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# COMPARATIVE NUMERICAL ANALYSES OF TOOTH RESTORED WITH HYDROXYAPATITE CERAMIC INSERT VERSUS TRADITIONAL COMPOSITE RESTORATION

**Aleksandar Bodić[1], Maja Ležaja Zebić[2], Milan Bojović[1], Djordje Veljović[3] and Vladimir Milovanović[1]**

[1] Faculty of Engineering, University of Kragujevac, Serbia
e-mail: abodic@uni.kg.ac.rs, mbojovic@outlook.com, vladicka@kg.ac.rs
[2] School of Dental Medicine, University of Belgrade, Serbia
e-mail: dr.maja.zebic@gmail.com
[3] Faculty of Technology and Metallurgy, University of Belgrade, Serbia
e-mail: djveljovic@tmf.bg.ac.rs

**Abstract**:

The aim of this study was to compare traditional composite restoration and restoration which include hydroxyapatite ceramic insert in replacing healthy tooth structures using comparative numerical analysis. The dental inserts discussed in this paper are based on nanostructured hydroxyapatite/yttrium stabilized zirconia and suits for dentin substitution only. Hydroxyapatite insert is biocompatible, and supposed to be used as is, without potential changes in dimensions unlike the composite which polymerize and shrink in the cavity. A 3D CAD model of a healthy tooth is created based on a 3D scan. The internal geometry of the healthy tooth was modified to contain I class cavity restored in one case with composite alone and in another case using dental inserts in combination with composite. For all three cases, a finite element mesh was created using prepared geometries. Boundary conditions and loads are set to simulate the real tooth testing procedure. The models pre- and post-processing was performed using the *Femap* software, while the calculation was carried out in the *Nastran* software. Comparing the calculation results, it can be observed that lower values of von Mises stress in dentin occur in the case of a restored tooth using a dental insert. Based on this, it can be concluded that restoration procedure using dental insert is more effective than classic one.

**Keywords**: finite element method, dental insert, tooth, 3D model.

## 1. Introduction

In order to restore the back teeth, direct restorations are most often used because of the lower cost, less need to remove healthy tooth substance compared to indirect restorations, and acceptable clinical performance [1]. The most commonly used material for direct posterior filling is resin composite, which has shown acceptable longevity in various studies [2, 3]. However, these materials still exhibit deficiencies despite significant improvements. The main reasons for long-term failure are secondary caries and fractures [4]. The use of dental inserts based on hydroxyapatite and yttrium-stabilized zirconium investigated in [5] shows significant potential for restoration of the major part of the tooth cavity with the material which does not change its dimensions after placement in the cavity and is made of completely biocompatible material at the same time.

This paper presents comparative numerical analyses of a healthy tooth, tooth restored using composite alone and tooth restored using dental insert as dentin substitute, in combination with composite used as enamel substitute. The tooth geometry was created based on 3D scan. Healthy tooth morphology CAD model was modified for two tooth restoration situations with the same total dimensions and shape. After that, within the *Femap* software, a finite element mesh was created, and boundary conditions and loads were set. Calculation was performed in the *Nastran* software [6].

A brief description of dental inserts for tooth restoration and the materials they are made of is given in section 2 of the paper.

In the third section of the paper, the procedure for creating tooth geometry based on 3D scans is presented.

In the fourth section of the paper, the created FE model of the tooth is shown as well as definition of boundary conditions and loads on it.

At the end of the paper, a comparison of the numerical analysis results for all three cases is given.

## 2. Composite nanostructured hydroxyapatite/yttrium stabilized zirconia dental inserts

Hydroxyapatite (HAp), or more accurately calcium hydroxyapatite, has been an attractive biomaterial for hard tissue replacement [7, 8, 9]. Due to its chemical and mechanical characteristics, as well as good bioactivity and biocompatibility, it is frequently used in orthopaedics, but also in dentistry [10, 11]. HAp can be used in dentistry in various ways, such as dental cements, scaffolds for replacement of damaged parts of the jawbone, filler in dental composites and adhesives etc [4, 5]. In addition to these applications, HAp can be used as a substitute for dentin in the form of dental inserts [12]. The use of dental restorative inserts (Fig. 1) can simplify the procedure, reduce the number of steps in the clinical protocol, and potentially reduce polymerization shrinkage stress due to the central position of the insert in the cavity [5].

