	B		127.93551
UV Light	A	B	C	123.89518
Distilled Water	A	B	C	115.28821
Coffee		B	C	112.96766
Aging			C	96.76035

Table 28: Analysis of Variance for Vita CAD Temp with Treatment as Variable

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	6370.0847	1274.02	40.6989	<0.0001
Error	54	1690.3893	31.30		
C.Total	59	8060.4740			

Table 29: Vita CAD Temp Differences, Standard Error Differences, Confidence Intervals, and p-Values with Treatment as Variable

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Static	UV Light	30.19875	2.502139	22.8062	37.59128	<.0001*
Static	Coffee	19.26085	2.502139	11.8683	26.65338	<.0001*
Static	Distilled Water	13.31769	2.502139	5.9252	20.71022	<.0001*
Static	Aging	9.73340	2.502139	2.3409	17.12593	0.0036*
Static	Fatigue	1.84400	2.502139	-5.5485	9.23653	0.9764

Table 30: Least Squares Means Differences Tukey Test for Vita CAD Temp with Treatment as Variable

Level					Mean
Static	A				105.25607
Fatigue	A				103.41207
Aging		B			95.52267
Distilled Water		B	C		91.93838
Coffee			C		85.99522
UV Light				D	75.05732

3.1.5 Microstructure SEM Analysis

The fractured disk specimens were observed under a Scanning Electron Microscope (Field Emission Variable Pressure Analytic Scanning Electron Microscope FESEM-VP- Hitachi SU6600 with Oxford Instrument AZtec X-Max 50 SDD Energy Dispersive Spectrometer, Hitachi High Tech, Oxford Instruments). The cross-sections of the fractures were evaluated for fracture patterns and the presence of any voids or defects. Figures 25 to 40 display images captured with scanning electron microscope.

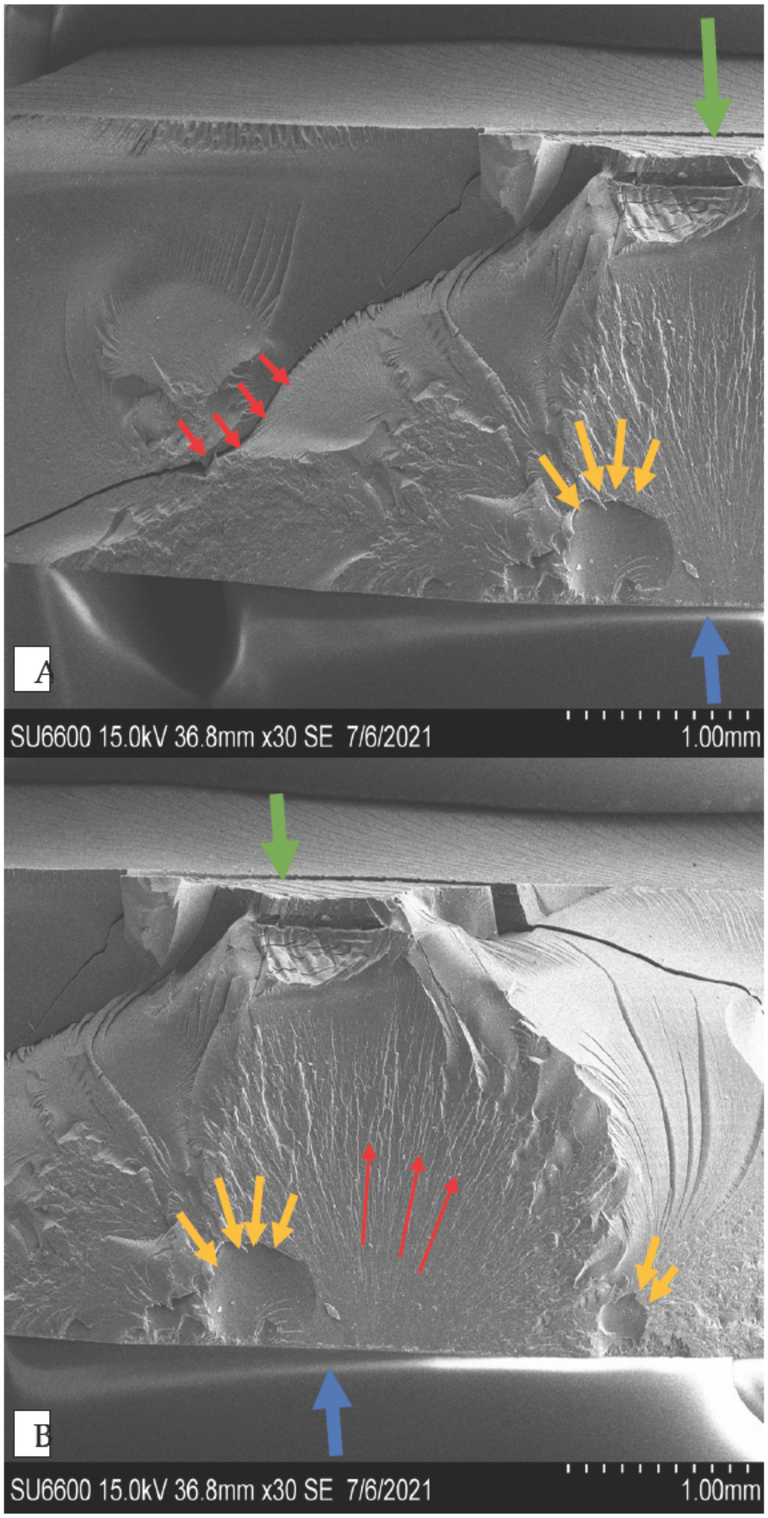


Figure 26: Scanning Electron Images of Fracture Cross-section of an untreated Dentca Disk with high Flexural Strength (222MPa).

In image A and B, the yellow lines mark the presence of a void. Image A, the red arrows show the fracture line. Image B, the yellow lines on the right point at the presence of another void. Around the void, the fracture pattern can be noted indicating that this is the origin of the fracture. Compared to Figure 32, we can see more deformation in this disk specimen. The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces. In image B, the red arrows denote the propagation of fracture.

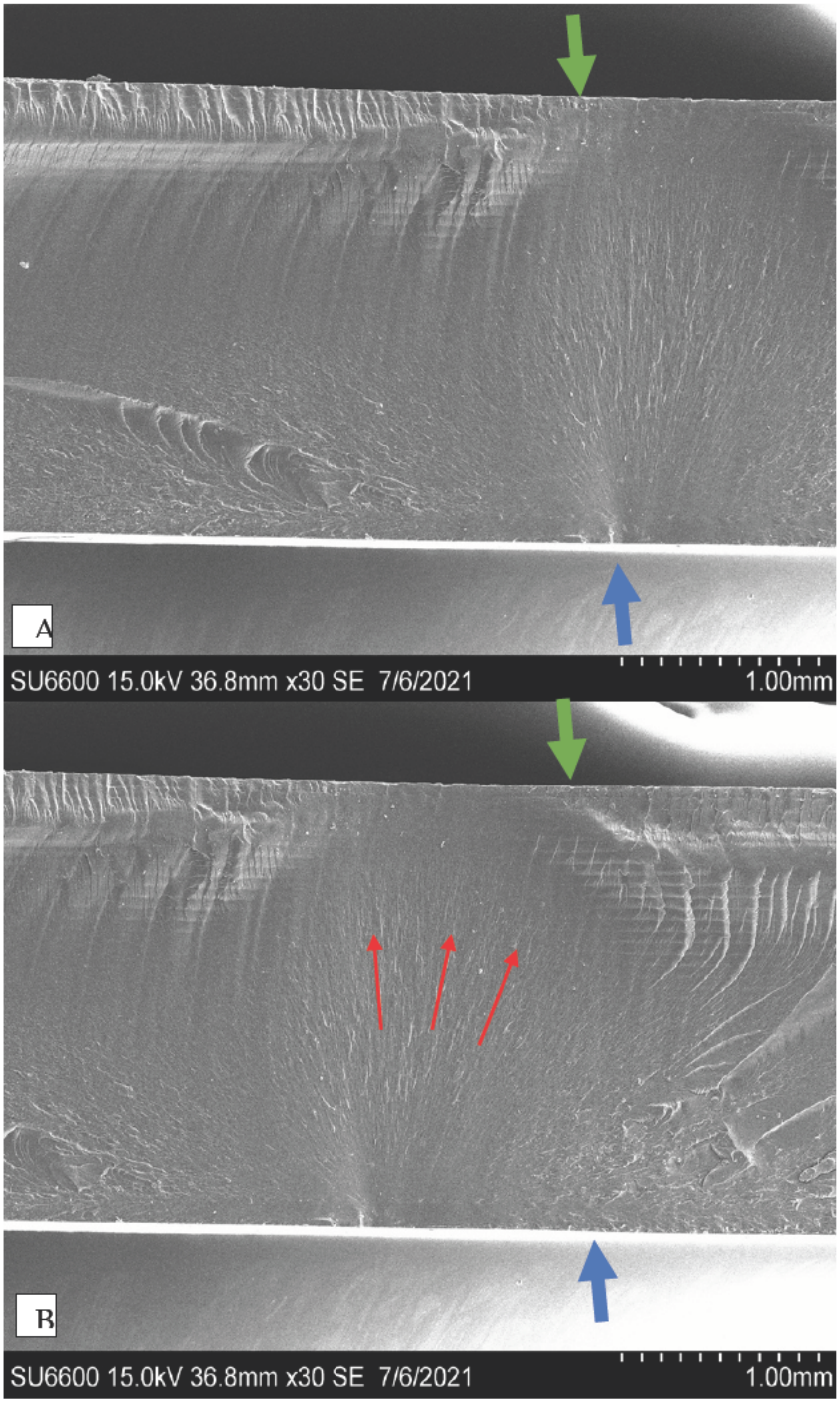


Figure 27: Scanning Electron Image of Fracture Cross-section of an untreated Dentca Disk with low Flexural Strength (94MPa).

Image A and Image B show the same disk specimen in different areas. There is less deformation compared to the disk specimen exhibited in Figure 31. The compression surface is towards the bottom of the image while the tension surface is towards the top of the image. The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces. The red arrow marks the origin of the fracture.

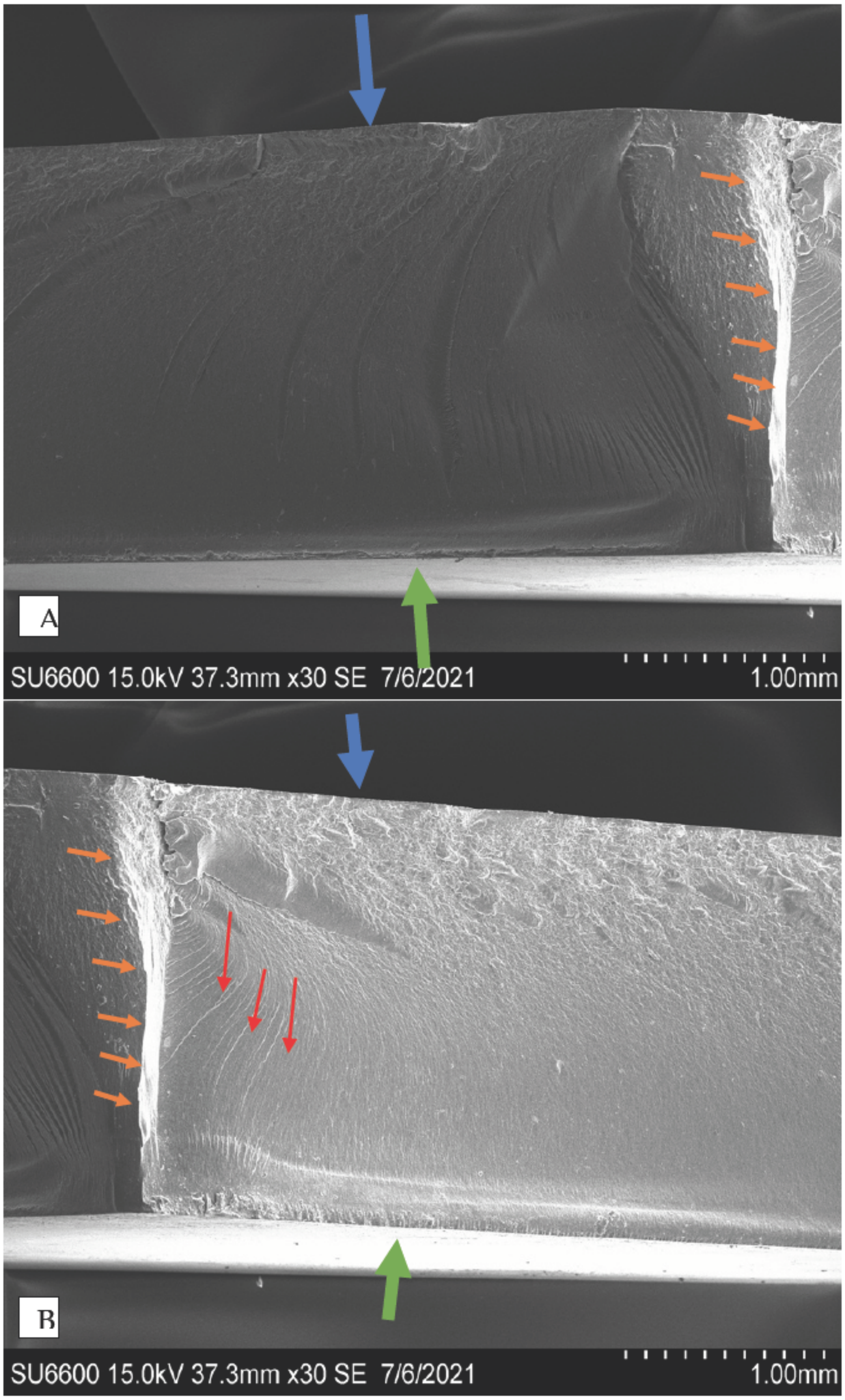


Figure 28: Scanning Electron Image of Fracture Cross-section of an untreated Bego VarseoSmile Crown Plus Disk with higher Flexural Strength (166MPa).
Image A and Image B both show the same disk but at different areas. The orange arrows point at the same fracture line. The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces. The red arrow marks the origin and propagation of fracture.

