Flexibility of Experimental Alumina/Feldspar and SR ADORO® Dental Composites

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ABSTRACT

Introduction: Flexure of a dental composite can be detrimental to the success of a restoration. Flexibility considerations are thus important when comparing dental materials to optimize the success of resin restorations.

Aims and objectives: Flexibility of 5.6 x 18.0 x 2.0 mm^3 experimental alumina/feldspar and SR ADORO® dental composites specimens were compared. It was hypothesized that alumina/feldspar composites would be less flexible under a load than SR ADORO® composites and that the flexibility would decrease significantly as the feldspar content was increased.

Methods: Alumina was chemically sintered or bonded with 40%, 50% and 60% feldspar mass, silanized and infiltrated with urethane dimethacrylate (UDMA) to prepare the alumina/feldspar dental restorative composite specimens. Three point bending tests were performed in the Instron 44® machine for flexural comparison to SR ADORO®.

Results and conclusions: The alumina/feldspar specimens showed lower flexibility (mm displacement) than SR ADORO® ($p<0.05$). Accurate flexibility comparisons were performed with 5.6 x 18.0 x 2.0 mm^3 specimens. Flexibility comparisons performed with 5.6 x 18.0 x 2.0 mm^3 specimens indicated that experimental alumina/feldspar dental composites may provide added marginal seal benefit. However confirmation via in vivo function of alumina/feldspar dental composites is recommended.

INTRODUCTION

Although the focal area of this paper compares the flexibility of dental composites it is important to first define the dental composite materials involved, since the experimental alumina/feldspar material design provides a unique and novel dental material that requires clinical trials.

Most dictionaries define a composite material under the following two points:

1. A structure or an entity made up of distinct components.
2. A complex material in which two or more distinct, structurally complementary substances combine to produce structural or functional properties not present in any individual component.

Although other materials such as metals and ceramics may be referred to as composites, in dentistry the definition of a dental composite is also given as "A highly cross-linked polymeric material reinforced by a dispersion of amorphous silica, glass, crystalline, or organic resin filler particles and/or short fibers bonded to the matrix by a coupling agent"[2]. This definition of a dental composite as applied to available resin composite materials may create some confusion in the dental profession as experienced with experimental alumina/feldspar resin infiltrated dental composites, since the alumina particles undergo a chemical bond before being enveloped and infiltrated with resin. In order to avoid controversy, that might surround defining and classifying new materials and for the purpose of this comparative study, a dental composite refers to the dictionary definition since it comprises a complex material in which two or more distinct, structurally complementary substances combine to produce structural or functional properties not present in any individual component; and includes at least two different compounds that are not chemically soluble, or bonded together to provide the distinction found in resin composite materials[2]. Having defined the dental composites relation for this study (and in doing so potentially opening the debate regarding whether dental resin based composites have been adequately defined in dentistry), flexibility of the materials in question can be considered.

FLEXIBILITY OF DENTAL COMPOSITE MATERIALS

Flexibility evaluation of dental composite materials is important since the marginal seal of composite bridges and inlays may be affected as a result of cyclic functional loading[1]. The stiffness of dental composite materials should be as high as possible in order to withstand compressive, flexural and shear stresses[2]. Marginal leakage that occurs from flexural and shearing stresses is increased as a result of wear that causes deformation to the bonded composite around the margins[3,4].

Marginal leakage, due to the plasticity of resin that increases flexibility of composites around the margins, has been limited when compared to composite shrinkage stress analysis[5-15]. Factors that prevent flexure should be considered more extensively in order to reduce marginal leakage.

Information regarding design influence as a result of flexibility of composites and resultant marginal leakage due to the plasticity

of resin is also limited[16]. Flexibility of composites is an important biomechanical consideration since forces on the unsupported top-middle area of a bridge pontic will tend to displace the most extreme mesial and distal margins of the bridge most. The area of the margin affected may change depending on the direction of the force applied, however the concentration of stress will still be referred to the marginal area. Bridge flexibility and influence on marginal seal can be visualized by viewing forces acting on a beam (representing a bridge) suspended between two stands (representing tooth support of the bridge) (Figure 1).