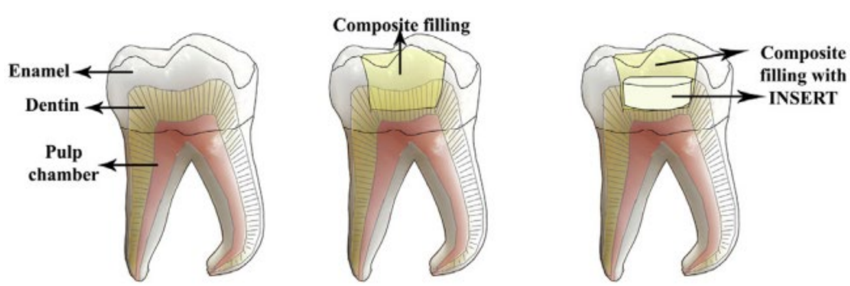


Fig. 1 Schematic representation of dental implants placement.

In order to increase the fracture toughness of HAp bioceramics, various sintering procedures are applied, as well as the addition of various nanoparticles. The procedure of adding optimal amount of tough partially stabilized zirconia particles of different sizes and shapes to optimize the mechanical properties of the HAp matrix is investigated in [5]. In this way, the composite material based on hydroxyapatite and yttrium-stabilized zirconium (YSZ) can be used as a dental insert. The use of dental insert on mechanical properties of restored tooth is still uninvestigated.

The material characteristics of the composite restoration and hydroxyapatite dental insert in the model are taken from [13].

### 3. Tooth geometry

The object of geometry reconstruction is the first molar in the lower right position shown in Fig. 2. To minimise the impact of boundary conditions in numerical simulations, immediate vicinity of the jaws is also reconstructed to set the boundary conditions.

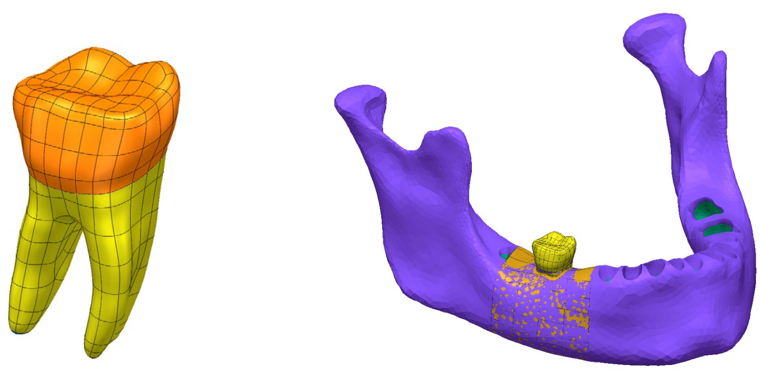

Fig. 2. Geometry of first molar (left); lower jaw mesh with reconstructed tooth geometry (right).

Tooth geometry is created using NURBS surfaces inside of patch boundaries based on polygonised points. The boundaries are defined by a 3D patch network (Fig. 3). The patch network can be created automatically or drawn manually. Although manual patching requires more time, it yields better results in terms of creating a clean and high-quality surface, which is very important for further geometry processing and FEA mesh generation. The deviation of created surface from the mesh is shown in Fig. 3. SThe deviation is less the 0.1mm.

