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NUMERICAL SIMULATIONS OF THE MECHANICAL BEHAVIOUR OF A DENTAL FILLING

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***Abstract*— Dental fillings must ensure good mechanical properties and last for years. Depending on the load conditions and on the resin used, wear and cracks, especially at the interface between the filling and the tooth, occur or not. A molar tooth was considered as a case study to determine, by means of numerical simulations carried out with COMSOL Multiphysics, the maximum stresses in the filling for three different positions of it in the tooth and for the same load condition. A comparison was made with the ultimate tensile strength of the resin to determine if there is the risk of a crack.**

Keywords—structural simulations, material properties, stress analysis

I. Introduction

The aim of this paper is to study, in typical load conditions, the stress distribution in a molar tooth which has been received a dental filling. The resin used is the low-shrinkage composite Premise, and three different positions of the filling have been chosen: at the center of the upper face of the tooth, at its edge and laterally, at the center of the face, as shown in Fig. 1-3. Normal and friction loads are applied to the upper face of the tooth, in order to take into account both compressive and shear stresses. This study has been carried out to verify whether there is a risk of fracture of the resin and of its interface due to traction stresses. A comparison of their maximum positive value with the flexural stress will be performed to see how close the risk of a crack is.

II. Simulations Settings

A. Geometries

The molar tooth is modeled as a cube having a side length of 8 mm. The filling has a cylindrical shape, a radius of 1 mm and a length of 3 mm. Fig. 1-3 show the tooth with its filling:

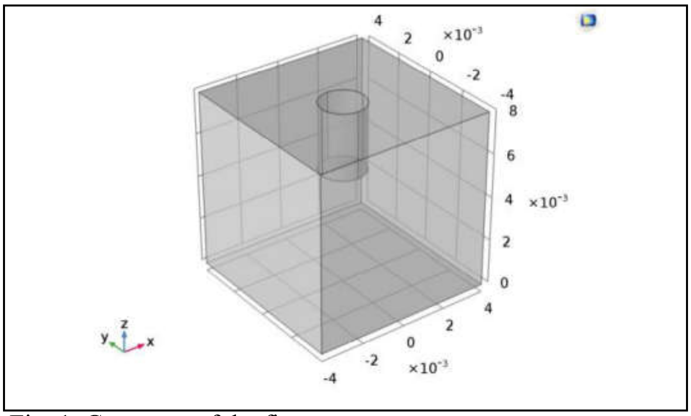

Fig. 1. Geometry of the first case

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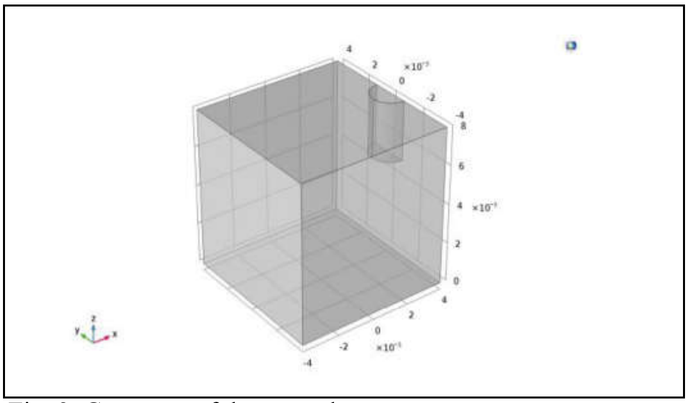

Fig. 2. Geometry of the second case

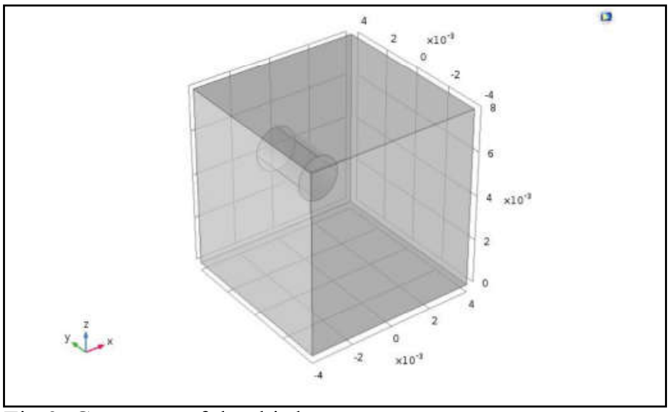

Fig.3. Geometry of the third case

The domain was discretized in over 200000 tetrahedral cells and a mesh refinement at the interface between the two materials was done. The solver is COMSOL Multiphysics, a finite-element package.

B. *Equations*

The structural model adopted in this study considers only a linear elastic behavior of both materials, resin and dentin. All simulations were performed in steady-state conditions without volume force or thermal stresses, so the equations are:

$$\vec{\nabla}[S] = \vec{0} \tag{1}$$

$$[\varepsilon] = \frac{1}{2} \cdot \left[\left(\vec{\nabla}\vec{u}\right)^T + \left(\vec{\nabla}\vec{u}\right) \right] \tag{2}$$

where $[S]$ is the stress tensor, $[\epsilon]$ is the deformations tensor and $\vec{u}$ is the displacements vector.

C. *Load conditions*

A compressive stress is applied on the upper face of the tooth, its value is 6.3 MPa. In addition to is, a frictional shear stress acts on that face because of the horizontal movement of the mandible with respect to the jaw during chewing. This movement is assumed to be in the x-positive direction and the friction coefficient between the tooth and its antagonist one is 0.8 [1]. So, the shear stress applied to the upper face of the tooth is 5.04 MPa.

