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Bond Strength between CAD/CAM PMMA Denture Base Resins and Characterisation Composites

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Abstract: Aim: To measure the bond strength between two different CAD/CAM PMMA denture base resins and three different types of gum characterisation composites. Materials and Methods: CAD/CAM single cross-linked (Telio CAD) and double cross-linked (Vivodent CAD) resins were prepared, obtaining a total of 180 bar specimens. Each specimen was prepared according to the manufacturer's instructions. The specimens were bonded to three different characterisation composites with varying viscosities; Kulzer Pala-creactive (P), Ivoclar SR Nexco (S), Shofu Ceramage (F). All the specimens were then tested using a chevron-notched three-point bond strength test in a universal testing machine to obtain fracture energy release toughness (MPa$\sqrt{m}$) and bond strength (MPa). The specimens were thermocycled to simulate 6 and 12 months of ageing in vivo. The results were statistically analysed (SPSS). The fractured surfaces of the tested specimens were examined with a scanning electron microscope (SEM) to evaluate the failure modes. Results: Pala-creactive characterisation composites showed the highest overall bond strength (3.49 $\pm$ 0.86 MPa) and fracture toughness (1.59 $\pm$ 0.34 MPa$\sqrt{m}$) when bonded to both CAD PMMA denture resins, which were statistically higher than the values obtained when they were bonded to Telio ($p < 0.001$). The Ceramage composite showed the lowest bond strength (1.05 $\pm$ 0.59 MPa) and fracture toughness (0.47 $\pm$ 0.4 MPa$\sqrt{m}$). The dominant mode of failure for all groups was mixed. Conclusion: Single cross-linked PMMA (Telio) showed a higher overall bond strength compared to double cross-linked PMMA when bonded to three different characterisation composites. Telio CAD showed a clear bond strength decrease after 6 and 12 months of artificial ageing, while Vivodent CAD showed a bond strength increase.

Keywords: bond strength; fracture toughness; characterisation composites; CAD/CAM; PMMA

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1. Introduction

The demand for removable restorations such as partial or complete dentures has been increasing, as the overall life expectancy of the population around the world has been increasing over the past years and is expected to further increase with time [1]. Conventional dentures fabricated using polymethylmethacrylate (PMMA) have been a popular treatment of choice for several years, and PMMA is still the most widely used material today. Methods of denture fabrication have been evolving ever since Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology has been introduced in 1971 [1,2]. In recent years, Janeva et al. (2018) reported that there has been a growing interest in CAD/CAM PMMA dentures over conventionally produced dentures due to increased time efficiency, higher retention, fit, and stability resulting in more favourable clinical and patient-centred outcomes [3].

Despite numerous benefits, CAD/CAM PMMA primarily exists in the form of tooth-coloured monochromatic discs, resulting in less natural-looking dentures [4,5], whereas heat-cured and self-cured PMMA contains red coloured fibres called veins to mimic a more natural gingival polychromatic colour effect. Therefore, this type of fabrication requires masking of the underlying material, to provide a natural appearance of healthy gingiva. To

overcome this limitation, dual-coloured CAD/CAM pucks became available from Ivoclar Vivodent (Ivotion), with the manufacturer claiming that no additional characterisation is required after denture production to create aesthetic dentures. However, anecdotal evidence by dental technicians regarding dual-coloured PMMA pucks reported that there is a need for gingival characterisation if the occlusal plane cannot be set and nested flat in the puck in the software. Moreover, gingival characterisation to mask the tooth-coloured PMMA puck is required when a patient has a high smile line.

The aim of denture fabrication is not solely for the replacement of missing teeth but also for the restoration of function, aesthetics and phonetics which impact the overall quality of life [6]. There is an increase in demand for aesthetics in patients, as they desire a denture that is more natural-looking, harmonized within dentition and soft tissues, unique, and personal to them, meaning the rigid and monolithic appearance of CAD/CAM PMMA dentures will simply not meet patients' needs and expectations [4,5]. As most digital dentures are milled out of pre-polymerised PMMA blocks, characterising the dentures in their final stages utilizing characterisation composites have made it possible to provide dentures with more natural-looking appearances which can help improve patients' confidence and allow them to smile more freely [4,5]. This also increases patients' acceptability of oral rehabilitation treatment [5]. In a questionnaire-based survey done in 2018, aesthetics was deemed important in 98% of denture-wearing participants, and 95% of them agreed that denture aesthetics impacted their confidence [6]. Moreover, once dentures are placed into the mouth, they are subjected to flexural stress upon mastication and thermal stress from consumption of hot and cold beverages, which can weaken their mechanical properties and place stress upon the bond interface resulting in debonding of the composite resin from the milled PMMA and ultimately leading to fracture of the prostheses [7].

The characterisation of conventional produced heat-cured and self-cured dentures is normally done through placing stains into the mould before the polymerisation process [4,5]. However, CAD/CAM milled dentures are fabricated from a puck that has been pre-polymerised, and hence, customised characterisation of complete dentures is normally performed after fabrication. This step is necessary to produce a more natural-looking appearance in the denture to satisfy the aesthetical needs and demands of patients (Figure 1). In recent years, characterisation composites have been introduced to enhance the ability to create customized and more natural-looking dentures. Since then, more companies have come up with different brands of characterisation composites that vary in composition and chemico-physical properties. They are often used to characterise fixed, removable, partial, and full prostheses. However, past studies revealed that the strength of the bonds between characterizing composite and dental resin can be insufficient and result in microleakage, bond chipping and failure [8,9]. The characterising material is available in various viscosities and wettabilities that allow a significant increase of the bond strength and an easier usage of the material by the dental technician [9,10]. However, this is still an under-reported area in research, and evidence-based information regarding characterisation composites and their chemical, physical and bonding properties remains scarce.