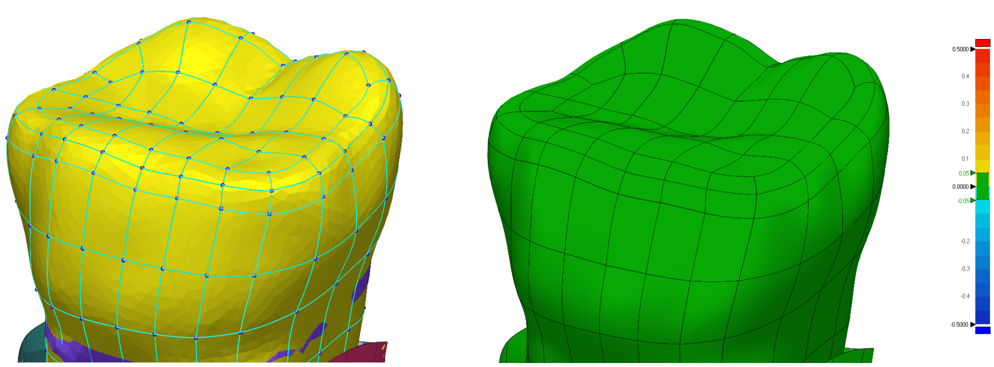

Fig. 3. Constructed patch network over mesh (left); surface deviation from mesh (right).

Surface Fitting is a unique method used in the Reverse Design process (creating geometry from 3D scanned data) that provides an efficient way in creating a 3D freeform surface body easily and precisely from the mesh's freeform shape.

## 4. Finite element model of tooth

Finite element model of tooth was created using *Femap software* (Fig. 4). The model was created based on tooth geometry for three situations: healthy tooth, restored tooth using a composite alone, and restored tooth using an insert in combination with composite.

The finite element model of tooth includes the following parts: mandible, dentine, pulp, enamel, cement, composite and insert (in the case of tooth restoration with an insert). The average size of the elements in the tooth is 0.2 mm with an increase of up to 1 mm in the mandible. All three tooth models were created using tetrahedral finite elements with midside nodes and consist of approximately 510 000 finite elements and 740 000 nodes.

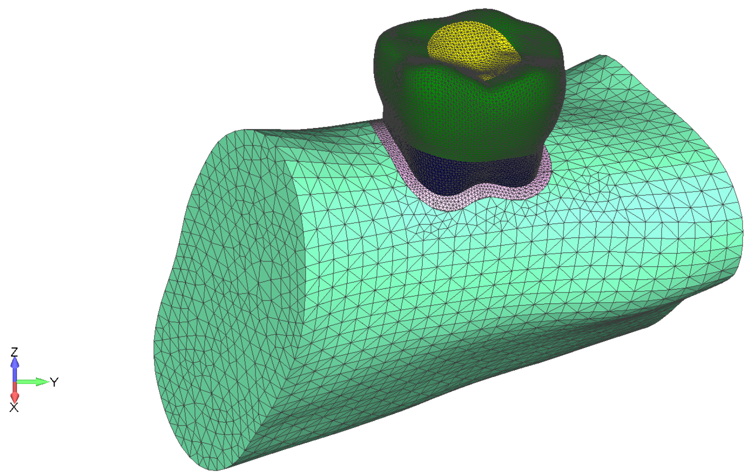


Fig. 4. Tooth tetrahedral mesh.

The loading of the model is set to match the real conditions of dental testing. For the purposes of testing the tooth model, a "ball" was created, through which the directional load was set. Contact is set between the surface of the test ball and the upper surface of the tooth. The ball touches the tooth in three points on the upper surface of the tooth and presses it with a force of 2000 N (Fig. 5).

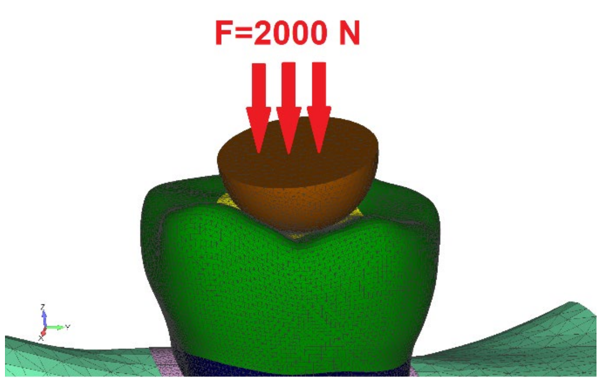


Fig. 5. Applying pressure to the upper surface of the tooth with a test ball.