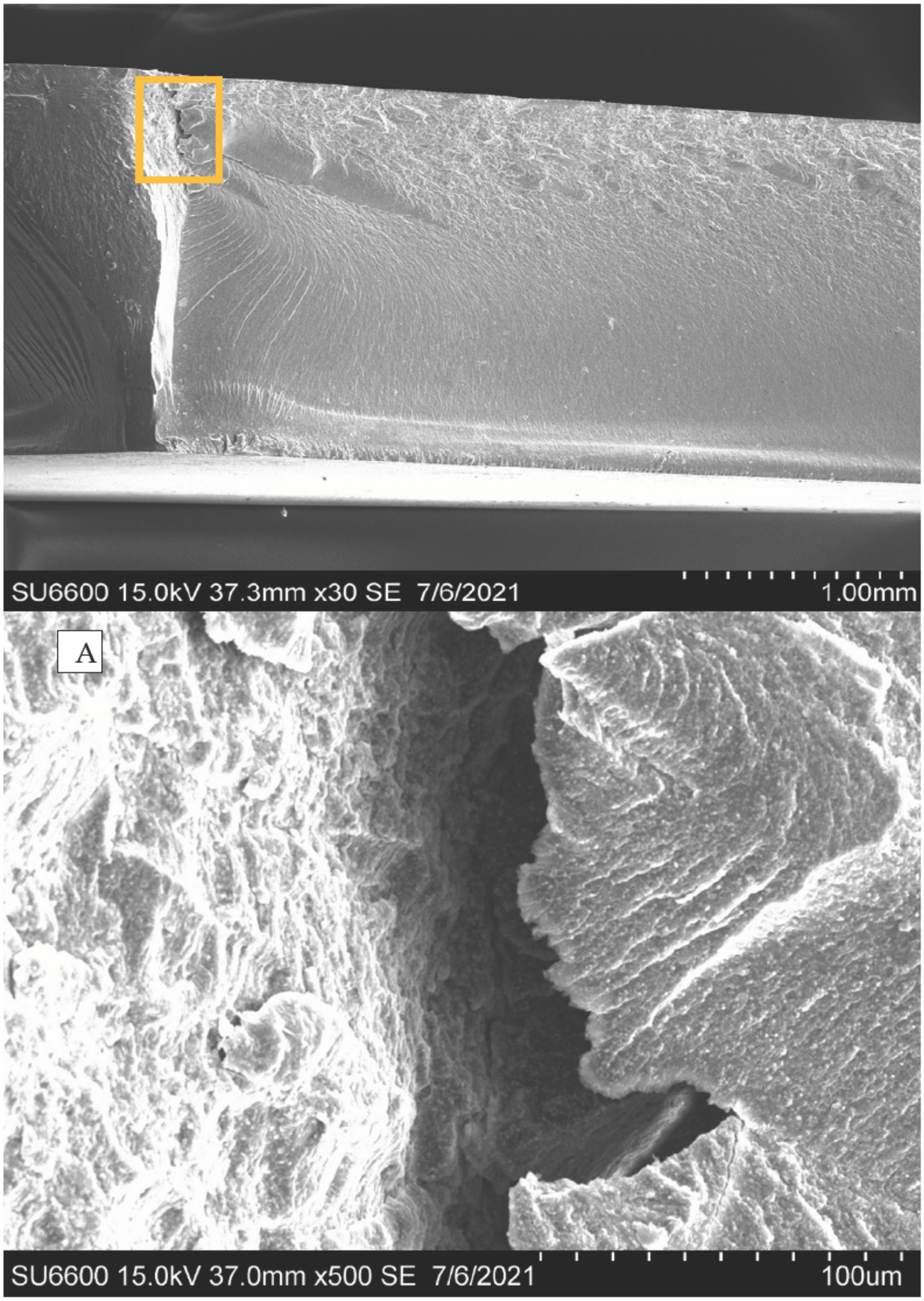


Figure 29: Scan g Electron Image of Bego VarseoSmile Crown Plus.
Image A is the same image in Figure 27. Image B is a higher magnification of the highlighted area in image A.

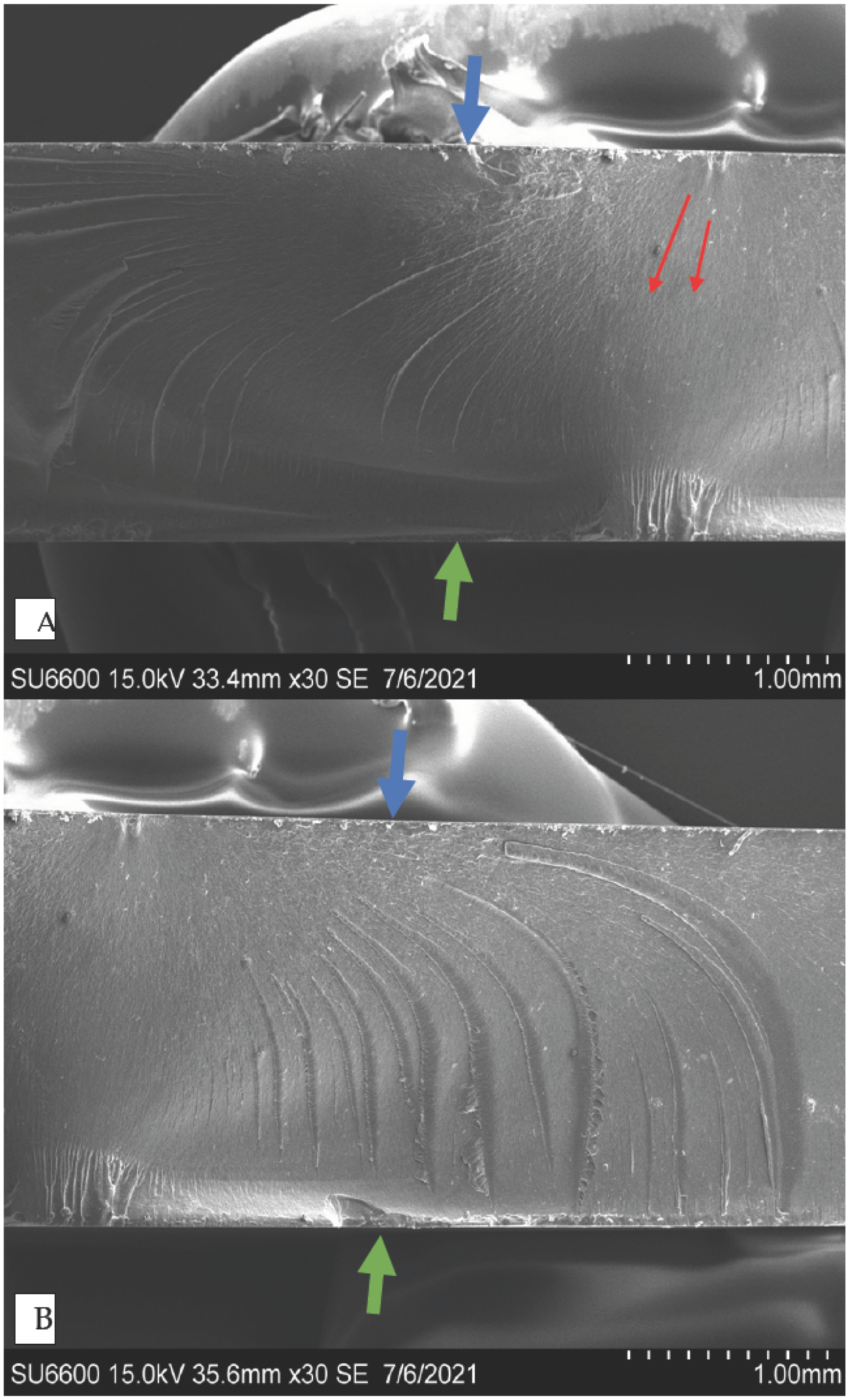


Figure 30 Scanning Electron Image of Fracture Cross-section of an untreated Bego VarseoSmile Crown Plus Disk with low Flexural Strength (79MPa).
Images A and B are of the same disk. Different fracture pattern can be noted as opposed to the disk in Figure 33. The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces.

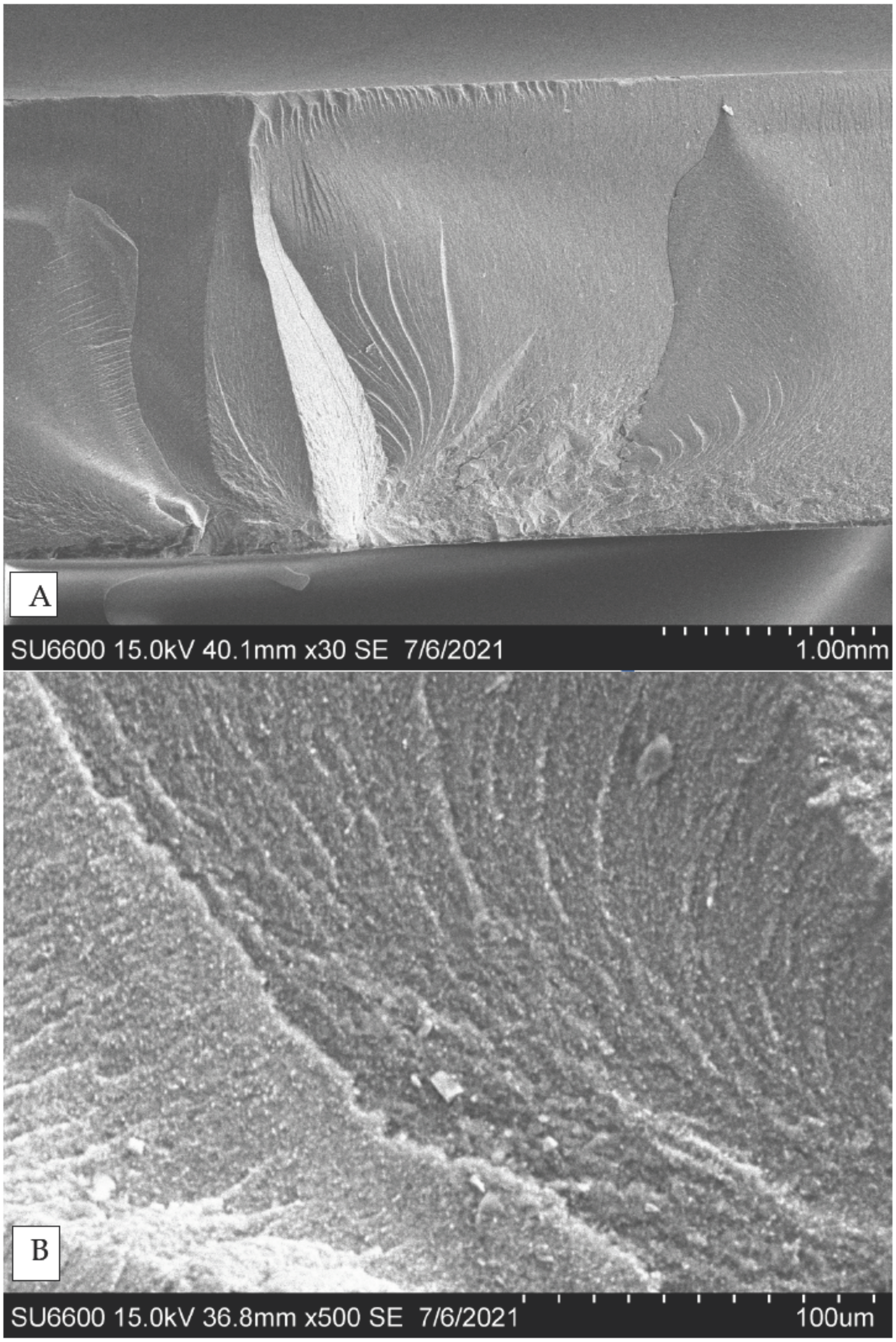


Figure 31: Image A displays a scanning electron image of a cross-section of an untreated Temporary CB disk specimen.