Various methods are used to measure the strength of the bonds between composites and denture resins on the basis of shear bond strength or micro-tensile bond strength [11–13]. The fracture energy method evaluating the fracture toughness is reported to be the most suitable for dental materials due to its focus on debonding stresses and interface [11,14,15]. CAD/CAM systems have several benefits as concerns their production and mechanical properties, such as short working time, strong and long-lasting materials with high-density polymers and highly crosslinked PMMA resin systems, which exhibit different mechanical properties due to their chemical composition. However, little is known about the bond strength with characterising composites [16]. In comparison to conventionally produced PMMA, CAD/CAM blocks have a more homogenous and stronger structure due to their pre-polymerization and no inhibition layer and therefore have no shrinkage during production [17]. Therefore, to simulate the aging of the material and mimic the oral environment, thermocycling is widely used where standardised conditions range from 5 to 55 °C. This

method enables the evaluation of the ageing influence on the bonding area and determines the time of the debonding of the composite and consequently the repair frequency, cost and time for the patient and the dental professional.

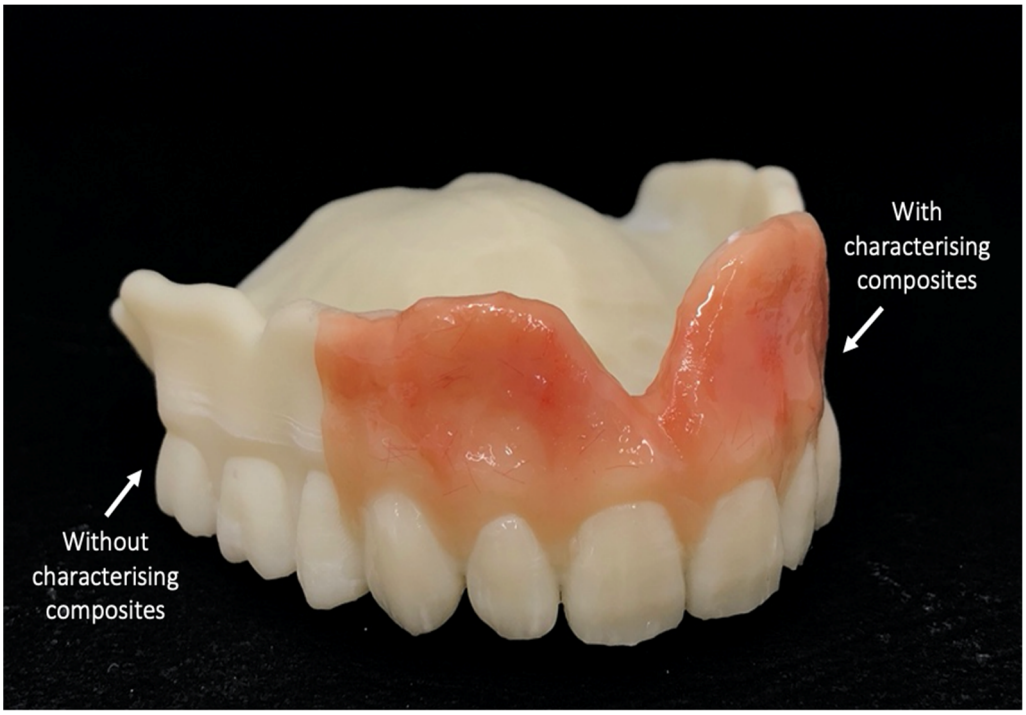

Figure 1. An example of tooth-coloured PMMA denture with characterising composites; note only the anterior portion is characterised, as an example.

The aim of this research was to investigate the bond strength between three commercially available denture characterizing composites and two CAD/CAM denture base materials after ageing for 6 and 12 months. The null hypothesis was that there was no statistically significant difference in the strength of bonds between CAD/CAM PMMA materials bonded and characterising composites.

2. Materials and Methods

2.1. Specimen Fabrication

Two types of CAD/CAM milled PMMA base materials were tested with three different types of characterization composites: Pala-Creative, SR Nexo and Ceramage. Details of the materials used and manufacturers are listed in Table 1. A total of 180 specimens of CAD/CAM milled PMMA blocks of each material were cut into the desired shape of $5 \times 15 \times 5$ mm^3 using a precision cutting machine (M1D13, Struers, Ballerup, Denmark) with diamond-impregnated cutting discs at 3000 RPM speed and 0.060 mm/s feeding rate under water cooling. Each specimen was polished to the required dimensions using P-350 grit water paper (SiC-Paper; Struers, Ballerup, Denmark) in a polishing machine (TegraPol-21; Struers, Ballerup, Denmark). Silicone putty moulds (Protesil labor, Vennini Dental, Grassina, Italy) ($5 \times 35 \times 5$ mm^3) were made and used as jigs for composite bonding. The extra length was to facilitate the addition of the bonding materials.

