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Thermal gradients and residual stresses in veneered Y-TZP frameworks

Michael J. Tholey[a,b,1], Michael V. Swain[c,*], Norbert Thiel[b,2]

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

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ABSTRACT

Objectives. The occurrence of "chipping" of all-ceramic restorations with Y-TZP frameworks has resulted in various designs and cooling procedures recommended for reducing such behavior. In this paper the temperature gradients during fast and slow cooling for conventional and anatomical designs are compared as well as an optical procedure to directly compare the influence of cooling rate on residual stress.

Methods. This investigation quantifies the temperature gradients between the inner and outer surfaces of crowns measured with thermocouples during two different cooling methods with uniform and anatomical frameworks. In the first method the crown was removed from the furnace after commencement of cooling whereas for the second method the crown was cooled to the glass transition temperature (600 °C) before removal. Direct observation of the residual stresses was made with an optical polarimeter and thin slices of veneered copings.

Results. This study observed that slow cooling decreases the temperature differences but still differences of up to 88 °C were observed. For the fast cooled crown, temperature differences of more than 100 °C for the uniform and 140 °C for the anatomical framework at temperatures above the glass transition temperature were recorded. Optical polarimeter observations indicated much lower stresses within the porcelain layer upon cooling by removing the crown below the glass transition temperature.

Conclusion. Slow cooling during the final veneering of dental restorations with zirconia frameworks reduces the temperature gradients and residual stresses within the porcelain layer, which represent one possible cause for chipping. An anatomical designed framework did not show the same reduction extent.

* *Corresponding author*. Tel.: +64 3 479 4196; fax: +64 3 479 7078.
E-mail addresses: m.tholey@vita-zahnfabrik.com (M.J. Tholey), michael.swain@stonebow.otago.ac.nz, mswain@mail.usyd.edu.au (M.V. Swain), n.thiel@vita-zahnfabrik.com (N. Thiel).
URL: http://www.otago.ac.nz (M.V. Swain).
[1] Tel.: +49 7761 562 377; fax +49 7761 562 398.
[2] Tel.: +49 7761 562 366; fax +49 7761 562 398.

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1. Introduction

The introduction of metal–ceramic system in 1962 enabled dentists and dental technicians to produce highly esthetic dental restorations. More recently with the development of dental all-ceramic systems especially with yttria partially stabilized zirconia (Y-TZP) or alumina as framework materials, esthetics have been further improved. These enhanced dental restorative materials come ever closer to that of natural teeth. In 2008 in Germany over 40% manufactured dental restorations were all-ceramic, but according to the broad-based consumer surveying company since then the demand has decreased to less than 25%. The reason for the decline is the clinical concern about failures and long-term stability of restorations especially with Y-TZP frameworks.

This apprehension, especially the occurrence of "chipping" of all-ceramic restorations with Y-TZP frameworks, has generated considerable research within the dental materials community [1]. Failures within the porcelain layer or breakage at the interface in metal–ceramic restorations are well known since their introduction. But this special "chipping" failure mode appears to arise predominantly with Y-TZP all-ceramic systems especially in the cusp area. The term "chipping" according to the dictionary definition implies that splinters occur, which realistically describes the characteristic features of this failure mode. The crack propagation occurs exclusively within the porcelain layer and does not appear to run to the interface between the veneering and the framework material. Added to the outer surface of a zirconia framework is generally a thin veneering layer beneath where the chipping event occurs [1,2].

With all-ceramic framework materials, especially with Y-TZP, the processing guidelines have been modified by most commercial suppliers compared with the well-known technique of the metal–ceramic systems. The consensus, although not as yet genuinely verified, is that residual stresses develop within the porcelain during rapid cooling and these contribute to chipping induced fracture. Residual stresses can be introduced during the firing process inside the porcelain layer and can be of two major origins; due to thermal expansion mismatch and tempering stresses associated with temperature gradients during cooling [3,4]. These residual stresses, which remain after the cooling in the porcelain layer, are one possible explanation for the differences of "chipping" failures between metal and Y-TZP based all-ceramic restorations. The materials parameters of all-ceramic restoration such as Young's modulus or coefficient of thermal expansion of the material partners as well as the glass transition temperature of the porcelain do not differ significantly from those of the well-known metal–ceramic porcelains. It has been argued that the drastically different thermal conductivity of the framework materials (gold has approximately 150-times higher thermal conductivity than zirconia) may be the origin of this special failure mode [3].

One goal of this investigation was to determine experimentally the temperature differences arising during the firing process of all-ceramic crowns with Y-TZP frameworks by the use of a rotational symmetric crown model. In addition two slightly different models (one framework with constant wall thickness and the other with anatomical supported structure) were cooled after firing in two different ways (fast and slow cooling). Another objective was the determination and visual presentation of the stress distribution with an optical imaging polarising system that can measure the optical polarization state of light transmitted through the porcelain. It is mainly based on the ability to build effective polarization state analysers that acquire the Stokes vectors corresponding to each pixel in the image [5,6]. This is done traditionally by rotating birefringent optical elements such as quarter-wave plates in front of a fixed polarizer [5].

Reductions of residual stresses within the veneering porcelain will possible result in more secure zirconia framework based dental restorations. The hypothesis investigated in this paper is that temperature gradients produced at temperatures above the glass transition temperature of the porcelain during cooling generate higher residual stresses. Optical polarimeter images are used to verify this hypothesis.

2. Materials and methods

2.1. *Crown/sample model*

A rotationally symmetric crown form similar to that previously invested by Lenz et al. [3] was selected to ensure the production of identical samples and to simplify the experimental determination of the surface temperature corresponding with the geometry of a premolar tooth. Anatomically precise crowns, while possible to evaluate in a similar manner would have drastically increased the difficulty of production, especially regarding thermocouple placement and subsequent cross-sectioning of similar veneered copings.

The copings (four of each group) were designed by the inLab software (inLab 3.80, Sirona, Germany) and milled using an inLab milling machine (inLab MC XL, Sirona, Germany). The Y-TZP partially sintered frameworks (VITA In-Ceram YZ) were sintered to full density for 2 h at 1530 °C in a furnace (VITA ZYrcomat, VITA, Germany). After sintering the wall thickness was on average 0.7 mm with constant thickness frameworks. The anatomically supported frameworks had a wall thickness of 0.7 mm at the cervical region, which increased within the middle and cusp range from 1.3 mm and within the occlusal region to 1 mm. The overall height of all copings, constant wall or supported framework was 6.95 mm (see Fig. 1, crown with constant wall thickness).

The first veneering step with the dentin porcelain (VM9; VITA, Germany) was the application of a very thin so called "wash-dentin layer" and fired at 950 °C. The first build up dentin firing was at 910 °C and the second was fused at 900 °C. Finally a glaze firing of the porcelain was carried out in each case at 900 °C in a Vacumat 4000 Premium T (VITA, Germany).

The veneer thickness of all samples was identical. At the cusp, complete thickness (framework and porcelain) of 1.4 mm was developed. Thus the porcelain thickness resulted in constant wall thickness framework copings of 0.7 mm on average. The porcelain of the anatomically supported crown had a maximum layer thickness of 0.4 mm.