The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces. The red arrows mark the origin and propagation of fracture. Image B displays a higher magnification of the microstructure.

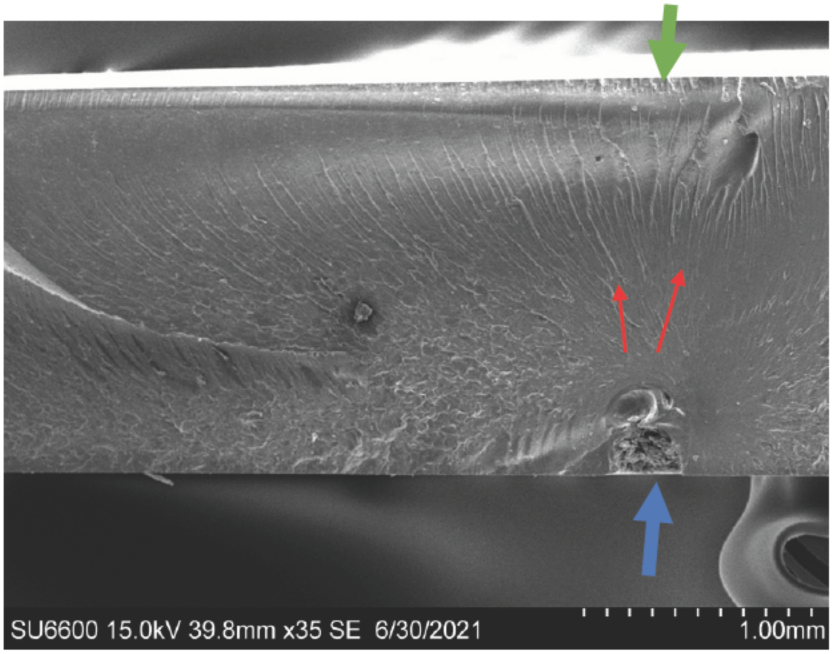


Figure 32: Scanning Electron Image of Fracture Cross-section of an untreated ProTemp Disk.
The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces

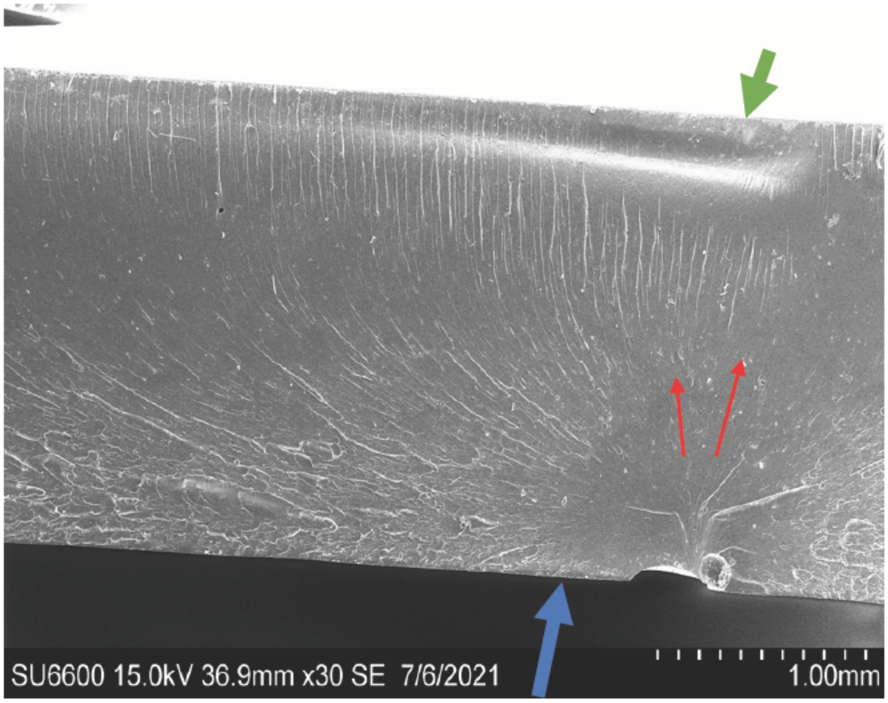


Figure 33: Scanning Electron Image of a fracture Cross-section of a ProTemp Disk after thermocycling.
The green arrows mark the tension surfaces where the blue arrows mark the compression surfaces.

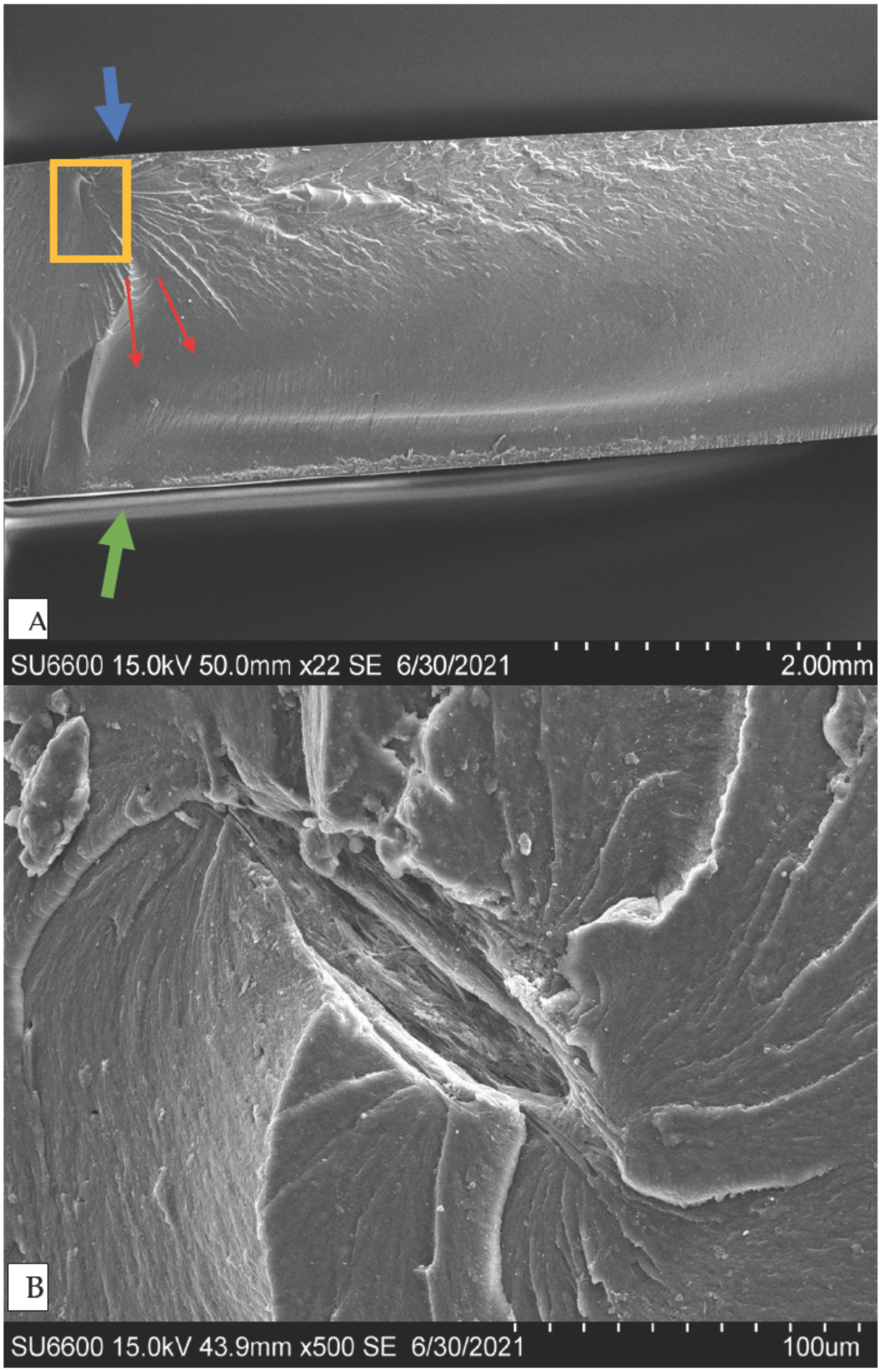


Figure 34: Scanning Electron Image of ProTemp Disk Specimen Fracture Cross Section after 15 days in Distilled Water.

The red arrow indicates the origin of the fracture. In image A, the red arrows indicates the origin of fracture. Image B shows a higher magnification of the area highlighted in yellow

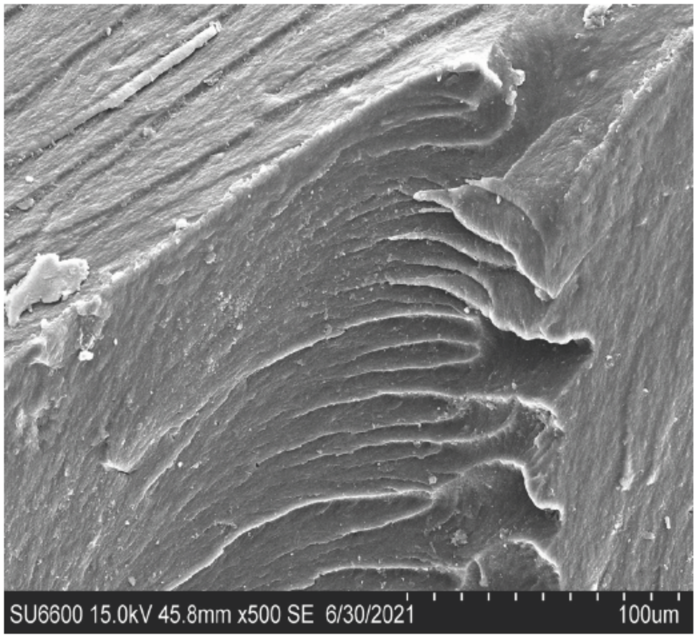


Figure 35: Scanning Electron Image of a Fatigued ProTemp Disk Specimen at 500x Magnification

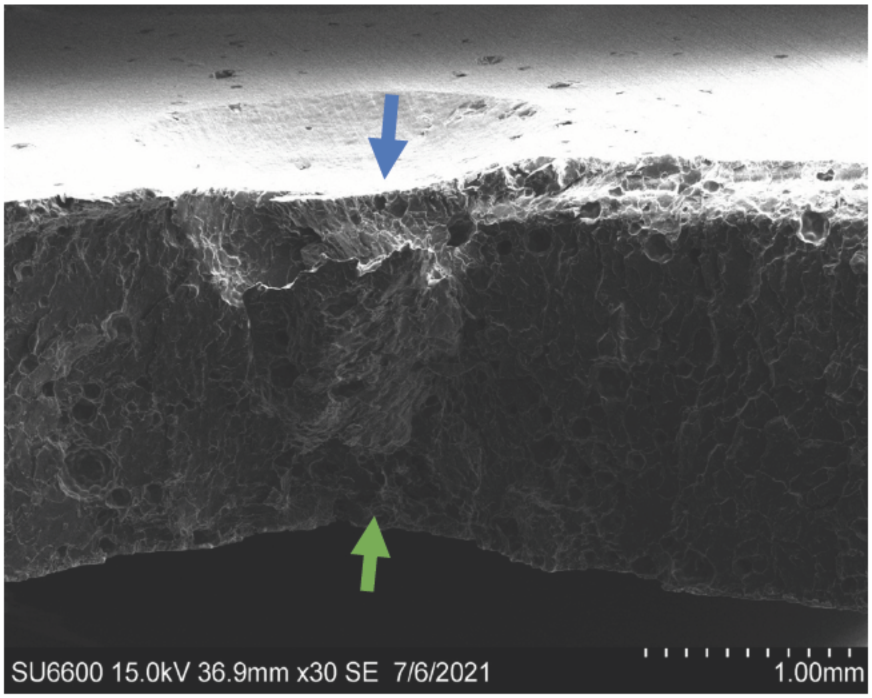


Figure 36: Scanning Electron Image of a Fracture Cross-Section of an untreated Jet Tooth Shade Disk Specimen.
Voids and pores can be noted in the cross section as well as on the surface. The indentation or compressed surface can be noted towards the top of the disk. The blue arrow indicates the compression surface while the green arrow indicates the tension surface.

