DENTAL MATERIALS 27 (2011) 1252–1258

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Failure responses of a dental porcelain having three surface treatments under three stressing conditions

Yang-Jin Yi[a], J. Robert Kelly[b,*]

[a] Department of Prosthodontics, Section of Dentistry, Seoul National University Bundang Hospital, Seongnam, Republic of Korea
[b] Department of Reconstructive Sciences, Center for Biomaterials, University of Connecticut Health Center, 263 Farmington Avenue, Farmington, CT 06030-1615, USA

ARTICLE INFO

Article history:
Received 20 June 2011
Received in revised form
14 September 2011
Accepted 14 September 2011

Keywords:
Dental ceramics
Testing
Sandblasting
Etching
Strength

ABSTRACT

Objectives. Surface conditions are of interest in all-ceramic restorations since they can control both bonding and strength. Tensile testing methods are commonly used to evaluate surface conditions of ceramics. This work evaluated tensile properties of a feldspathic ceramic as-finished, sandblasted and etched under three stressing conditions: (1) biaxial flexure; (2) monotonic mastication loading, dry; and, (3) cyclic mastication loading, wet.
Materials and methods. Feldspathic CAD/CAM blocks were sliced into Tabs 1 mm thick, $n = 135$ specimens were divided into 3 groups assigned to as-finished (600 grit SiC; control), sandblasted, and etched. Of the 45 specimens per group, 35 specimens were used for bonded tests and 10 specimens for biaxial flexure testing. Pin-on-three ball biaxial testing was performed per ISO 6872. 35 specimens were bonded to dentin-analog bases and loaded to radial crack pop-in beneath a 3 mm diameter piston. 20 specimens were tested dry with failure determined by acoustic emission methods. 15 specimens, bonded to bases having micro-channels for water transport, were cyclically loaded beneath the 3 mm piston under water at 15 Hz for 500,000 cycles.
Results. Biaxial flexure distinguished among all three surface conditions ($p < 0.05$, ANOVA). Monotonic testing could not distinguish among groups. Cyclic testing could not distinguish between sandblasted and etched groups but both were weaker than as-finished.
Conclusions. Mastication loading of bonded specimens creates a different stress state than simple flexure due to contributions of the cement–ceramic interface. Water adds a damage accumulation effect. Tensile stress conditions need to be chosen with the desired outcomes considered.

1. Introduction

Use of all-ceramic restorations is increasing due to demands for esthetics and biocompatibility, the advent of automated fabrication systems, new materials having improved durability and handling, and the growing body of positive clinical survival data for systems still on the market. Single-layer (monolithic) ceramics are today commonly used as veneers, inlays, onlays and anterior single-unit crowns. While clinical survival data is quite favorable, brittle fracture is still a common reason for failure, so there has been attention on the strength of esthetic ceramics for the long-term survival rate.

* *Corresponding author*. Tel.: +1 860 679 3747.
E-mail address: Kelly@nso1.uchc.edu (J.R. Kelly).
0109-5641/$ – see front matter © 2011 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.dental.2011.09.002

Clinically-determined and laboratory-determined factors often discussed as controlling "use" strength include material characteristics [1–4], lab processing [5], surface treatment [6,7], cement type [8] and characteristics of the oral environment. Because cracks initiate from surface flaws during clinical failure [9–11], methods of surface treatment have received much attention [12–14].

Evidence for improved clinical (and laboratory) performance with bonding has been growing for decades. Usually ceramics need surface treatment to increase the bonding strength, and etching or sandblasting are the most common treatment methods [6–8,12,13]. Although etching is well known for increasing the bonding strength by developing an evenly roughened surface, it depends on the type of ceramic [15–17] and shows sensitivity to etchant concentration and etch time [16,17]. On the other hand, sandblasting is easy to use but the volume loss can be highly variable according to the blasting time [18] and residual damage can be sever [7,12]. While many studies have focused on the effect of etching and sandblasting on the bonding strength, very little attention has yet been given to the fracture resistance of bonded feldspathic porcelain under mastication-derived crack development following surface treatment. For bonded and fully supported ceramics, contrary to flexure tests [19,20], effects such as flaw "healing" or bridging by resin and the influence of dentin elastic properties can be also expected. Therefore the results of mastication load tests can be more clinically relevant than tensile tests in bending for effects related to ceramic–cement interactions.

