Wear and Flexural Strength Comparisons of Alumina/Feldspar Resin Infiltrated Dental Composites

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ABSTRACT

Introduction: Incorporating a feldspar chemical bond between alumina filler particles is expected to increase the wear-resistant and flexural strength properties.

Aims and Objectives: An investigation was carried out to evaluate the influence of the feldspar chemical bonding between alumina filler particles on wear and flexural strength of experimental alumina/feldspar dental composites. It was hypothesized that wear resistance and flexural strength would be significantly increased with increased feldspar mass.

Methods: Alumina was chemically sintered and bonded with 30% and 60% feldspar mass, silanized and infiltrated with UDMA resin to prepare the dental restorative composite material.

Results and conclusions: Higher wear-resistant characteristics resulted with increased feldspar mass of up to 60% ($p<0.05$). Higher flexural strength characteristics resulted as the feldspar mass was increased up to 60% ($p>0.05$). Feldspar chemical bonding between the alumina particles may improve on the wear-resistance and flexural strength of alumina/feldspar composites.

INTRODUCTION

The benefits of providing feldspar chemical bonding between alumina filler particles is seen because the silane bond to alumina deteriorates with time and water absorption, resulting in reduction in longevity and weakening of the composite material[2,3]. Addition of feldspar chemical bonding between alumina particles would reduce reliance on silane bonding since the chemical bond is expected to increase the strength of the composite material. Such a modification would influence the wear since it was also found that there is a positive correlation between wear resistance and impact strength[4].

Historically the initial dental composite materials did not provide the wear-resistant properties sought for posterior stress bearing areas [6-10]. With time the surfaces of these materials deteriorated substantially due to wear and fatigue[1,5,11]. Although the wear-resistance of dental composites have improved the surface deterioration combined with polymerization, shrinkage still contributes to caries and pulpal injuries around the restoration due to microleakage[12,14]. More recently dental composite materials have been reported to provide acceptable wear- resistance in posterior stress-bearing areas for small restorations[15]. Insufficient evidence to support acceptable wear-resistance of dental composite materials for dental composite bridges and large cusp bearing restorations suggests that wear for small restorations is less significant due to protection from surrounding tooth structures[15].

It was hypothesized that flexural strength and wear-resistant characteristics would increase significantly as the feldspar mass between the traditional size alumina filler particles (up to 50μm) was increased. Based on this information, the investigation was carried out to evaluate wear and flexural strength of feldspar bonding in experimental alumina/feldspar dental composites with that of SR ADORO®. SR ADORO® composite material was included in order to provide comparisons of the performance of experimental alumina/feldspar composites in relation to a dental composite material that sets a high standard with regard to wear resistance. Since no other resin infiltrated ceramic composite material exists (as an established dental product) for comparison with alumina/feldspar composites, SR ADORO® (filler particles dispersed in resin) was used because of its wear-resistant properties. The rationale was to choose a wear-resistant dental composite material with adequate flexural strength. If the wear resistance of alumina/feldspar composites could be improved on as compared to SR ADORO® without a reduction in flexural strength the desired results would be obtained.

SR ADORO® is a newly developed, wear-resistant, microfilled, light/heat-curing composite for full coverage veneers and partial veneers[2]. It was hypothesized that wear-resistance of alumina/feldspar composites that were infiltrated with urethane dimethacrylate (UDMA) resin would increase as the feldspar mass (chemical bond) between the alumina

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is increased. The experimental group with a wear-resistance higher than that of SR ADORO® will be recommended for commercial production, however on condition that the flexural strength will not be below that of SR ADORO®.

METHODS

Chemical bonding between alumina filler particles was introduced by incorporating feldspar which allows the traditional alumina particles (50μm and below, Figure 1a) to be bonded together chemically once fired (Figure 1b).

