dental materials xxx (2018) xxx–xxx

Available online at www.sciencedirect.com

ScienceDirect

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

Chairside CAD/CAM materials. Part 3: Cyclic fatigue parameters and lifetime predictions

Michael Wendler [a,b,*], *Renan Belli* [a], *Diana Valladares* [a], *Anselm Petschelt* [a], *Ulrich Lohbauer* [a]

[a] *Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Zahnklinik 1 – Zahnerhaltung und Parodontologie, Forschungslabor für dentale Biomaterialien, Glueckstrasse 11, 91054 Erlangen, Germany*

[b] *Department of Restorative Dentistry, Faculty of Dentistry, University of Concepción, Concepción, Chile*

ARTICLE INFO

Article history:
Received 14 December 2017
Received in revised form
13 March 2018
Accepted 23 March 2018
Available online xxx

Keywords:
Subcritical crack growth
Cyclic fatigue
B3B-test
Lifetime estimation
SPT diagram
CAD/CAM
Dental ceramics
Resin composites

ABSTRACT

Objectives. Chemical and mechanical degradation play a key role on the lifetime of dental restorative materials. Therefore, prediction of their long-term performance in the oral environment should base on fatigue, rather than inert strength data, as commonly observed in the dental material's field. The objective of the present study was to provide mechanistic fatigue parameters of current dental CAD/CAM materials under cyclic biaxial flexure and assess their suitability in predicting clinical fracture behaviors.

Methods. Eight CAD/CAM materials, including polycrystalline zirconia (IPS e.max ZirCAD), reinforced glasses (Vitablocs Mark II, IPS Empress CAD), glass-ceramics (IPS e.max CAD, Suprinity PC, Celtra Duo), as well as hybrid materials (Enamic, Lava Ultimate) were evaluated. Rectangular plates ($12 \times 12 \times 1.2\,mm^3$) with highly polished surfaces were prepared and tested in biaxial cyclic fatigue in water until fracture using the Ball-on-Three-Balls (B3B) test. Cyclic fatigue parameters n and A^* were obtained from the lifetime data for each material and further used to build SPT diagrams. The latter were used to compare *in-vitro* with *in-vivo* fracture distributions for IPS e.max CAD and IPS Empress CAD.

Results. Susceptibility to subcritical crack growth under cyclic loading was observed for all materials, being more severe ($n \le 20$) in lithium-based glass-ceramics and Vitablocs Mark II. Strength degradations of 40% up to 60% were predicted after only 1 year of service. Threshold stress intensity factors (K_{th}) representing the onset of subcritical crack growth (SCG), were estimated to lie in the range of 0.37–0.44 of K_{Ic} for the lithium-based glass-ceramics and Vitablocs Mark II and between 0.51–0.59 of K_{Ic} for the other materials. Failure distributions associated with mechanistic estimations of strength degradation *in-vitro* showed to be useful in interpreting failure behavior *in-vivo*. The parameter K_{th} stood out as a better predictor of clinical performance in detriment to the SCG n parameter.

Significance. Fatigue parameters obtained from cyclic loading experiments are more reliable predictors of the mechanical performance of contemporary dental CAD/CAM restoratives than quasi-static mechanical properties.

DOIs of original articles:https://doi.org/10.1016/j.dental.2016.10.009, https://doi.org/10.1016/j.dental.2016.10.008

* *Corresponding author at:* Department of Restorative Dentistry, Faculty of Dentistry, University of Concepcion, Roosevelt 1550, 4070369 Concepcion, Chile.
E-mail address: mwendler@udec.cl (M. Wendler).

https://doi.org/10.1016/j.dental.2018.03.024
0109-5641/

1. Introduction

Clinical indications of dental restorative materials are traditionally based on their mechanical strength, by relating experimental fracture loads to load ranges occurring intraorally. This concept is flawed in many aspects [1], yielding very arbitrary safety limits for clinical fracture. Also, ranking materials according to their strength as means to predict clinical performance disregards important underlying chemical and mechanical fatigue degradation processes that take place in the oral environment. One of them is the so-called *subcritical crack growth* (SCG) [2], well documented for dental ceramics [3–7] and resin composites [8–10], where stable crack extension occurs at stress levels far below those observed in quasi-static strength tests. Speaking in mechanistic terms, processes involved in SCG lead to the stable growth of strength-limiting defects at stress intensities (K_I) below the material's critical stress intensity, K_{Ic} (or fracture toughness) [11]. Cracks in such conditions grow to sizes larger than theoretically predicted for critical conditions in inert fast-fracture procedures.

