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Influence of Thermal Cycling on Flexural Properties and Simulated Wear of Computer-aided Design/ Computer-aided Manufacturing Resin Composites

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Clinical Relevance

Computer-aided design/computer-aided manufacturing resin composites have different physical properties, and care should be taken when selecting one for clinical use.

SUMMARY

Objective: The purpose of this study was to evaluate the influence of thermal cycling on the flexural properties and simulated wear of computer-aided design/computer-aided manufacturing (CAD/CAM) resin composites.

Methods: The six CAD/CAM resin composites used in this study were 1) Lava Ultimate CAD/CAM Restorative (LU); 2) Paradigm MZ100 (PM); 3) CERASMART (CS); 4) Shofu Block HC (SB); 5) KATANA AVENCIA Block (KA); and 6) VITA ENAMIC (VE). Specimens were divided randomly into two groups, one of which was stored in distilled water for 24 hours, and the other of which was subjected to 10,000 thermal cycles. For each material, 15 specimens from each group were used to determine the flexural strength and modulus according to ISO 6872, and 20 specimens from each group were used to examine wear using a localized wear simulation model. The test materials were subjected to a wear challenge of 400,000 cycles in a Leinfelder-Suzuki device (Alabama machine). The materials were placed in custom-cylinder stainless steel fixtures, and simulated localized wear was generated using a stainless steel ball bearing (*r*=2.387 mm) antagonist in a water slurry of polymethyl methacrylate beads. Simulated wear was determined using a noncon-

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DOI: 10.2341/16-046-L

tact profilometer (Proscan 2100) with Proscan and AnSur 3D software.

Results: The two-way analysis of variance of flexural properties and simulated wear of CAD/CAM resin composites revealed that material type and thermal cycling had a significant influence ($p<0.05$), but there was no significant interaction ($p>0.05$) between the two factors. The flexural properties and maximum depth of wear facets of CAD/CAM resin composite were different ($p<0.05$) depending on the material, and their values were influenced ($p>0.05$) by thermal cycling, except in the case of VE. The volume losses in wear facets on LU, PM, and SB after 10,000 thermal cycles were significantly higher ($p<0.05$) than those after 24 hours of water storage, unlike CS, KA, and VE.

Conclusion: The results of this study indicate that the flexural properties and simulated wear of CAD/CAM resin composites are different depending on the material. In addition, the flexural properties and simulated wear of CAD/CAM resin composites are influenced by thermal cycling.

INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM) systems have developed in the field of dentistry over last two decades.[1] CAD/CAM materials available for restorations include glass ceramics, resin composites, aluminum-oxide, zirconia, and titanium.[2] Clinicians' interest in fabricating restorations using CAD/CAM systems continues to grow worldwide, and the demand for nonmetallic restorations from both clinicians and patients has encouraged researchers to seek alternative materials.[3]

Current resin composite technology has made considerable progress with the development of nanoparticle fillers.[4] It has been reported that nano-filled resin composites exhibit good mechanical properties,[5,6] improved surface characteristics and esthetics,[7] better gloss retention,[8] reduced polymerization shrinkage,[9] and reduced wear.[10] In conjunction with the improvement of resin composite technology, CAD/CAM resin composites that include nanoparticle fillers also have been introduced for clinical use.[11] CAD/CAM resin composites are fabricated by high pressure and temperature polymerization, resulting in improved physical properties that might make them more suitable as materials for applications from inlays to single crown restorations.[12] In addition, restorations produced from CAD/CAM resin composites can be more easily fabricated and repaired than restorations made from CAD/CAM ceramics.[13] However, there is a limited amount of independent research on CAD-CAM resin composites, creating a need for an evaluation of their physical properties. The measurement of parameters such as flexural properties and simulated wear will provide novel insight into the dynamic behavior of CAD/CAM resin composites under simulated occlusal stresses.

In clinical situations, occlusal stress is transmitted to resin composite restorations through the rigid and brittle fillers into the more flexible and ductile resin matrix during both function and parafunction.[14] Stress concentrations at the filler-resin matrix interface may result in filler dislodgement and exposure of the resin matrix leading to wear.[15] Such stress concentrations may also be generated by cyclic temperature changes.[16] During such temperature changes, differences in thermal expansion coefficients between fillers and resin matrices in resin composite restorations may lead to high interfacial stresses.[17] A thermal cycling test is the process of subjecting specimens to temperature changes that simulate intraoral conditions.[18] A previous study[19] established that 10,000 thermal cycles (TCs) correspond to one year of clinical function of restorations; this estimate is based on the hypothesis that such cycles might occur 20 to 50 times a day. Evaluation of the interaction effects between occlusal and thermal stresses on material properties is important because the stability of materials is related to the long-term clinical success of restorations. Thus, evaluation of the physical properties of CAD/CAM resin composites after thermal cycling may give valuable information about restoration longevity. However, there are few studies regarding the influence of thermal cycling on the flexural properties and simulated wear of CAD/CAM resin composites.

