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Research Letter

Wear of MgO-CaO-SiO_2-P_2O_5-F-Based Glass Ceramics Compared to Selected Dental Ceramics

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Wear of a glass-ceramic produced through controlled crystallization of a glass in the MgO-CaO-SiO_2-P_2O_5-F system has been evaluated and compared to various commercial dental ceramics including IPS Empress 2, Cergo Pressable Ceramic, Cerco Ceram, and Super porcelain EX-3. Wear tests were performed in accord with the ASTM G99 for wear testing with a pin-on-disk apparatus. The friction coefficient and specific wear rate of the materials investigated were determined at a load of 10 N and at ambient laboratory conditions. Microhardness of the materials was also measured to elucidate the appropriateness of these materials for dental applications.

1. INTRODUCTION

All-ceramics have been widely used in dental restorations for the past two decades due to their aesthetic characteristics [1, 2], structural durability, chemical inertness, biological compatibility, adequate strength, fracture toughness, and wear resistance [1–3]. Attempts have been made to use all-ceramic crowns and inlays for the restoration of posterior occlusal surfaces [3, 4]. However, there are certain anxieties related to wear of all-ceramic systems. In particular, the wear of the restoration and that of the opposing enamel or restoration are of serious concern in clinical applications, especially, when enamel is in occlusal contact with a harder ceramic restoration [5]. Therefore, new ceramic materials are constantly evolving in dentistry to minimize their abrasiveness to opposing natural dentition [6].

Glass-ceramics containing apatite and wollastonite crystals have been shown to exhibit good mechanical properties, chemical durability and resistance to slow crack growth, and the ability to form tight chemical bonds with living bone [7–9]. Apatite-wollastonite (A-W) glass-ceramics have found use especially in the replacement of natural bone due to their bioactivity and enhanced mechanical properties. The utilization of A-W glass-ceramic in prosthetic dentistry has been limited since it is abrasive to the natural dentition and it is also bioactive [10]. Recently, Park and Ozturk [11] have recognized that A-W glass-ceramics show structure-oriented properties. Hence, the wear resistance of these materials could be customized to meet the requirements of dental applications.

The purpose of this present study is to assess wear of a glass-ceramic in the MgO-CaO-SiO_2-P_2O_5-F system, and to compare its wear properties with six different commercial dental ceramics. Hardness of the materials was also measured since it is one of the important properties in selecting materials for restorative dentistry.

2. MATERIALS AND METHODS

The details for the preparation of the two apatite-wollastonite glass-ceramics studied in this investigation (A-W GC1 and A-W GC2) and the procedure for the determination of the tribological properties were given in the previous publication [11]. A-W GC1 is the sample on which the tests were performed on the free surface. It mutually contains apatite and wollastonite phases. A-W GC2 is obtained after removing 0.5 mm from the free surface of A-W GC1 through mechanical grinding and polishing. Phase analysis revealed that it consists of apatite phase only.

Table 1: The materials studied and their manufacturer. The commercial dental materials are identified only for comparison purpose. They do not imply endorsement by the authors or institution supporting this work.

ID Code	Material	Manufacturer
A-W GC1	A-W Glass-ceramic 1	This study
A-W GC2	A-W Glass-ceramic 2	This study
CCS1	Cergo ceram DC2 dentin porcelain	Degudent GmbH
CCS2	Cergo ceram S1 incisal material	Degudent GmbH
CPC	Cergo pressable ceramic Dentin A2, (type 2, class 1)	Degudent GmbH
E2	IPS Empress 2, Ingots 100, (type 2, class 1)	Ivoclar Vivadent
SPE1	Super porcelain EX-3 A_2B dentin	Noritake Dental Supply
SPE2	Super porcelain EX-3 E_2 enamel	Noritake Dental Supply

The details of the six commercial dental materials studied are given in Table 1. The commercial dental materials were obtained in powder or pressable ingot form from the manufacturers. Three test samples of each material were fabricated according to the instructions quoted by the manufacturers. The nominal dimensions of the disk-shaped specimens were 12×2 mm (diameter and thickness). The opposite faces of the test specimens were polished to assure the surface smoothness and parallelism prior to the wear tests. The samples were ground flat by 240, 400, 800, and 1200 grit silicon carbide abrasive papers, polished consecutively with 1 and 0.3 μm alumina powder solution on a cltoh. Before the start and after the completion of the wear tests, a portable surface roughness tester (Taylor Hobson Precision Ltd.,UK) was employed to determine the surface roughness of the samples. Mean roughness (Ra) of the polished surfaces of the samples prior to the wear tests was adjusted to $0.15 \pm 0.01\,\mu$m.

The wear tests were performed at a load of 10 N, rotating speed of 0.25 cm/s, sliding distance of 50 m using a pin-on-disk tribometer (CSM Instruments, Switzerland). All of the tests were conducted at ambient atmospheric conditions at room temperature (25°C) and relative humidity between 50% and 60%. Lubrication was not applied to avoid the complication of tribo-chemical effects. The wear track diameter was 8 mm.