The hardening (polymerization contraction) effect of the composite is achieved by setting the temperature difference between the composite and the external surfaces on the model. First, a thermal analysis was performed with set temperatures of 10° C on the composite surfaces and 36° C on the outer surfaces of the model. The temperature field obtained by the thermal analysis was then used as a load in the static calculation (Fig. 6).


Fig. 6. Composite hardening effect - assigned temperature field as the difference between external and composite temperatures.

The material parameters of the tooth models are given in Table 1.

| Environment of model | E [MPa] | ν [-] |
|---|---|---|
| Pulp | 6.8 | 0.45 |
| Dentine | 18600 | 0.31 |
| Enamel | 84100 | 0.3 |
| Cement | 16600 | 0.24 |
| Mandible | 199.5 | 0.3 |
| Cement (below and side) | 4000 | 0.35 |
| Composite | 16600 | 0.24 |
| Insert | 5220 | 0.3 |

Table 1. Material parameters.

The calculation was performed using *Nastran* solver. A comparative analysis of the results for three tooth models is given in the next section.

## 5. Results

As dentin represents the key component that makes up the largest part of the tooth and gives it its shape, it the focus of the numerical analysis results. The results are presented in the form of Von Mises stress fields for all three models.

The Von Mises Stress field for the healthy tooth model is given in Fig. 7 and Fig. 8.

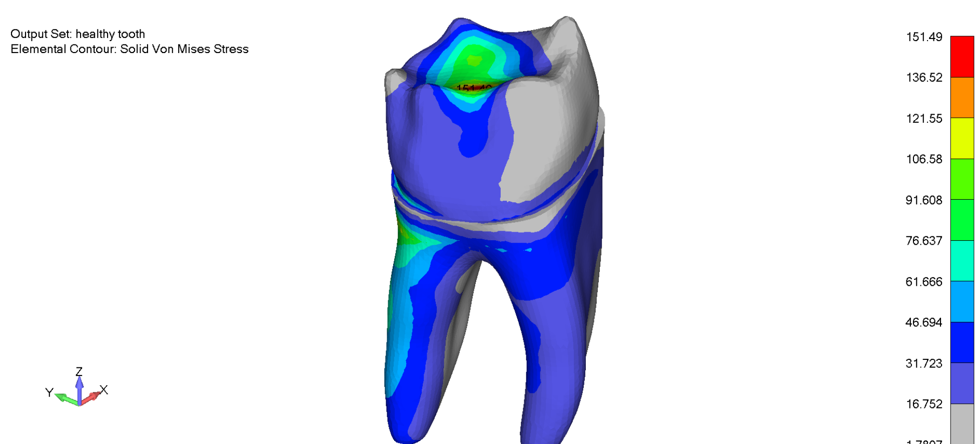


Fig. 7. Von Mises Stress – isometry.

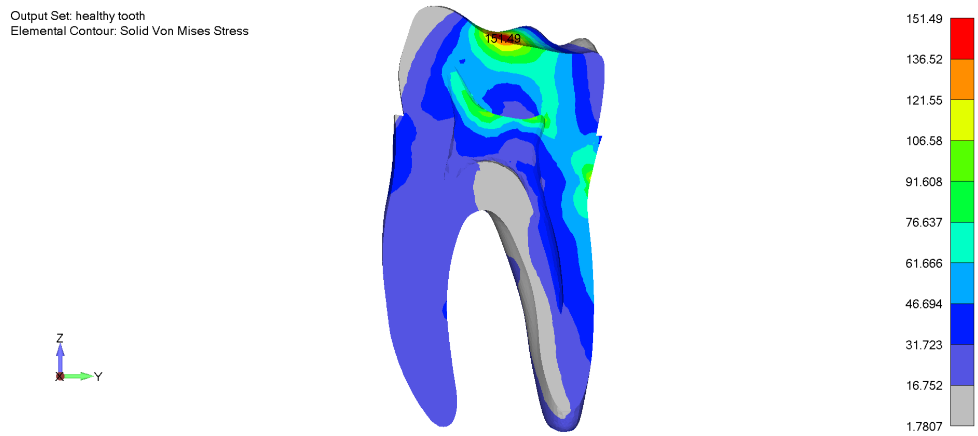


Fig. 8. Von Mises Stress – vertical cross section.