The purpose of this study was to investigate the influence of thermal cycling on the flexural properties and simulated wear of CAD/CAM resin composites. The null hypotheses to be tested were the following: 1) there is no significant difference in flexural properties and simulated wear of CAD/CAM resin composites; and 2) flexural properties and simulated wear of CAD/CAM resin composites are not influenced by thermal cycling.

METHODS AND MATERIALS

The six CAD/CAM resin composites in this study were 1) Lava Ultimate CAD/CAM Restorative (LU;

Table 1: *CAD/CAM Resin Composites Used in This Study*

CAD/CAM Resin Composite (Code, Shade)	Resin Matrix Composition	Inorganic Filler (Content)	Manufacturer (Lot No.)
Lava Ultimate CAD/CAM Restorative (LU, A2-LT)	Bis-GMA, UDMA, Bis-EMA, TEGDMA	SiO_2, ZrO_2, aggregated ZrO_2/SiO_2 cluster (80.0 wt%)	3M ESPE, St Paul, MN, USA (N400900)
Paradigm MZ100 Block (PM, A2)	Bis-GMA, TEGDMA	zirconia-silica ceramic (85.0 wt%)	3M ESPE, St Paul, MN, USA (N723583)
CERASMART (CS, A2-LT)	Bis-MEPP, UDMA, dimethacrylate	silica, barium glass (71.0 wt%)	GC, Tokyo, Japan (1407281)
Shofu Block HC (SB, A2-LT)	UDMA, TEGDMA	silica powder, microfused silica, zirconia silicate (61.0 wt%)	SHOFU, Kyoto, Japan (061401)
KATANA AVENCIA Block (KA, A2-LT)	UDMA, TEGDMA	aluminum filler, silica filler (62.0 wt%)	Kuraray Noritake Dental, Tokyo, Japan (000011)
VITA ENAMIC (VE, M2-T)	UDMA, TEGDMA	feldspar ceramic enriched with aluminum oxide (86.0 wt%)	Vita Zahnfabrik, Bad Säckingen, Germany (39440)

Abbreviations: Bis-EMA, ethoxylated bisphenol A-glycol dimethacrylate; Bis-GMA,bisphenol A-glycidyl methacrylate; Bis-MEPP, 2,2-Bis(4-methacryloxypolyethoxyphenyl)propane; CAD/CAM, computer-aided design/computer-aided manufacturing; SiO_2, silicon dioxide; TEGDMA, triethylene glycol dimethacrylate; UDMA urethane dimethacrylate; ZrO_2, zirconium dioxide.

3M ESPE, St Paul, MN, USA); 2) Paradigm MZ100 block (PM; 3M ESPE); 3) CERASMART (CS; GC, Tokyo, Japan); 4) SHOFU Block HC (SB; SHOFU, Kyoto, Japan); 5) KATANA AVENCIA Block (KA; Kuraray Noritake Dental, Tokyo, Japan); and 6) VITA ENAMIC (VE; Vita Zahnfabrik, Bad Säckingen, Germany). The CAD/CAM resin composites are listed in Table 1 with the associated lot numbers and components.

Flexural Strength and Elastic Modulus Measurement

Flexural properties were determined using a three-point bending test according to ISO 6872.[20] The bar-shaped specimens, 4.0 mm wide, 14.0 mm long, and 1.2 mm thick, were prepared using a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). All six sides of the specimen were wet ground with 1200-grit silicon carbide (SiC) paper to achieve the required dimensions of $4.0 \pm 0.2 \times 14.0 \pm 0.2 \times 1.2 \pm 0.2$ mm. The specimens were prepared under ambient conditions of 23° ± 2°C and 50% ± 10% relative humidity. Thirty specimens of each CAD/CAM resin composite were randomly divided into two groups ($n=15$ per group). Specimens from the first group were transferred to distilled water and stored at 37°C for 24 hours (24 h water storage). The other group was allocated 10,000 TCs between 5°C and 60°C (10,000 TCs). Thermal cycling was conducted using a custom-built machine. Each cycle consisted of water bath incubation lasting 30 seconds, with a transfer time of five seconds.