A high purity zirconia ball with 5 mm diameter was chosen as the antagonist since zirconia has recently achieved wide spread use in dentistry as a core material in fixed dental prostheses [12]. After each individual wear test, the wear track depth and wear area of the sample were measured by using the surface roughness tester. The wear volume of the sample was calculated by measuring the average worn area of each worn track on the disks following the wear test from the profiles recorded at four different locations across the wear track, and then by multiplying the cross-sectional area of each wear track by the circumference of the track. A window-based data acquisition software program (CSM Instruments, Switzerland) was used to determine the wear rates from the wear volumes calculated. The same software program was also used to monitor the friction coefficient in μ.

The hardness of the specimens was measured using a Knoop Hardness tester (Dukson tester, USA). At least five measurements were done at different locations through application of 500 gf for 15 seconds.

3. RESULTS AND DISCUSSION

Values of Knoop hardness (KH), wear rate, and mean friction coefficient for the materials studied are presented in Table 2. The numbers in parentheses indicate the ± standard deviation of the data from the averages. KH values of the materials studied varied from 509 (±8) H_V(for SPE2) to 671 (±5) H_V (for E2). The KH value of A-W GC1 was close to that of E2, being the second highest among the materials studied. The KH for A-W GC2 was within the range of the experimental error limits of that for CPC though it was not significantly different from the values for CCS1, CCS2, and SPE2.

The hardness values measured for A-W GC1 and A-W GC2 are in accord with the values reported in the literature for A-W glass-ceramics [13]. The results reveal that hardness of A-W GC1 is approximately 25% greater than that of A-W GC2. The difference is attributed to structure depended changes in properties caused by surface crystallization [11]. It is obvious that wollastonite content and variation in the crystal morphology between the surface and interior of the sample had an effect on the hardness. Similar results have been recently reported for E2 by Albakry et al. [3] who concluded that hardness anisotropy is seen due to the alignment of crystals. Based on the hardness values among the A-W glass ceramics and the commercially produced dental ceramics, it is foreseen that A-W GC2 is more compatible during direct contact with the natural dentition than A-W GC1.

Wear rate of the materials studied varied from 0.18 (±0.01) $\times 10^{-4}\,mm^3/N{\cdot}m$ (for E2) to 3.44 (±0.10) $\times 10^{-4}\,mm^3/N{\cdot}m$ (for SPE2). The wear rate of A-W GC1 was four times greater than that of E2, but it was still second lowest among the materials studied. The wear rate of A-W GC2 was not much different from that of the dentin porcelain materials such as CPC and CCS1. The wear rate of A-W GC1 and that of A-W GC2 are diverse. The difference is attributed to the variation of wollastonite content in these materials. No comparative data in the literature were found for the direct assessment of the results obtained on the wear rate of the materials studied. However, Clelland et al. [14] suggested that variations in ceramic composition and microstructure may

Table 2: Values of the hardness, wear rate, and friction coefficient for the materials studied.

Material	Knoop hardness (Hv)	Wear rate ($\times 10^{-4}$ mm^3/N·m)	Mean friction coefficient (μ)
E2	671 (±5)	0.18 (±0.01)	0.56
A-W GC1	650 (±12)	0.75 (±0.05)	0.75
SPE1	546 (±10)	2.38 (±0.26)	0.86
CCS1	527 (±9)	2.59 (±0.03)	0.83
CPC	521 (±3)	2.75 (±0.03)	0.84
A-W GC2	520 (±8)	2.93 (±0.15)	0.87
CCS2	514 (±5)	3.38 (±0.08)	0.85
SPE2	509 (±8)	3.44 (±0.10)	0.88

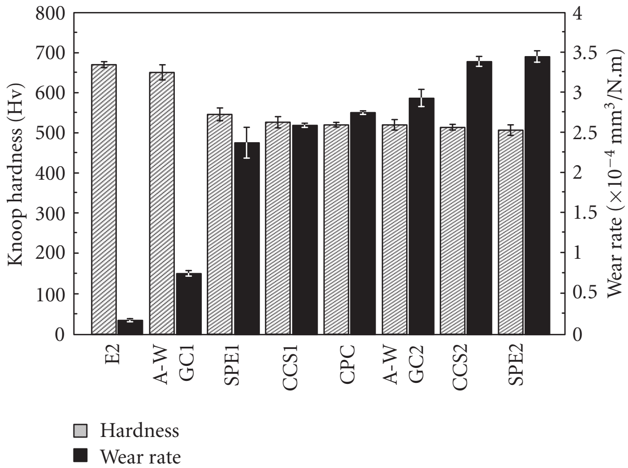

Figure 1: Knoop hardness and wear rate of the materials studied. The error bars indicate the ± standard deviation of the data from the averages.