Table 1. Materials used in this study, abbreviations for each material and its manufacturer.

	Material	Composition	Abbreviation	Manufacturer
CAD/CAM Milled PMMA Base Materials	Telio CAD	• >98% PMMA (Polymethyl Methacrylate)	*T*	Ivoclar Vivodent, Schaan, Liechtenstein
	Vivodent CAD	• PMMA (Polymethyl Methacrylate)	*V*	Ivoclar Vivodent, Schaan, Liechtenstein
Characterising Composite Resins	Pala Cre-ative	• Aliphatisches Polyestertriurethantriacrylat. (10–25%); • 1,12-dodecandioldimethacrylate (5–10%); • 2-Propenoic acid,2-methyl-, 1,1′-[(1-methylethylidene)bis(4,1-phenyleneoxy-2,1-ethanediyl)]ester (0–5%); • Diphenyl (2,4,6- trimethylbenzoyl) phosphine oxide (<1%)	*P*	Kulzer, South Bend, Indiana, USA
	SR Nexco	• Dimethacrylates (Aromatic aliphatic urethane dimethacrylate and decandiol dimethacrylate (17–19 wt%) • Copolymer and silicone dioxide (82–83 wt%) • Additional contents are stabilizers, catalysts and pigments (<1 wt.%) • Zirconium oxide • Barium glass	*S*	Ivoclar Vivodent, Schaan, Liechtenstein
	Ceramage	• Zirconium silicate filler (amorphous) [Cas No.14940-68-2] (50–60%) • Urethane dimethacrylate (UDMA) [Cas No.72869-86-4] (5–15%)	*F*	Shofu, Kyoto, Japan

2.2. Surface Treatment and Characterisation of the Composite–Resin Bonding

Telio CAD (*T*) ($n = 90$) and Vivodent CAD (*V*) ($n = 90$) materials were assigned to three subgroups and bound to different characterisation composites: Pala-creactive (*P*) ($n = 30$), SR Nexco (*S*) ($n = 30$), Ceramage (*F*) ($n = 30$). Prior to testing, the end of each PMMA specimen was subjected to different surface treatments according to the manufacturers' instructions. A chevron-notched shaped Teflon sticker (3M Graphic Film, Saint Paul, MN, USA) was placed at the 5 mm × 5 mm end of the PMMA side of the two bonded surfaces to act as a separator prior to bonding the composite, so as to limit the area of bonding to the chevron notch shape [18]. The surface to be bonded with composite was then conditioned with their respective primers or adhesives according to the manufacturer's instructions and then light-cured for 20 s using the composite light curing machine Dentalux-2 (Mega-Physik, Rastatt, Germany). The prepared specimens were then fitted into the silicone putty moulds, and the composites were bonded incrementally onto the previously treated surfaces to fabricate the final specimens. Characterisation composite resins (SR Nexco, Pala Cre-active, Ceramage) were applied incrementally in 2 mm thickness and light-cured for 40 s using a composite light curing machine (DentaLux-2, Mega-Physik, Rastatt, Germany) to build up the composite to the final dimensions. Each specimen was then removed from the silicon mould, and the composite was beam light-cured for a further 80 s. The specimens were then polished all around using 350 grit silicon carbide paper, then ultrasonically cleaned for

3 min in water to remove any debris particles before testing. Each subgroup (*P*, *S*, *F*) was divided into three subgroups (n = 10): control (*C*, 0 months), 6 months (6), and 12 months (12). The 6 and 12 months groups were subjected to thermocycling (5000 and 10,000 cycles equivalent to 6 and 12 months in vivo, respectively), in a temperature range of 5–55 °C (Proto Tech, Dental Research Instruments, Liberty Lake, WA, USA) and with a dwell time of 30 s [19].

2.3. Mechanical Testing of the Bonded Specimens

Each bonded specimen was then measured three times for its width and height using a digital calliper (150 mm electronic digital calliper, Mitutoyo 500-197-20/30, Takatsu-ku, Japan). The mean of each specimen was calculated and recorded. All specimens were tested using a three-point fracture toughness test using a self-aligning 3-point bending jig (Flexural strength of ceramics test fixture ASTM C 1161, configuration A, fixture number WTF-CF-43, Wyoming Test Fixtures, Salt Lake City, UT, USA) (distance between lower support rollers 20 mm) in a universal testing machining (Instron Model 3369, Instron Corporation, Norwood, MA, USA) at room temperature (Figure 2). A 100 N load cell was attached to the upper part of the testing jig. All specimens were loaded to failure at a crosshead speed of 0.05 mm/min, and the failure load readings (N) were recorded using BlueHill 3 software (version 2.3.359, Instron Corp., Norwood, MA, USA). The three-point fracture toughness K_{Ivb} was calculated using the following equation (ASTM C1421-10, 2014):