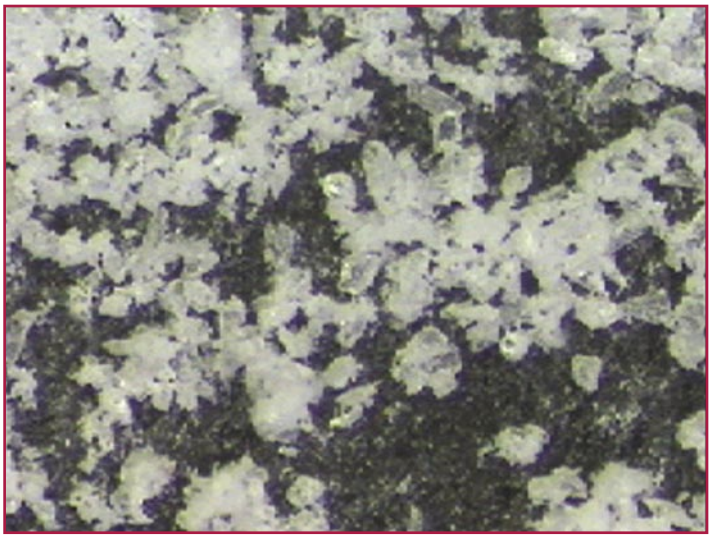


Figure 1a: Magnified image (with aid of a Nikon SMZ800 Microscope) depicting the distribution of alumina particles up to 50 μm.

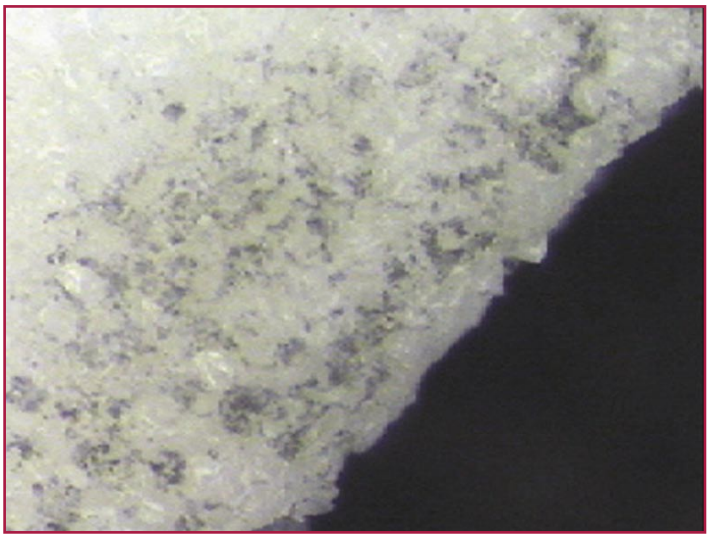


Figure 1b: Magnified Image of fired porous alumina/feldspar material before resin infiltration.

Sintered alumina, and alumina sintered with 30% and 60% feldspar mass were infiltrated with urethane dimethacrylate (UDMA) resin after firing. Thereafter, flexural strength and wear tests were performed with an Instron® mini 44 and a Minimet® polishing machine respectively.

Alumina sand of 50μm and below was used to produce sintered alumina (group 1), alumina with 30% feldspar mass (group 2), and alumina with 60% feldspar mass (group 3) experimental composites. Urethane dimethacrylate resin (5 drops) was placed on top of each fired specimen and allowed to infiltrate (due to gravity and capillary action) between the alumina/feldspar particles. SR ADORO® composite specimens were used as a comparison to determine which group of the experimental materials improved the most in terms of wear- resistant and flexural strength properties.

The alumina/feldspar specimens were fired at 1100°C for 10 minutes in a Vacumat® 300 porcelain furnace and thereafter infiltrated with UDMA and heat cured. Before UDMA infiltration the uncontaminated fired alumina/feldspar specimens were saturated for 60 seconds in silane (Monobond–S), according to manufacturer instructions. The specimens were then removed from the silane and air dried to form a single even layer (in a clean dust free cabinet) before UDMA infiltration. Table 1 provides information related to the materials used to manufacture experimental alumina/feldspar resin infiltrated composites.

Table 1: Manufacturers/supplier, purity, lot numbers and rationale for materials used to design experimental alumina/feldspar dental composites

Material	Manufacturer/ Supplier	Purity	Lot Number	Rationale for use of material
Feldspar (Vitadur N)	Nova dental Johannesburg (Vita Agent)	99.9%	Special kit no 12	CTE compatible with alumina to bond alumina filler particles
Alumina	Nova dental Johannesburg (Vita Agent)	99.6%	Special order 01/2003	Wear resistant filler
Silane (Monobond-S)	Ivoclar Vivadent Lichtenstein	100%	E 24026	To bond UDMA resin to alumina/ feldspar filler
UDMA resin	Ivoclar Vivadent Lichtenstein	100%	G23130	For resin infiltration

Specimen preparation and evaluation

One hundred and twenty 18mm x 5.6mm x 2,0mm specimens (30 specimens for each group 1, 2, 3 and SR ADORO®) were manufactured for wear analysis. The experimental material for each group was applied in a brass mould with a movable base to facilitate removal of each specimen. The base depth of the mould allowed the correct amount of alumina/feldspar to be built up so that after firing the specimens had a desired thickness of 2.0mm. The alumina/feldspar powder was mixed with distilled water and condensed into the brass mould for consistent production. The specimens were fired at a temperature of 1100°C. Incorporating more than 60% feldspar mass with alumina in order to improve wear resistant characteristics was not recommended because the pores between the alumina particles with 60% feldspar mass were reduced to such an extent that resin infiltration throughout was reaching a limit.

