

Finite Element Analysis of Full Ceramic Crowns with and without Zirconia Framework

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Abstract—Simulation of occlusal function during laboratory material's testing becomes essential in predicting long-term performance before clinical usage. The aim of the study was to assess the influence of chamfer preparation depth on failure risk of heat pressed ceramic crowns with and without zirconia framework by means of finite element analysis. 3D models of maxillary central incisor, prepared for full ceramic crowns with different depths of the chamfer margin (between 0.8 and 1.2 mm) and 6-degree tapered walls together with the overlying crowns were generated using literature data (Fig. 1, 2). The crowns were designed with and without a zirconia framework with a thickness of 0.4 mm. For all preparations and crowns, stresses in the pressed ceramic crown, zirconia framework, pressed ceramic veneer, and dentin were evaluated separately. The highest stresses were registered in the dentin. The depth of the preparations had no significant influence on the stress values of the teeth and pressed ceramics for the studied cases, only for the zirconia framework. The zirconia framework decreases the stress values in the veneer.

Keywords—Finite element analysis, full ceramic crown, zirconia framework, stresses.

I. INTRODUCTION

GIVEN its strength and transformation toughening, zirconia may be regarded as the most suitable substructure ceramic for prosthetic restorations [1].

For dental applications, yttrium oxide is usually added (2-3% mol of Y₂O₃) to the pure zirconia to stabilize the tetragonal phase at room temperature, generating a multiphase material. When assessing a weld it is important to note the type of discontinuity, its size and location. Each of these factors and all together are decision makers and, based on an established standard might transform a discontinuity in a defect. The utilization of yttria-tetragonal zirconia polycrystals (Y-TZP) in the areas of high tensile stresses of core and fixed partial denture (FPDs) connectors is indicated due to its inherent ability to suppress crack propagation. Limited clinical data are available concerning the reliability of zirconia core-porcelain veneer crowns [1].

Great effort has been expended in the development of more reliable ceramics. Fracture strengths have been progressively increased from glass ceramic to alumina and zirconia. The intermediate elastic modulus of zirconia is an advantage in

reinforced layered structures, shifting damage and fracture modes into the porcelain veneer layer. Fracture of the veneer or the framework is a major reason for technical complications of all-ceramic crowns. Only recently reported is a fatigue study on anatomically correct crowns which reported cohesive failure in the porcelain veneer and in the veneer/core bond. Different studies were designed to evaluate an all-ceramic crown fatigue test method that would reproduce clinical failure modes [2].

Simulation of occlusal function during laboratory material's testing becomes essential in predicting long-term performance before clinical usage [1]. Finite element analyses indicated high stress levels below the load and at margins, in agreement with only single-cycle fracture origins [2].

For prosthetic restorative materials, the ability to withstand the masticatory forces in the oral cavity is essential. The elastic modulus of the material is an important property in the longevity of the dental restoration. Ideally, the elastic properties of restorative materials should be close to those of the tooth structure to yield a more uniform stress distribution. However, the tooth consists of enamel and dentin that are very different elastically [1]. The elastic modulus of pressed ceramics is close to that of the enamel and this is an advantage as restorative material [3].

The effect of masticatory stresses on teeth is variable [4].

Modern design and valuation in order to obtain an adequate strength involves numerical simulations. Finite element analysis (FEA) has been widely employed in many researches to investigate the impact and effect of dental materials and restorative techniques on stress distribution. FEA is deemed as an effective tool to evaluate the biomechanical characteristics of these dental restorative materials and systems, whereby the results carry significant clinical implications [5].

II. OBJECTIVE

The aim of the study was to assess the influence of chamfer preparation depth on failure risk of heat pressed ceramic crowns with and without zirconia framework by means of finite element analysis.

III. MATERIALS AND METHODS

Experimental 3D models of the central upper incisor were achieved in order to design and analyze teeth, and ceramics crowns. Surfaces were modeled according with anatomical dimensions. The nonparametric modeling software (Blender 2.57b) was used in order to obtain the shape of the crown, with enamel, dentin and pulp structures.

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The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. These points were used to extrapolate the shape of the object, a process called reconstruction.

3D models of maxillary central incisor, prepared for full ceramic crowns with different depths of the chamfer margin (between 0.8 and 1.2 mm) and 6-degree tapered walls together with the overlying crowns were generated using literature data (Fig. 1, 2). The crowns were designed with and without a zirconia framework with a thickness of 0.4 mm.