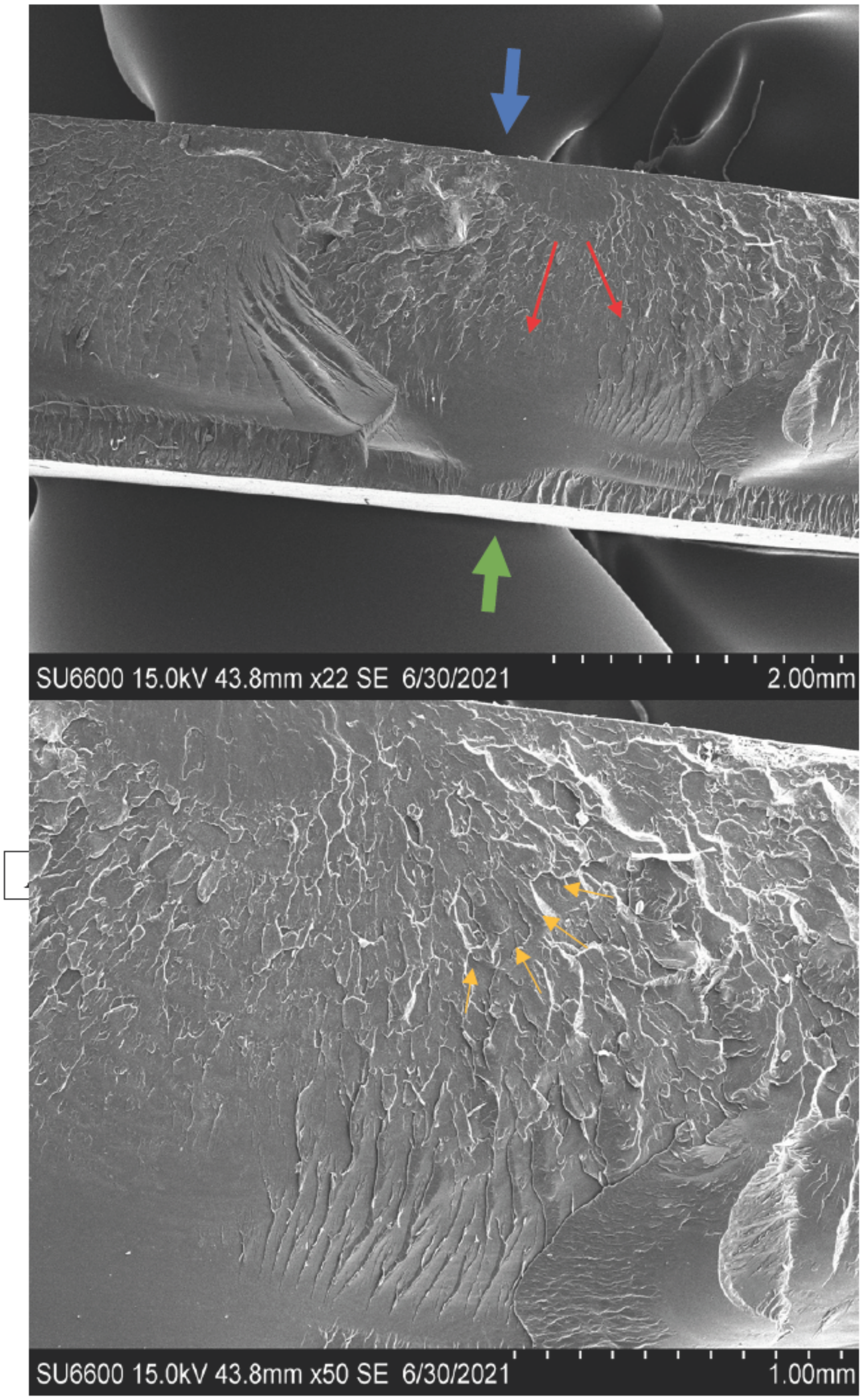


Figure 37: Scanning Electron Image of Fracture Cross-section of Non-treated Telio CAD Disk Specimen.

Image A and B are of the same disk specimen but in different magnifications. In Image A, the red arrows indicate the propagation of fracture.The green arrow indicates the tension surface while the blue arrow indicates the compression surfaace. The yellow arrows point at the plastic deformation

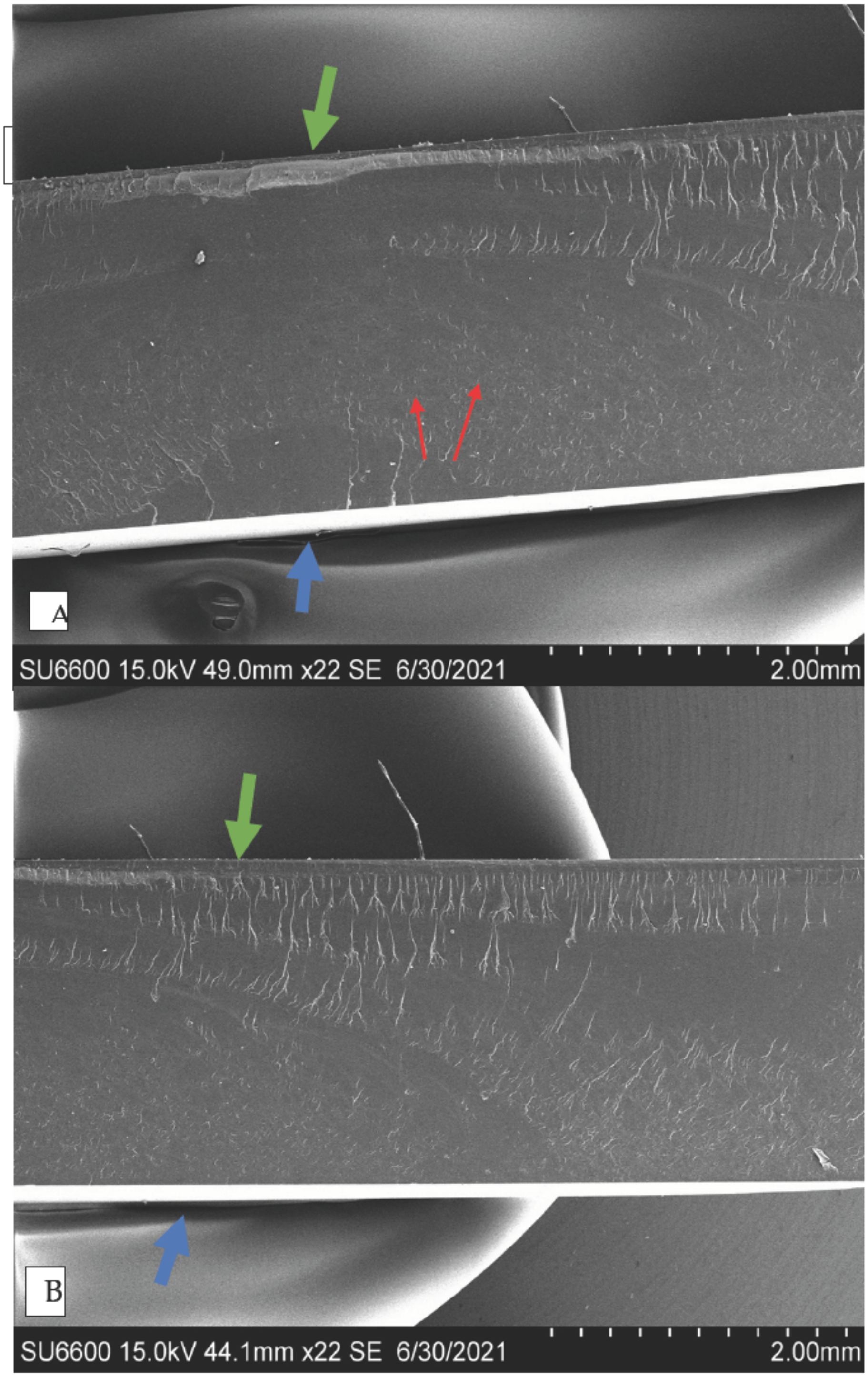


Figure 38: Scanning Electron Image of Fracture Cross-section of UV light Treated Telio CAD Disk Specimen.

Images A and are of the same disk specimen. Compared to Figure 39, there is less plastic deformation. The green arrows indicated the tension surface while the blue arrows indicated the compression surface.

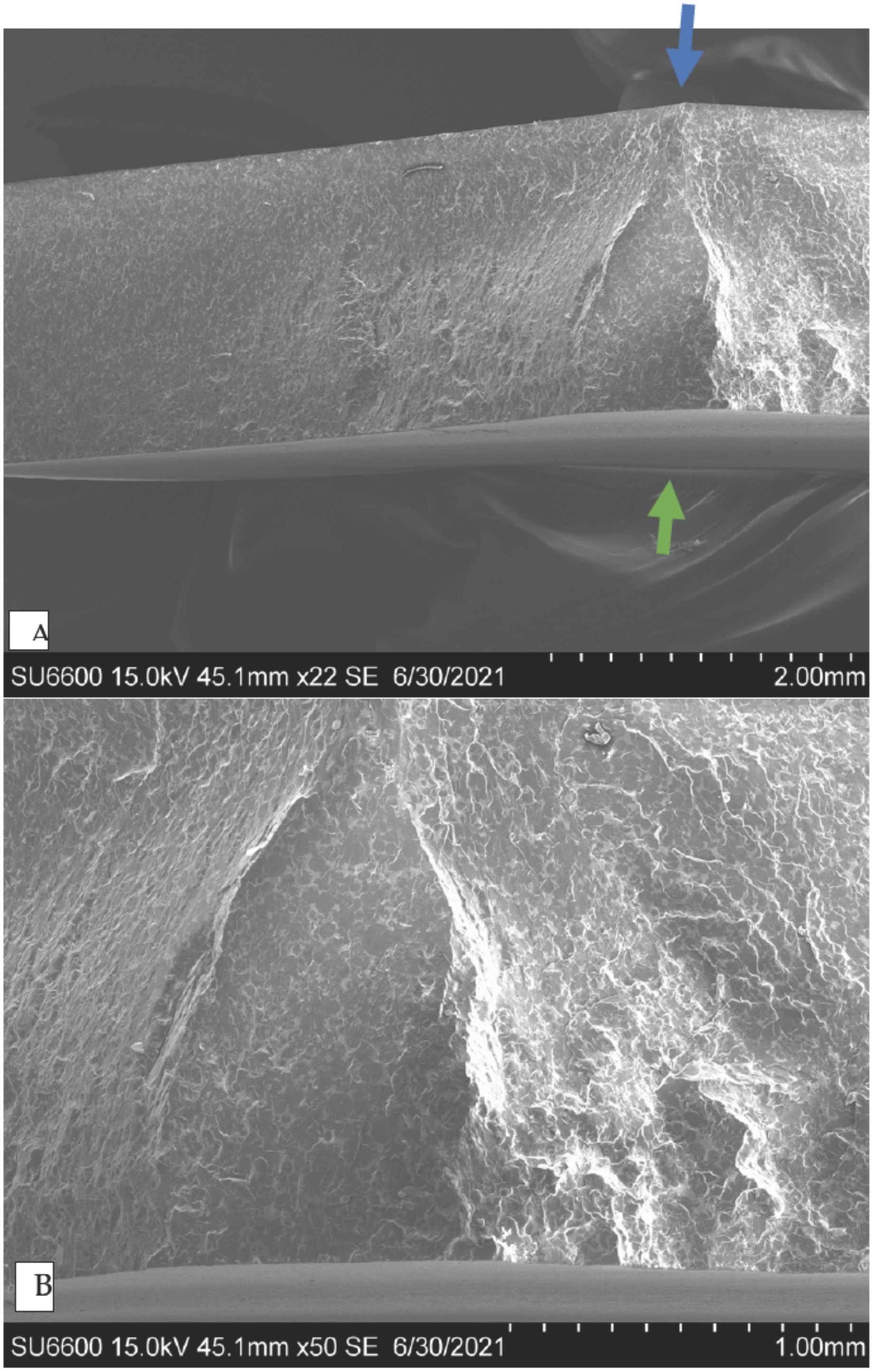


Figure 39: Scanning Electron Image Fracture Cross-section of Non-treated Vita CAD Temp Disk Specimen.
Images A and B show the same disk specimen at different magnifications. In Image A, the blue arrow indicates the compression surface while the green arrow indicates the tension surface.