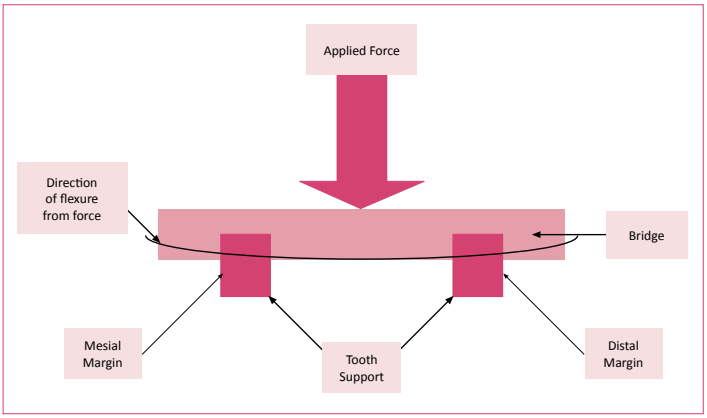


Figure 1: Schematic depicting the likely displacement (of mesial and distal margins) of a bridge

The composite material must resist flexure as far as possible in order to prevent marginal seal distortion and failure of the cementing agents. Li *et al*., (*2004*) supplied some understanding to composite bridge design by using finite element analysis (FEA) in order to quantify specific stress and displacement distributions within the analysis domain[17,18]. According to Li *et al*, (2004) the fundamental composite bridge model consisted of five different material parts:

(i) abutment dentin,
(ii) crown (enamel),
(iii) composite pontic,
(iv) reinforced fibre,
(v) adhesive layers on abutment/pontic, abutment/fibre and pontic/fibre interface[17,18].

With FEA (limited to linear elastic evaluation) Li *et al*, (*2004*) found that the highest stress levels are distributed from the pontic to the margins and the connectors[17,18]. The high marginal stress was not counted as a failure stress because the strength of abutment is generally much higher than that in the connector of the bridge. Finite element analysis applied to bridges by Li *et al*, (*2004*), unfortunately, focused on material failure and not marginal seal failure which is just as critical to longevity[17,18]. Poor analysis regarding the influence of flexibility on composite margin integrity restricts knowledge on optimum bridge design[19,20]. The need to reduce flexibility is however acknowledged by Visvanathan *et al*, (*2007*) who report that improving flexural modulus and flexural strength will yield better marginal integrity[1].

Obtaining modulus of elasticity values for some dental composites are problematic because ISO specifications require a specimen length of 25mm which in turn requires the material curing to be overlapped because of restricted curing areas[21]. The 25mm specimens are in addition larger than tooth size[22-27]. The performance of 25mm long specimens for modulus of elasticity permits comparison of all dental materials, but not in relation to flexure perimeters experienced clinically. Flexibility tests of smaller specimens limits comparisons to various materials of similar size that undergo the same flexibility test conditions since calculation of a modulus of elasticity value may not be possible. Nevertheless flexibility tests comparisons of smaller specimens are suggested to be examined as a more practical comparative tool to test composite rigidity[22-27]. This study was restricted to flexibility of alumina/feldspar and SR ADORO® specimens within clinical perimeters and as a result the modulus of elasticity of alumina/feldspar resin infiltrated composites was not determined.

This study compared the influence of three variations of the feldspar chemical bond on flexibility of alumina/feldspar resin infiltrated composites with the flexibility of SR ADORO® composites. Increasing feldspar chemical bond between alumina particles was expected to reduce the flexibility of the material as compared to SR ADORO®.

