THERMAL STRESS ANALYSIS FOR RESTORED AND SANE LOWER SECOND MOLAR

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***Abstract**. In this work a thermo-mechanical finite element analysis of a second molar is proposed to simulate the ingestion of cold (4^{o}C) and warm (60^{o}C) food. The model was generated from data presented in the last edition of COBEM (*Cornacchia et al., 2003*), and the results are compared to the literature. The purpose of the analysis is to compare the behavior under thermal variation of sane(not restored) teeth and those restored with resin and porcelain, materials of choice in dentistry due to their aesthetic and functional characteristics. The three-dimensional model was based on a dental atlas for a second molar with two roots and included the maxilla digitalized from CT data. Thermo physical properties partly obtained from the literature and in some cases measured experimentaly. A transient analysis was performed for determining the temperature distribution in the tooth, followed by a linear elastic stress analysis. The obtained results for hot temperatures agree with the ones found in the literature. The results for exposure to cold show high stress levels, specially when regarded in the perspective of coupling with residual stresses, mastication loads and parafunctional loading. The results show that different restoring materials, porcelain and resin, should be selected after taking into account their response to mechanically induced stresses in different loading conditions, as well as in their possible combinations.*

***Keywords**: indirect dental restoration, thermo mechanical analysis, finite element method.*

1. Introduction

The use of resin and porcelain dental restorations without metallic base, named inlays/onlays allows the dentists to restore posterior teeth joining functional and anatomic aspects to aesthetic considerations (Vieira et al., 1995). The restoration systems using these materials are based on adhesive dentistry, requiring an effective and durable connection to the dental tissues. These materials provide better results from an aesthetic perspective when compared to metals, but much remains to be learned and improved on their physical behavior in the oral environment.

According to Magne and co-workers (Magne, Verluis and Douglas, 1999), ceramic restorations connected to the dental structure are subjected to a number of different mechanical loads. Resin contraction due to polymerization of resinous cement and temperature changes in the mouth are factors to be considered.

According to Anusavice (Anusavice, 1998), the analysis of the effect of thermal fluctuations on restored teeth should be considered, as it has direct impact on the stresses in the adhesive interface due to the difference between the thermal properties in tooth and restoring materials, affecting the durability of the interface. The clinical consequences of cracks in the adhesive layer are marginal leak and the occurrence of recurrent caries.

In this paper, a numerical analysis using the finite element program Ansys is described, comparing the response of a sane Lower Second Molar with two others, one restored using resin, the other porcelain. Indirect restorations – those prepared outside the patient's mouth and fixed through an adhesive procedure – are considered.

2. Methodology

The geometric model for the Second Molar was based on data from a dental atlas (Wheeler 69) and in measurements performed in vitro. To model the internal tooth structure, including enamel thickness and geometry of the pulp chamber, the tooth was sectioned using carborundum disks. A molar with two roots was considered, as well as a section of the mandible obtained from a CT image (Fig. 1).

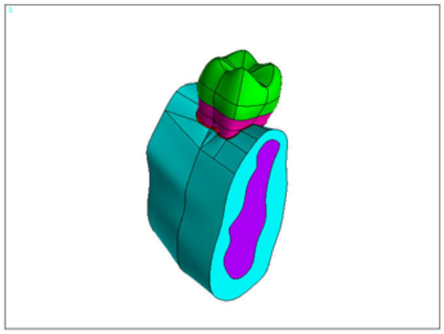


Figure 1- Geometric model

A transient thermal finite element analysis was performed, followed by a static elastic linear analysis.

