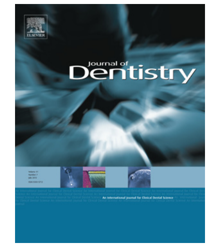
JOURNAL OF DENTISTRY 43 (2015) 335–341

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/jden



Laminated ceramics with elastic interfaces: A mechanical advantage?

Anna Karina F. Costa [a,b], Robert D. Kelly [a], Garry J.P. Fleming [c], Alexandre Luiz S. Borges [b], Owen Addison [a,*]

[a] Biomaterials Unit, University of Birmingham School of Dentistry, St. Chad's Queensway, Birmingham B4 6NN, UK
[b] Dental Materials and Prosthodontics Unit, Sao Jose dos Campos Dental School, Institute of Technology and Science, SP, Brazil
[c] Materials Science Unit, Dublin Dental University Hospital, Lincoln Place, Trinity College Dublin, Dublin 2, Ireland

ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form
15 December 2014
Accepted 18 December 2014

Keywords:
CAD/CAM
Bi-axial flexure strength
Fractography
Elastic interface
Lamination

ABSTRACT

Objectives: As CAD/CAM technologies improve we question whether adhesive lamination of ceramic materials could offer mechanical advantages over monolithic structures and improve clinical outcomes. The aim was to identify whether an adhesive interface (a chemically cured resin–cement) would influence the biaxial flexure strength (BFS) and slow-crack growth in a machinable dental ceramic.

Methods: Monolithic and adhesively laminated (with a chemically cured dimethacrylate resin–cement) feldspathic ceramic discs of identical dimensions were fabricated. BFS testing was performed on the Group A monolithic specimens ($n = 20$), on Group B laminated specimens with the adhesive interface positioned below the neutral bending axis ($n = 20$) and Group C laminated specimens with the adhesive interface positioned above the neutral bending axis ($n = 20$). To study subcritical crack growth additional laminated specimens received controlled indentations and were exposed to thermo-mechanical fatigue. BFS data was analysed using parametric statistics ($\alpha = 0.05$). Fractographic analyses were qualitatively assessed.

Results: No significant differences between the mean BFS data of Groups A and B were observed ($p = 0.92$) but the mean BFS of Group C was slightly reduced ($p < 0.01$). Lamination reduced the stiffness of the structure and fractographic analysis demonstrated that energy consuming crack deflection occurred. Thermo-mechanical fatigue caused subcritical extension of radial cracks associated with indentations adjacent to the adhesive interface. Crack growth was limited to parallel to the interface and was arrested or deflected in a direction normal to the interface.

Conclusions: Ceramic lamination increased the damage tolerance of the structure and could limit or arrest subcritical crack growth at regions near the 'interlayer'.

Clinical Significance: Lamination of a dental ceramic with a polymeric 'interlayer' could offer toughening effects which could potentially delay or arrest sub-critical crack growth at regions near the interface and thereby improve restoration longevity.

* *Corresponding author*. Tel.: +44 121 466 5506; fax: +44 121 466 5491.
E-mail address: addisono@adf.bham.ac.uk (O. Addison).

http://dx.doi.org/10.1016/j.jdent.2014.12.012
0300-5712/

1. Introduction

Over the previous two decades there have been significant developments in Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technologies for dental applications which now enable the fabrication of restorations from a range of materials, to a high level of dimensional accuracy.[1,2] More recently, ceramic CAD/CAM systems that employ a digital workflow to independently design and manufacture different layers of a dental restoration before they are subsequently joined together using an interface adhesive have been introduced.[3,4] The development allowed for ceramic core-veneer restorations to be manufactured with favourable residual stressing patterns.[3–5] The approach also reduces operator induced variability associated with the manual build-up of the veneering ceramic layer.[6,7] However, as CAD/CAM technologies improve further the question arises as to whether 'laminated structures consisting of multiple (possibly functionally graded) adhesively bonded ceramic layers could offer mechanical advantages that would improve clinical outcomes'?