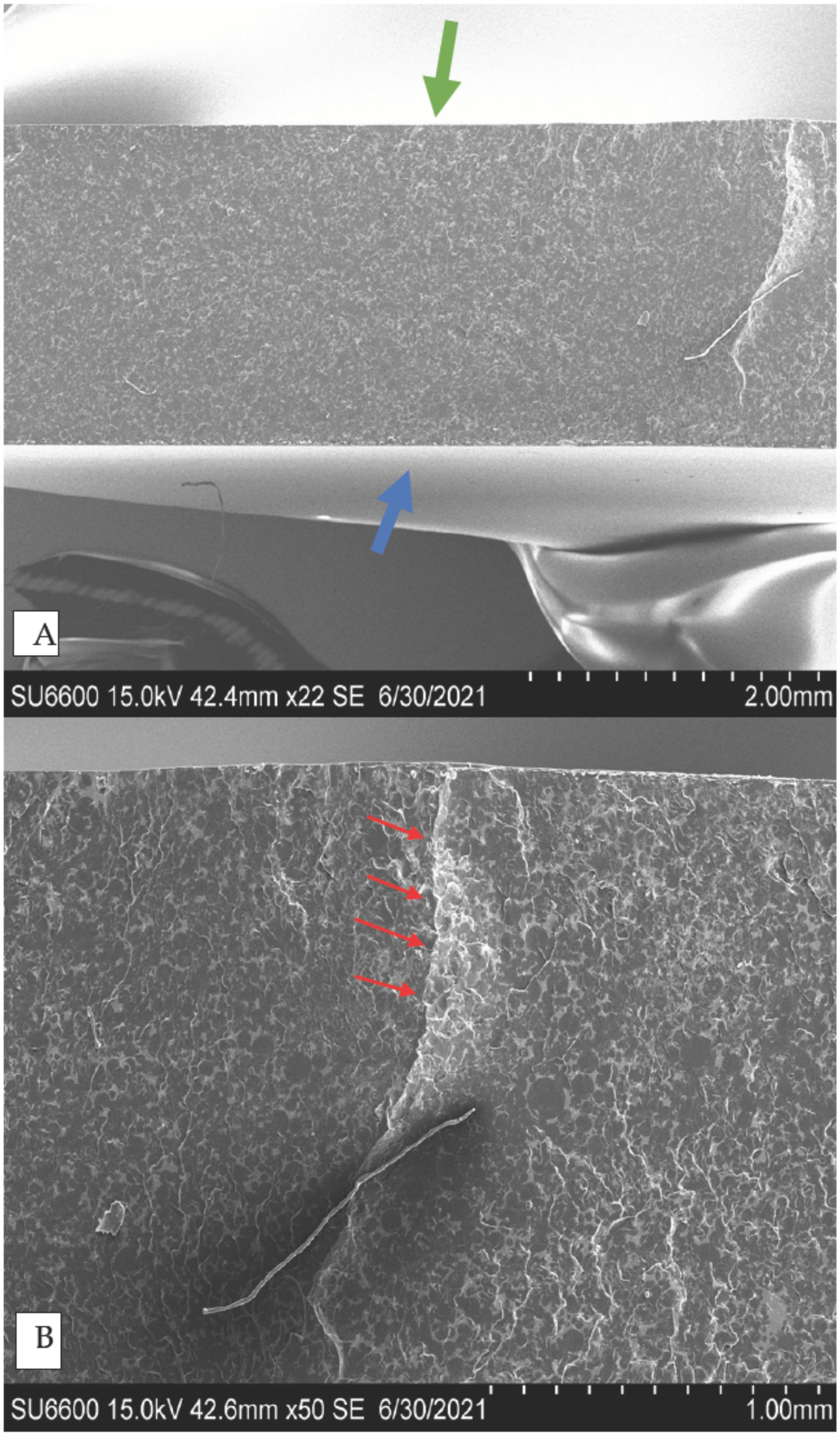


Figure 40: Scanning Electron Image of a Fracture Cross-section of UV light treated Vita CAD Temp Disk Specimen.

Images A and B show the same disk specimen at different magnifications. In Image A, the blue arrow indicates the compression surface while the green arrow indicates the tension surface.

3.2 Color Difference (ΔE*)

Color differences and the effect of different treatments collectively on all the polymers were statistically analyzed. The performance of each material relative to one another was also be assessed in terms of color stability. A summary of all findings is illustrated in Figure 41 where each bar represents ΔE* of each material under each treatment separately. ANOVA (Analysis of Variance) was done and the results are displayed in Table 31. An analysis of variance demonstrated in Table 29 shows that a statistically significant difference exists between the overall color difference of the different materials and treatments with a p value of less than 0.0001. Both, the material and treatment were significant as shown in the effects test summarized in Table 32. Table 33 shows that the treatment variable had the highest effect with a LogWorth of 28.00, which indicates that treatment was the dominant effect on color change.

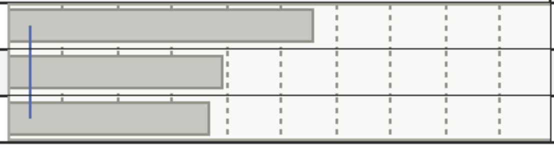
Table 31: Analysis of Variance for Overall Color Difference ΔE^*

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	27	1013.8470	37.5499	17.4564	<0.0001
Error	252	542.0704	2.1511		
C.Total	279	1555.9174			

Table 32: Effects Tests for Overall Color Differences (ΔE^*) that displays both material and treatment as significant interactions

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Material	6	6	259.10425	20.0756	<.0001*
Treatment	3	3	377.88825	58.5581	<.0001*
Material*Treatment	18	18	376.85451	9.7330	<.0001*

Table 33: Variables Effects on Overall Color Difference Values (ΔE^*)

Source	LogWorth		PValue
Treatment	28.031		0.00000
Material*Treatment	19.620		0.00000
Material	18.435		0.00000

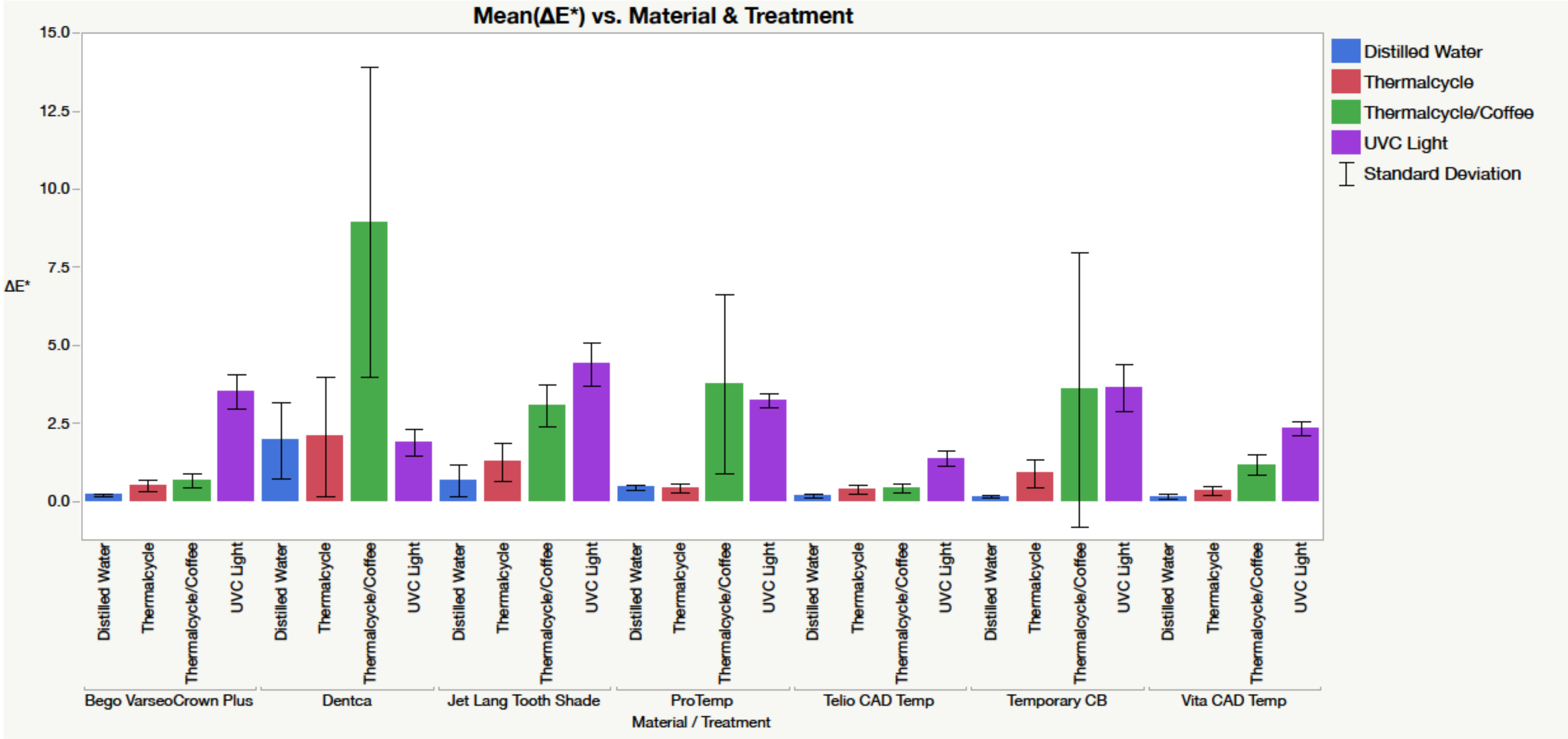


Figure 41: Graph with Color Difference (ΔE*) of Each Material and Treatments

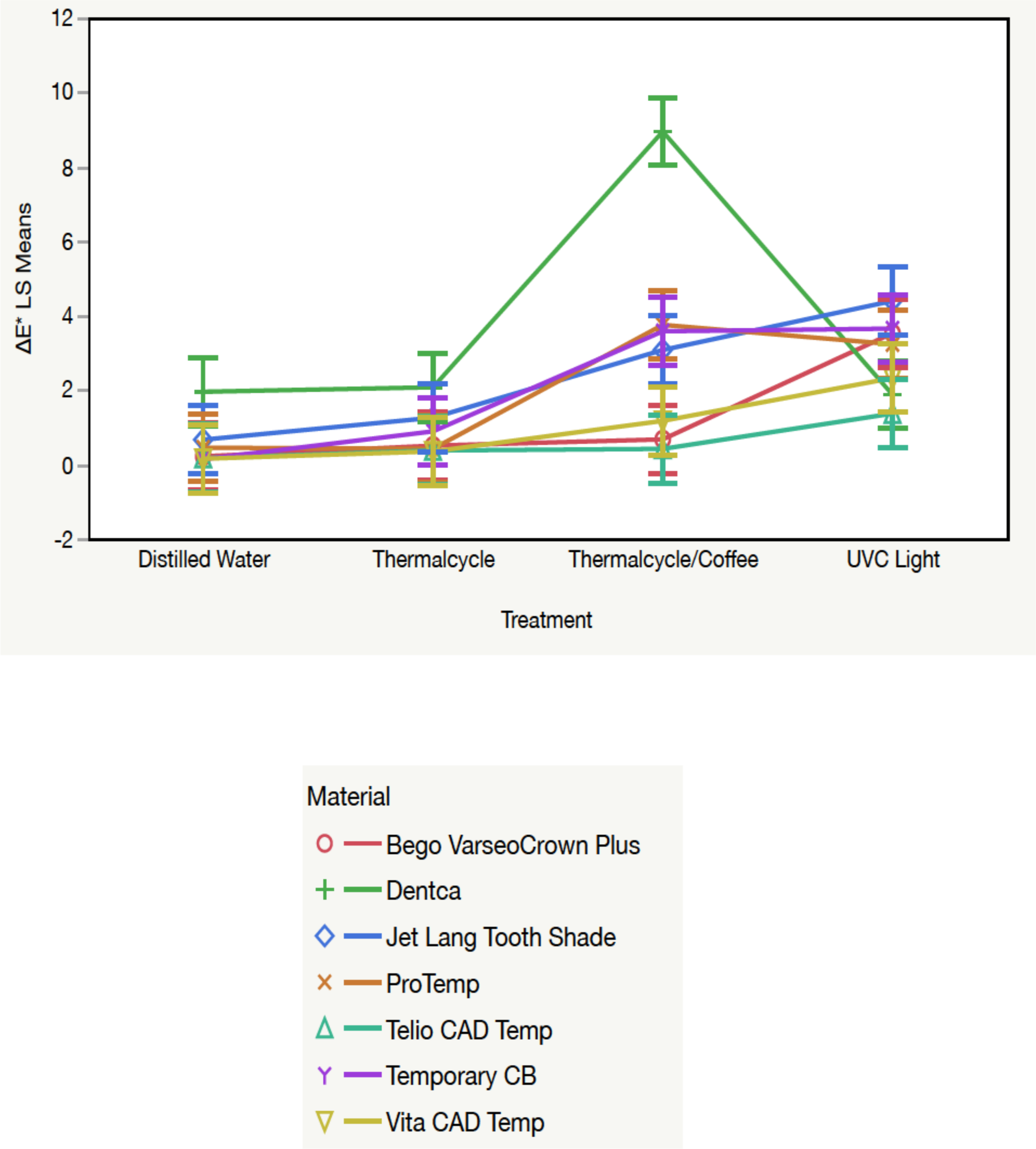


Figure 42: Plot Graph of Color Differences (ΔE^{*}) of Each Material vs. Treatment

