Short communication

A note on the temperature dependence of the flexural strength of a porcelain

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Abstract

Objectives: The purpose of this study is to determine the temperature dependence of the flexural strength of a dental porcelain (IPS-Classic Dentin; manufacturer: Ivoclar, Liechtenstein) with temperature between its glass transition ($T_g = 581.7$ °C) and room temperature.

Methods: The flexural strength was measured in three-point bending tests on an Instron 4204 testing apparatus. The strength values were determined for the temperatures $T = 20, 300, 400, 450, 500, 550$, and 600 °C.

Results: In the temperature interval $20 \le T \le 400$ °C the flexural strength decreased slightly from ~80 to ~73 MPa (mean values), as temperature increased. That is a decay of less than 10%. At higher temperatures the flexural strength increased to a maximum of ~98 MPa at 500 °C, probably due to the closure of microcracks in the surface on account of the onset of viscous flow. A further increase of the temperature delivered again decreasing strength values. At its glass transition temperature the porcelain's flexural strength was ~76 MPa which is only about 5% less than the value at room temperature.

Significance: In order to be able to evaluate the risk of fracture of ceramometallic crowns and bridges due to high temperature gradients and accompanying large transient thermal stresses in the veneer during the fabrication process, flexural strength values at high temperatures must be known. This study was carried out to fill this knowledge gap because to the authors' knowledge there was little published in the literature.
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Keywords: Dental material; Porcelain; Flexural strength; Three-point bending; Temperature dependence

1. Introduction

In several papers the development of transient and residual thermal stresses in porcelain-fused-to-metal (PFM) crowns during the cooling phase after firing was investigated by the authors. To achieve this, the temperature variations in a number of surface points of the interior frame and of the exterior ceramic veneer were measured as a function of cooling time using thermocouples. These data were smoothed numerically to obtain the surface temperature distribution as a function of position and time. This temperature distribution was finally used as loading within a finite element (FE) analysis (ANSYS 5.3) to compute the temperature and stress distribution within the crown as a function of position and cooling time [1–4]. The numerical simulations revealed in particular that directly after opening the lid of the porcelain furnace, high temperature gradients

were observed, and thus large transient thermal stresses were developed in the ceramic veneer of the crown with a maximum, about 30 s after opening.

In order to be able to employ these results in strength analyses, strength criteria for dental ceramics at elevated temperatures, preferably in the complete interval between their glass transition temperature and room temperature, should be known. Since the authors could not find such data in the literature, they decided to measure, as a beginning, the flexural strength $R_{b,f}$ as a function of temperature of that porcelain (IPS-Classic Dentin; manufacturer: Ivoclar, Liechtenstein) which was used in the experimental-numerical investigations [1–4].

2. Materials and methods

The flexural strength was determined in a three-point bending testing apparatus. The nominal dimensions of the ceramic specimens were chosen as 35 mm × 3 mm × 4 mm (length L × width B × height H). Since the fabrication

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Table 1

Mean values and standard deviations (in parentheses) of the flexural strength of IPS-Classic Dentin porcelain at room temperature and elevated temperatures

Temperature T (°C)	Flexural strength $R_{b,f}$ (MPa) (n: number of specimens)	Coefficient of variation (%)
20	80.3 (8.4) ($n = 13$)	10.5
300	75.4 (4.0) ($n = 8$)	5.3
400	73.2 (13.0) ($n = 8$)	17.8
450	79.5 (10.8) ($n = 9$)	13.6
500	98.0 (10.0) ($n = 8$)	10.2
550	87.0 (9.0) ($n = 8$)	10.3
600	68.9 (10.0) ($n = 8$)	14.5

process delivered unavoidable small variations of the nominal width and height for the majority of the specimens, their dimensions were thoroughly measured prior to the experiments, and the flexural strength value finally determined from the failure load F_{fail} according to

$$R_{b,f} = \frac{3L_s F_{fail}}{2BH^2}$$

where the span L_s between the supports was chosen as $L_s = 22.5$ mm in the experiments.

To fabricate the specimens, a dough consisting of the porcelain powder, a solvent (Isopropanol) and a polymer (Polyox; manufacturer: Union Carbide, USA) was prepared and pressed into plates with a cold steel mould. The plates were cut into strips and, for debonding the ceramic from the polymer, heated for 20 min in a preheating furnace at 400 °C on honeycomb firing trays using fiber fleece to prevent the specimens from sticking to the firing tray. After debonding the specimens were fired in a dental porcelain furnace (Programat P 90; manufacturer: Ivoclar, Liechtenstein) at 950 °C for 2 min.

After firing the majority of the specimens were distorted

so that extensive grinding was necessary. They were first ground even on one side by hand and then glued with cyanoacrylate on metal supports which could hold up to 20 specimens, followed by a wet grinding with a metallurgical diamond disc (manufacturer: Bühler, Switzerland) to a rough width of ~3.2 mm and finally ground smooth with SiC-paper to a width of (3 ± 0.15) mm. Thereafter, the specimens were removed from the metal support by heating to 300 °C, and the identical grinding process repeated for the other surfaces until a sufficient number of straight specimens with rectangular cross-sections of (3 ± 0.15) mm × (4 ± 0.20) mm was attained.