MATERIALS AND METHODS

In order to reduce inconsistencies in production and to obtain optimal test measurements the SR ADORO® specimens were obtained from the manufacturing company (Ivoclar Lichtenstein) and machined to size (5.6 x 18.0 x 2.0 mm^3). The alumina specimens (5.6 x 18.0 x 2.0mm^3) of particle size ≤50µm, with 40%, 50% and 60% feldspar mass were treated with silane and infiltrated with urethane dimetacrylate (UDM) after they were fired at 1100°C. The specimens were treated with 3 drops of silane (Monobond S®), and allowed to dry for 12 hours before being infiltrated with UDM resin for a further 24 hours to ensure complete infiltration of the pores. UDM resin infiltration from gravity and capillary action was obtained by placing excess resin on top of each specimen. The specimens were placed between two smooth metal plates 10mm apart; to allow free movement during the flexure strength test and resultantly the flexibility measurements for all the specimens are relevant to specimen measures of 5.6 x 10.0 x 2.0mm^3.

Excess UDM was wiped from the specimens after infiltration using tissue paper before they were cured in a Sharp® R-341C microwave oven set to 1000W. Each specimen was cured for four minutes on a ceramic plate (specimens were turned at one minute intervals). The alumina/feldspar mix was applied in a depth gauge (Figure 2).

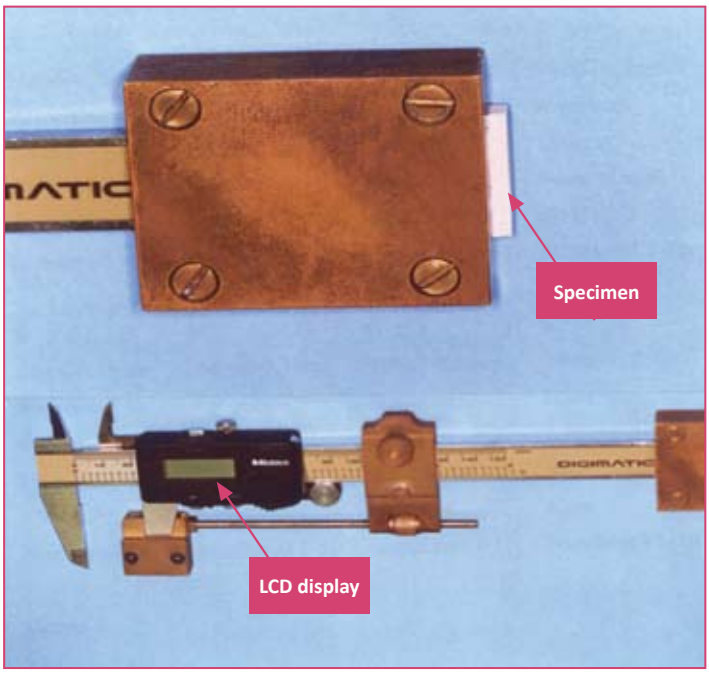


Figure 2: Depth gauge for the alumina/feldspar layering technique

Table 1: Firing cycle for alumina/feldspar specimens

Cycle	Temperature	Time
Holding time:	600°C	3 minutes
Temp increase:	68°C	6 minutes
Final temp:	1100°C	10 minutes
Vacuum:	600°C to 1020°C	15 minutes

The alumina/feldspar powder was mixed with water to a creamy paste consistency and applied with a brush into the brass rectangular container attached to the measuring device of the depth gauge. The particles were condensed by tapping the sides of the container and removing the excess water, with the aid of a hair dryer. The rectangular shaped alumina specimens were pushed out with the plunger and fired on a honeycomb firing tray (1100° C for 10 minutes) to produce a fired porous structure that was ground to a consistent specimen thickness (2.0mm). The firing cycle is indicated in Table 1.

The maximum volumetric variation (uncompensated firing shrinkage) for all specimens was 3.5 %. Forty alumina/feldspar specimens (10 for each feldspar mass variation and ten SR ADORO® specimens) were evaluated. Flexibility measurements just prior to fracture (mm) for the specimens were obtained using an Instron® mini 44 testing machine. The material, suppliers, purity, lot numbers and rationale for use to manufacture the experimental alumina/feldspar specimens are given in Table 2.