3.2.1 Effect of Material Type on Color Difference

A statistical analysis was done to determine any significant differences in color amongst the different polymers across all treatments. The Least Squares Means of Color Difference (ΔE*) are listed in Table 34, along with standard errors and means. Table 35 lists the results of the Least Square Means Difference Tukey HSD test in terms of color stability presented in ΔE* values. Table 36 lists differences, standard error differences, confidence intervals, and p-values for color differences (ΔE*). Dentca demonstrated significantly higher color differences than Telio CAD Temp (p-value < 0.0001), Vita CAD Temp (p-value < 0.0001), Bego VarseoSmile Crown Plus ((p-value < 0.0001), ProTemp (p-value < 0.0001), Temporary CB (p-value < 0.0001), and Jet Tooth Shade (p-value = 0.0009).

Jet Tooth Shade has a statistically significantly higher color difference than Bego VarseoSmile Crown Plus (p-value=0.0013), Vita CAD Temp (p-value= 0.001), and Telio CAD Temp (p-value < 0.0001).

Temporary CB has a significantly higher color difference than Telio CAD Temp (p-value = 0.0002) and Vita CAD Temp (p-value = 0.0223) and significantly lower only than Dentca (p-value < 0.0001).

ProTemp only has a significantly higher color difference than Telio CAD Temp (p-value = 0.0007) and significantly lower only than Dentca (p-value < 0.0001).

Bego VarseoSmile Crown Plus has no significantly higher color differences than any material. However, Bego VarseoSmile Crown Plus did have significantly lower color differences than Dentca (p-value < 0.0001) and Jet Tooth Shade (p-value = 0.0134)

Vita CAD Temp demonstrated significantly lower color differences than Dentca (p-value < 0.0001), Temporary CB (p-value = 0.0223), and Jet Tooth Shade (p-value = 0.001). No other statistically significant differences were found.

Telio CAD Temp showed the least color difference and is significantly lower than Dentca (p-value < 0.0001), Jet Tooth Shade (p-value < 0.0001), Temporary CB (p-value = 0.0002) and ProTemp (p-value = 0.0007).

Table 34: Least Squares Means of Color Differences ($\Delta E^{\cdot}$) of all Polymers with Material as Variable

Level	Least Sq Mean	Std Error	Mean
Bego VarseoSmile Crown Plus	1.2291257	0.23189830	1.22
Dentca	3.7087647	0.23189830	3.70
Jet Tooth Shade	2.3458170	0.23189830	2.34
ProTemp	1.9612057	0.23189830	1.96
Telio CAD Temp	0.5819613	0.23189830	0.58
Temporary CB	2.0621452	0.23189830	2.06
Vita CAD Temp	0.9976153	0.23189830	0.99

Table 35: Color Differences ($\Delta E^{*\cdot}$) LS Means Difference Tukey HSD with Material as Variable

Level						Least Sq Mean (ΔE^{*})
Dentca	A					3.70
Jet Tooth Shade		B				2.35
Temporary CB		B	C			2.06
ProTemp		B	C	D		1.96
Bego VarseoCrown Plus			C	D	E	1.23
Vita CAD Temp				D	E	0.99
Telio CAD Temp					E	0.58

*Letters not connected by the same letter are significantly different

Table 36: Differences, Standard Error Differences, Confidence Intervals, and p-Values with Material as Variable for Color Differences (ΔE^*)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Dentca	Telio CAD Temp	3.126803	0.3279537	2.15202	4.101588	<.0001*
Dentca	Vita CAD Temp	2.711149	0.3279537	1.73637	3.685934	<.0001*
Dentca	Bego VarseoSmile Crown Plus	2.479639	0.3279537	1.50485	3.454423	<.0001*
Jet Lang Tooth Shade	Telio CAD Temp	1.763856	0.3279537	0.78907	2.738640	<.0001*
Dentca	ProTemp	1.747559	0.3279537	0.77277	2.722343	<.0001*
Dentca	Temporary CB	1.646620	0.3279537	0.67184	2.621404	<.0001*
Temporary CB	Telio CAD Temp	1.480184	0.3279537	0.50540	2.454968	0.0002*
ProTemp	Telio CAD Temp	1.379244	0.3279537	0.40446	2.354029	0.0007*
Dentca	Jet Lang Tooth Shade	1.362948	0.3279537	0.38816	2.337732	0.0009*
Jet Lang Tooth Shade	Vita CAD Temp	1.348202	0.3279537	0.37342	2.322986	0.0010*
Jet Lang Tooth Shade	Bego VarseoSmile Crown Plus	1.116691	0.3279537	0.14191	2.091475	0.0134*
Temporary CB	Vita CAD Temp	1.064530	0.3279537	0.08975	2.039314	0.0223*
ProTemp	Vita CAD Temp	0.963590	0.3279537	-0.01119	1.938375	0.0550

Temporary CB	Bego VarseoSmile Crown Plus	0.833019	0.3279537	-0.14176	1.807804	0.1497
ProTemp	Bego VarseoSmile Crown Plus	0.732080	0.3279537	-0.24270	1.706864	0.2821
Bego VarseoSmile Crown Plus	Telio CAD Temp	0.647164	0.3279537	-0.32762	1.621949	0.4343
Vita CAD Temp	Telio CAD Temp	0.415654	0.3279537	-0.55913	1.390438	0.8661
Jet Lang Tooth Shade	ProTemp	0.384611	0.3279537	-0.59017	1.359395	0.9038
Jet Lang Tooth Shade	Temporary CB	0.283672	0.3279537	-0.69111	1.258456	0.9773
Bego VarseoSmile Crown Plus	Vita CAD Temp	0.231510	0.3279537	-0.74327	1.206295	0.9922
Temporary CB	ProTemp	0.100939	0.3279537	-0.87384	1.075724	0.9999

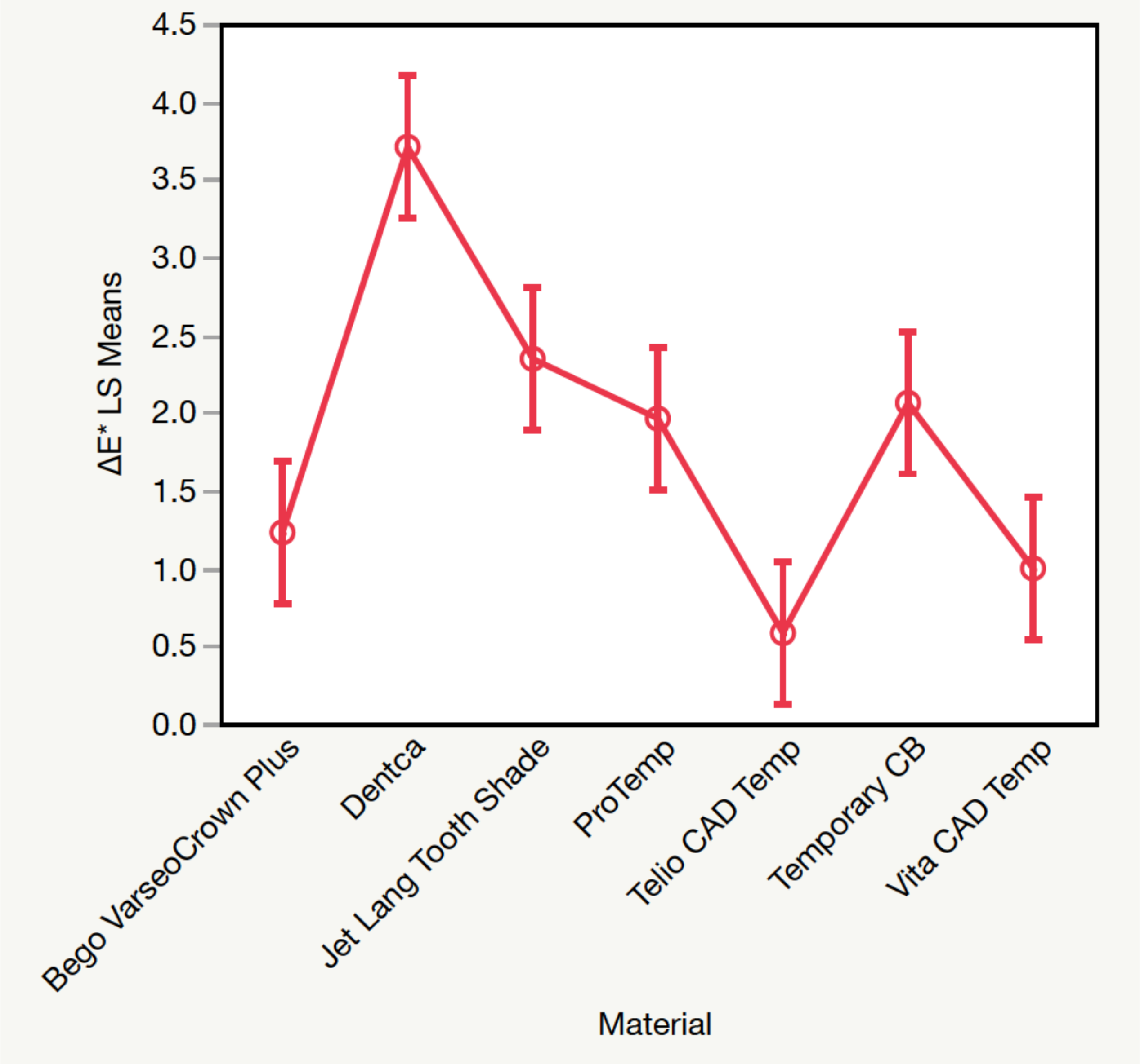


Figure 43: Plot of Color Difference (ΔE^*) with Material as Variable

3.2.2 Effect of Treatment on Color Difference

A statistical analysis was done to evaluate if any of the treatments had a significant effect on color difference (ΔE^*) of all polymers collectively. A plot graph shown in Figure 44 demonstrates that UV light along with Thermocycling/Coffee Treatments had the highest color differences. This is confirmed with a Tukey HSD test that shows both treatments (p-value < 0.0001) had a statistically significant effect on color difference compared with the treatments of thermal-cycling and distilled water. This can be visualized Table 37 and Table 38. Table 36 lists the differences, standard error differences, confidence intervals and p-values.