The UDMA resin was cured in a Sharp® R-341C microwave oven set on 1000W. Each specimen was cured for four minutes on a ceramic plate (specimens were turned at one min-

ute intervals). The specimens were prevented from bonding to the ceramic plate upon which they were cured by having them rest on 2 raised ceramic ridges on the ceramic plate.

Wear testing

A three body wear test was performed on each specimen using dentifrice (Mentadent P Micro Granules®, Unilever Durban) as the third body. The specimens were all placed in the same acrylic mould attached to a Minimet® polishing machine so that the amount of wear under the same conditions could be compared. Each specimen was tested using the Minimet® polishing machine set on speed 4 (240 oscillations at 6 oscillations/s), time setting 1 and minimum load setting 1 (variable load between 5 and 20 N). The Minimet® patented polishing action as observed by the first author of this paper involves 6 continuous small circular shifting cycles in simultaneously motion within a large circular movement contained within an 18 mm radius.

Each specimen was orientated so as to have one corner in contact with an opposing graphite surface at a 45° angle in order to facilitate measuring wear of a 90° cusp. The width of worn area on a magnified (22x) photographic image (with aid of a Nikon SMZ800 Microscope) was measured and thereafter divided by 22 in order to obtain actual specimen size measurements (mm).

Flexural strength testing

Comparative flexural strength tests with SR ADORO® were performed as follows:

Three point bending tests were conducted on 20 specimens (10 SR ADORO® specimens and 10 alumina with 60% feldspar mass specimens) by means of an Instron 44® universal testing machine (Apollo Scientific South Africa) operating at 95% confidence level. The Instron 44® test rate was set to a constant speed of 10 mm per minute. The specimens were placed between two smooth metal plates 10 mm apart, to allow free rotation during the flexure strength test. The Instron 44® universal testing machine contained a moving arm connected to a load cell that measured the maximum force exerted by the convex surface of a 7mm diameter steel rod as it applied a force through the centre of each specimen. At the point that the specimens fractured the force in Newtons (N) was recorded for each specimen.

Statistical analysis

One-way ANOVA specimen analysis comparing each group with SR ADORO® was performed on the wear and flexural strength data. Post HOC tests were conducted to evaluate the results between each tested group for wear and flexural strength.

RESULTS AND DISCUSSION

Wear results and discussion

Table 2 shows the wear results (mm) between the sintered/alumina; alumina with 60% feldspar; alumina with 30% feldspar mass and SR ADORO® composite specimens.

The SR ADORO® group gave a mean wear result of 1.38mm.

Table 2. Wear measurements (mm) of the four groups of materials tested ($p<0.05$).

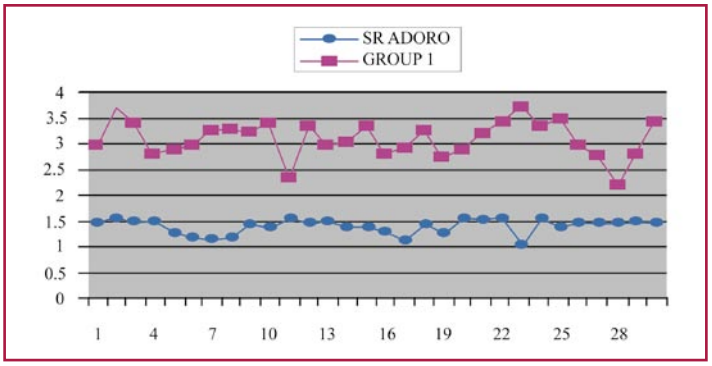
No.	Sintered alumina	60% Feldspar	30% Feldspar	SR ADORO®
1	2.95	1.22	2.95	1.45
2	3.68	1.20	2.50	1.54
3	3.38	1.13	2.95	1.50
4	2.77	1.22	2.59	1.50
5	2.86	1.09	2.31	1.27
6	2.95	0.97	2.59	1.18
7	3.22	0.94	2.50	1.13
8	3.25	1.13	2.59	1.18
9	3.20	1.13	2.18	1.43
10	3.36	0.95	2.54	1.38
11	2.31	1.31	2.50	1.54
12	3.31	1.09	2.00	1.45
13	2.95	1.22	2.36	1.50
14	3.00	0.81	3.40	1.36
15	3.31	1.09	2.50	1.36
16	2.77	1.04	2.45	1.27
17	2.90	0.77	2.40	1.09
18	3.22	1.27	2.77	1.43
19	2.72	1.04	2.50	1.25
20	2.86	1.18	2.63	1.54
21	3.18	0.77	2.50	1.52
22	3.40	0.95	2.04	1.54
23	3.68	1.22	2.54	1.00
24	3.31	1.36	2.22	1.54
25	3.45	1.18	3.09	1.36
26	2.95	1.45	2.95	1.45
27	2.77	1.06	2.68	1.47
28	2.18	1.27	2.50	1.45
29	2.77	1.22	2.54	1.50
30	3.40	1.12	2.36	1.45
Mean	3.06	1.11	2.43	1.38