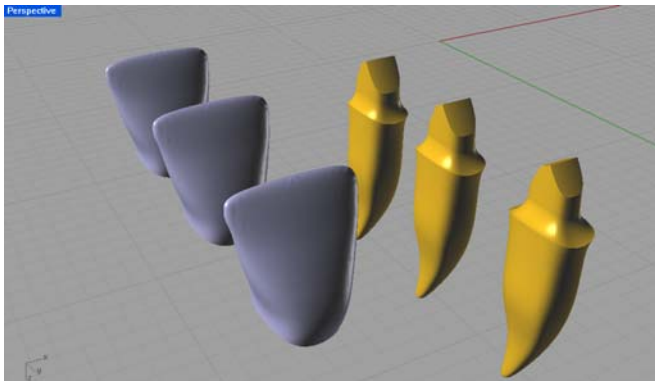


Fig. 1 3D models of the prepared tooth and the overlying complete ceramic crown

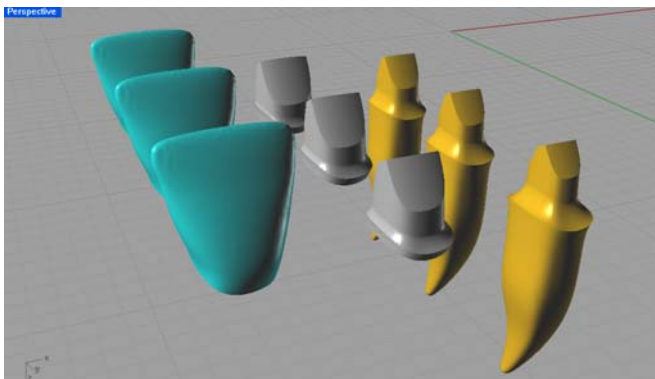


Fig. 2 3D models of the prepared tooth and the overlying complete ceramic crown with zirconia framework

The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 3).

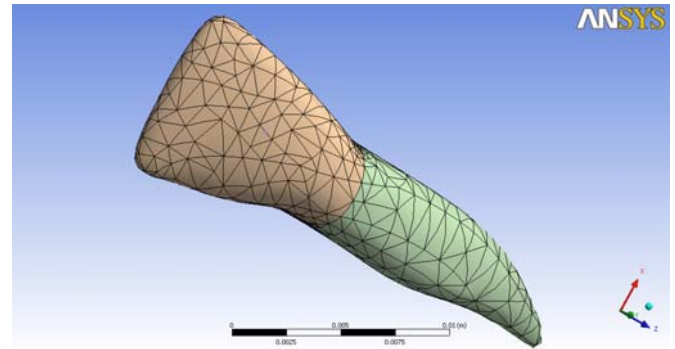


Fig. 3 Mesh structure of the incisor covered with a ceramic crown

A palatal load of 50 N was conducted, and stresses occurring in the teeth and restorations were calculated (Fig. 4).

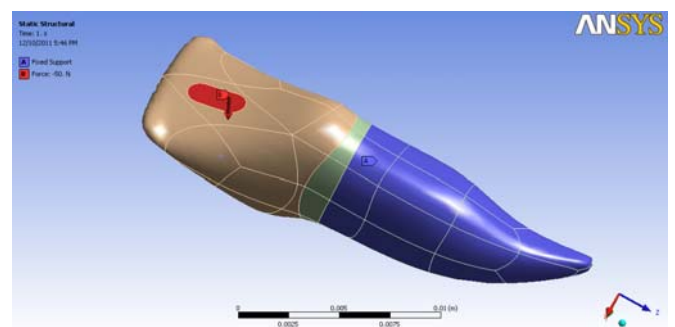


Fig. 4 Point selected for loading on the restored incisor

In making the finite element models, the characteristics of a tooth structures, and ceramics used for the restorations were entered into the computer program.

IV. RESULTS AND DISCUSSIONS

For all preparations and crowns, stresses in the pressed ceramic crown, zirconia framework, pressed ceramic veneer, and dentin were evaluated separately (Table I, II).

The highest stress values were exhibited in the dentin in the most of the cases.

TABLE I
 MAXIMAL VON MISES EQUIVALENT STRESS VALUES IN THE PREPARED INCISOR AND IN THE PRESSED CERAMICS CROWN

Chamfer depth [mm]	Maximal Von Mises equivalent stress [Pa]	
	dentin	ceramic crown
0.8	3.01E+07	1.97E+07
1	2.66E+07	1.89E+07
1.2	2.91E+07	1.71E+07

TABLE II
 MAXIMAL VON MISES EQUIVALENT STRESS VALUES IN THE PREPARED
 INCISOR AND IN THE CROWN: ZIRCONIA FRAMEWORK AND PRESSED
 CERAMICS VENEER

Chamfer depth [mm]	Maximal Von Mises equivalent stress [Pa]		
	dentin	zirconia	ceramic veneer
0.8	3.02E+07	3.02E+07	1.51E+07
1	2.67E+07	2.75E+07	1.34E+07
1.2	2.91E+07	1.92E+07	1.56E+07

In the dentin maximal stresses were distributed around the cervical areas, the most under the preparation line, oral (Fig. 5, 7).

The load on a tooth restored with ceramic crown produces stress around the contact areas and the cervical line (especially for the restoration without zirconia framework) in the restorations (Fig. 6, 9).

In the zirconia framework the stress values are similar with those in the dentin and decrease with the increase of the chamfer depth. The stress distribution is in the oral part of the framework and the cervical areas (Fig. 8). The zirconia framework decreases the stress values in the veneer.