The SCG process can be studied by direct observation of the crack progression in pre-cracked samples (e.g. double-torsion specimen) or alternatively by indirect estimation of the crack propagation rate, using static, dynamic or cyclic fatigue tests [11,12]. The latter make use of specimens with natural flaw populations using simple testing set-ups, but demand larger sample sets and extensive testing periods. Most studies in the dental literature address the fatigue behavior of dental restoratives by means of dynamic flexural tests to derive crack propagation velocities from strength data acquired at various loading rates [11,13]. SCG parameters obtained this way or from static tests, however, are limited to the stress corrosion effect on crack growth, and disregard any contributing mechanical degradation mechanism [14]. In essence, stress-corrosion is a time-dependent chemical reaction between environmental water and the Si-O (or Zr-O, Al-O, etc.) bonds at crack tips under stress, in glassy and oxide ceramics [2]. In a purely mechanical process, structural damage is introduced to the material as a consequence of the frictional stresses during the loading-unloading phases [11,15]. With this, toughening mechanisms such as crack bridging and phase-transformation zones are importantly degraded, increasing the susceptibility of the material to SCG [15]. Therefore, more realistic scenarios are created using cyclic fatigue tests, where both phenomena can be induced simultaneously [12]. This is of particular relevance for the fatigue testing of materials that contain secondary phases embedded in a matrix or polycrystalline microstructures, such as most dental restoratives.

In the first two contributions of this series we tried to provide a deeper insight into the microstructure, elastic properties [16] and strength testing [1] of the main currently available dental CAD/CAM materials. To accommodate for shape restrictions of small chairside blocks, we provided in Ref. [1] a solution for square cross-sectional geometries to be used in the ball-on-three-balls (B3B) test, a more accurate alternative to the common piston-on-three-balls version of the biaxial flexure method. Going a step further, we investigate in this contribution the mechanical behavior of the same materials under cyclic loading using the B3B test with square specimens, in order to obtain fatigue parameters for lifetime estimation and ultimately try to draw a parallel between laboratorial and clinical fracture data.

2. Material and methods

2.1. *Materials and specimen preparation*

The materials used in the present study correspond to the same batches of those used in the first two parts of this series, so to ensure that the same flaw populations in the bulk of the material were being sampled both in the inert strength and in the fatigue specimens. They were selected to span over a wide range of the currently available restorative spectrum, including a 3 mol% yttria-stabilized tetragonal zirconium dioxide (3Y-TZP, IPS e.max ZirCAD), a lithium disilicate (IPS e.max CAD), two lithium (di)-silicate/phosphate glass-ceramics (Suprinity PC and Celtra Duo), a leucite-based glass (IPS Empress CAD) and a feldspar-reinforced aluminosilicate glass (Vitablocs Mark II) to compose the ceramic assortment. In addition, two composite materials that compete with many of the abovementioned ceramics in some clinical indications were selected: a polymer-infiltrated reinforced-glass network, PIRGN (Enamic), and a nano-particulated pre-polimerized resin composite (Lava Ultimate). Their quasi-static mechanical properties are listed in Table 1.

Table 1 – Relevant properties of the materials evaluated in this study: characteristic strength (σ_0), Weibull modulus (m) and fracture toughness (K_{Ic}).

Material	Manufacturer	σ_0 (MPa)	m	K_{Ic} (MPam$^{1/2}$)
IPS e.max ZirCAD	Ivoclar-Vivadent	1286.65	17.3	4.87 *
IPS e.max CAD	Ivoclar-Vivadent	609.8	12.8	2.06 ¶
Suprinity PC	VITA Zahnfabrik	548.41	5.5	1.40 ¶
Celtra Duo	Dentsply Sirona	565.8	5.5	1.52 ¶
Vitablocs Mark II	VITA Zahnfabrik	118.65	19	1.01 ¶
IPS Empress CAD	Ivoclar-Vivadent	188.8	18.2	1.02 ¶
Enamic	VITA Zahnfabrik	193.45	18	1.28 ¶
Lava Ultimate	3M ESPE	300.64	10.4	1.14 *

Values for σ_0 and m calculated using data from [1]. Values for K_{Ic} obtained using the Compact Tension (C(T)) specimen method (*) [18] or the B3B-K_{Ic} test (¶) [17].

Please cite this article in press as: Wendler M, et al. Chairside CAD/CAM materials. Part 3: Cyclic fatigue parameters and lifetime predictions. Dent Mater (2018), https://doi.org/10.1016/j.dental.2018.03.024