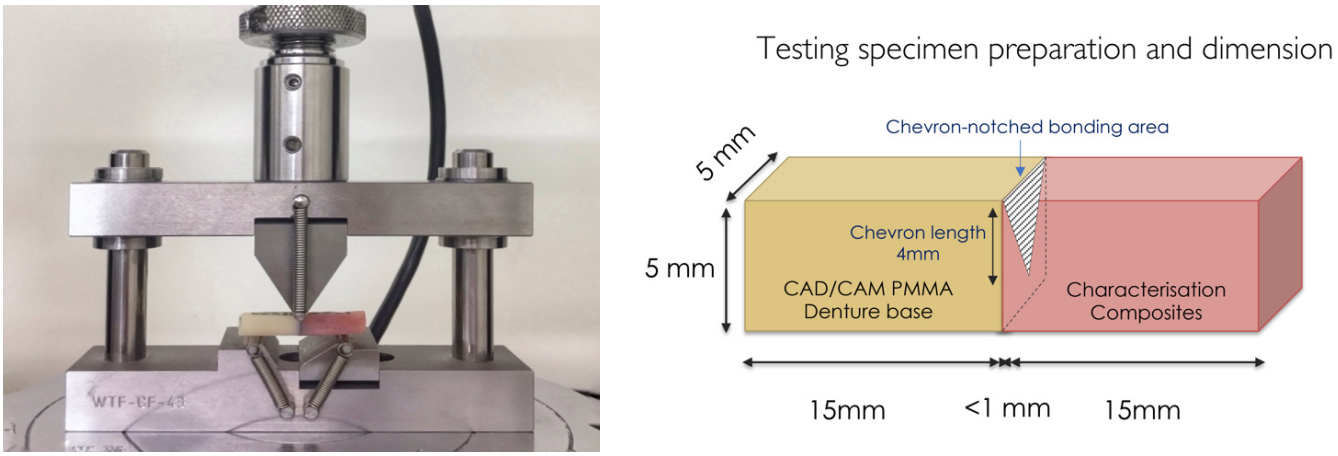

Figure 2. Images showing the chevron-notch three-point bend flexure bond test set up and specimen dimension (Chevron notch dimension is an equilateral triangle with a side of 5 mm).

$$KIvb = \mathrm{Y} * \min \left[\frac{P_{max}[S_o - S_i]10^{-6}}{BW^{3/2}} \right] \quad (1)$$

$\mathrm{Y} * \min = (a_o/W, a_1/W)$, the minimum stress intensity factor coefficient as determined from

$$\frac{0.7601 - 3.6364(a_o/W) + 3.1165(a_1/W) - 1.2782(a_1/W)^2 + 0.3609(a_1/W)^3}{1.000 - 3.1199(a_o/W) + 3.0558(a_o/W)^2 - 1.0390(a_o/W)^3 + 0.0608(a_1/W)}$$

$P_{\max}$ = relevant maximum force (N)
S_o= outer span (m)
S_1= inner span (m)
B = side-to-side dimension of the test specimen
W = top to bottom dimension of the test specimen
a_o = initial crack length ($W - CL$)
a_1 = (W + W)/2.

The flexure bond strength (MPa) was calculated by dividing the maximum force applied prior to fracture (N) by the chevon (bonding) area (mm^2). The values of K_{1vb} fracture toughness and bond strength were analysed using ANOVA at a significance level of 5%, using Statistical Package for Social Studied (SPSS) version 27 (IBM, Chicago, IL, USA). Tukey's post hoc test was conducted for comparisons between each test groups and factors. For each group, a representative specimen was selected for scanning electron microscopy (SEM) analysis for the point of initiation failure and surface fractographic analysis using ×25 magnification.

3. Results

The mean fracture toughness and bond strength of all groups are shown in Table 2 and Figures 3 and 4. The sample groups were designated by the letters *T*—Telio, *V*—Vivodent, *P*—Pala-creative, *S*—SR Nexco, *F*—Ceramage; *C*—Control, 6—6 months, 12—12 months. Composites that were bonded to the *T* groups had overall statistically significant higher fracture toughness and bond strength in comparison to those bonded to the *V* groups ($p < 0.001$). However, no statistically significant difference was observed within all subgroups when comparing control, 6 and 12 months of thermocycling. Within the *T* groups, the *P* group demonstrated a statistically significant difference in fracture toughness with respect to the *S* and *F* groups ($p < 0.001$); however, no statistically significant difference was observed within the *S* and *F* groups ($p = 0.896$). Within the *V* group, the *P* and *S* subgroups showed no statistical difference between each other ($p = 0.354$); however, they showed a statistically significant difference when compared to *F* ($p < 0.001$). Overall, within both CAD materials, the lowest fracture toughness was exhibited by the TS12 group, corresponding to 0.52 ± 0.3 Mpa$\sqrt{m}$ after 12 months of artificial ageing.

Table 2. Summary of fracture toughness (Mpa$\sqrt{m} \pm$ SD) and flexure bond strength of all test groups (Mpa ± SD).