The Von Mises Stress field for the model of tooth restored using composite is given in Fig. 9 and Fig. 10.

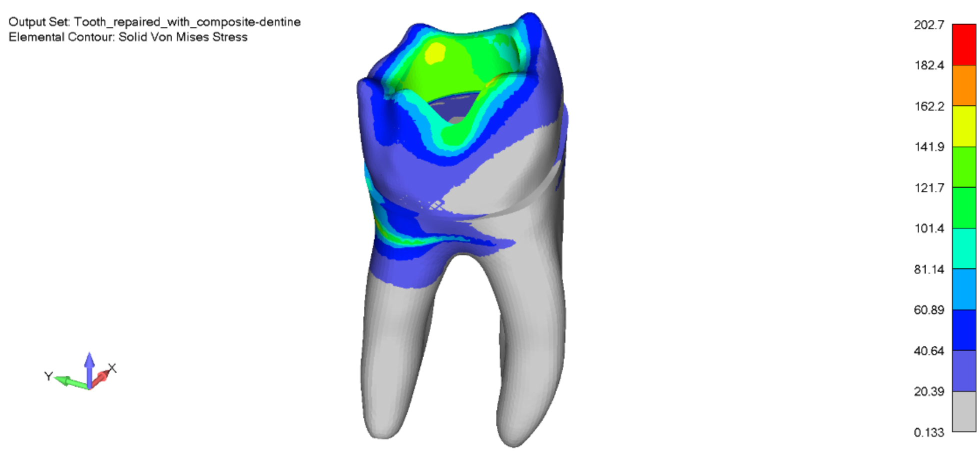


Fig. 9. Von Mises Stress – isometry.

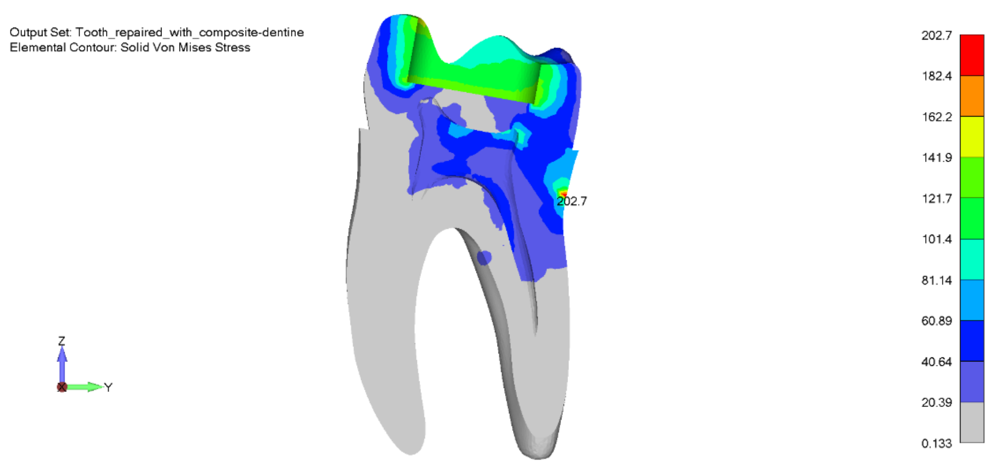


Fig. 10. Von Mises Stress – vertical cross section.

The Von Mises Stress field for the model of tooth restored using insert is given in Fig. 11 and Fig. 12.