FLEXIBILITY TESTING

Prior to the flexibility tests each specimen was subjected to the Minimet® polishing cyclic wear described by Le Roux (2008)[28].

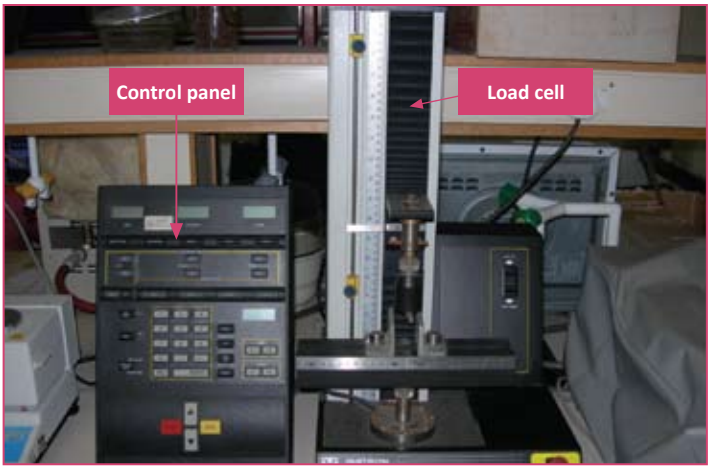


Figure 3: Instron® 44 Testing Machine

The 3 point flexural bending tests were conducted by means of the Instron 44® (Figure 3) universal testing machine (Apollo Scientific CC South Africa) operating at 95% confidence level. The Instron® 44 was set so that specimens fractured at a constant speed of 10 mm per minute. The specimens were placed between two smooth metal plates 10 mm apart, to allow free movement during the flexure test. At the point that the specimens fractured (first fatigue value) a reading of amount of possible flexure (mm) for each specimen was recorded.

Statistical Analysis

One-way ANOVA comparing each alumina/feldspar group with SR ADORO® was performed as well as Post HOC tests to evaluate the results between the alumina/feldspar groups (for each alumina mass variation).

RESULTS

Table 3 depicts the mean, flexibility value (mm), standard deviation (SD), coefficient of variance (CV) and p-values, for flexibility of the SR ADORO® and 3 alumina/feldspar sample groups.

The SR ADORO® group gave a mean flexibility value of 0.38mm which was significantly different to the Alumina/Feldspar groups. There were significant differences between the alumina feldspar groups as well with the 40% Feldspar group, the 50% Feldspar group and the 60% Feldspar group resulting in mean flexibilities of 0.22mm, 0.17mm and 0.19mm respectively ($p< 0.01$). The Standard Deviation (SD) for the SR ADORO®, the 40% Feldspar group, the 50% Feldspar group and the 60% Feldspar group were 0.06, 0.05, 0.10 and 0.09 respectively. The Coefficient of variance for the SR ADORO®, the 40% Feldspar group, the 50% Feldspar group and the 60% Feldspar group were 15.78, 22.72, 58.82, and 47.36 respectively.

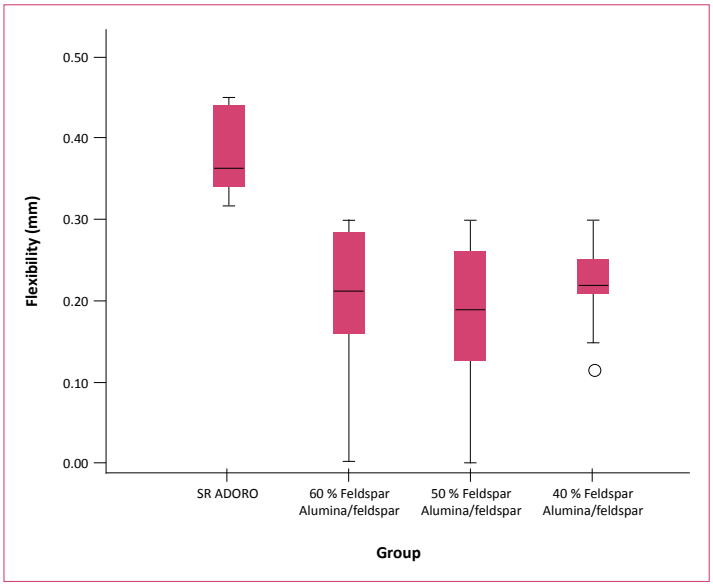
Statistical p-values (< 0.05) indicated that the sample size (n=10) for each group was sufficient for comparison using One-way ANOVA and Post HOC tests. The alumina/feldspar specimens showed lower flexibility (mm displacement) than SR ADORO® ($p<0.05$) (Graph 1). Small significant (< 0.05) mean flexibility