	Fracture Toughness (MPa$\sqrt{m} \pm$ SD)			Bond Strength (MPa ± SD)		
Groups	**Control**	**6-Months**	**12-Months**	**Control**	**6-Months**	**12-Months**
TP	1.59 ± 0.34	1.39 ± 0.32	1.12 ± 0.44	3.49 ± 0.86	3.28 ± 0.96	2.61 ± 1.43
TS	1.07 ± 0.55	0.87 ± 0.31	0.52 ± 0.0.3	2.42 ± 1.43	2.42 ± 1.19	1.42 ± 0.85
TF	0.98 ± 0.28	0.72 ± 0.24	0.6 ± 0.29	2.10 ± 0.59	1.67 ± 0.62	1.47 ± 0.82
VP	1.05 ± 0.42	0.86 ± 0.5	1.13 ± 0.44	2.53 ± 1.28	1.93 ± 0.91	2.29 ± 0.87
VS	0.8 ± 0.47	1.02 ± 0.57	0.71 ± 0.29	1.9 ± 1.32	2.50 ± 1.31	1.79 ± 0.94
VF	0.56 ± 0.27	0.47 ± 0.4	0.69 ± 0.12	1.05 ± 0.59	1.02 ± 0.67	1.51 ± 0.27

A statistically significant difference was observed in bond strength of the *T* group with *P* and *S* and *F* ($p < 0.001$); meanwhile, the bond strengths for *S* and *F* showed no statistically significant difference ($p = 0.016$). For the *V* group, a statistically significant difference was found for the strength of the bonds with *P* and *S* ($p < 0.001$). No statistically significant difference was observed within subgroups; however, *F* and *S* showed a slight increase in bond strength after artificial ageing of 12 months and 6 months.

The SEM images of each group are shown in Figures 5 and 6. For the *V* groups (double cross-linked PMMA), the VP groups showed a predominantly adhesive failure at the PMMAs/composite interface from the control to the 6- and 12-month aging groups. The VS groups showed a cohesive failure within the composite in the control but switched to adhesive failure at the PMMAs/composite interface in the 6- and 12-month aging groups. The VF groups showed a cohesive failure within the composite in the control but switched to adhesive failure at the PMMAs/composite interface in the 6-month aging group and to a mixed mode—adhesive and cohesive—in the 12-month aging group. For the *T* groups, the *P* and *S* groups went from a predominantly adhesive failure at the PMMAs/composite

interface to a mixed mode of adhesive and cohesive failure in both the 6- and 12-month aging groups. In the *F* group, the dominant mode of failure was cohesive within the composite for the control and the 6- and 12-month aging groups.

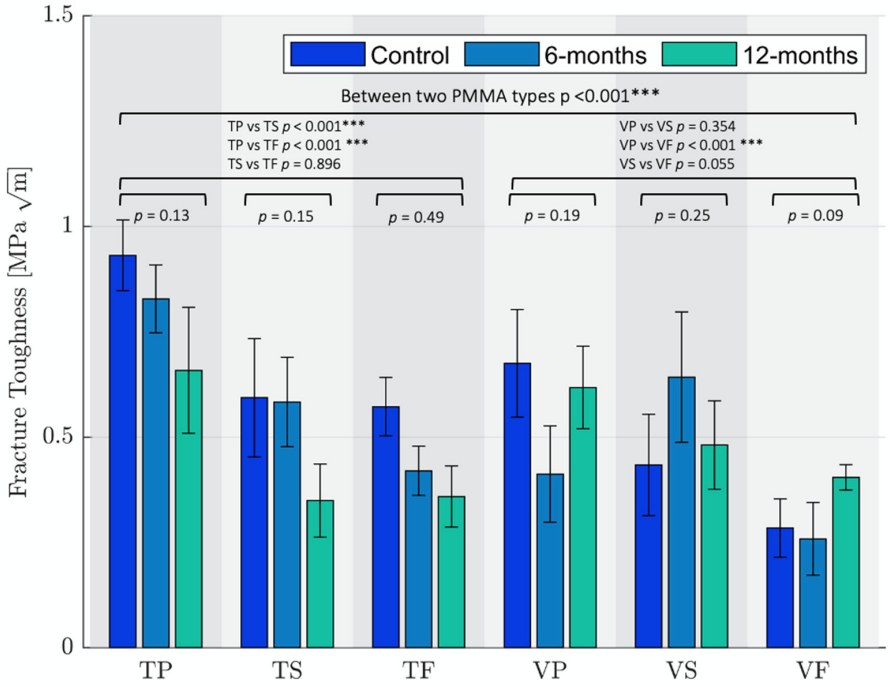

Figure 3. Fracture toughness of all sample groups representing control, 6 months and 12 months. The vertical lines represent 95% Confidence Interval ranges for Tukey's pairwise comparisons. *** indicates a statistical significance level $p < 0.001$.