Experiments preceding the final glazing process showed that distinct deformations of the specimens only occurred at a temperature of 700 °C and above and a holding time of 10 min. All specimens were glaze fired without vacuum on plane honeycomb firing trays. To prevent adhesion to the trays a fiber fleece was used on the trays. For this cycle a holding time of 10 min at 650 °C was chosen to guarantee a uniform heating of the specimens. This temperature of 650 °C was well above the glass transition temperature of the porcelain ($T_g = 581.7$ °C) so that healing of most surface microcracks in the specimens would be expected.

For the flexural strength experiments in three-point bending an Instron 4204 (maximum heating rate: 600 °C/h) was used. Before each measurement and after reaching the nominal temperature, a holding time of 30 min was needed to secure a homogeneous temperature in the specimen. The cross-head-speed was chosen as 1 mm/min. The measurements were carried out at temperatures $T = 20, 300, 400, 450, 500, 550$, and 600 °C, where at each temperature a number $n \geq 8$ of specimens was employed. Additional measurements in the interval $20 < T < 300$ °C were not made because the strength values at 20 and 300 °C were not significantly different.
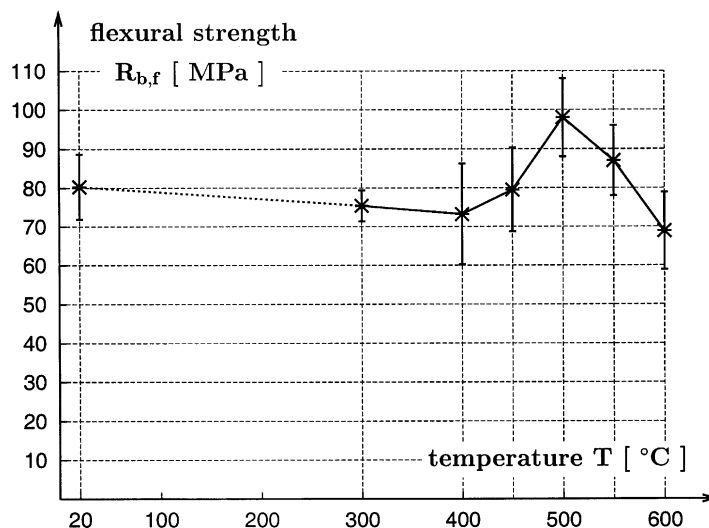

Fig. 1. Flexural strength in three-point bending of IPS-Classic Dentin porcelain as a function of temperature (mean values and standard deviations).

3. Results

Table 1 presents the flexural strength values of the porcelain as measured for the different temperatures.

These results are summarized in the diagram of Fig. 1 which shows the flexural strength as a function of temperature.

4. Discussion

Fig. 1 shows that within the temperature interval $20 \leq T \leq \sim 400\,^{\circ}\mathrm{C}$ the flexural strength of the porcelain is practically constant. The mean values decrease within this interval slightly from 80.3 to 73.2 MPa, or by about 9%. In the following temperature interval $400 \leq T \leq 500\,^{\circ}\mathrm{C}$ an increase of the mean values of the flexural strength to a maximum of 98.0 MPa, or by about 34%, is observed. This must most likely be attributed to the beginning of viscous flow of the glass phase, which could lead to a closure of microcracks in the porcelain surface and to an enhancement of the strength. Temperatures $T > 500\,^{\circ}\mathrm{C}$ produce a lowering of the flexural strength with growing temperature. The value $R_{\mathrm{b,f}} \approx 76.0$ MPa at the glass transition temperature $T_{\mathrm{g}} = 581.7\,^{\circ}\mathrm{C}$ lies only $\sim 5\%$ below the corresponding value at room temperature.

5. Conclusions

In contrast to the authors' hypothesis that there would be a distinct reduction of the ceramic's flexural strength at temperatures approaching its glass transition temperature, the experiments reveal no significant drop in strength over the complete relevant temperature interval. Of course, only one special porcelain was tested in this study, so this fact cannot yet be generally stated for all dental ceramics.

The analyses in Refs. [1–4] showed that immediately after opening the lid of the porcelain furnace high temperature gradients build up in the ceramic veneer of a PFM-crown which temporarily lead to large transient thermal stresses of the magnitude of the residual stresses at room temperature. If the strength of the porcelain would be considerably reduced at these temperatures (around $500\,^{\circ}\mathrm{C}$), crowns and likewise bridges would be highly likely to fail. Such failures do not occur often in practice, however. This might indeed indicate that dental porcelains generally exhibit more or less a temperature dependence of their flexural strength as tested here for IPS-Classic Dentin. A confirmation of this behavior must be left to further investigations.

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