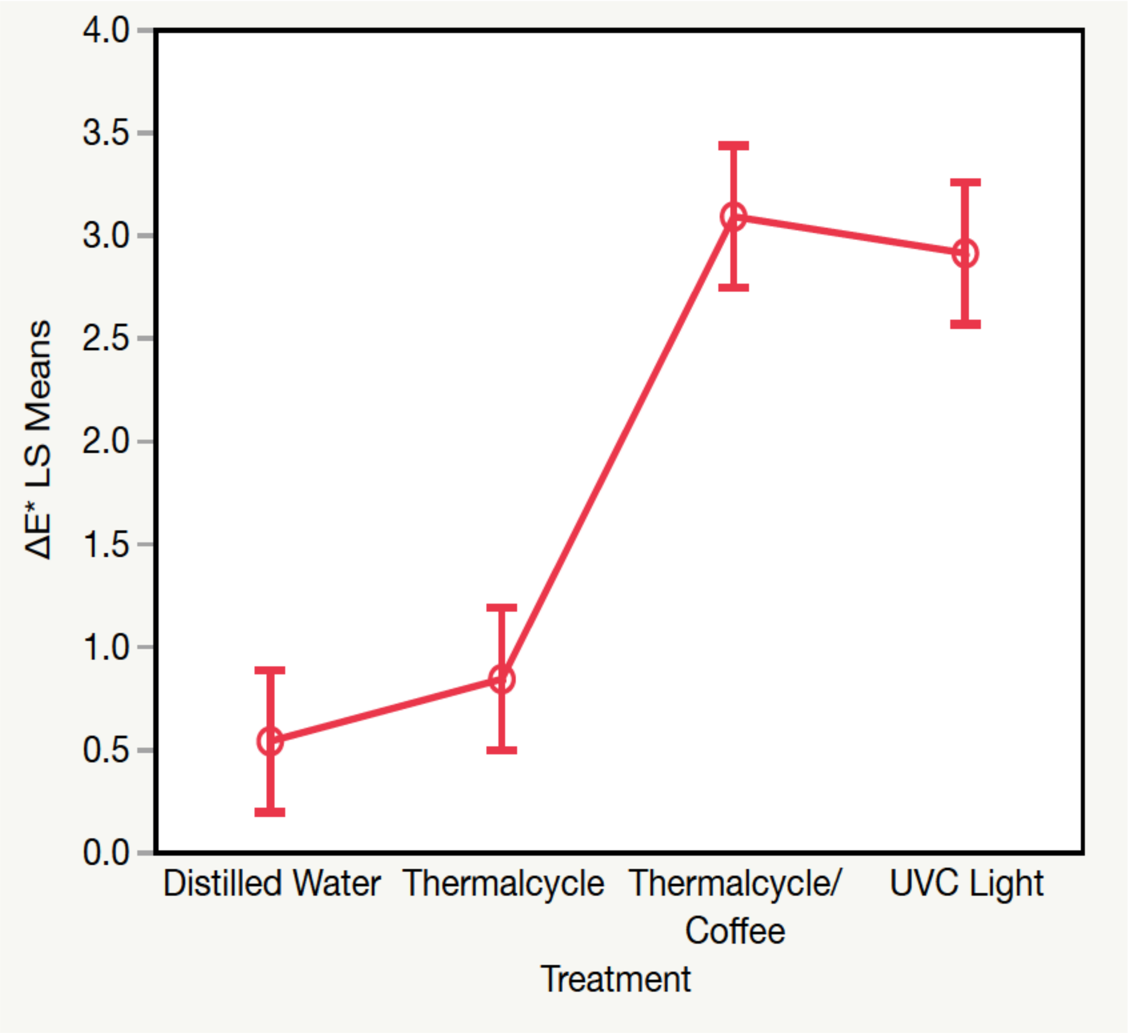


Figure 44: Plot Graph of Color Difference (ΔE*) for Different Treatments

Table 37: Color Differences ($\Delta E^{\cdot}$) LS Means Difference Tukey HSD by Treatment

Level			**Least Sq Mean (ΔE)**
Thermalcycle/Coffee	A		3.09
UVC Light	A		2.91
Thermalcycle		B	0.84
Distilled Water		B	0.53

Table 38: Differences, Standard Error Differences, Confidence Intervals, and p-Values with Treatment as Variable for Color Differences (ΔE*)

Level	**- Level**	**Difference (ΔE)**	**Std Err Dif**	**Lower CL**	**Upper CL**	**p-Value**
Thermalcycle/Coffee	Distilled Water	2.550397	0.3492122	1.64776	3.453032	<.0001*
UVC Light	Distilled Water	2.372303	0.3492122	1.46967	3.274938	<.0001*
Thermalcycle	Distilled Water	0.302385	0.3492122	-0.60025	1.205021	0.8224

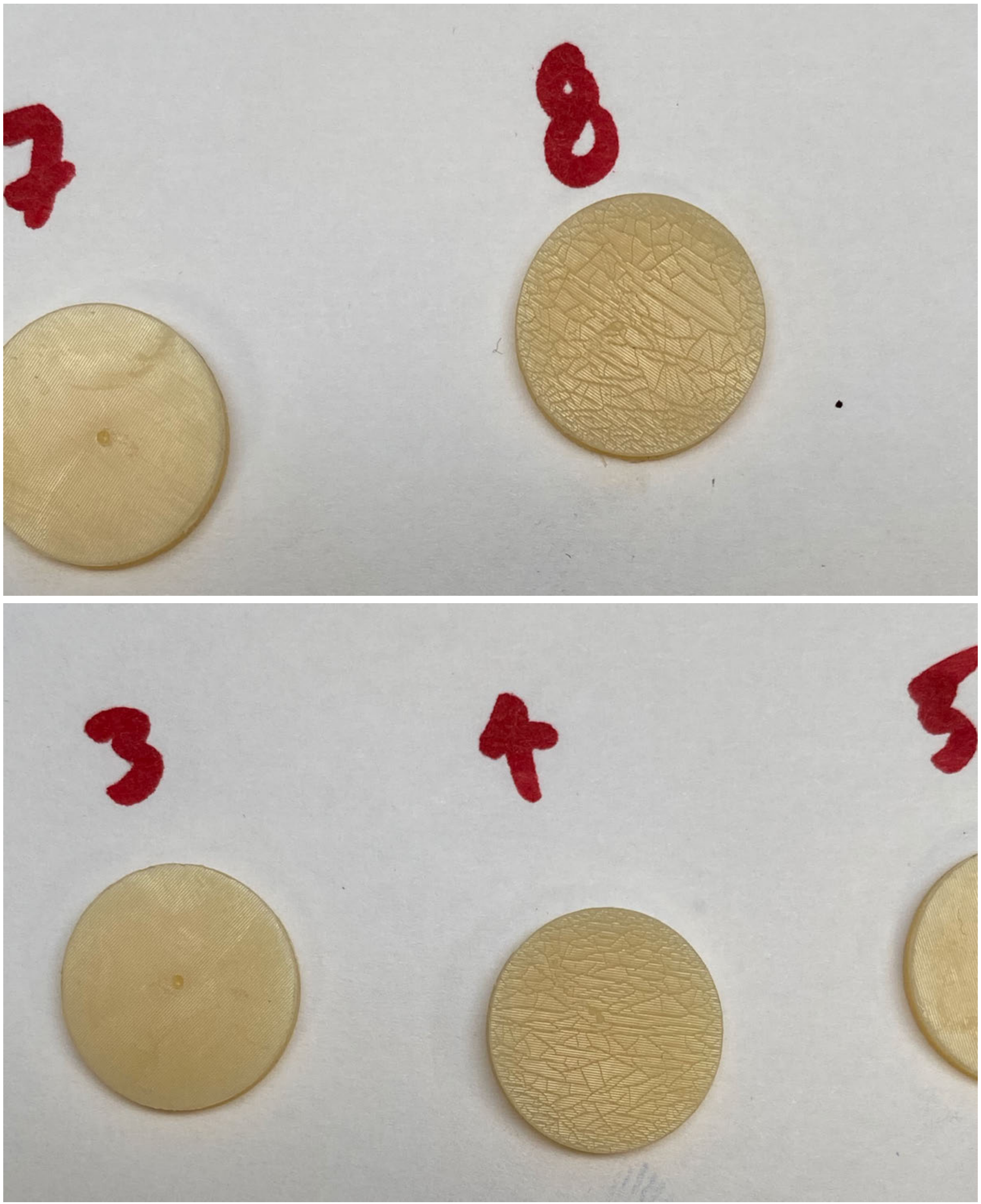


Figure 45: Dentca Disk Specimens Post Thermocycling, with surface artifacts. Disks numbered 4 and 8 both developed the same artifacts while 3, 5 and 7 are void of any artifacts.

3.2.3 Effect of Material and Treatment on Color Difference (ΔE*)

A two-way ANOVA was done to demonstrate a significantly different pattern of the effect by post-treatment for the different materials on color difference. Figure 38 displays the least square means plot of color difference with both treatment and material as variables. Figure 43 displays the least squares mean differences Tukey Test for material and treatment interaction on color difference (ΔE*).

Table 39: Least Squares Means Differences Tukey Test for Material and Treatment Interaction on Color Difference (ΔE*)

Level									Least Sq Mean
Dentca,Thermalcycle/Coffee	A								8.9397008
Jet Lang Tooth Shade,UVC Light		B							4.3906001
ProTemp,Thermalcycle/Coffee		B	C						3.7475833
Temporary CB,UVC Light		B	C	D					3.6470081
Temporary CB,Thermalcycle/Coffee		B	C	D	E				3.5753121
Bego VarseoSmile Crown Plus,UVC Light		B	C	D	E				3.5239615
ProTemp,UVC Light		B	C	D	E	F			3.2297499
Jet Tooth Shade,Thermalcycle/Coffee		B	C	D	E	F	G		3.0734558
Vita CAD Temp,UVC Light		B	C	D	E	F	G	H	2.3195793
Dentca,Thermalcycle		B	C	D	E	F	G	H	2.0716005
Dentca,Distilled Water		B	C	D	E	F	G	H	1.9515881
Dentca,UVC Light			C	D	E	F	G	H	1.8721696
Telio CAD Temp,UVC Light			C	D	E	F	G	H	1.3657868

Jet Tooth Shade,Thermalcycle				D	E	F	G	H	1.2548953
Vita CAD Temp,Thermalcycle/Coffee					E	F	G	H	1.1696133
Temporary CB,Thermalcycle						F	G	H	0.8877052
Bego VarseoSmile Crown Plus,Thermalcycle/Coffee							G	H	0.6726084
Jet Tooth Shade,Distilled Water							G	H	0.6643169
Bego VarseoSmile Crown Plus,Thermalcycle								H	0.5038277
ProTemp,Distilled Water								H	0.4485792
ProTemp,Thermalcycle								H	0.4189106
Telio CAD Temp,Thermalcycle/Coffee								H	0.4172414
Telio CAD Temp,Thermalcycle								H	0.3741153
Vita CAD Temp,Thermalcycle								H	0.3483782
Bego VarseoSmile Crown Plus,Distilled Water								H	0.2161052
Telio CAD Temp,Distilled Water								H	0.1707018
Vita CAD Temp,Distilled Water								H	0.1528903
Temporary CB,Distilled Water								H	0.1385552

Chapter 4: Discussion

With the advent of the digital revolution in all industries, scientists have searched for ways to standardize production and quality. The dental field is no exception where conventional methods of manufacturing are being rapidly replaced by both subtractive and additive technologies. These digital methods of manufacturing have given rise for experimentation with new materials. A substantial amount of effort has been given to polymers. These polymers have been put to use in removable dentures, occlusal guards, surgical stents, provisional restorations and even definitive restorations. This study aimed at evaluating the performances of these materials in terms of flexural strengths and color stability after subjecting them to different materials.

However, it should be noted that color differences have a subjective component. In addition, the (ΔE^*) value for threshold for perceptible color difference (ΔE^*) should be established. Controversy and disagreement still exist in the dental community regarding the (ΔE^*) thresholds for perceptible and unacceptable color differences. In a study by Johnston and Kao (16), the mean perceptibility threshold for (ΔE^*) was found to be 3.7. In another study by Douglas et al. (17), it was concluded that fifty percent of dental practitioners could detect a color difference (ΔE^*) value of 2.6 and would remake a restoration if the color difference (ΔE^*) was 5.6.

4.1 Machinable Materials

The null hypothesis stated earlier was that there is no significant difference in terms of flexural strength or color stability between the conventional, machinable and printed dental polymers. The statistical analysis has found a significant difference so that the null hypothesis is rejected.

However, in terms of dental polymers, the mode of fabrication and the material itself are both variables when it comes to evaluating mechanical properties. This can be seen in the difference between Telio CAD Temp and Vita CAD Temp. Telio CAD Temp has out-performed all materials in the overall flexural strength tests with the exception of ProTemp. Telio CAD Temp was only significantly affected by UV light treatment unlike ProTemp that was significantly affected by distilled water, fatigue, and aging. If UV light treatment was taken out of equation, Telio CAD Temp would probably have performed and registered statistically significantly higher values than ProTemp. UV light and its effect on certain polymers is discussed later in this chapter.