Different tensile test methods can create different stress states and be expected to manifest different responses due to interfacial interactions (ceramic–cement) and mechanisms of damage accumulation. Pure bending tests such as 3-point and 4-point bending and biaxial flexure differ mainly in the surface area at risk, and strengths measured by these techniques can be normalized by the simple Weibull scaling relationship as in Eq. (1) below for converting 4-point results to 3-point:

$$\left(\frac{\sigma_{3\text{-point}}}{\sigma_{4\text{-point}}}\right) = \left(\frac{a_{4\text{-point}}}{a_{3\text{-point}}}\right)^{1/m} \quad (1)$$

where σ, failure stress; α, surface area under tensile stress; m, Weibull modulus.

While such bend tests have been used to characterize the influence of thin layers of cement [19,20], and sandblasting [7,13] they may not replicate sufficiently the stress state under mastication loading. For example, the influences of cement-dentin bonding, coefficient of friction (ceramic–cement) increasing with load, and three dimensional stresses due to cement shrinkage within a constrained space are not replicated. Damage accumulation under the influence of high numbers of low loads in the presence of water is also not reproduced during simple bend testing.

Additionally, tests attempting to simulate clinical loading using spherical indenters do not create clinically-relevant failure and their results should be discounted [21]. Clinical failure has consistently been reported to originate from the cementation surface, not from occlusal surface damage [9–11,22]. No fractographic analyses of retrieval specimens has found failure to involve surface damage at or below wear facets, such as complete Hertzian cone cracks or incomplete cone cracks due to sliding Hertzian contact [9–11,22]. In fact, one analysis specifically found that the single Hertzian crack present (the only one ever found associated with a clinical fracture surface) was clearly created during post-fracture edge chipping [22]. Unfortunately, an enormous bulk of in vitro simulation literature involves either rather unsophisticated monotonic "load-to-failure" using various small diameter ball indenters [23–28] or sophisticated surface damage analyses under Hertzian fatigue loading or Hertzian sliding contact, ironically termed "mouth motion" [29–32]. These approaches create a stress state resulting primarily in surface damage not seen as part of clinical failure and therefore do not stress the flaws (or flaw locations) thought to be involved with the majority of clinical failures.

Relevant testing is needed as new material and techniques are being developed continuously. This present work examines two common surface treatments, etching and sandblasting (along with as-finished), under three tensile stressing conditions: (1) dry, monotonic, biaxial flexure; (2) dry, monotonic, mastication loading; and, (3) wet, cyclic, mastication loading. Given the ubiquity of literature examining failure under each of these stressing conditions for each of the three surface conditions and the general assumption that all failure tests produce a similar failure mechanism, the null hypothesis of this study is: Ranking of failure stresses among all surface conditions will not differ among the three tensile tests.

2. Materials and methods

Cerec Vitablocs Mark II (Vita Zahnfabrik, Germany) feldspathic porcelain was used. Mark II blocks were cut into 1.1–1.2 mm thickness with a diamond saw (Isomet 1000, Buehler Ltd., IL, USA) and 135 specimens were prepared. Specimens were divided into 3 groups randomly and groups were as-finished (control), sandblasted, and etching. Of the 45 specimens per group, 35 specimens were used for bonded tests and 10 specimens for biaxial flexure testing. Specimens of each group were gradually as-finished manually to 600 grit SiC paper under water circulation, and this status, as-finished specimens were used as a control group. This "as-finished" surface is much more clinically realistic than a fully polished surface since the intaglio surfaces of crowns are never highly polished. Sandblasting group had 20 μm more thickness for compensation of the volume loss from the blast procedure. This amount was set from the preliminary test. Specimens of sandblasting group were air blasted with 50 μm aluminum oxide particle at a 2 cm distance, under 2.7 bar pressure for 5 s; sufficient to see a visible change and within the parameters from many published studies. Specimens of etching group were treated with 9% buffered hydrofluoric acid (Porcelain Etch, Ultradent Products Inc., Germany) for a minute, per recommendations from the porcelain manufacturer (personal communication from Dr. Norbert Thiel, Vita Zahnfabrik). All specimens were cleaned in the ultrasonic cleaner and dried thoroughly before bonding. Specimen thicknesses were measured using a digital micrometer rated with a resolution of 2.54 μm and an accuracy of 4.06 μm (Fowler, MA, USA). The final thickness of each