# NUMERICAL STRESS AND RELIABILITY ANALYSIS OF ALL-CERAMIC FIXED-PARTIAL DENTURES.

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## INTRODUCTION

Due to their superior optical properties, ceramics have become a standard application as a dental restorative material to mimic natural tooth esthetics. Dental ceramics have evolved over the past 20 years and are used to fabricate dental crowns, inlays, onlays, and bridges. Over the last years, several all-ceramic systems such as IPS Empress, Cerec Mark, In-Ceram Alumina, and In-Ceram Zirconia have become established on the market [1-3]. Their optical properties, like translucency and brightness make it possible to manufacture more esthetic Fixed-partial Dentures (FPD) than with the Porcelain fused to Metal (PFM) restorations. Clinical applications, however, suggest a relatively high failure rate of all-ceramic FPDs like 3-unit bridges [4,5]. The application of modern ceramics (Zirconia-TCP) with much higher flexural strength and toughness could improve the mechanical performance and significantly reduce the failure probability of FPDs.

In this study we investigated the stress distribution and structural reliability of four different ceramic systems: IPS Empress-2; In-Ceram Alumina; In-Ceram Zirconia; and DC-Zircon (Zirconia-TCP). All analyses were purely numerically and were performed by the use of the Finite Element Method (FEM) and the FEM – postprocessing software NASA – Cares/Life [6].

## MATERIALS AND METHODS

### FEM Analyses

A standard all-ceramic posterior 3-unit bridge, replacing the first model, was digitized using a Sirona CEREC InLab system. Polygon-meshes, generated from the point-clouds were converted into spline-surfaces. The resulting solid CAD model was completely meshed with 10-node tetrahedral and 8-node shell elements. For each of the four ceramic systems, two different finite element models were generated: one containing only elements (47109) for the dentin / core-ceramic component and the other one containing elements (87524) for all components – dentin / core-ceramic / veneer-ceramic (Figure 1). This was done to investigate the influence of the veneer ceramic layer on the stress distribution and on the structural reliability separately.

A unit vertical load of 100N was applied at the center of the upper surface representing a 3-point-bending loading condition similar to associated standard experimental test. Linear-elastic stress analyses were performed. All FE analyses were conducted with ANSYS 5.7.

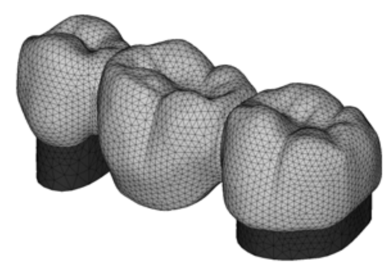

**Figure 1. Finite Element Model of the FPD.**

### Reliability Analyses

CARES/Life (Ceramics Analysis and Reliability Evaluation of Structures) is an integrated computer program developed by Nemeth et al. [6,7] at the NASA Glenn Research Center. It uses fracture statistics to predict the fast fracture reliability of isotropic ceramic components. Numerically determined stress results from Finite Element Analyses can be used as data input for the reliability estimation. Typical mechanical properties of ceramic materials like characteristic strength and Weibull modulus (Table 1) are needed to predict the failure probability of complete ceramic components under simulated loading conditions. The failure probabilities of two load intensities were used to determine the characteristic failure strength of the complete FPD.

**Table 1. Material Properties [8].**

| Product | Young's Modulus Core/Veneer | Weibull Modulus [/] | Characteristic Strength Volume/Surface |
|---|---|---|---|
| ISP Empress II | 96/73 GPa | 7.70 | 230/375 MPa |
| In-Ceram Alumina | 270/110 GPa | 11.9 | 385/525 MPa |
| In-Ceram Zirconia | 225/110 GPa | 13.9 | 502/655 MPa |
| DC-Zircon | 210/73 GPa | 18.4 | 937/1142 MPa |

## RESULTS

Figure 2 shows the typical stress distribution (1st principal stress) in a 3-unit bridge (DC-Zircon) for the core-only and core/veneer configuration under the unit load of 100N. The stresses are shown for the central frontal section.