After the designated storage time, the specimens for the test group were subjected to the three-point bending test (span distance: 14 mm) using a universal testing machine (5500R, Instron Worldwide Headquaters, Norwood, MA, USA)at a cross-head speed of 1.0 mm/min until the specimen fractured. The peak breaking stress and the elastic modulus were determined from the stress-strain curve using a computer with custom software (Bluehill 2 Ver. 2.5, Instron Worldwide Headquaters) linked directly to the testing machine).

Wear Simulation

Twenty specimens of each of the CAD/CAM resin composites after 24 h water storage and after 10,000 TCs were prepared for simulated localized wear (occlusal contact area [OCA] wear). The surfaces of the CAD/CAM resin composites were polished flat to 4000-grit using a sequence of SiC papers (Struers, Cleveland, OH, USA).

A Leinfelder-Suzuki device (Alabama machine) was used for this study. The simulator has a plastic water bath, and the custom-wear fixtures were mounted inside the four-station bath. A brass cylinder was then placed around each fixture in the bath to serve as a reservoir for the abrasive media (water slurry of unplasticized polymethyl methacrylate [PMMA] with an average particle size of 44 μm). The media was placed inside the brass cylinders to cover the surface of the resin composite in the custom fixtures. The water slurry of PMMA inside the brass cylinders was approximately 6 mm in height over the surface of the resin composite.

The antagonist for the localized (OCA) wear simulation was a stainless steel ball bearing ($r = 2.387$ mm). The antagonist tips were mounted on spring-loaded pistons to deliver the wear challenges. During the application of the load, the antagonists rotated approximately 30° as the maximum force was reached (maximum load of 78.5 N at a rate of 2 Hz), and then they counterrotated to the original starting position as the load was relaxed to complete the cycle. Each set of specimens was exposed to 400,000 cycles in the wear simulator.

Wear Measurements

Prior to wear simulation, each resin composite specimen was profiled using a Proscan 2100 noncontact optical profilometer (Scantron Industrial Products Ltd, Taunton, England) with a 10 × 10 μm^2 resolution. These profiles provided the pretest digitized contours (20 specimens for each of the six CAD/CAM resin composites after 24 h water storage and 10,000 TCs for localized wear testing).

Following the 400,000 wear cycles, the specimens were ultrasonically cleaned (L&R Solid State Ultrasonic Cleaner T-14B, L&R Manufacturing Company, Kearny, NJ, USA) in distilled water for three minutes and then profiled again using the Proscan 2100 unit. The x-, y-, and z-coordinates of the before and after scans from the Proscan software were exported to another computer for analysis with AnSur 3D software (Minnesota Dental Research Center for Biomaterials and Biomechanics, University of Minnesota, Minneapolis, MN, USA).

Wear measurements were determined from the differences between the before and after data sets (before and after surface contours). A computerized fit was accomplished in AnSur 3E with the before and after data sets. Maximum depth (μm) and volume loss (mm^3) of the wear facets on the CAD/CAM resin composites were generated and recorded for each localized wear specimen.

Statistical Analysis

The flexural strength, flexural modulus, maximum depth, and volume loss of the wear facets of the CAD/CAM resin composites were analyzed using a commercial statistical software package (SPSS Statistics Base, International Business Machines, Armonk, NY, USA). A two-way analysis of variance (ANOVA) and Tukey post hoc test were used for analysis of each data set with a significance level of 0.05.

Scanning Electron Microscopy

Ultrastructural observations were completed on the polished surfaces of CAD/CAM resin composites with argon-ion etching using field-emission scanning electron microscopy (SEM; ERA 8800FE, Elionix, Tokyo, Japan). The surfaces were polished with 600-, 1200-, and 4000-grit SiC paper using a grinder-polisher (Ecomet 4/Automet 2, Buehler). The surfaces were polished with abrasive discs (Fuji Star Type DDC, Sankyo-Rikagaku, Saitama, Japan) followed by a series of diamond pastes down to 0.25 μm particle size (DP-Paste, Struers) to bring the surfaces to a high gloss. SEM specimens of the polished surfaces were dehydrated by immersion in ascending concentrations of aqueous tert-butanol (50% for 20 minutes, 75% for 20 minutes, 95% for 20 minutes, and 100% for 2 hours) and were then transferred to a critical-point dryer (Model ID-3, Elionix) for 30 minutes. These polished surfaces were etched for 30 seconds using an argon ion-beam (EIS-200ER; Elionix) directed perpendicularly to the surface at an accelerating voltage of 1.0 kV and an ion current density of 0.4 mA/cm^2. This treatment enhances the visibility of filler particles.[21] Surfaces were coated with a thin film of gold in a vacuum evaporator (Quick Coater Type SC-701, Sanyu Electron, Tokyo, Japan). SEM observations were carried out using an operating voltage of 10 kV.

