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The influence of pigments on the slow crack growth in dental zirconia

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ABSTRACT

Objectives. Partially yttria stabilized zirconium oxide was introduced as core material for core-veneered full ceramic dental restorations, because of its biological inertness, high mechanical strength, and toughness. In order to improve the esthetical possibilities pigments in the core are introduced, that might influence the stabilization by yttrium.
Methods. Double torsion tests were performed to study the influence of the pigments in the core ceramics on its fracture toughness.
Results. A significant difference was observed in the stress intensity factor (K_{10}) as well as in the R-curve behavior between the ceramic with and without pigment.
Significance. The lower stress intensity factor for the ceramic with pigment could affect the clinical performance of dental zirconia restorations with this material.

1. Introduction

The introduction of zirconia based polycrystalline framework materials to the dental field widened up the possibilities of all-ceramic restorations [1,2] and made long span, extensive, and accurate all-ceramic restorations possible due to the high flexure strength of these zirconia framework materials [3]. As pure zirconia is brittle and not strong enough, yttria is added to zirconia to stabilize the particular crystal structure of zirconium oxide at room temperature. In this way a strong and tough stabilized ceramic is created.

The flexure strength of zirconia framework materials was always reported using highly polished specimens, while in reality these materials are often exposed to unavoidable different types of surface damage. The CAD/CAM milling procedure, airborne-particle abrasion, and milling with hard tools as during fit check or dimensional corrections all together introduce surface damage and increase surface roughness leading to significant strength reduction [4]. The produced surface damage could unexpected result in catastrophic failure under low loads keeping in mind that microscopic cracks could be very effective in concentrating high stresses at the crack tip region resulting in slow crack propagation [4]. This might not be applicable to direct shaping procedures like pressing without further processing.

A characteristic property of partially stabilized zirconia framework materials is their unique transformation toughness. Under mechanical, chemical, or thermal stresses the partially stabilized tetragonal phase could transform to the relatively larger monoclinic phase (4% increase in volume) and the accompanied compressive stresses result in stopping the

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propagating crack front. Understanding of these toughening mechanisms is necessary to predict the life-time of zirconia restorations.

The reported fracture toughness of contemporary zirconia framework materials ranges from 3.6 to 11.5 MPa $m^{1/2}$. Such variation is not only related to the different fracture toughness evaluations, but also to their applications [5–8]. Moreover, in recent studies it was observed that different zirconia framework materials have different grain sizes and shapes, different chemical structure in relation to their stabilizing element and coloring pigments [1,7]. Colored zirconia was introduced to enhance shade match of these restorations and to simplify the layering procedure of the veneering ceramic. Direct advantages of colored zirconia frameworks are the reduction in veneer thickness required to mask the white color of the underlying framework and discard the masking liner material, which is applied before layering the veneer ceramic. However, the bond strength between the veneering ceramic and the zirconia is reported to be less for colored zirconia [1]. The flexure strength showed no difference between colored and uncolored zirconia [7]. The aim of this study was to investigate the influence of the pigments in the zirconia on its fracture toughness.

Once the sub-critical crack reaches a critical size where the stress concentration at the crack tip exceeds the fracture toughness of the materials, catastrophic fracture is expected [9]. Changes in crack length could only be estimated and not the actual crack growth rate (change in length/time under different loading rates) [9–12]. The rate of crack growth is not a constant value, but it varies with changes in the mechanical and chemical environment. The crack grows varies with the crack growth due to the presence of pre-stresses, transformation activity, crack shielding mechanisms, or due to the phenomenon of rising R-curve activity [13,14].

Different crack growth observation procedures were investigated as by attaching sensitive microphones to the specimens, measuring electrical conductivity, or by using ultra-sound waves. Nevertheless, these methods offered only a rough prediction and were only valuable to relatively large crack sizes [15].

Under controlled loading conditions, the compliance of a test specimen linearly increases as the crack size increases [16].

For a 3-point flexure test setup, the bending of a bar under load increases by the increase in the length of an intentionally made pre-crack or notch till a level where failure occurs. The compliance of the specimen is used as an indirect measure of the crack length under controlled loading conditions (constant load increase or fixed crosshead speed). The direct benefit of the compliance calibration method is that it only requires recording the load, deformation of the loading point, and time in order to estimate the rate of crack growth [17]. Other test designs as double canti-lever beams and crack split methodologies required mathematical corrections to compensate for the interaction of undesirable factors and thus the obtained data could not be directly compared [18–20]. The double torsion test setup as proposed by Kies and his associate has shown to be a valuable method to determine toughness and slow crack growth [16]. The stress intensity factor in this setup was independent from crack length and extension and thus crack growth rate could be directly plotted against the calculated stress intensity factor [21].

Therefore, this test has been performed to study the influence of coloring pigments in zirconia on the slow crack growth of this ceramic framework material.

2. Materials and methods

2.1. Theoretical backgrounds

The determination of the stress intensity factor K_1 is based on a compliance calibration method suggested by Williams and Evans [22]. The first assumption is that the compliance C in the double torsion (DT) test varies linearly with crack length a:

$$C = Ba + D \tag{1}$$

and

$$a = \frac{C - D}{B} \tag{2}$$

where B and D are constants, depending on the material properties.

Although in the original work of Williams and Evans the stress intensity factor was just a function of the applied load and specimens dimensions [22] several authors found that the stress intensity factor was also dependent on crack length and needed to correct their formulas accordingly [14,21,23].

$$K_1 = HP\left\{\frac{a}{a_0}\right\}^{6/32} \tag{3}$$

where P is the applied load and H is given by:

$$H = \frac{W_m}{T}\left[\frac{3(1+\upsilon)}{\psi(T/W)W}\right]^{1/2} \tag{4}$$

where W and W_m are the width of the specimen and the moment arm, T the thickness, υ is the Poisson ratio and $\psi(T/W)$ is a calibrating factor.

$$\Psi\left(\frac{T}{W}\right) = 1 - 0.6302\left(\frac{2T}{W}\right) + 1.2\left(\frac{2T}{W}\right)\exp\left(\frac{-\pi}{2T/W}\right) \tag{5}$$

2.2. Material properties

Zirconia

Young's modulus 210 GPa

Poisson ration 0.3

2.3. Specimen

The materials used were the commercial dental zirconia; Cercon® Base, an yttria stabilized tetragonal zirconia with grain size between 0.25 and 1.4 μm (Degudent GmbH, Hanau-Wolfgang, Germany) and a non commercial colored Cercon® with the same grain size.

The specimen with dimensions according to Fig. 1 were prepared by cutting CAD/CAM zirconia milling blocks of the