Vita CAD Temp on the other hand was only significantly stronger than Jet Tooth Shade and weaker than the rest of the polymers in the study. Furthermore, Vita CAD Temp was also susceptible to all treatments with the exception of fatigue. Both Telio CAD Temp and Vita CAD Temp are machinable blocks but the materials are different. Telio CAD Temp is a block composed of 99% crosslinked polymethyl and less than 1% in pigments. Vita CAD Temp is a composite block that consists of microfiller filled polyacrylic network. The microfiller is silicon dioxide that provides additional crosslinking for the chains which translates to enhanced mechanical properties. The quality of the bond between filler and the matrix also determines the performance of the material post-treatment. If the quality of the bond is poor, any treatment may cause the bonds to break and hence lead to diminished flexural strength. Furthermore, Vita CAD Temp contains vinyl groups in the polymer, which are two double bonded carbon atoms. This makes it reactive and hence may explain the reasons for lower strengths (14). This perhaps is the explanation why Vita CAD Temp is the most susceptible to the different treatments.

In terms of color stability, both Telio CAD Temp and Vita CAD Temp outperformed the other materials. Both have a color difference value (ΔE) of less than 1. This may be due to the fact that these materials are polymerized under pressurized and standardized conditions. This means that there is likely decreased residual monomer and hence less monomer to react to foreign substances and possible produce color change.

With color stability and flexural strength tests, the machinable materials produced the least coefficients of variation. Therefore, the processing conditions of the machinable blocks may result in a more reliable and reproducible product unlike the additively manufactured polymers that demonstrated a large coefficient of variation in both color stability and flexural strengths.

4.3 Additive Manufacturing and Standardization

The polymers produced via additive manufacturing displayed the highest coefficient of variance. The highest coefficient of variance is seen especially with the Dentca disk specimens printed via Carbon 3D printer as seen in Table 4. In addition, the disk specimens behaved differently after thermocycling where only three disks showed the same artifacts that represent small cracks on the surface. This can be seen in Figure 45. Additionally, these three disks also fractured at below 50 MPa. The rest of the disk specimens demonstrated great variation where one disk fractured at 190 MPa, even after thermocycling. The summary of Dentca's flexural strength values and fractured pieces is shown in Table 8.

Additionally, the fracture cross-section was analyzed for the different disk specimens that broke at these different values during the static flexural strength tests. Figure 26 is a scanning electron image of a fracture cross-section of a Dentca disk specimen with a flexural strength of 222 MPa. On the other hand, Figure 27 shows a scanning electron image of a fracture cross-section of a Dentca disk specimen that broke at a significantly lower value of 94 MPa. Very different fracture patterns can be seen with the two disk specimens. The disk specimen with the lower flexural strength fractured into two pieces and showed less plastic deformation.

The disk with the higher static flexural strength fractured into five pieces and had more plastic deformation during testing. Any uncured residual resin will have an impact on the mechanical properties. This also highlights the importance of post-processing and post-curing to remove any residual resin to ensure optimum mechanical properties and biocompatibility. The source of variation needs to be located as well whether it’s coming from the printer, resin itself, or post-processing protocol. Figure 26 also shows the presence of a large pore.

The other two additively manufactured polymers Bego VarseoSmile Crown Plus and Temporary CB also demonstrated higher coefficients of variation but to a lesser extent than Dentca. Figure 31 shows a scanning electron image of a Bego VarseoSmile Crown Plus specimen that broke at a higher flexural strength value of 166 MPa. On the other hand, Figure 28 shows the Bego VarseoSmile Crown Plus specimen that fractured at a value of 79 MPa. The differences in fracture pattern can be noted as well. Due to the high variation in the printed polymers, a higher sample size would have been needed to conclude a statistically significant difference.

The additively manufactured polymers also produced the highest color differences. This may be due to residual resin or the existence of defects between the layers. Incomplete curing may be a possibility as well. However, for clinical implications, a glazing layer may be needed to avoid esthetic concerns.

4.2 Bis-acryls and Future Experimentation

The flexural strength values of the bis-acryl material analyzed in this study, ProTemp, were not significantly lower than Telio CAD Temp. However, ProTemp was susceptible to multiple treatments including distilled water, fatigue, and aging. ProTemp is conventionally produced and hence may have uncured resin or residual monomer. This translates to the possibility of leaching of filler molecules or residual monomer. This has implications on mechanical properties as well as biocompatibility. Another notion to mention is water sorption which causes hydrolytic breakdown of some of the bonds between the fillers and matrix as well as have a plasticizing effect. The plasticizing effect will cause softening of the polymer and eventually the softening of the material. (15). This in turn is expected to have implications on the flexural strength as well as the color stability. Figure 33 shows scanning electron image of a fracture cross section of a ProTemp disk specimen with no treatment. Figure 31 shows a scanning electron image of a fracture cross section of a ProTemp disk specimen after 5000 thermal cycles. Figure 32 shows a scanning electron image of a fracture cross section of a ProTemp disk specimen after 15 days immersion in distilled water.

Since ProTemp demonstrated good performance in flexural strength color stability studies as a conventional chairside material, experimentation should attempt to transform ProTemp into a machinable block or for use in a 3d printer. This can also aid in making bis-acryl into a more durable material. However, there has been question with relining bis-acryls.

4.4 Conventional PMMAs and Clinical Implications.

Jet Tooth Shade is a conventional PMMA used as a provisional material. It is used both as a provisional restoration and to reline machined provisional restorations. Conventionally produced polymers usually have issues with voids and porosities. In this study, the conventional PMMA, Jet Tooth Shade has registered the lowest flexural strength values. It has also performed poorly in the color stability tests. Again, this may be due to residual monomer in addition to the voids and porosities. Figure 35 shows a fracture cross-section of a Jet Tooth Shade specimen. The voids and porosities are evident. More importantly, conventional PMMAs are usually used to reline machined provisional restorations after adjusting the tooth preparation. The clinician will need to keep in mind the mechanical properties as this will negatively affect the performance of the provisional restoration. However, flexural strength studies of bilayered specimens need to be further evaluated.

4.5 UVC Light Effects on Flexural Strength and Color

With the rise of the COVID19 pandemic, there has been an increased use of novel ways to disinfect surfaces. UVC light has been used as one method to disinfect multiple dental materials, instruments and equipment. This study evaluated the effect of UVC light on dental polymers. In this experiment, UV light significantly affected the color stability of all polymers in general. It also affected the flexural strength values. According to an article you Yousif and Raghad (17), UV radiation may cause significant degradation of polymers through photooxidative degradation. This causes breakage in the polymer chains as we all as reduce the molecular weight. This will detrimentally affect the mechanical properties, as well as the optical properties.

The UVC light significantly affected the Telio CAD Temp disk specimens. Telio CAD Temp was a fairly durable material and was not affected by any treatment with the exception of UV light. Figure 37 shows a scanning electron image of the fracture pattern on a non-treated Telio CAD Temp disk specimen.

However, in Figure 38, after ten hours of UV light treatment, there seems to be a change in the fracture pattern. This needs to be evaluated with further studies on a molecular level.

Vita CAD Temp was another material that was affected by UV light. The color difference as well as the flexural strength were affected. In fact, UV light was the treatment that made the most color difference for Vita CAD Temp, more so than the treatment of 1500 thermal cycles followed by 15 days in coffee. The flexural strength of Vita CAD Temp was also adversely affected as it dropped from 105 MPa to 75 MPa. Figure 39 displays the scanning electron image of a non-treated Vita CAD Temp disk specimen. Figure 40 shows the fracture pattern of a UV light treated Vita CAD Temp disk specimen.

From this study, the use of UV light as a method to disinfect the tested polymers is not recommended as this has adversely affected both color stability as well as flexural strength. Further analysis of what happens on a molecular level is further needed to understand the material more.

4.6 Limitations of this Study

This study had numerous limitations. Only two properties were analyzed in this experiment. Other mechanical properties should be evaluated such as fracture toughness. In addition, the ability to repair and adjust the polymers by adding material should be evaluated by shear bond strength tests. Adding material is required to reline as well as change occlusion and esthetics for diagnostic purposes. The idea of testing the flexural strength and other mechanical properties of bilayered polymers is required as clinicians usually reline digitally produced provisional restorations with conventional chairside materials.

Another limitation is the fatigue testing and, in this experiment, it has only affected ProTemp. All the other materials were not affected. The number of cycles may be increased as well as the percentage of mean load to failure applied to the material during fatigue.

Another issue is the printed polymers having large coefficients of variation. Larger sample sizes may have resulted in statistically significant differences. Bego VarseoSmile Crown Plus and Dentca disk specimens demonstrated the highest standard deviations and coefficient of variation in the static flexural strength groups. We can calculate the sample size needed by the following equations.

$$Necessary\ Sample\ Size = \frac{(Z\ score)^2 \times\ (StdDev) \times (1 - StdDev)}{(margin\ of\ error)^2}$$

The aim is to have a 5% margin of error and a confidence interval of 95%, which is a Z score of 1.96. The standard of deviation can be assumed to be 0.4, when evaluating the numbers from the static flexural strength values.

$$Necessary\ Sample\ Size = \frac{(1.96)^2 \times\ (0.4) \times (0.6)}{(0.05)^2}$$

Using this equation, we need a sample size of 369 disk specimens.

Chapter 5: Conclusion

With the limitations of this study the following can be concluded:

1) Telio CAD Temp had the highest overall flexural strength. It was significantly higher than all materials with the exception of ProTemp. In addition, Telio CAD Temp was resistant to all post fabrication treatments except for UV light.
2) ProTemp had the second highest overall flexural strength but was susceptible to multiple post fabrication treatments like distilled water, fatigue, and aging.
3) The printed specimens had flexural strength values lower in the middle range of all tested materials.
4) Powder and Liquid based cold-cured PMMA had the lowest overall flexural strengths.
5) In terms of treatment, UV light and coffee/thermocycling had the biggest impact on the overall color stability values.

Bibliography

1. Burns DR, Beck DA, Nelson SK. A review of selected dental literature on contemporary provisional fixed prosthodontic treatment: report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics. Journal of Prosthetic Dentistry 2003;90:474–97.

2. D.R. Federick The provisional fixed partial denture. Journal of Prosthetic Dentistry 34. 1975, pp. 520-526.

3. Christensen, Gordon. 2003. "The Fastest and Best Provisional Restorations" 134 (5): 637–39.

4. McLean JW. The failed restoration: causes of failure and how to prevent them. International Dental Journal 1990;40:354

5. Rayyan, Mohammad et al. Comparison of interim restorations fabricated by CAD/CAM with those fabricated manually. Journal of Prosthetic Dentistry. 2015 Vol 3 Issue 3 414-419

6. Tamimi, Faleh and Hiroshi Hirayama, eds. Digital Restorative Dentistry. 2019 56-73

7. Ban S, Anusavice KJ. Influence of test method on failure stress of brittle dental materials. Journal of Dental Research 1990;69:1791.

8. Smith, T. and Guild, J. (1931) The C.I.E. colorimetric standards and their use. Transactions of the Optical Society, 1931: 10.1088/1475-4878/33/3/301.

9. Alghazzawi TF. Advancements in CAD/CAM technology: options for practical implementation. Journal of Prosthodontic Research 2016;60(2):72–84

10. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. International Dental Jouranl. 2014;2014:783948

11. Braian M, et al. Geometrical accuracy of metallic objects produced with additive or subtractive manufacturing: a comparative in vitro study. Dental Materials Journal. 2018;34(7):978–93

12. Revilla-León M, Meyers MJ, Zandinejad A, Özcan M. A review on chemical composition, mechanical properties, and manufacturing work flow of additively manufactured current polymers for interim dental

resto- rations. Journal of Esthetic and Restorative Dentistry. 2019;31:51–57. https://doi.org/ 10.1111/jerd.12438

13. Alharbi N, Osman R, Wismeijer D. Effect of build direction on the mechanical properties of 3D printed complete coverage interim dental restorations. Journal of Prosthetic Dentistry. 2016;155:760-767

14. Jiajing Yao, Jing Li, Yuhua Wang, Hui Huang,Comparison of the flexural strength and marginal accuracy of traditional and CAD/CAM interim materials before and after thermal cycling. Journal of Prosthetic Dentistry 2014. Volume 112. Issue 3, Pages 649-657

15. Y. Zhang, J. Xu Effect of immersion in various media on the sorption, solubility, elution of unreacted monomers, and flexural properties of two model dental composite compositions Journal of Materials Science: Materials in Medicine, 19 (2008), pp. 2477-2483

16. W.M. Johnston, E.C. Kao Assessment of appearance match by visual observation and clinical colorimetry Journal of Dental Research, 68 (1989), pp. 819-822

17. R.D. Douglas, T.J. Steinhauer, A.G. Wee Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch Journal of Prosthetic Dentistry, 97 (2007), pp. 200-208

18. Photodegradation and photostabilization of polymers, especially polystyrene: review Emad Yousif, Raghad Haddad Springerplus. 2013; 2: 398. Published online 2013 Aug 23. doi: 10.1186/2193-1801-2-398

Curriculum Vitae

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