SEM (TM3000 Tabletop Microscope, Hitachi-High Technologies, Tokyo, Japan) examinations were also accomplished on the wear facets of the CAD/CAM resin composites. Following the wear analysis, three representative specimens per group were coated with a gold-palladium thin film in a vacuum evaporator (Emitech SC7620 Mini Sputter Coater, Quorum Technologies, Ashford, UK). The SEM observations were carried out using an operating voltage of 15 kV.

RESULTS

The results for the flexural properties of CAD/CAM resin composites are shown in Table 2. The two-way ANOVA revealed that material type and thermal cycling had a significant influence ($p<0.05$) on the flexural strength and modulus. In addition, there was no significant ($p>0.05$) interaction between the two factors. The flexural strength of CAD/CAM resin composites after 24 h water storage and 10,000 TCs ranged from 143.6 to 197.3 MPa and 140.3 to 178.7 MPa, respectively. The flexural modulus after 24 h water storage and 10,000 TCs ranged from 9.9 to 23.2 GPa and 8.2 to 22.2 GPa, respectively. Flexural properties after 24 h water storage and 10,000 TCs were significantly different ($p<0.05$) depending on the material. The flexural properties of CAD/CAM resin composites after 10,000 TCs were significantly lower ($p<0.05$) than those after 24 h water storage except for VE.

Table 2: *Flexural Properties of CAD/CAM Resin Composites*[a]

CAD/CAM Resin Composite	24 h Water Storage		10,000 TCs	
	Flexural Strength (MPa)	Elastic Modulus (GPa)	Flexural Strength (MPa)	Elastic Modulus (GPa)
LU	180.3 (11.8) a,A	13.8 (0.9) a,A	159.3 (12.5) a,B	12.5 (0.9) a,B
PM	168.5 (14.5) b,A	9.9 (1.3) b,A	144.7 (14.0) b,B	8.2 (0,7) b,B
CS	197.3 (14.2) a,A	12.2 (1.1) c,A	178.7 (10.7) c,B	11.1 (0.9) c,B
SB	175.2 (12.3) a,b,A	10.1 (0.7) b,A	150.6 (13.5) a,b,B	9.7 (0.7) b,B
KA	189.8 (12.8) a,A	12.4 (0.8) c,A	170.4 (11.9) c,B	10.4 (0.8) b,c,B
VE	143.6 (9.7) b,A	23.2 (1.4) d,A	140.3 (10.7) a,c,A	22.2 (1.4) d,A

Abbreviations: CAD/CAM, computer-aided design/computer-aided manufacturing; CS, CERASMART; KA, KATANA AVENCIA Block; LU, Lava Ultimate CAD/CAM; PM, Paradigm MZ100 Block; SB, SHOFU Block HC; VE, VITA ENAMIC.
[a] *Values in parentheses are standard deviations (n = 15). Same small letter in columns indicates no significant difference ($p > 0.05$). Same capital letter in rows indicates no significant difference ($p > 0.05$).*

The results for the localized simulated wear of CAD/CAM resin composites are shown in Table 3. Two-way ANOVA revealed that material type and for thermal cycling had a significant influence ($p<0.05$) on the maximum depth or volume loss. In addition, there was no significant interaction ($p>0.05$) between the two factors. The maximum depth and volume loss of wear facets after 24 h water storage and 10,000 TCs were significantly different ($p<0.05$) depending on the material. The maximum depths of wear facets on CAD/CAM resin composites after 10,000 TCs were significantly higher ($p<0.05$) than those after 24 h water storage except for VE. The volume loss of wear facets on LU, PM, and SB after 10,000 TCs was significantly higher ($p<0.05$) than that after 24 h water storage, unlike for CS, KA, and VE.

Representative SEM images of polished CAD/CAM resin composite surfaces with argon-ion etching are shown in Figure 1. There were clear differences in filler-particle size, shape, and distribution. The resin composites exhibited a wide variety of filler-particle sizes and shapes. The particle size distribution of LU, PM, and SB appeared to include larger particles than either CS or KA. On the other hand, the polished VE surfaces showed a different structure compared with other CAD/CAM resin composites, and an irregular ceramic network was observed.