Table 3: Mean flexibility value (mm), standard deviation (SD), coefficient of variance (CV) and p-value between groups.

	SR ADORO (n=10)	60% Feldspar (n=10)	50% Feldspar (n=10)	40% Feldspar (n=10)
Mean	0.38	0.19	0.17	0.22
SD	0.06	0.09	0.10	0.05
CV	15.78	47.36	58.82	22.72
P-value	< 0.01	< 0.01	< 0.01	< 0.01

Table 2: Manufacturers/suppliers, purity, lot numbers and rationale for materials used to design experimental alumina/feldspar dental composites.

Material	Manufacturer/ Suppliers	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
SR ADORO®	Ivoclar Vivadent Lichtenstein	Manufacturer specifications	Special order	For flexibility comparison



Graph 1: Mean flexibility (mm) of alumina/feldspar and SR ADORO® specimens

differences were observed between the alumina/feldspar groups (Table 3). Graph 1 depicts the median (50th percentile), 25th and 75th percentiles (interquartile range) as well as the range of values for each group.

DISCUSSION

The hypothesis, that the alumina/feldspar resin infiltrated composites would flex less than the SR ADORO® specimens, was accepted, since the mean flexibility of all three alumina/feldspar specimen groups where virtually half as much as the SR ADORO® group (Graph 1). The mean differences between the alumina/feldspar groups were not linear with the 10% linear increase in feldspar mass. The hypothesis that an increase in feldspar mass would reduce the flexibility of alumina feldspar resin infiltrated composites was rejected. The 50% feldspar mass group provided the most resistance to flexibility and flexibility increased slightly as the feldspar mass was increased or decreased by 10% from the 50% feldspar by mass group. The small flexibility differences between alumina/feldspar groups suggest that these composites may behave more like a ceramic material than a composite material as a result of the chemical ceramic bond that existed throughout the alumina/feldspar structure. Comparative behaviour of alumina/feldspar resin infiltrated composites with ceramic specimens can only be determined through further flexibility comparisons with ceramic specimens.

RECOMMENDATIONS

Experimental alumina feldspar composites are expected to result in less marginal stresses due to greater flexure resistance than SR ADORO®, though it is recommended that this hypothesis still needs to be tested in vivo. Should the alumina/feldspar resin infiltrated dental composites be developed for commercial use as a dental composite material (or to be established in a different class as a result of variations in defining and establishing dental material classification), the modulus of elasticity would need to be established for each feldspar mass variation. Further recommendation is that comparative behaviour of alumina/feldspar resin infiltrated composites be determined through further flexibility comparisons with ceramic specimens in order to determine similarities in flexure resistance.

CONCLUSION

Statistically relevant comparisons were possible between all sample groups using flexibility (mm) rather than modulus of elasticity data. From the results of this study the alumina/feldspar resin infiltrated composites were less flexible than the SR ADORO® composite specimens. Flexibility differences, though statistically different, between the Alumina/Feldspar groups were small in comparison to that of SR ADORO®.

Although flexibility of the specimens were restricted to comparisons of the material groups in this study and not relevant to comparisons of other materials because the modulus of elasticity of the alumina/feldspar resin infiltrated composites could not be determined, the importance of comparing and understanding the need to reduce flexibility of dental composites has been highlighted.

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Additional references (20-28) are available on www.sada.co.za