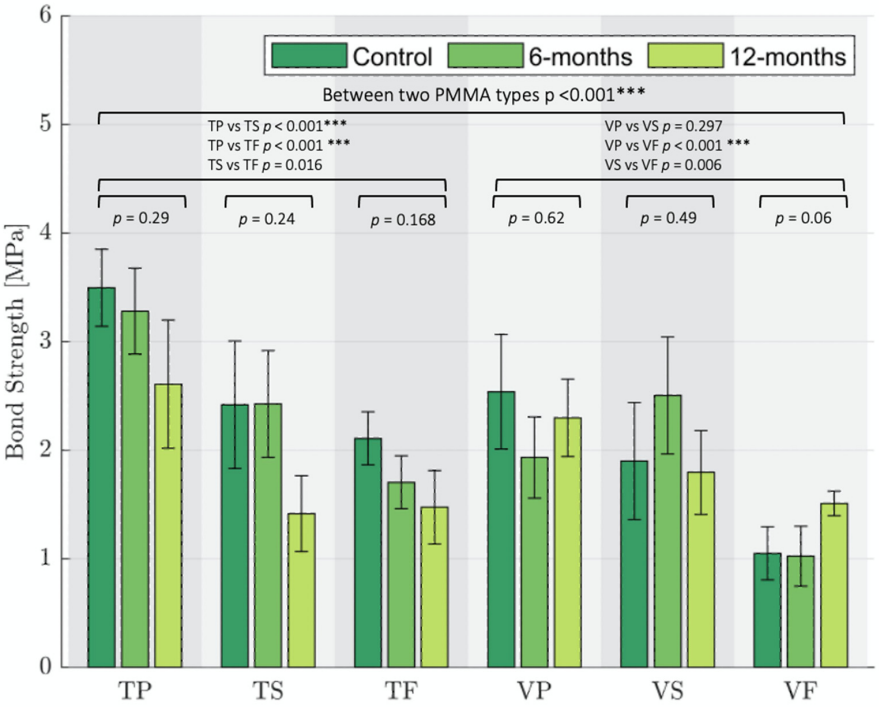

Figure 4. Flexural bond strength (MPa with mean bars) of all sample groups representing control, 6 months and 12 months. The vertical lines represent 95% Confidence Interval ranges for Tukey's pairwise comparisons. *** indicates a statistical significance level $p < 0.001$.

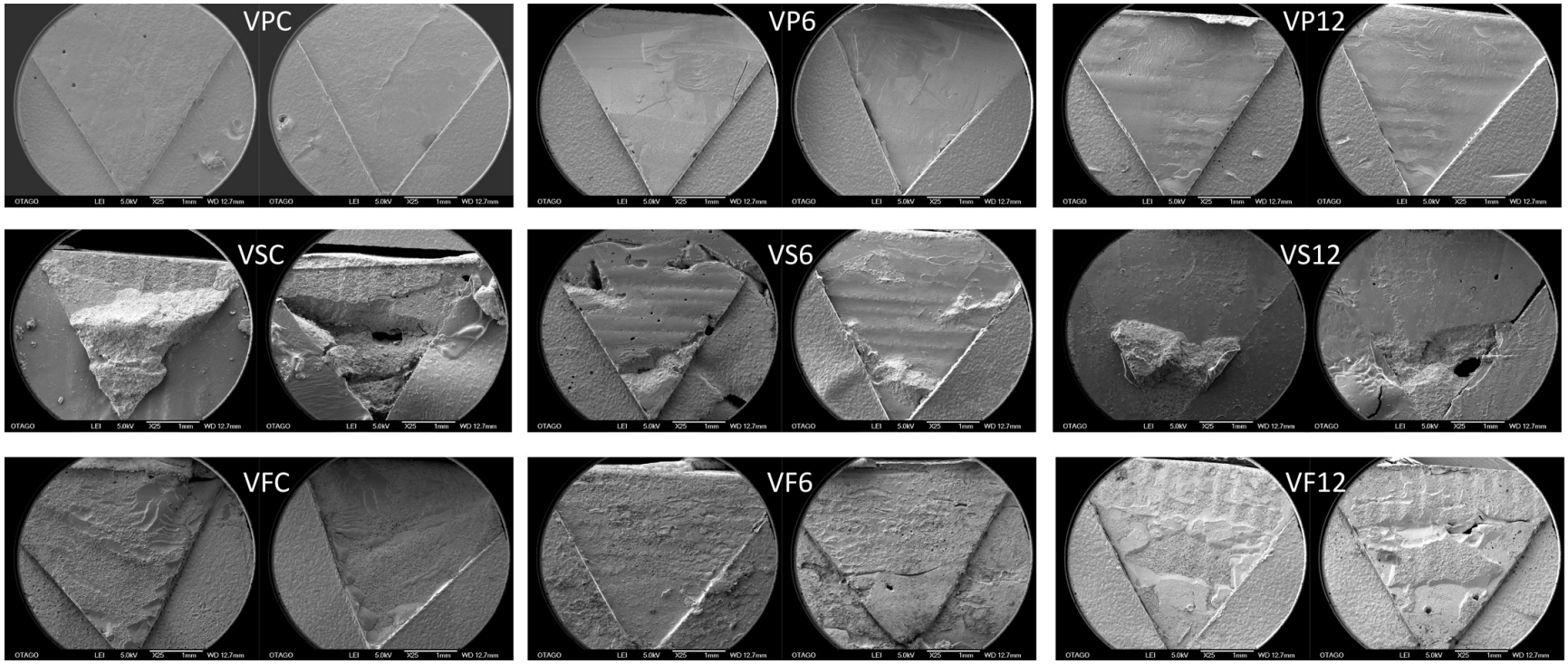

Figure 5. Representative SEM images (×25 magnification) of one specimen per group (*T*: Telio CAD, *V*: Vivodent CAD, *S*: SR Nexo, *F*: Ceramage, *C*: control, 6: 6 months, 12: 12 months). on the left-hand side of each slide, the composite is shown, on the right-hand side of each slide, CAD material is shown.