Representative SEM images of the localized wear facets after 10,000 TCs are shown in Figure 2. The worn surfaces showed evidence of particle loss (plucking). There did appear to be a qualitative morphological difference, in that LU, PM, and SB seemed to have more filler-particle plucking than CS, KA, and VE. This observation is consistent with the difference in volume loss of wear facets after 10,000 TCs.

DISCUSSION

In the present study, the measurement of flexural properties of CAD/CAM resin composites was conducted according to ISO 6872, a standard normally used to measure the flexural properties of dental ceramics.[20,22] On the other hand, the flexural strength measurement using the three-point bending test specified by ISO 4049[23] is widely used to evaluate the flexural properties of polymer-based restorative materials.[11] Therefore, flexural strength measurement using the three-point bending test

Table 3: *Simulated Localized Wear of CAD/CAM Resin Composites*

CAD/CAM Resin Composite	24 h Water Storage		10,000 TCs	
	Maximum Depth (μm)	Volume Loss (mm^3)	Maximum Depth (μm)	Volume Loss (mm^3)
LU	102.5 (14.9) a,A	0.025 (0.008) a,b,A	121.1 (14.9) a,B	0.035 (0.009) a,b,B
PM	133.7 (17.3) b,A	0.035 (0.009) b,A	150.7 (14.3) b,B	0.047 (0.010) b,B
CS	74.2 (11.4) c,A	0.021 (0.009) a,A	98.1 (12.1) c,B	0.028 (0.009) a,A
SB	127.1 (18.7) b,A	0.032 (0.010) a,b,A	147.8 (15.7) b,B	0.046 (0.011) b,B
KA	90.4 (12.8) a,A	0.024 (0.008) a,A	107.4 (12.8) c,B	0.028 (0.010) a,A
VE	69.2 (10.3) c,A	0.019 (0.007) a,A	74.2 (12.3) d,A	0.021 (0.010) a,A

Abbreviations: CAD/CAM, computer-aided design/computer-aided manufacturing; CS, CERASMART; KA, KATANA AVENCIA Block; LU, Lava Ultimate CAD/CAM; PM, Paradigm MZ100 Block; SB, SHOFU Block HC; VE, VITA ENAMIC.
[a] *Values in parentheses are standard deviations (n = 20). Same small letter in columns indicates no significant difference ($p > 0.05$). Same capital letter in rows indicates no significant difference ($p > 0.05$).*

