JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 34 (2014) 124–133

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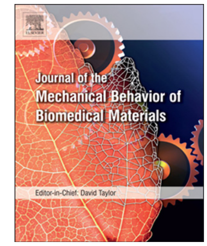

Research Paper

Hertzian contact response and damage tolerance of dental ceramics

Andrea Coldea[a,b,*], *Michael V. Swain*[a,1], *Norbert Thiel*[b,2]

[a]*Department of Oral Sciences, School of Dentistry, P.O. Box 647, 9001 Dunedin, New Zealand*
[b]*Research and Development Department VITA Zahnfabrik, Ballyweg 6, 79713 Bad Saeckingen, Germany*

ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form
27 January 2014
Accepted 3 February 2014
Available online 8 February 2014

Keywords:
Hertzian contact
Dental ceramics
Interpenetrating phase composite
Strength degradation
Force–displacement curves

ABSTRACT

Objectives: To determine the contact response and damage tolerance or strength degradation of a range of dental CAD/CAM ceramic materials including novel polymer-infiltrated-ceramic-network (PICN) materials by means of spherical indentations at various loads and indenter radii.
Methods: The seven tested materials included Mark II, PICN test materials 1 and 2, In-Ceram Alumina, VM 9, In-Ceram YZ (Vita Zahnfabrik, Bad Saeckingen, Germany) and IPS e.max CAD, (Ivoclar Vivadent, Schaan, Liechtenstein). To evaluate the damage tolerance and role of indenter size, indentations with tungsten carbide spheres (0.5 mm and 1.25 mm radius) were placed on bending bars with varying loads (1.96–1000 N). The indented bending bars were subsequently loaded to fracture in three-point bending. The contact induced damage was analyzed by light microscopy (LM) and SEM. The spherical contact response was measured on polished surfaces.
Results: The initial strengths for the individual materials were found to reduce above specific indentation loads, which were a function of the indenter radius. Employing a 0.5 mm radius sphere resulted in the following strength degrading loads and ordering of materials: VM9 (98 N) < MarkII–PICN1 (147 N) < ICAlumina–e.maxCAD (300 N) < PICN2–YTZP (500 N). For the materials indented with the 1.25 mm sphere, higher loads were required for the onset of strength degradation: VM9 (190 N) < MarkII (300 N) < PICN1 (400 N) < e.maxCAD (500 N) < ICAlumina (700 N) < PICN2 (1000 N) < YTZP (above 1000 N). Two different damage modes were observed by SEM and LM – brittle cone cracking and plastic deformation. The PICN materials exhibited elastic–plastic behavior with creep. In contrast YTZP showed entirely elastic behavior upon loading with both spheres.
Significance: This study aims to emulate the likely clinical behavior of contact loading by opposing cusps to dental restorative ceramic materials by utilizing spherical indentations at various loads and sphere diameters.

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*Corresponding author at: Research and Development Department VITA Zahnfabrik, Ballyweg 6, 79713 Bad Saeckingen, Germany. Tel.: +49 7761 562 307; fax: +49 7761 562 398.
E-mail addresses: a.coldea@vita-zahnfabrik.com (A. Coldea), michael.swain@otago.ac.nz (M.V. Swain), n.thiel@vita-zahnfabrik.com (N. Thiel).
[1]Tel.: +64 3 479 4196; fax: +64 3 479 7078.
[2]Tel.: +49 7761 562 366; fax: +49 7761 562 398.

http://dx.doi.org/10.1016/j.jmbbm.2014.02.002
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1. Introduction

Enamel, the natural tooth substance exposed to the oral cavity, is composed of hydroxyapatite, water and organic matrix (Bechtle et al., 2010). It is a biocomposite and in combination with dentin optimized by nature to withstand the localized forces applied during chewing and generally to endure different types of load applications (chewing, grinding, and crushing) in the oral environment. In the human oral posterior region maximum biting forces are reported to be in the range of 150–665 N (Da Silva et al., 2008) but occlusal forces during masticatory contacts are generally much lower than maximum biting forces. Furthermore the high posterior forces are distributed over the opposing cusps of several teeth and in general these forces do not exceed 10 N (Da Silva et al., 2008). The load resulting from chewing or crushing is transferred by opposing cuspal radii of 2–4 mm as reported in previous studies (Rueda et al., 2013; Peterson et al., 1998a; Lawn, 1998). However damage to teeth and dental materials may arise from biting with the inadvertent presence of small seeds and stones. When lost tooth substance is replaced by dental restorative materials the requirement on the materials is their load bearing capacity to the aforementioned forces and radii of the contacting surfaces.