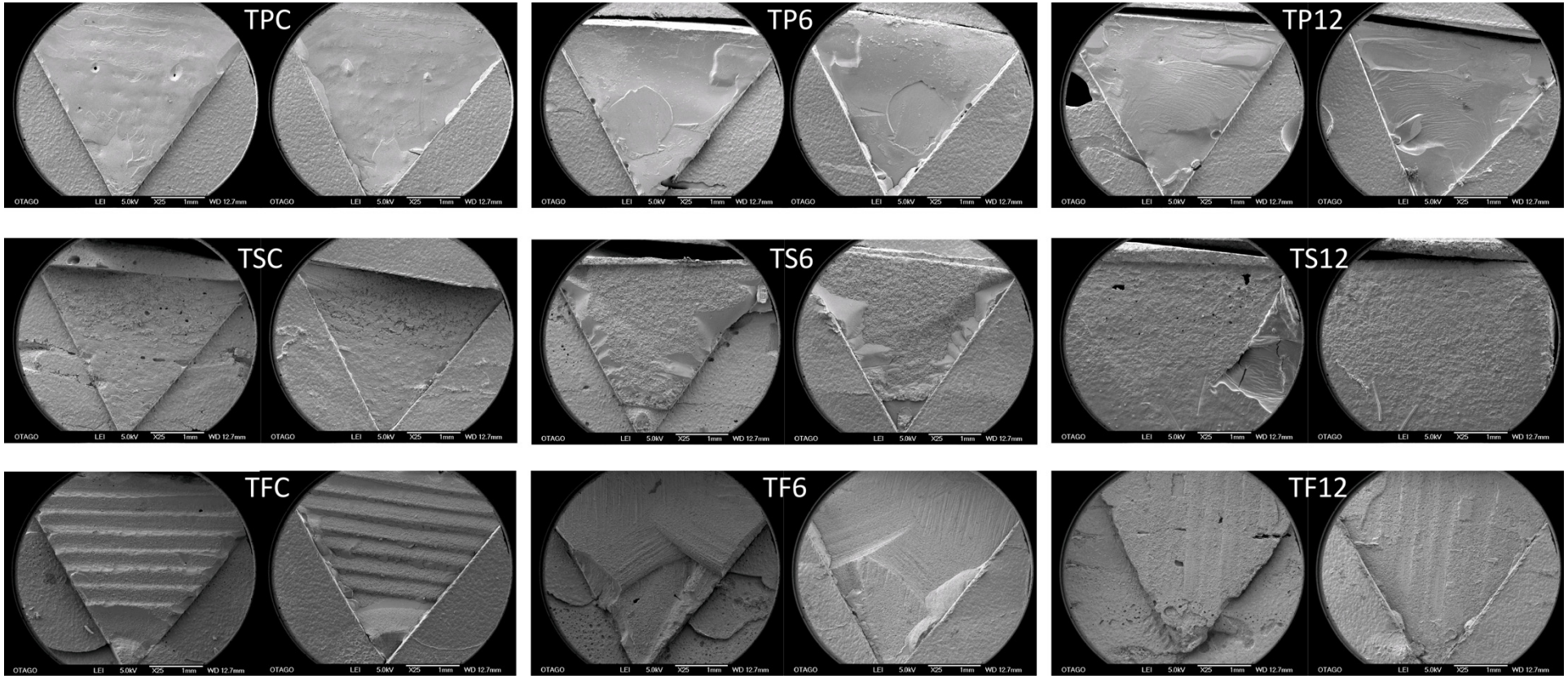

Figure 6. Representative SEM images (×25 magnification) of one specimen per group (*T*: Telio CAD, *P*: Pala-Creative, *S*: SR Nexo, *F*: Ceramage, *C*: control, 6: 6 months, 12: 12 months). On the left-hand side of each slide, the composite is shown, on the right-hand side of each slide, CAD material is shown.

4. Discussion

This study aimed to compare the bond strength between two CAD/CAM PMMA materials and three different characterization composites. The null hypothesis was rejected in this study, as there was a statistically significant difference in bond strength for the different CAD/CAM materials and within the characterising composite groups.

Previous research compared bond strength between CAD/CAM PMMA and conventional composites and composite-based polymers [20,21]. Conventional composites differ in composition, viscosities and filler particles, which would result in different bond strength values. It is important to emphasise that the tested characterising composites had different viscosities: the *F* composite was significantly stiffer and harder to work with, whereas *P* was more flowable, resulting in different mechanical properties of the material after ageing. In addition, previous studies used the shear bond strength test which has been reported to be inadequate to evaluate the true bond strength between two different materials, with large discrepancies and inconsistencies in results [11,21]. Hence, the present study used the fracture energy approach with the chevron notch beam method to determine fracture toughness bond strength between CAD/CAM milled PMMA dentures and characterisation composites, as suggested by previous researchers [11,18,22,23]. The fracture toughness value K_{1vb} informs one of the resistance of an adhesive to crack growth. This allows for the determination of a material's ability to resist cracks when subjected to known load conditions. Therefore, the fracture toughness test was deemed suitable for this study and of value, as there are limited studies that investigated the fracture toughness of the bond between CAD/CAM PMMA and characterisation composites. However, making a direct comparison between the study results and previous studies is difficult.