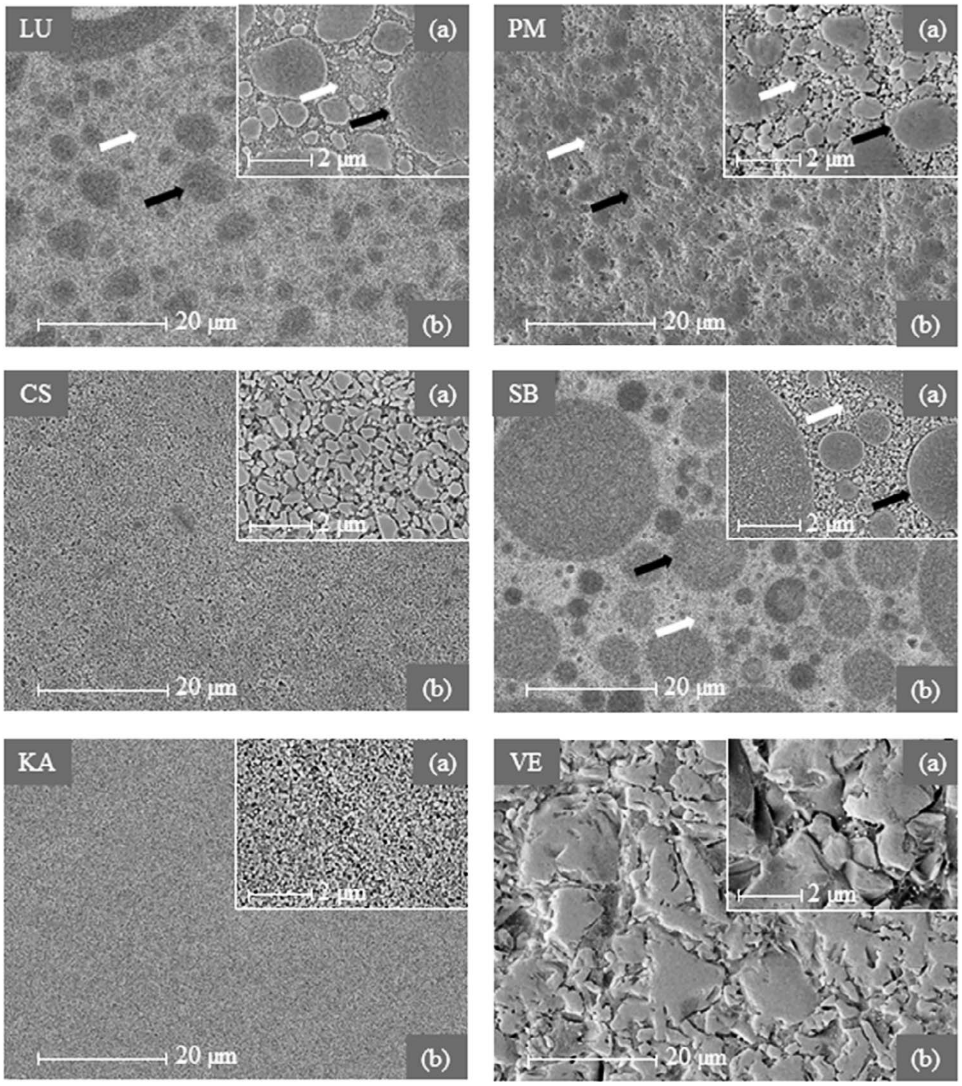

Figure 1. *Representative SEM images of the polished CAD/CAM resin composite surfaces at (a): 20,000× magnification and (b): 2500× magnification. LU, wide size range (1-20 μm) of irregular particles (black arrow) and small irregular particles (white arrow); PM, wide size range (1-15 μm) of irregular particles (black arrow) and small irregular particles (white arrow); CS, uniform small irregular particles; SB, wide size range (1-20 μm) of spherical particles (black arrow) and small spherical particles (white arrow); KB, uniform small irregular particles; VE, uniform irregular ceramic network. Size and distribution of fillers of CAD/CAM resin composite blocks were different, depending on the material.*

specified by ISO 4049 may appear to be a better way to evaluate the flexural properties of CAD/CAM resin composites. However, it has been pointed out that, whereas the ISO 4049 specifications for width and thickness are acceptable, the recommended length is clinically unrealistic.[24] In addition, it has been reported that although the flexural properties of resin composites measured by these test methods were not identical, the tests do provide similar results, even though the specifications use different specimen sizes.[25] The specimen size specified in ISO 6872 is as follows: length, 12.0 to 40.0 ± 0.5 mm; width, 4.0 ± 1.1 mm; thickness, 2.1 ± 1.1 mm . On the other hand, ISO 4049 specifies as follows: length, 25.0 ± 2.0 mm; width, 2.0 ± 0.1 mm; thickness, 2.0 ± 0.1 mm. Therefore, it is possible to use smaller specimens following ISO 6872. Due to the limited size of CAD/CAM resin composite blocks and tested materials, including the hybrid ceramic materials (VE), flexural strength measurement using the smaller specimens in this study.

The results showed that the flexural strength and modulus after 24 h water storage and after 10,000 TCs were different depending on the material. The results that are provided by the manufacturers of the inorganic filler contents show high variance (Table 1). Although increasing the filler load of resin composites purportedly increases the flexural strength and modulus,[26] there does not seem to be a clear relationship between flexural properties and inorganic filler contents in the present study. Therefore, it is speculated that the type of resin matrix, degree of conversion, and surface treatment of the filler might contribute to the flexural properties of CAD/CAM resin composites in the same manner as has been reported for other resin