D. *Materials properties*

The resin and the dentin properties as reported respectively in Tab. I and II from [2] and [3]:

Table I – Resin properties

Young's modulus (GPa)	***Poisson's modulus***	***Flexural strength (MPa)***
3.2	0.3	93

Table II – Dentin properties

Young's modulus (GPa)	***Poisson's modulus***	***Flexural strength (MPa)***
10	0.1	230

As it can be seen, the resin is less rigid and weaker than dentin. The application of a uniform load on the surface of the tooth will induce different deformations in the two materials and therefore stresses at the interface between them.

III. Results

In the following sections, the x normal-directed stress will be shown on the xz plane for the first two simulations, and on the plane parallel to the xz plane containing the external surface of the filling.

A. *Simulation 1*

Fig. 4 shows the x normal-directed stress on the above mentioned plane. As it can be seen, the friction load make the filling tend to rotate around the y axis clockwise. As the resin's Young modulus is lower than the one of the dentin, the latter behaves roughly as a rigid body, whereas the filling deforms more. As a result, compression and traction loads appear on the interface between the two materials.

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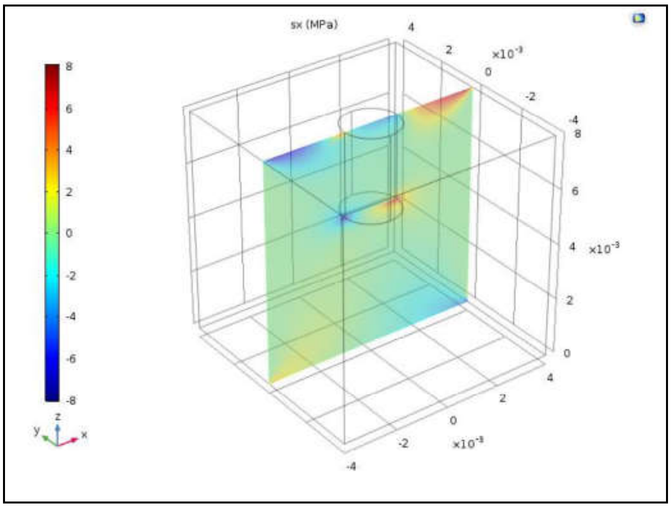

Fig. 4. x normal stresses

B. Simulation 2

Fig. 5 shows the x normal-directed stresses on the xz plane. The filling is in this case at the edge of the tooth, and so part of its surface is not in contact with the internal one of the tooth. So, as the friction load tends to make the resin rotate around the y axis and the filling is not completely surrounded by the tooth, the stresses are higher.

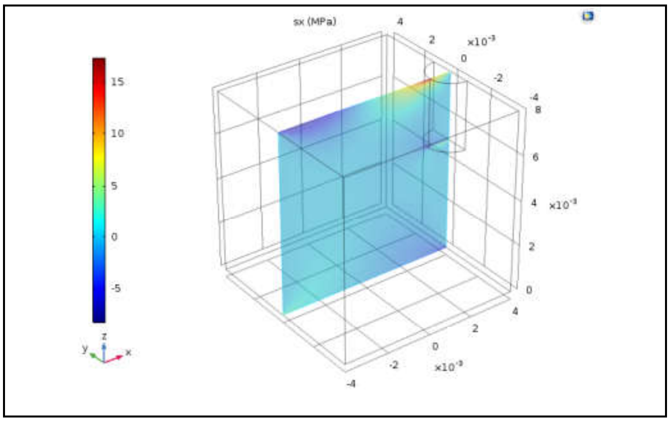

Fig. 5. x normal stresses

C. Simulation 3

Fig. 6 shows the x normal-directed stresses on the plane passing through the external face of the filling. In this case, the friction load is fully applied to the dentin surface, and therefore the above mentioned stresses are lower at the interface between the two materials.

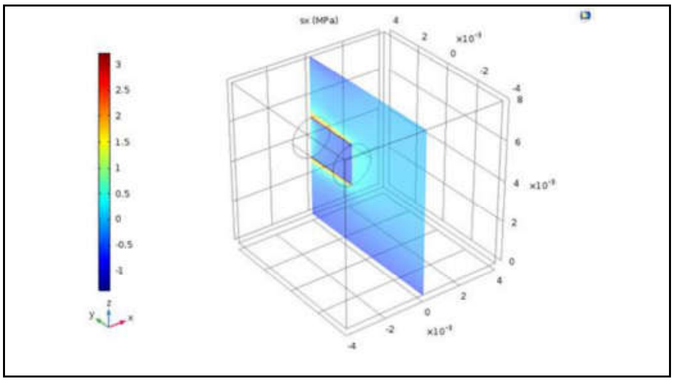

Fig. 6. x normal stresses

D. Comparisons

Tab. III reports the maximum values of the traction stresses which are always reached at the interface.

Table III. Maximum x normal-directed stresses

Simulation	Maximum x normal-directed stresses (MPa)
1	11.119
2	18.77
3	9.71

The results show that the worst case is the second one. Due to the position of the filling, the latter remains connected to the tooth only thanks to a limited contact surface, which causes higher stresses. Furthermore, this filling is the one which is mostly exposed to chemical attack by bacteria, and so it weakens more rapidly, as it is well known by the dentists. For these reasons, a crack of the interface is expected sooner for this position of the filling.

IV. Conclusions

3-D numerical simulations of the behavior of a dental filling in a molar tooth for three different positions have been carried out under compressive/friction load conditions. It has been found that due to the different mechanical properties of resin and dentin, differential deformations occur and cause stresses at the interface between the two materials. It was also found that the worst position is the one where the filling is at the edge of the tooth. This study confirms the need to develop filling materials as similar as possible to the natural one they have to partially replace and to bind to.

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