First, the initial temperature of the entire model was set to 37º C, and thermal loads, resulted from convective coefficients and bulk temperatures of 4º (cold load) and 60ºC (hot load), were applied. These temperature ranges were based on the work of Palmer and his group (Palmer, Barco and Billy, 1992), where they described the temperature measured in the oral environment. The period considered in the analysis was 2 seconds, corresponding to normal duration of exposure to hot and cold food. According to Fenner (Fenner et al., 98), this is the period of time that a hot liquid is retained in the mouth at near constant temperature. A standard finite difference method, with an algorithm that recalculates an appropriate time-step after the first one was performed, was used. Fenner states that contact occurs between food and the lingual and occlusal surfaces (corresponding to the mastication and internal regions). Thus, convection was considered only in these surfaces. Jacobs and co-workers (Jacobs; Thompson and Brown, 1973) point to the need of considering a convection coefficient (h) when studying the heat transfer process. Constant h was taken as 5.95×10^{-4} (J mm^{-2} s^{-1}C^{-1}), for cold load, corresponding to the ingestion of ice cream, and 7.37×10^{-4} (J mm^{-2} s^{-1}C^{-1}), for the ingestion of hot liquids (Jacobs; Thompson and Brown, 1973).

In order to verify the sensibility of the solution to first time step variations, values of 0.01, 0.1 and 0.4 seconds for this parameter were tested. The solver was not affected by the time step, as shown in Fig. 2, and a value of 0.1 was used, to get a more complete description of temperature fields along the time.

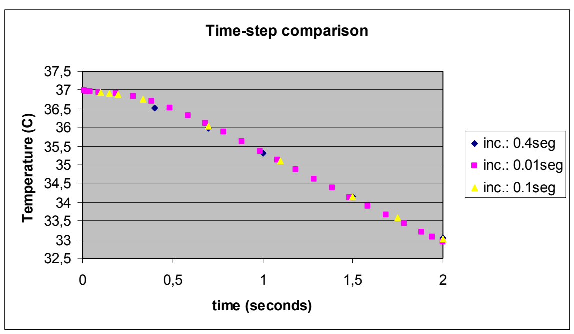


Figure 2 – Time step sensitivity

The element used for the determination of the heat distribution was a quadratic ten node tetrahedral with temperature as the only degree of freedom, due to its flexibility in meshing complex geometries.

In the static elastic linear analysis, a similar element was used with three translational degrees of freedom freedom in each node, instead of the temperature scalar value. So, the same mesh of the thermal transient analysis could be used. The loads in this case were the temperatures previously obtained at 0.1, 1.1 and 2.0 seconds.

The mesh was tested for convergence of temperatures and stresses generated by the cold load in sane tooth after 2 seconds, with the results for a selected node shown in Figs. 3 (for temperatures) and 4 (for stresses).

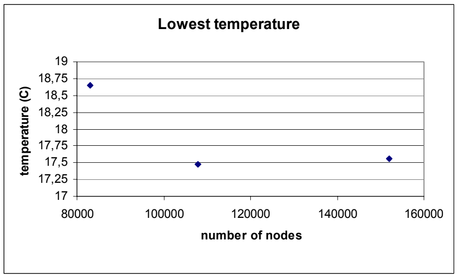


Figure 3 Convergence for temperature analysis

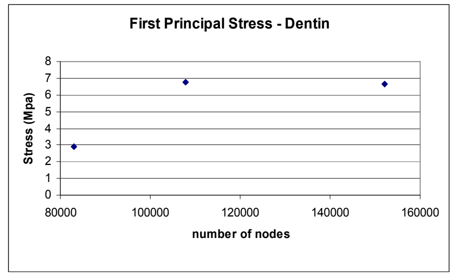


Figure 4 Convergence for stress analysis

The stress fields obtained for the two more refined meshes are shown in Figs. 5 and 6. Mesh 2 was chosen for the analysis, as the results, with the more refined mesh was quite similar with higher computational costs. The difference in peak stresses occurred artificially at points where the shape of the modeled geometry had corners, while the overall stress distribution was basically the same.