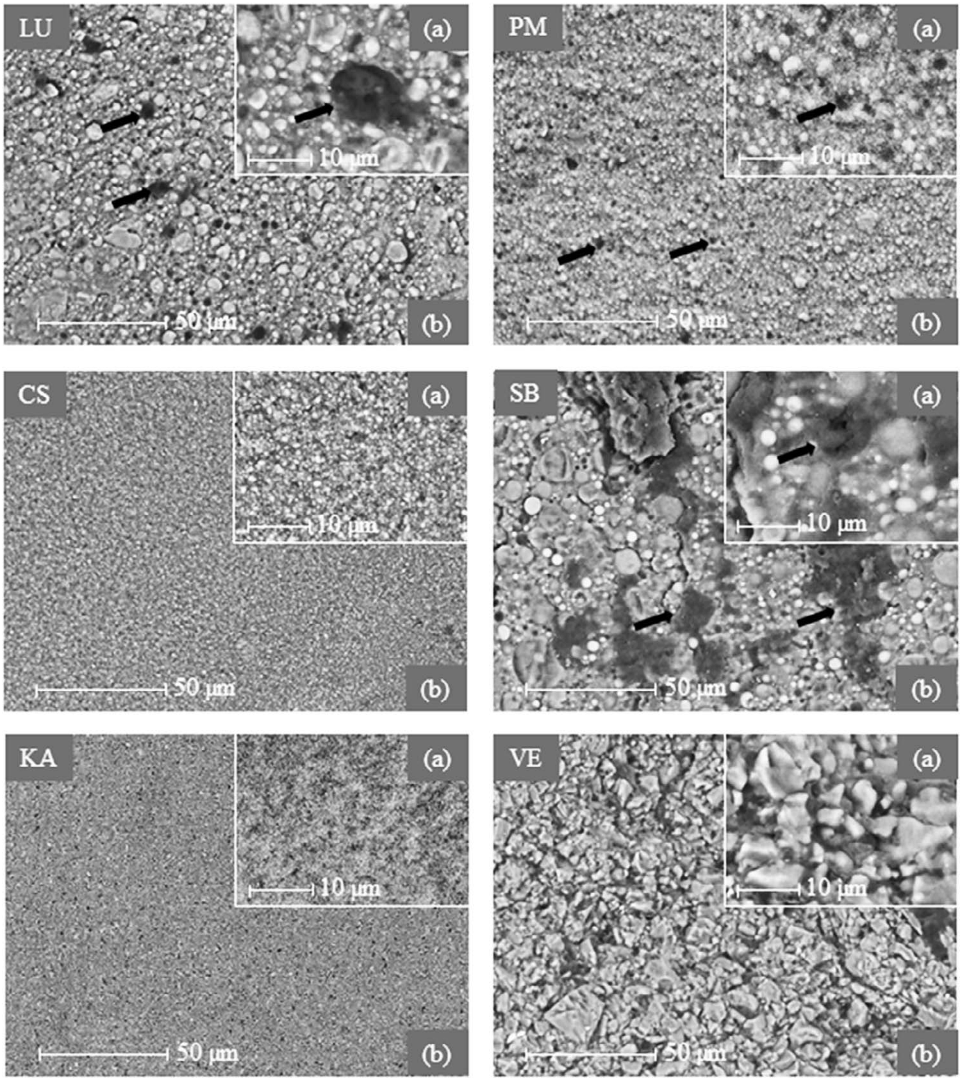

Figure 2. *Representative SEM images of the localized wear facets of CAD/CAM resin composites after 10,000 thermal cycles at (a): 20,000 × magnification and (b): 2500× magnification (b). The worn surfaces of CAD/CAM resin composites showed evidence of particle loss (plucking) from the simulated localized wear. There appeared to be a qualitative morphological difference: LU, PM, and SB seemed to have more filler-particle plucking than CS, KA, and VE.*

composites.[27] In addition, SEM observation of the polished CAD/CAM resin composite surfaces with argon-ion etching revealed that the size, shape, and distribution of fillers were different, depending on the material. A previous study[28] of resin composites revealed correlations between filler size, distribution of filler particles, and flexural properties. This may be one of the reasons why the flexural properties differed according to the materials used. It has also been reported that the type of polymerization has an effect on the physical properties of CAD/CAM resin composites.[14,29] Unfortunately, information about the polymerization methods from manufacturers is so limited that, in this respect, no further comparison can be made.

The flexural strength and modulus after 10,000 TCs were significantly lower than those after 24 h water storage but not those of VE. Immersion in water causes water penetration into the resin matrix of the resin composite, softening the polymer.[30] Furthermore, the absorbed water would cause hydrolysis of the interfacial silane coupling agent, especially in the case of zirconium dioxide, which cannot be effectively silanized due to its high crystalline content.[31] Accordingly, the flexural properties of CAD/CAM resin composites, especially LU, PM, and SB, which include zirconium dioxide, decreased after thermal cycling. However, VE, which is a polymer-infiltrated ceramic network enriched with aluminum, has unique characteristics as seen in the SEM observation of polished surfaces with argon-ion etching, and may be categorized as a CAD/CAM hybrid ceramic material.[32] It is thought that the amount of water absorption in this material is lower than that of the others. Moreover, the ceramic component of the material forms an interconnected microstructure, which may explain the resistance of the resin-ceramic bond to hydrolytic degradation. Therefore, the flexural properties of the CAD/CAM hybrid ceramic material were not influenced by thermal cycling, unlike those of CAD/CAM resin composites.

