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Using glass-graded zirconia to increase delamination growth resistance in porcelain/zirconia dental structures

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ABSTRACT

Objective. Porcelain fused to zirconia (PFZ) restorations are widely used in prosthetic dentistry. However, their tendency to delaminate along the P/Z interface remains a practical problem so that assessing and improving the interfacial strength are important design aspects. This work examines the effect of modifying the zirconia veneering surface with an in-house felspathic glass on the interfacial fracture resistance of fused P/Z.

Methods. Three material systems are studied: porcelain fused to zirconia (control) and porcelain fused to glass-graded zirconia with and without the presence of a glass interlayer. The specimens were loaded in a four-point-bend fixture with the porcelain veneer in tension. The evolution of damage is followed with the aid of a video camera. The interfacial fracture energy G_C was determined with the aid of a FEA, taking into account the stress shielding effects due to the presence of adjacent channel cracks.

Results. Similarly to a previous study on PFZ specimens, the fracture sequence consisted of unstable growth of channel cracks in the veneer followed by stable cracking along the P/Z interface. However, the value of GC for the graded zirconia was approximately 3 times that of the control zirconia, which is due to the good adhesion between porcelain and the glass network structure on the zirconia surface.

Significance. Combined with its improved bonding to resin-based cements, increased resistance to surface damage and good esthetic quality, graded zirconia emerges as a viable material concept for dental restorations.

1. Introduction

Porcelain (veneer) fused to zirconia (PFZ) is commonly used in crowns and fixed dental prostheses (FDPs). However, as

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demonstrated in numerous clinical research [1–4] and laboratory fatigue studies [5–7] of PFZ restorations, delamination between porcelain and zirconia may become a detrimental factor once occlusal cracks grow all the way to the porcelain/zirconia (P/Z) interface. In general, when cracks in the porcelain veneer reach the veneer/core interface, they tend to graze along the interface before deflecting back into the porcelain veneer rather than penetrate the stiffer and tougher zirconia core [4,7]. This type of failure is motivated by the low interfacial fracture energy G_C of PFZ [8,9] as well as presence of deleterious residual tensile stresses, formed during the veneer firing or glaze firing process due to mismatch in thermal expansion coefficients between veneer and core and low thermal diffusivities characterizing both porcelain and zirconia [10–16]. The weak delamination resistance of the P/Z interface is generally attributed to the chemical inertness of the zirconia phase. Attempts at modifying the surface of the latter by techniques such as grit blasting or the use of an intermittent glass bonding layer between zirconia and porcelain generally yield only marginal improvement. More recently, a good improvement in shear bond strength was reported due to the application of a composite interlayer between porcelain and a zirconia substrate containing surface holes [17].

A promising concept for enhancing mechanical properties of dental restoration is the use of glass-ceramic infiltration techniques to produce functionally graded glass-zirconia materials [18]. A recent application of this approach to the bonding between resin-based dental cements and zirconia led to a considerable increase in the Mode I interfacial fracture energy [19]. This benefit, maintained under stringent testing program including thermal cyclic stressing, was due to the better adhesion between composite cement and the interconnected glass network in the graded zirconia surface. On the other hand, grit blasting of the zirconia bonding surface was of little consequence. Accordingly, in this work we explore the use of the graded zirconia approach for improving the fracture resistance of the P/Z interface.

Assessing interfacial strength of porcelain-veneered zirconia restorations is often done by subjecting the structure to some form of external forces and examining the ensuing fracture pattern [20–23]. While useful for routine material screening, the results are often marred by large experimental scatter reflecting sensitivity to flaws, geometric misalignments of the test specimen and loading fixture, and uneven stress distribution at the interface. These difficulties may be circumvented using fracture mechanics concepts, which involve the recording of crack lengths and associated load levels. The results are expressed in terms of fracture energy (per unit area) G_C. A popular test specimen for assessing interfacial strength is the four-point-bending (FPB) bilayer [24]. This specimen was used to determine interfacial fracture energy of porcelain fused to zirconia [8] or metal [9,25] copings. More recently, the FPB specimen was applied to glass/polymer [26] and PFZ [27] combinations where the evolution of damage was observed in situ using a high-power zoom lens. As demonstrated in Fig. 1, this approach revealed an interesting sequence of fracture events involving the growth of multiple channel cracks in the veneering layer, initiation of delamination from the tips of channel cracks, and stable growth

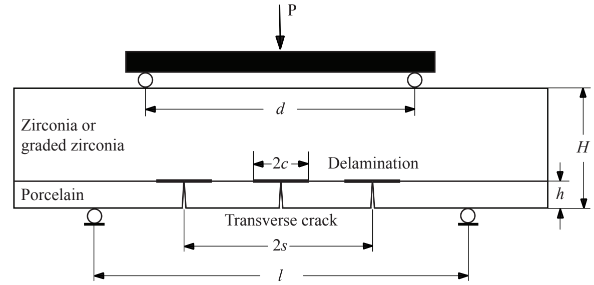

Fig. 1 – The four-point-bending apparatus used to determine the interfacial fracture energy of porcelain fused to zirconia or graded zirconia. The fracture model shown is based on in situ observations. In this work, the calculation of interfacial fracture energy G_C is limited to the onset of delamination growth ($c = 0$), as determined from the video footage.

of ensuing cracks along the veneer/core interface. A finite element analysis (FEA) of the fracture behavior showed that the presence of channel cracks greatly alter the delamination growth behavior and in turn the calculation of G_C [26,27]. In this study we examine the merit of using the glass-graded zirconia approach for improving fracture resistance in fused P/Z interfaces. The tests and data reduction schemes are much similar to those used in a previous study on unmodified PFZ systems [27].

2. Materials and methods

2.1. Specimen preparation

Three different material groups are used: porcelain fused to zirconia (PFZ), graded zirconia (PFGZ) and graded zirconia in the presence of glass interlayer (PFGGZ). Prior to veneering, the zirconia (Y-TZP, Tosoh TZ-3Y-E grade, CTE = $10.5 \times 10^{-6}\,K^{-1}$) surface was sandblasted with 50 μm Al_2O_3 particles for 5 s at a standoff distance of 10 mm and a compressed air pressure of 2 bars. The graded Y-TZP was prepared as described earlier [18]. Briefly, an in-house prepared glass with composition similar to dental porcelain in the form of powder slurry was first applied on pre-sintered Y-TZP (1350 °C for 1 h). Glass infiltration and densification occurred in a single process at 1450 °C for 2 h. This produced a structure consisted of a ~30 μm thick outer surface residual glass layer followed by a ~120 μm thick graded glass-zirconia layer where the content of intergranular glass gradually diminishes and finally transitions into a dense Y-TZP interior [18]. The glass-infiltrated zirconia bars were randomly divided into 2 groups. For the PFGGZ group, the surface residual glass was lightly polished with 6 μm diamond grits. For the PFGZ group, the surface residual glass layer was gently removed by polishing, again using 6 μm diamond grits, to expose the graded glass-zirconia layer. Prior to veneering, the recipient surface of the PFGZ and PFGGZ groups were etched with 4% hydrofluoric acid for 5 min, water rinsed and dried. A commercially available porcelain powder (Heraceram Zirconia, leucite-reinforced porcelain, CTE = $10.5 \times 10^{-6}\,K^{-1}$, Heraeus Kulzer GmbH, Hanau, Germany) was used to veneer