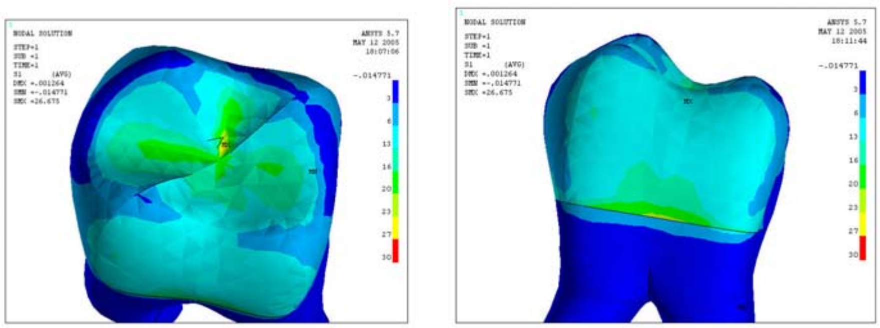


Figure 5 Stresses for mesh 2

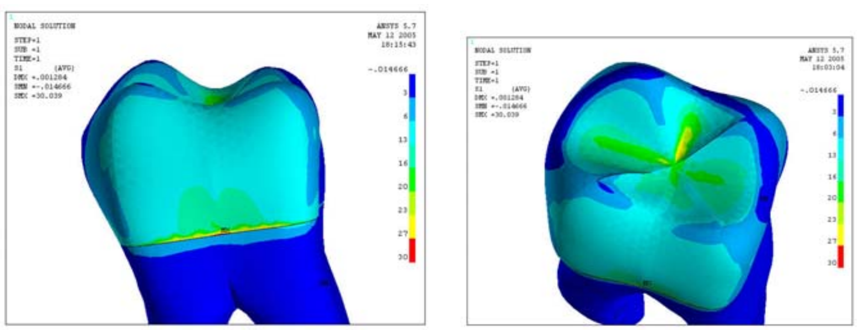


Figure 6 Stresses for mesh 3

The physical properties used in the analysis, for the different materials, are listed in Tab. 1.

Table 1 Thermal and mechanical properties of materials used in the FE model

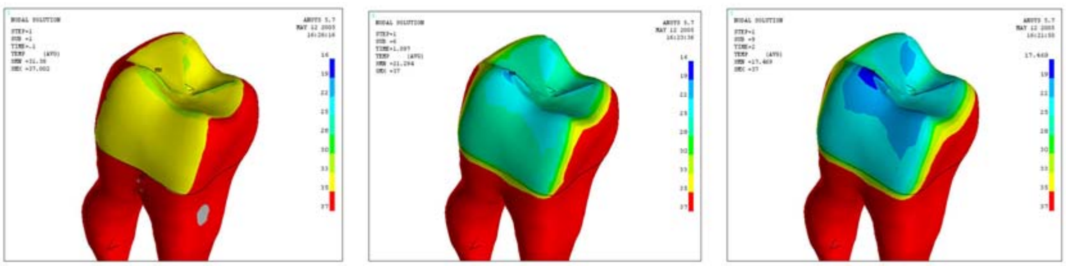
Material	Density (Kgmm^{-3}x 10^{-6})	Specific heat (Jkg^{-1} ^{o}C^{-1})	Coeff. thermal expansion (x10^{-6} ^{o}C^{-1})	Young's modulus (GPa)	Poisson's ratio	Tensile strength (MPa)	Comp. strength (MPa)
Enamel	2.97	752	17	84.100	0.33	10	262
Dentin	2.14	1170	10.6	14.7	0.31	50	234
Resin	1.58	200	35	25	0.30	70	300
Porcelain	2.22	210	7,1	74	0.19	50	149

It stands out the fact that a great variety of values for the properties listed in Tab. 1 is available in the literature, as collected by Cornacchia (Cornacchia, 2005) and the choices made in this work affected directly the obtained results.

3. Results -Finite element analysis

3.1 Thermal analysis

The temperature distribution verified in different time steps under cold temperatures is shown in Fig. 7, for the sane tooth.