This value was much lower than the mean result of 3.06mm for the sintered alumina specimen group. The SR ADORO® mean wear result (1.38mm) was also lower than the mean result of 2.43mm for the alumina with 30% feldspar mass specimen group. The SR ADORO® mean wear result (1.38mm) was however higher than the mean result of 1.11mm for the alumina with 60% feldspar mass specimen group. Only the alumina with 60% feldspar mass specimens provided higher wear resistance than SR ADORO®. The mean difference between all groups is significant at the 0.05 level. The statistical method applied was the univariate analysis of variance. Post hoc tests were conducted to evaluate the results between groups.

Sintered alumina specimens

Graph 1 illustrates that the sintered alumina specimens wear resistance was approximately half of that of the SR ADORO® specimen group. Higher standard deviation and standard error values indicated that the sintered alumina material will not

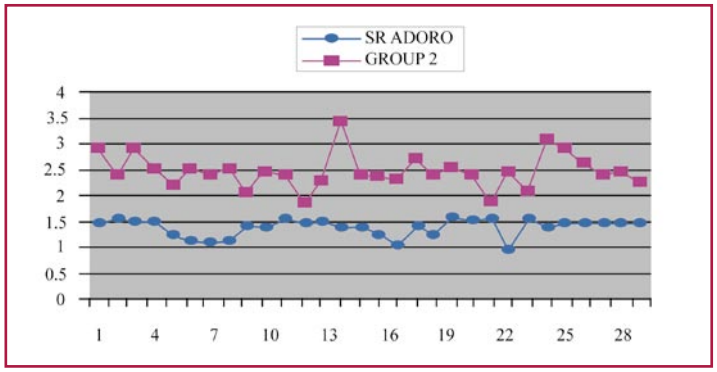
produce as consistent production results as the SR ADORO® composite material. This material was not recommended for commercial production since the wear resistant properties were not better than that of SR ADORO®.



Graph 1: Wear measurements (mm) of 30 group 1 specimens (sintered alumina) compared with 30 SR ADORO® specimens ($p<0.05$). Wear measurements are shown on the vertical axis and specimen number along the horizontal axis.

Alumina Specimens with 30% feldspar mass

Graph 2 is a graphical representation of the wear values (mm) of the alumina with 30% feldspar mass specimens compared to the wear values of the SR ADORO® composite specimens. The alumina with 30% feldspar mass group resulted in a higher mean wear than the SR ADORO® specimen group. Higher standard deviation and standard error values indicated that the alumina with 30% feldspar mass material will not produce results as consistent as the SR ADORO® composite material. This material did not meet the expected requirements set for commercial production since the wear resistance was not better than that of SR ADORO®. The need to introduce a more effective chemical bond is seen when compared to the results of Graph 1. These results indicate that silane bonding with alumina particles is not as effective as feldspar and silane bonding combined.



Graph 2: Wear measurements (mm) of 30 group 2 specimens (alumina with 30% feldspar mass) compared with 30 SR ADORO® specimens ($p<0.05$). Wear measurements are shown on the vertical axis and specimen number along the horizontal axis.

Alumina specimens with 60% feldspar mass

The majority of the alumina with 60% feldspar mass specimens showed a lower level of wear (Graph 3) than the SR ADORO® specimen group. Similarly the standard deviation and standard error values indicate that the alumina with 60% feldspar mass material will produce as consistent results as the SR ADORO® composite material. This material was recommended for commercial production on condition that the mean flexural strength would not be below that of SR ADORO®. These results indicate that silane bonding with alumina particles is not as effective as feldspar and saline bonding combined and that doubling the feldspar mass resulted in higher wear resistance (Table 2).