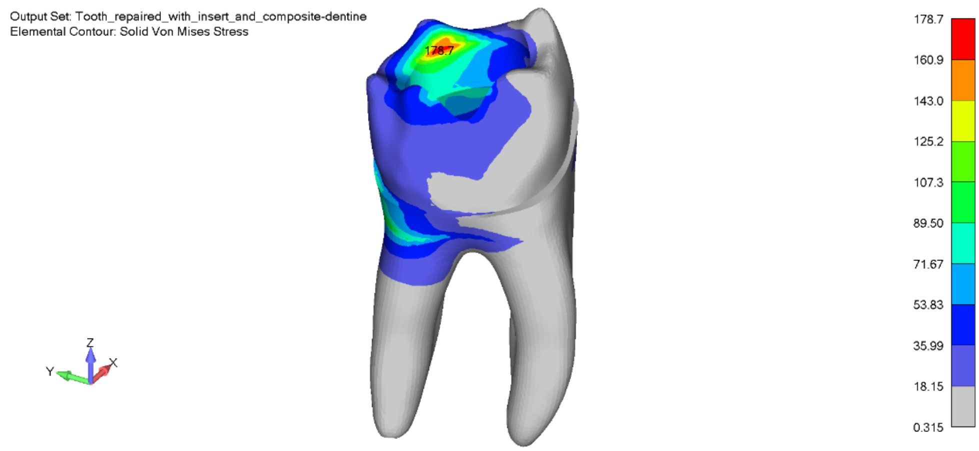


Fig. 11. Von Mises Stress – isometry.

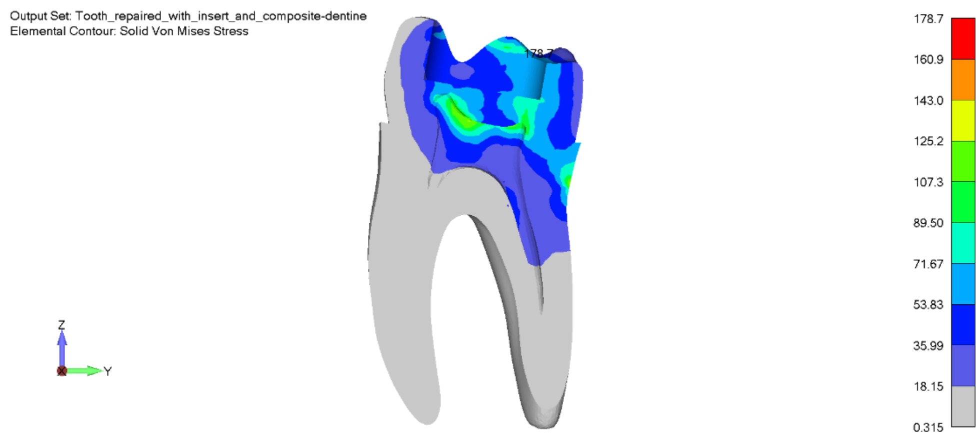


Fig. 12. Von Mises Stress – vertical cross section.

Analysing the results from the previous figures, it can be concluded that the most favourable variant is the healthy tooth in which the lowest Von Mises stress values occur. In addition, looking at the results for both situations of tooth restoration, it can be concluded that lower stress values occur for the case of a restored tooth with a dental insert. Therefore, using this method of restoration, better mechanical characteristics of the tooth are obtained, and the incidence of tooth fracture occurrence is lowered.

## 6. Conclusions

In this paper, a numerical analysis was conducted to compare a healthy tooth, tooth restored with composite, and a tooth restored with dental insert. Dental inserts based on nanostructured hydroxyapatite/yttrium stabilized zirconia composite were considered. First, a three-dimensional CAD model of a healthy tooth was created based on a 3D scan. After that, two models of the restored tooth were created by modifying a healthy tooth geometry: using composite and using dental insert. Based on these geometries, finite element meshes were created for all three situations. Boundary conditions and loads where set to correspond to real tooth testing conditions.

By comparing the calculation results, it can be concluded that lowest values of von Mises stress in dentine occur in the case of a healthy tooth. When it comes to the two tooth restoration procedures considered in this paper, based on the presented results, it can be observed that lower stress values occur in the tooth restored using dental insert. Considering that the use of a dental insert can potentially simplify and shorten the duration of the tooth restoration process, it can be concluded that this procedure has great potential to be applied as standard tooth restoration procedures.

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