0.1 sec. 1.1 sec. 2.0 sec.

Figure 7 Temperatures at different time steps (cold sane tooth)

The values found for the three materials in study for the time of 2 seconds under hot and cold temperatures are shown in Tab. 2.

Table 2 – Maximum and minimum temperatures in ^{o}C at dentin and complete model for different temperatures.

Load case (temperature)	Material	Sane tooth	Porcelain	Resin
Tooth exposed to cold temperature	Tooth (minimum)	17	8.5	6.6
Tooth exposed to cold temperature	Dentin (minimum)	25-30	24.5-30	25-30
Tooth exposed to hot temperature	Tooth (maximum)	52	57.6	58.6
Tooth exposed to hot temperature	Dentin (maximum)	46-41	46-41	46-41

3.2 Stress analysis

When analyzing the stresses at times 0.1, 1.1 and 2.0s it was verified a rise in the stress values of the stresses from 0.1 to 1.1s, and latter up to the time of 2.0s, no significant variation in the values found was verified. This result of small variation of values of stresses after 1s is in accordance with results reported by Arola (Arola and Huang, 2000). Thus, the stresses for the final time of 2 seconds will be used in the analysis (Tab. 3).

Table 3. – Maximum and minimum principal stresses after 2 seconds for different temperatures.

Load case (temperature)	Material and Stress type (MPa)	Sane tooth	Porcelain	Resin
Tooth exposed to cold temperature	Cervical enamel (σ_1)	20.23	18.46 to 20.95	19.3 to 23.15
Tooth exposed to cold temperature	Restoration (σ_1)		6.02 a 8.51	15.5
Tooth exposed to cold temperature	Dentin (σ_3)	-3.10	-2.29 a -1.18	-9.79
Tooth exposed to hot temperature	Cervical enamel and Restoration (σ_3)	-18.6 to -10.9	-16.25	-17.34
Tooth exposed to hot temperature	Dentin (σ_1)	1.2 a 2.4	.71	7.11

4. Discussion

It was observed that temperatures at the external surface present different values for the three materials under study but that they are leveled after 2s at the internal surface of the dentin. This fact can be explained by the low value of thermal diffusivity of the dentin, i.e., the temperature that arrives at dentin's surface spreads out slowly in this tissue.

Under thermal load, the largest values of stresses were obtained for the tooth restored with resin. Those peak stresses occurred for both types of loads, at enamel, restoration itself and dentin surface immediately under the restoration. This fact can be explained by the larger coefficient of thermal expansion of resin (35 x 10^{-6}) compared to enamel and porcelain (17 x10^{-6} and 7x10^{-6}, respectively).

The obtained results for cold load are in accordance with Toparly and his group (Toparli, Gokay and Aksoy, 2000) that report, in a tooth restored with resin, compression stresses of about -4 MPa in the internal surface of the restoration or dentin surface and traction stresses of about 18MPa in the external surface. In this study, in the internal surface or dentin surface, it was verified compression stresses of about -2,2 to 9.8MPa and traction stresses of about 15.5MPa in the external surface.

As to the heat load for a tooth restored with resin by the direct method, Fenner obtained a traction stress of 9 MPa. They had not considered this value relevant in relation to the adhesive resistance of the resin, whose considered value is of 23MPa. In this study, a value of 7.1MPa for tensile stress was found for the resin restoration

Clinically, this finding justifies the high occurence of spots and leaks noted at the borders of resin restorations, even though many times they are not submitted to oclusal loads. Another very important consideration to clinical practice is that, in cases where a reconstruction with a base of different material is needed, it would not be advisable to make it with resin for pure porcelain restorations, due to the stresses under thermal variations which risk fracturing the porcelain restoration. As to the numerical values for the obtained stresses, they should not be considered as exact, as the properties of dental tissues and restoring materials available in the literature have a wide range of variation, and tooth geometry also vary with type and individual.

5. Acknowledgements

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