Since the alumina with 60% feldspar mass specimens showed improved wear-resistant characteristics as compared to the SR ADORO® composite specimens, the hypothesis that the incorporation of feldspar will result in improved wear-resistant properties was accepted. The failure of the alumina with 30% feldspar specimens to improve on the wear-resistance of SR ADORO® shows that further additions of feldspar were required supporting the hypothesis that increasing the mass of feldspar would result in increased wear-resistance since the alumina particles are more firmly bound together.

Improvements in wear-resistance obtained with the alumina with 60% feldspar group demonstrated that the wear-resistance of dental composite materials with alumina filler particles of up to 50μm can be improved by a chemical bond between filler particles, when a sufficient amount of feldspar is added to the alumina. Further evaluations on the reliance of silane bonding (which appeared restricted in relation to the influence of the feldspar mass increase) on wear-resistance of experimental alumina/feldspar composites should be performed to establish whether silane may be discarded completely from resin based dental composite materials. Unfortunately a limit was reached in improving wear-resistance by incorporating more than 60% feldspar mass with alumina because the pores between the alumina/feldspar particles were reduced to such an extent that resin infiltration throughout was reaching a limit. Graph 3, illustrates the wear-resistant benefits of incorporating 60% feldspar mass with alumina as compared to the wear-resistance values of the SR ADORO® composite specimens.

Graph 3: Wear measurements (mm) of 30 group 3 specimens (alumina with 60% feldspar mass) compared with 30 SR ADORO® specimens ($p<0.05$). Wear measurements are shown on the vertical axis and specimen number along the horizontal axis.

Flexural strength results and discussion

Table 3 shows the results (N) of the flexural strength tests between the alumina with 60% feldspar mass and SR ADORO® composite specimens. The flexural strength comparisons of the alumina with 60% feldspar mass specimens were compared to flexural strength values of the SR ADORO® composite specimens. The SR ADORO® group gave a mean result of

Table 3. Flexural strength measurements (N) of the 60% Feldspar mass with alumina and SR ADORO® composite specimens (p>0.05).

No	SR ADORO®	60% feldspar
1	127.40	122.80
2	148.70	103.70
3	139.20	142.90
4	114.00	132.10
5	89.40	124.40
6	111.70	132.30
7	91.49	90.74
8	112.0	150.10
9	97.83	136.20
10	123.20	131.70
Mean	115.49	119.79

115.49 N. This value was slightly lower though comparable to the 119.79 N mean value of the alumina with 60% feldspar mass specimens. The mean difference between flexural strengths of the two groups was not statistically significant ($p>0.05$). The statistical method applied was the univariate analysis of variance. Post hoc tests were conducted to evaluate the results between groups.

Flexural strength comparisons between the SR ADORO® and alumina with 60% feldspar mass specimens showed that flexural strength of the alumina with 60% feldspar mass specimens improved, though not significantly ($p>0.05$). The condition that the mean flexural strength should not be below that of SR ADORO® was met. In order to improve on wear- resistant properties of dental composite materials the alumina with 60% feldspar mass composite group is recommended for commercial production. Further investigations to improve the flexural strength of this material by using different infiltration resins, curing techniques and adhesive bonding techniques should be done.

CONCLUSIONS AND RECOMMENDATIONS

In an attempt to improve the wear-resistance and flexural strength of dental composites the silane bonding between the alumina filler particles was replaced with feldspar in order to provide a chemical bond. The addition of a chemical bond between the alumina particles in order to improve on the physical properties of SR ADORO® was successful when alumina with 60 % feldspar mass was added to the alumina powder. With the alumina with 60% feldspar mass specimens the wear was significantly improved compared to SR ADORO®. As the feldspar mass was increased both the wear-resistance and flexural strength of the experimental materials were increased providing support in accepting the hypothesis of this study. The flexural strength difference, although not significantly higher, was slightly better than that of SR ADORO®. Wear and strength improvement by incorporating higher feldspar mass than 60% was not recommended because the pores between the alumina with 60% feldspar mass were reduced to such an extent that resin infiltration throughout was at a limit.

It is recommended that the alumina material with 60% feldspar mass be investigated for use as a new generation dental composite material due to its potential advantages in wear- resistance and flexural strength. Further improvements to wear-resistance and flexural strength of experimental alumina/feldspar resin infiltrated composites by using different infiltration resins, curing techniques and adhesive bonding should be investigated.

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