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On the interfacial fracture resistance of resin-bonded zirconia and glass-infiltrated graded zirconia

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ABSTRACT

Objective. A major limiting factor for the widespread use of zirconia in prosthetic dentistry is its poor resin-cement bonding capabilities. We show that this deficiency can be overcome by infiltrating the zirconia cementation surface with glass. Current methods for assessing the fracture resistance of resin-ceramic bonds are marred by uneven stress distribution at the interface, which may result in erroneous interfacial fracture resistance values. We have applied a wedge-loaded double-cantilever-beam testing approach to accurately measure the interfacial fracture resistance of adhesively bonded zirconia-based restorative materials.

Methods. The interfacial fracture energy G_C was determined for adhesively bonded zirconia, graded zirconia and feldspathic ceramic bars. The bonding surfaces were subjected to sandblasting or acid etching treatments. Baseline G_C was measured for bonded specimens subjected to 7 days hydration at 37 °C. Long-term G_C was determined for specimens exposed to 20,000 thermal cycles between 5 and 55 °C followed by 2-month aging at 37 °C in water. The test data were interpreted with the aid of a 2D finite element fracture analysis.

Results. The baseline and long-term G_C for graded zirconia was 2–3 and 8 times greater than that for zirconia, respectively. More significantly, both the baseline and long-term G_C of graded zirconia were similar to those for feldspathic ceramic.

Significance. The interfacial fracture energy of feldspathic ceramic and graded zirconia was controlled by the fracture energy of the resin cement while that of zirconia by the interface. G_C for the graded zirconia was as large as for feldspathic ceramic, making it an attractive material for use in dentistry.

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1. Introduction

In recent years, zirconia has emerged as a promising restorative material for dental crowns and fixed dental prostheses due to its superior mechanical properties and excellent biocompatibility. However, owing to its chemical inertness zirconia suffers from poor bonding to adhesive resin cements, which greatly limits its applications in adhesively bonded dental restorative prostheses such as Maryland bridges, cantilever bridges, partial crowns, inlays and onlays. Several surface treatment approaches for improving zirconia-resin bonding were offered which may be categorized as mechanical, chemical or a combination of both. Successful examples for mechanical treatments are sandblasting with alumina particles [1–3] and porous nano-structured alumina coating [4–6], whereas those for chemical treatments include thin silica-based coatings [7,8] and surface functionalization using various chemical treatments [9,10]. Chemo-mechanical treatments have also been widely used for this purpose, including co-jet sandblasting [11] and more recently surface glass-infiltration [12,13]. It has been reported that modification of zirconia surface by glass-infiltration improves the esthetics of dental crowns [14], as well as flexural strength [6,15–17] and resistance to veneer/core delamination [18] yet without compromising key mechanical properties such as resistance to occlusal cracking [14,19] and edge chipping [20,21]. An important benefit of this approach in the present context is that it provides a glass rich surface that allows the application of standard etching-silane cementation techniques. The resin-cement bonding quality of the surface of the glass-infiltrated graded zirconia, the latter to be referred here as "graded zirconia", has not been examined, however.

A number of testing approaches for evaluating bond strength in applications to restorative prosthetic materials have been suggested, the most commonly used in adhesive dentistry being the shear bond strength (SBS) and microtensile bond strength (MTBS) (e.g., [22–24]). Such methods have been used to evaluate the effect of surface treatment or thermocycling of ceramic restorative materials [25,26]; thermocycling has been used extensively to simulate aging of resin cement in an intra-oral environment [9,27]. While relatively simple, such testing concepts are generally marred by large variations in the bond failure stress, the effect that may be attributed to the joint's sensitivity to geometric misalignments and the tendency for tensile stresses to concentrate at the bond terminus [28,29]. An alternative means for assessing bond strength is the use of fracture mechanics. In this approach, the bond includes an initial crack starter which facilitates a smooth crack initiation and growth thus eliminating the sensitivity to flaws and stress gradients and reducing the effect of geometric misalignments. The quantity of interest in this case is the fracture energy (per unit area) needed to extend the starting crack, G_C, rather than the failure stress. A popular means for evaluating G_C in applications to adhesively bonded joints is the double-cantilever-beam (DCB) specimen. In this case, the bond is subjected to tensile stress at the crack tip, which is generally associated with the most critical form of fracture [30]. In addition to the relative ease in specimen fabrication and testing, the calculated fracture energy is little sensitive to the cement layer thickness [30,31], which may vary greatly in a clinical setting.

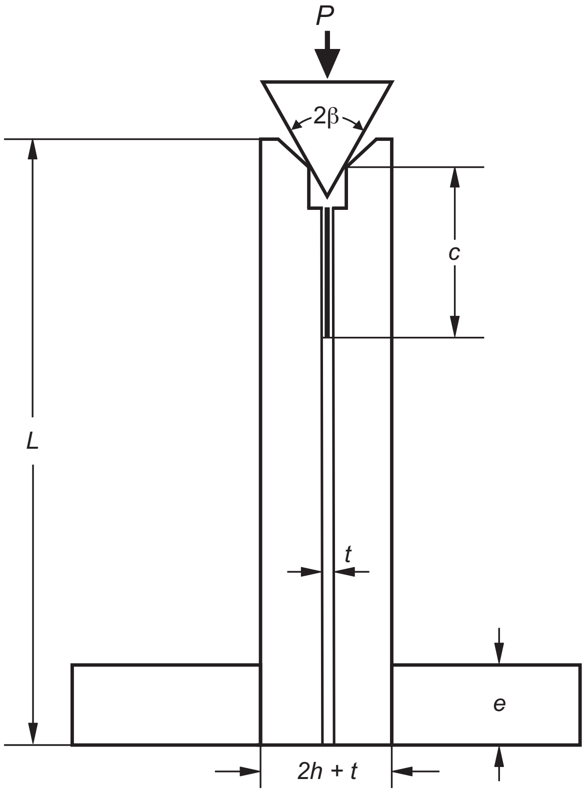

Fig. 1 – The wedge double-cantilever-beam (WDCB) adhesive bond specimen used. Pairs of bars (zirconia, graded zirconia, or feldspathic ceramic) are bonded by a resin composite. A crack starter is created using aluminum foil separator. The compression load P is applied by a 60° hardened steel wedge which is positioned on a 90° beveled clearance at the specimen edge. This load has a transverse component which opens up the crack faces.

In this work, we examined the efficacy of surface glass-infiltration on the resin-cement bond properties of zirconia. The interfacial fracture energy was determined using the DCB specimen. Both short-term (7 days hydration at 37 °C) and long-term (20,000 thermal cycles between 5 and 55 °C followed by a 2-month aging at 37 °C) in vitro simulations were considered. A widely used commercial dental feldspathic ceramic was chosen as a reference bonding material.

2. Materials and methods

Fig. 1 shows the wedge double-cantilever-beam specimen (WDCB) used. Details of the fabrication and testing procedures follow.

2.1. Materials

Three ceramic restorative materials were tested: zirconia, graded zirconia and feldspathic ceramic. The zirconia (5.18 wt.% Y_2O_3, TZ-3Y-E grade, Tosoh, Tokyo, Japan)