The precedent for using adhesively laminated ceramics and glasses for structural purposes is widespread.[8–10] A large body of evidence from outside of the dental literature has demonstrated a modification of the mechanical properties of brittle materials when used in laminated structures such as thermal barrier coatings,[11,12] architectural laminated glass[13] and automotive windscreens.[14] Researchers identified adhesive lamination changes the pattern of fracture when compared with monolithic structures of equal composition and dimensions.[14,15] Investigations on glass substrates identified adhesive lamination reduces the effective stiffness of the structure whilst maintaining, or in some cases improving, the flexural strength.[16] The selection of interface material and laminate design can be tailored to modify the load bearing capacity of the particular system.[17] However, it has also been recognised that mechanical improvements can be unpredictable because of the brittle nature of the glass and the sensitivity to pre-existing defects and residual stress states.[17] A consequence of the interfaces created can be the inadvertent introduction of new strength limiting flaws which may be absent in the monolithic substrate but may ultimately determine the strength of the system.[17]

If processing routes can be identified to minimise the introduction of strength limiting defects, it is possible to 'toughen' a ceramic or glass structure by laminating with a polymer adhesive interface.[14] Therefore, on application of an external load, the laminating adhesive ('interlayer') can absorb energy elastically[17] and allow shear transfer, thereby, transporting the location of the load-reaction away from the concentrated point of application.[14] In the event where a crack does propagate through the 'interlayer', strain generated in the adhesive in the crack wake can act as a crack-bridge and arrest further extension.[10] Subsequently if one laminate layer fails, others can retain some load bearing capacity to retain overall function.[10] The flexural stresses generated in the 'interlayer' remain small in comparison due to a substantially lower elasticity of the typical 'interlayer' materials when compared with the ceramic or glass laminates.[10]

The overall objective of the current study was to investigate the concept of introducing polymer adhesive interfaces into dental ceramic materials to create laminated structures. The specific aim was to identify whether an adhesive interface (a chemically cured resin–cement) would influence the biaxial flexure strength (BFS) and slow-crack growth in a machinable feldspathic dental ceramic. Given the lack of evidence in this subject area the null hypotheses tested were that lamination would have no impact on both the BFS and the slow crack growth in a feldspathic dental ceramic.

2. Materials and methods

2.1. *Preparation of ceramic discs*

Feldspathic ceramic blocks (40/19 VITA Mark II–VITA, Bad Säckingen, Germany, LOT 36990) were rounded to a 15 mm diameter cylinder using a diamond impregnated core drill under copious water lubrication. The cylinders were sectioned to produce circular discs using a low-speed diamond impregnated saw (IsoMet Low Speed, Buehler, IL, USA) with water as a lubricant. The discs were manually polished on one surface using P120 silicon carbide abrasive paper followed by P500, P800, and P1200 (Struers, Glasgow, UK) to achieve final thicknesses of 1.50 ± 0.01 mm ($n = 20$); 1.00 ± 0.03 mm ($n = 43$) and 0.50 ± 0.02 mm ($n = 43$) measured using a digital micrometer accurate to 10 μm (Mitutoyo Corporation, Tokyo, Japan).

2.2. *Preparation of ceramic samples for biaxial flexure strength (BFS) determination*

Three different sample geometries were fabricated (Fig. 1). The polished surface of each 1.0 mm and 0.5 mm ceramic discs was etched with 9.6% hydrofluoric (HF) acid gel for 60 s (Ultradent Porcelain Etch, Ultradent Products, Cologne, Germany), thoroughly washed with water and allowed to air dry. The etched surface was silane coated (Ultradent Silane, Ultradent Products, Cologne, Germany) and allowed to air dry for 10 min. Group A specimens were 1.5 mm thickness

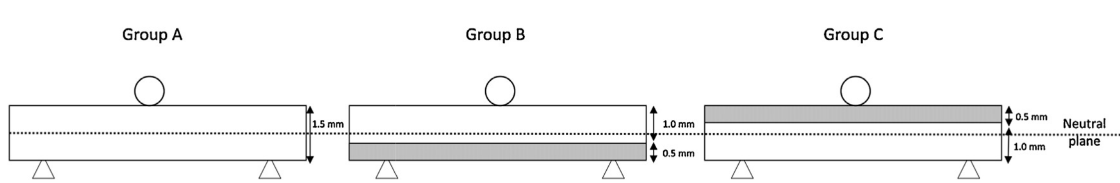


Fig. 1 – Schematic representation of the ceramic specimens from Group A (monolithic), Group B (adhesive interface below the neutral plane during BFS testing), Group C (adhesive interface above neutral plane during BFS testing) investigated in the study.