Amongst other factors, the microstructure of ceramic based dental materials as well as intrinsic flaws, the design, finishing of restorations and wear in function dominates the behavior under loading conditions. The loading of materials with flaws present can result in fatal fractures of restorations. A further consideration is the restoration of implants with ceramic materials, because of their higher rigidity and absence of propreception. As a consequence the implant supra-structure has to sustain higher loading and bending forces than periodontal ligament supported natural teeth. To predict the clinical performance of restorations more closely, not only the intrinsic flexural strength of dental ceramics should be investigated, but also the in vitro contact response, strength degradation and associated fracture mechanics upon loading with spherical indenters.

Compared to the strength degradation associated with sharp diamond indentations, where the *R*-curve behavior can be determined, blunt spherical indentation emulates masticatory loading conditions more closely compared to conventional mechanical tests. The Blunt or Hertzian indentation method was employed in previous studies on dental ceramics (e.g. Peterson et al., 1998a, 1998b; Jung et al., 1999) and human enamel (He and Swain, 2007). The method utilizes indentations with hard metal spheres (in this study: tungsten carbide) and subsequent analysis of fracture mechanics, flexural strength and contact response of tested materials. Masticatory forces, various contact and cusp radii can be simulated with this method by varying the maximum load and indenter radius.

The purpose of this paper is the in vitro comparative examination of ceramic based dental materials by means of controlled flaw introduction with varying spherical indenter sizes and loads to simulate the likely clinical behavior during mastication. In this study the materials tested were four CAD/CAM ceramics (MarkII, IPS e.max CAD, In-Ceram YZ, and In-Ceram Alumina) and one veneering ceramic (VM9) already on the market as well as two experimental polymer-infiltrated-ceramic-network materials (PICN). Mark II, IPS e.max CAD and In-Ceram YZ are already used clinically as monolithic materials. PICN test materials 1 and 2 are intended for the application as monolithic CAD/CAM materials. The PICN materials are interpenetrating phase composites composed of two continuous networks of ceramic and polymer and described in earlier papers (Coldea et al., 2013a, 2013b; He and Swain, 2011; He et al., 2011, 2012). In this study the two PICN materials differed in their ceramic–polymer ratio. PICN test material 1 had a higher ceramic fraction (75 vol% ceramic and 25 vol% polymer respectively) than PICN test material 2 (69 vol% ceramic and 31 vol% polymer respectively). Contrary to manufacturer's instructions In-Ceram Alumina was investigated without a veneering layer.

The in vivo strength degradation of restorations based on dental ceramics may occur in oral environments as a consequence of masticatory and parafunctional forces. Flaws of different magnitudes present within restorations in combination with loading may be the origin of subsequent fractures. This study addresses the issue of controlled flaw application in dental ceramics, using blunt indentations. The specific aim of this paper was to determine the contact response and damage tolerance of ceramic materials containing contact flaws produced by spherical indenters, as a function of indentation load.

2. Materials and methods

2.1. *Materials*

In this study the seven investigated materials included Mark II, PICN test material 1, PICN test material 2, In-Ceram Alumina, VM 9, In-Ceram YZ (all Vita Zahnfabrik, Bad Saeckingen, Germany) and IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) (Table 1).

2.2. *Methods*

2.2.1. *Indentation strength measurement*

Bending bars of MarkII, PICN, ICAlumina, YTZP and emaxCAD were cut out of blocks with a diamond saw. To compensate the sintering shrinkage YTZP bending bars were cut oversized und sintered according to manufacturer's instructions. For the VM9 bending bar preparation, a mold to shape and a furnace (Vita Vacumat 4000, Vita Zahnfabrik, Bad Saeckingen, Germany) to sinter the specimens was used. The sintering was conducted according to manufacturer's instructions. ICAlumina bars were glass-infiltrated after cutting according to manufacturer's instruction. Subsequently the bending bars were lapped (MDF 400 PR, Bierther submicron, Bad Kreuznach, Germany) then diamond grit polished (15 μm diamond suspension) to a size of 18 mm × 4 mm × 1.2 mm or 3 mm (for higher loads). The edges of all bending bars were chamfered according to ISO 6872 (ISO Standard 6872:2008, 2009) in order to minimize stress concentration due to machining flaws. After machining (lapping and chamfering) of YTZP bending

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