Wear in OCA is caused by opposing tooth contact, which is considered a localized process mainly related to local microfracture.[33] Barkmeier and others[34] developed a laboratory simulated model capable of evaluating localized wear. This system transfers masticatory stresses to a composite specimen by means of a stainless steel conical stylus in the presence of a slurry of PMMA beads. This methodology has facilitated the development of *in vitro* studies capable of helping to predict *in vivo* performance. A previous study using clinical data from two study sites on two resin composites found a good relationship between simulated localized wear in the laboratory and OCA clinical wear.[35] Using this system, simulated localized wear of CAD/CAM resin composites was also evaluated in this study.

In the present study, the maximum depth and volume loss of wear facets on the CAD/CAM resin composites after 24 h water storage and 10,000 TCs were significantly different, depending on the material. If we consider the CAD/CAM resin composites (excluding VE), the maximum depth and volume loss of wear facets on CS and KA after 24 h water storage and 10,000 TCs were significantly smaller than those of LU, PM, and SB. The mean filler size has previously been reported to affect the wear properties of resin composites, and smaller-sized filler particles were associated with less wear.[27,36] From the SEM observations of the polished CAD/CAM resin composite surfaces with argon-ion etching, equally distributed nanoparticle fillers were observed on CS and KA, whereas a wide size range of larger particle fillers was observed on the polished surfaces of LU, PM, and SB. Therefore, it is speculated that the lower wear of some CAD/CAM resin composites can be attributed to the smaller particle of their fillers. Such improved wear resistance has been hypothesized to result from smaller inter-particle spacing between the fillers of small-particle composites.[37] The smaller particle fillers become more closely packed, so that the resin between them is protected from further abrasion from neighboring particles.[38] Furthermore, the flexural properties of resin composite have previously been correlated[39] with quantitative wear data and specifically seem to reflect wear performance. If little energy is needed to fatigue and fracture the materials, cracks appear to form more readily, resulting in an increased wear rate. Consequently, CS and KA, with relatively high flexural properties, demonstrated less wear than LU, PM, and SB, with lower flexural properties.

Although the maximum depth of wear facets after 10,000 TCs was significantly higher than those after 24 h water storage, except in VE, the volume loss of wear facets on LU, PM, and SB after 10,000 TCs was significantly higher than that after 24 h water storage, unlike in CS and KA. From the SEM observations of the localized wear facets after 10,000 TCs, the LU, PM, and SB materials seemed to have more filler-particle plucking than CS and KA. In addition, the flexural strengths of LU, PM, and SB after 10,000 TCs were significantly lower than those of CS and KA. This may be one reason why LU, PM, and SB showed higher volume loss of wear facets after 10,000 TCs than after 24 h water storage. Furthermore, the maximum depth and volume loss of wear facets on VE after 24 h water storage and after 10,000 TCs did not show any significant difference, whereas the flexural properties of VE were not influenced by thermal cycling. Overall, there may be a relationship between flexural properties and simulated wear in CAD/CAM resin composites. However, it is important to bear in mind that there are a number of different ways to simulate wear, and the method chosen may influence the results.[40] Therefore, different results may be obtained if the testing is performed using a different wear simulator. Further research is needed to confirm that these findings can be reproduced using different approaches to wear simulation.

According to the results of this study, the first null hypothesis (there are no significant differences in flexural properties and simulated wear of CAD/CAM resin composites) was rejected. The second null hypothesis (flexural properties and simulated wear of CAD/CAM resin composites are not influenced by thermal cycling) was also rejected.

CONCLUSION

The results of this study indicate that the flexural properties and simulated wear of CAD/CAM resin composite are different, depending on the material. In addition, the flexural properties and simulated wear of CAD/CAM resin composites were influenced by thermal cycling. It appears that the selection of a CAD/CAM resin composite for clinical use should be carefully made with special considerations regarding the physical properties of the material. Clinicians should put more weight on the difference in physical properties, as well as degradation by thermal stress and hydrolysis, between CAD/CAM resin composites and ceramics when making clinical decisions.

Acknowledgements

The authors thank Mr Jason M Moody for technical contributions. This work was supported, in part, by a Grant-in-Aid for Young Scientists (B) 10608409 from the Japan Society for the Promotion of Science. This project was also supported, in part, by the Sato Fund and by a grant from the Dental Research Center of the Nihon University School of Dentistry, Japan.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 9 April 2016)

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