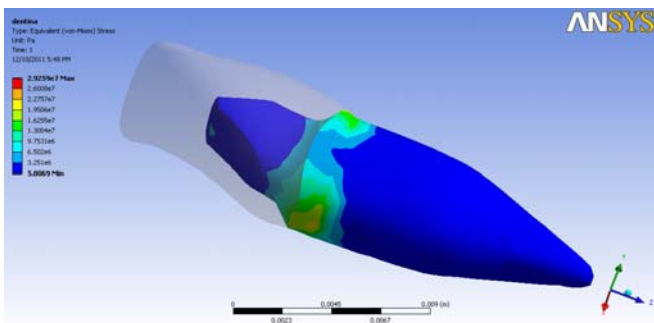


Fig. 5 Von Mises equivalent stress in the dentin of the incisor prepared for ceramics crown (preparation with chamfer depth of 1.2 mm)

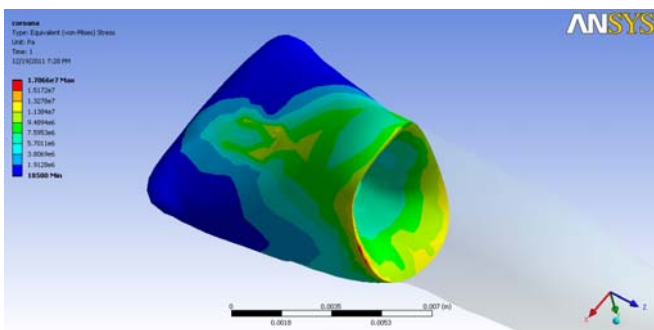


Fig. 6 Von Mises equivalent stress in the ceramic crown (preparation with chamfer depth of 1.2 mm)

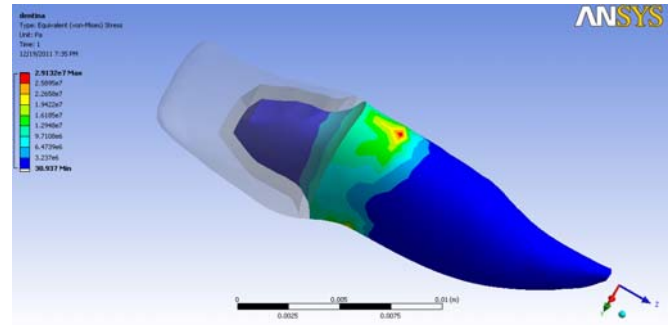


Fig. 7 Von Mises equivalent stress in the dentin of the incisor prepared for a full ceramic crown with zirconia framework (preparation with chamfer depth of 1.2 mm)

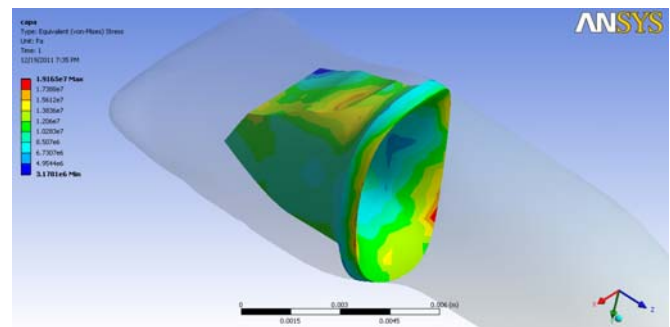


Fig. 8 Von Mises equivalent stress in the zirconia framework of a full ceramic crown (preparation with chamfer depth of 1.2 mm)

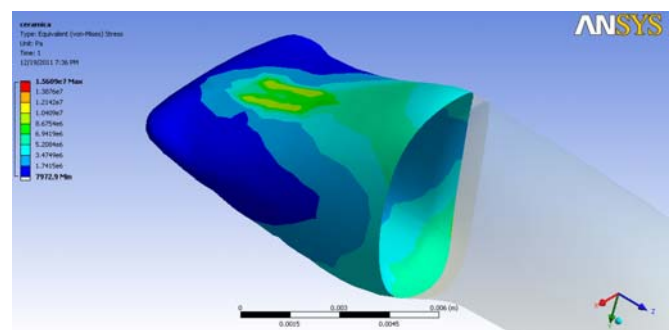


Fig. 9 Von Mises equivalent stress in the ceramic veneer of a crown with zirconia framework (preparation with chamfer depth of 1.2 mm)

Regarding the chamfer preparation depth no significant variations regarding stress values in the prepared teeth and pressed ceramics were registered in the studied interval (0.8 and 1.2 mm).

V. CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

- Ceramic crowns transfer functional stress to the teeth structures. The highest stresses were registered in the dentin.
- The depth of the preparations had no significant influence on the stress values of the teeth and pressed ceramics for the studied cases, only for the zirconia framework.
- The zirconia framework decreases the stress values in the veneer.

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