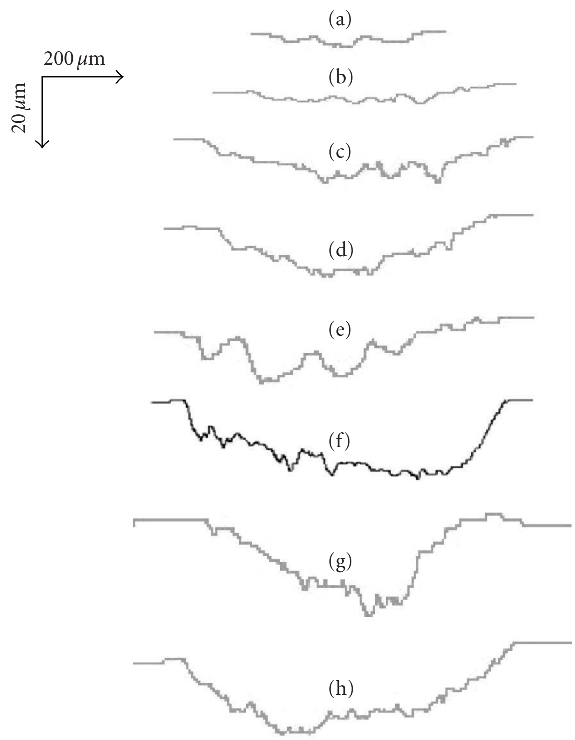

Figure 2: Wear track profiles obtained after wear tests of the materials studied. (a) E2, (b) A-W GC1, (c) SPE1, (d) CCS1, (e) CPC, (f) A-W GC2, (g) CCS2, (h) SPE2,

affect the opposing enamel wear. In terms of wear properties, A-W GC2 might be a choice of materials used in restorative dentistry in the regions where direct contact with natural dentition occurs since it wears out at approximately the same rate as the enamel it replaces, and does not increase the wear rate of an opposing enamel surface.

The results of this study suggest that there is an inverse relationship between the hardness and wear rate. The harder materials revealed more wear resistance as shown in Figure 1. Although similar results have been reported by Borgioli et al. [15], several studies have found no correlation between hardness and wear due to the complexity of the wear process [4, 16–18].

Materials having higher hardness exhibited relatively narrow and shallow wear tracks. This was apparent from the surface profile of wear tracks obtained after wear tests in Figure 2. The appearance of the surface profiles of the materials studied is different although the test conditions are identical. The difference in the appearance of wear tracks is attributed to the compositional and microstructural dissimilarity between the materials. E2 and A-W GC1 indicated smooth wear surfaces as compared to the other materials studied which exhibited much wider and deeper wear profiles implying material loss occurred during wear test. The surface profiles of the materials suggest that lower hardness results in less surface protection during the time of testing. It is probable that, in the absence of a lubricant, ceramic particles removed from the surface become part of the abrasive system and contribute to an increase in roughness rather than smoothing of the surface.

Mean friction coefficient (μ) of the materials studied varied from 0.56 μ (for E2) to 0.95 μ (for A-W GC2). Mean friction coefficient of A-W GC1 was close to that of E2, being the second lowest among the materials studied. Results of μ for the commercial dental materials studied are within the ranges of the values published in the literature [19, 20]

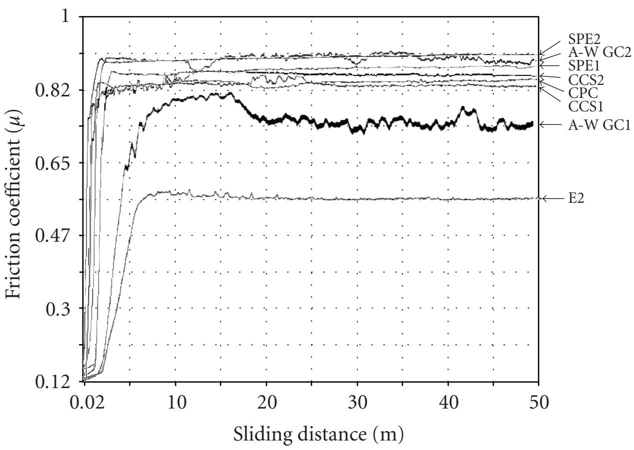

Figure 3: Variation in the friction coefficient with sliding distance for the materials studied.

although the zirconia ball was used as a counterface material and the test conditions were not identical.

Representative curves showing the variation of μ with sliding distance are illustrated in Figure 3. The μ of the materials studied was minimal at the beginning of the testing but increased rapidly and reached a steady state with increasing sliding distance. It is evident that A-W GC1 displays lower μ than the other materials studied, except E2. However, A-W GC2 has the second highest μ of all the materials studied. In general, materials comprising higher hardness exhibited relatively lower μ than those having lower hardness. Based on the friction values, A-W GC2 may be utilized as a material in restorative dentistry in the regions where natural dentition is in contact with restorative material if the problems associated with its bioactivity are somehow defeated.

4. CONCLUSIONS

Glass-ceramics produced in the MgO-CaO-SiO_2-P_2O_5-F system have appropriate wear properties and hardness to reflect their application to restorative dentistry. They are potential restorative materials of choice when fabricating restorations that require moderate wear rate and hardness.

Apatite-wollastonite glass-ceramics show structure-oriented differences in the wear properties due to the variation in crystal morphology. It may be feasible to produce them in similar wear properties as exhibited by the natural dentition. The free surface of this glass ceramic exhibits similar wear properties with the commercial core materials such as E2 and CPC, while the interior part of it exhibits similar wear properties with the commercial dentin porcelain materials such as CCS1 and SPE1.

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