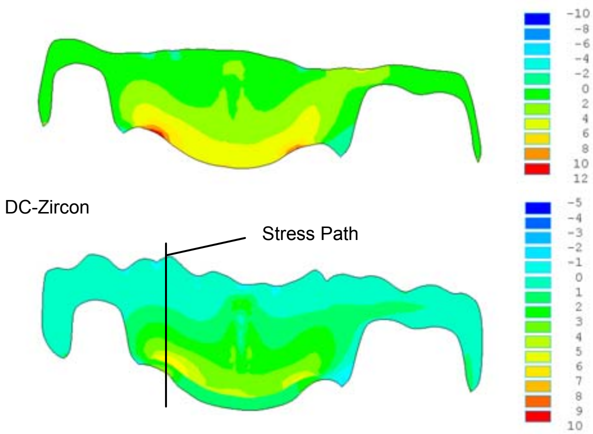


**Figure 2. 1st principal stress distribution [MPa] for the core-only (top) and core/veneer configuration (bottom).**

The highest stress concentrations are always located at the bottom surface of the core component within the connector region – whether in the core-only or core/veneer configuration. But there is a significant reduction of the stress intensities in the core component when a veneer layer existents (Table 2).

**Table 2. Minimum/maximum core stress values.**

| Product | core-only min/max $\sigma_1$ [MPa] | core/veneer min/max $\sigma_1$ [MPa] |
|---|---|---|
| ISP Empress II | -9.38/13.36 | -5.58/4.95 |
| In-Ceram Alumina | -5.88/16.22 | -3.41/8.44 |
| In-Ceram Zirconia | -6.54/15.68 | -3.68/7.46 |
| DC-Zircon | -6.79/15.48 | -4.10/8.60 |

Figure 3 displays the 1st principal stresses along the connector path (Figure 2) for all four systems under the load of 100N. The curves show clearly the strong stress discontinuities at the lower core/veneer interface as well as the peak stresses for the systems.

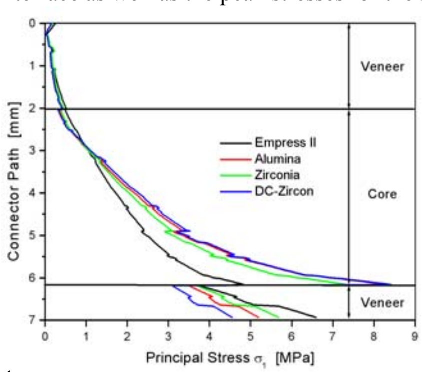


**Figure 3. 1st principal stress along a vertical path (Figure 2) intersecting the connector region.**

The estimated characteristic strength values for the four ceramic systems are shown in Figure 4. The core/veneer configuration exhibits in all cases higher strength values than in the core only configuration. The following values were determined (core-only/core-veneer): Empress-II: 2055/4067 N; In-Ceram Alumina: 2998/5435 N; In-Ceram Zirconia: 4066/7948 N; DC-Zircon: 7402/13309 N.

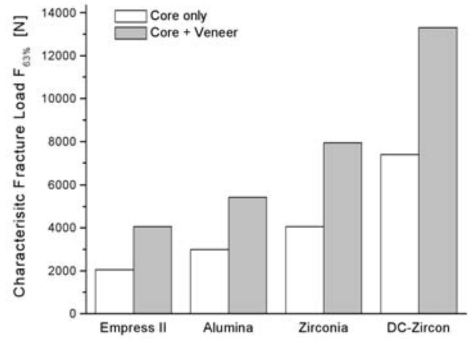


**Figure 4. Characteristic Strength for core-only/core + veneer configuration of all ceramic systems.**

## DISCUSSION

The computed stress distributions show not only the influence of the veneer layer but also of the stiffness mismatch between core and veneer ceramics. Systems with a small stiffness mismatch like Empress-II experience lower peak stresses as well as smaller stress discontinuities at the core/veneer interface as systems with a high stiffness mismatch like DC-Zircon. It becomes clear that stress distribution alone is not sufficient to evaluate the mechanical performance. The characteristic strength of the actual material has to be taken into account, too. Although DC-Zircon experiences the highest peak stresses it also demonstrates the highest fracture strength. The stress discontinuities at the material interface cause more or less severe shear stress concentrations, which can cause the debonding of the core-veneer interface. These effects were not taken into account in this investigation. Comparison with unpublished experimental data of fracture tests suggest a strong overprediction of the strength values. This is probably due to unrealistic material properties, which were generated from specimens with highly polished surfaces. Nevertheless, the investigation shows the superior quality of DC-Zircon compared with established systems. It also shows the potential of these numerical tools to evaluate and eventually optimize new dental ceramic systems.

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