A significant difference between fracture toughness results was obtained between the *T* group and the *V* group ($p < 0.001$). The *T* group produced overall higher fracture toughness results in comparison to the *V* group, which could suggest the influence of the amount of cross-linking within PMMA. *T* CAD is a single cross-linked PMMA, whereas *V* CAD is a double cross-linked PMMA. *T* bonded to the *P* group showed the highest fracture toughness (0.93 ± 0.20 MPa$\sqrt{\text{m}}$) in all control groups and in the 6 and 12 months aged groups. Overall, the TP group showed a significant difference between the TS and the TF groups ($p < 0.001$), whereas The *F* and TS groups showed no statistically significant difference between each other ($p = 0.896$). There were significant differences in the fracture toughness results between the VP and VF groups ($p < 0.001$), whereas there was no significant difference between VP and VS groups ($p = 0.35$), VS and VF groups ($p = 0.055$), TP and TF groups ($p = 0.22$). This is similar to the results of previous studies where increased cross-linked PMMA exhibited lower bond strength values [24–26]. Although an increase in cross-linking in PMMA increases its mechanical properties, it also increases its resistance to chemical and mechanical abrasion which would decrease the effectiveness of surface treatment methods [27]. Thus, it could inhibit the diffusion of the monomer in the composites into CAD/CAM PMMA to form an interpenetrating network that significantly affects bond strength. Choi. et.al [28] reported that *V* CAD filler particles are composed of silica and alumina, which was not indicated by the manufacturer. The inclusion of alumina in the filler particles could also affect the overall bond strength between the composites and CAD/CAM PMMA [29].

The *T* CAD specimens overall showed higher bond strength values in comparison to the *V* CAD specimens, with statistically significant differences ($p < 0.001$). In addition, there was a decrease in bond/fracture toughness strength as the viscosity of the composite increased in both the *T* and the *V* groups. The *P* composites had lower viscosity than the S composites, and their flowability mimics that of flowable composites. The decrease in viscosity in *P* could increase the diffusion of the free monomer into CAD PMMA and increase the interpenetrating network, resulting in increased bond strength with VP [28].

The *V* groups showed an increase in fracture toughness and bond strength in VP and VF as a result of thermal aging for 12 months, despite an initial decrease at 6 months. VS showed an increase in fracture toughness and bond strength after 6 months of aging and

then a slight decrease compared to the control at 12 months. The cause of this phenomenon is probably the heating phase of the aging process facilitating additional polymerisation of the free monomer in the composites at the bond interface [30,31]. The VP group with the lower viscosity composite would have had a higher amount of free monomer and resin available for contact with the bond surface than the more viscous *F* composite which has a higher percentage filler content and therefore less resin available for contact at the VF bond interface. In contrast to this, the *T* groups showed a continuous decrease in fracture toughness and bond strength, as aging progressed from 6 to 12 months. This was probably due to the effects of water in the aging bath on the composite at the bond interface. A previous study by Ayman (2017) stated that an aged resin composite has lower adhesion than newly made ones due to the reduced chemical coupling between materials and their bonded interface; it also reported that after the material is polymerised and stable, it will continue to polymerize for a while, resulting in chemical and mechanical degradation that may reduce the bond strength [32,33]. Therefore, the use of in vitro ageing, which can mimic clinical conditions, cannot fully be relied on as a predictor of in vivo bond strength, as shown by the two opposing results for the *T* and *V* groups.

When examining the fractured surfaces of the specimens by SEM, the dominant mode of failure in the double cross-linked *V* groups (Figure 5) was adhesive failure at the PMMA/composite interface, with the exception of the VSC and VFC control groups which showed a dominant cohesive failure mode in the composite. In contrast, the dominant mode of failure in the *T* groups (Figure 6), which were not double cross-linked, was a mixed and cohesive failure within the composite, apart from the TPC and TSC control groups which showed adhesive failure. There appears to be no correlation between the mode of failure and the bond/fracture toughness strength values, nor between the different viscosities of the three composite groups. A limitation of this study is that only one specimen per group was selected for SEM analysis, and this was probably insufficient to obtain a representative picture of the dominant mode of failure and its relationship to the strength values. In future, a larger sample for each group should be examined to remediate this problem.

Clinically defining the adequate bond strength required between CAD/CAM PMMA and characterisation composites would add value to this research findings and aid in better understanding and interprete the bond strength results. Clinically adequate bond strength values have yet to be defined and are actively researched. Dentures are subjected to different types of forces in different directions in the oral cavity, and the clinical effectiveness of bonding between characterisation composites and CAD/CAM PMMA would be more accurately measured in more relevant conditions similar to the complex natural environment. The main limitation of this research is the inability to fully mimic an oral environment by, for example, exposing the materials to multiple environments and multidirectional forces instead of one directed force, as done in this research. Light curing of composites in jigs may have infleunced the bonding, as the composites would receive a direct light source in real life opposed to losing it through the experimental specimen fabrication jig, as reported by a previous study [34]. Therefore, further studies addressing these limitations may be beneficial for more comprehensive and precise results.

5. Conclusions

Considering the limitations in this study, the following conclusions were drawn:

Telio CAD PMMA showed a higher overall bond strength compared to Vivodent CAD PMMA when bonded to three different characterisation composites ($p < 0.001$).

Pala Cre-ative characterisation composites showed a higher overall bond strength when bonded with Telio CAD PMMA and Vivodent CAD PMMA, with a significant difference in the Vivodent CAD group ($p < 0.001$) and no significant difference in the Telio CAD group ($p = 0.063$).

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