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CALCULATION OF TEMPERATURE DISTRIBUTION ON A CROWN TOOTH BY USING THREE-DIMENSIONAL FINITE ELEMENT METHOD

H. Aykul *, M. Toparlı **, N.S.Köksal*

*Department of Mechanical Engineering, Faculty of Engineering, Celal Bayar University, Muradiye- Manisa, Türkiye

**Department of Metallurgical and Materials Engineering, Faculty of Engineering, Dokuz Eylül University, Bornova- İzmir, Türkiye

Abstract- The finite element was used to temperature changes with time to Au-AgPd alloy and porcelain crowns in three dimensional models of average maxillary second premolar. Temperature changes some critical nodes were calculated as a result of hot/cold liquid. Calculation programs were prepared by authors using FORTRAN 77. The tooth was assumed isotropic, homogenous, elastic and unsymmetric.

1. INTRODUCTION

A crown is a cemented veneer restoration which replaces the morphology, function, and contour of the damaged coronal portions of a tooth. It should protect the remaining tooth structure from further damage. If it covers all of the clinical crown, it is a full veneer crown. If only portions of the clinical crown are veneered, it is a called partial veneer crown. A veneer restoration may be fabricated entirely of gold or some other nontarnishable metal, porcelain fused to metal, porcelain only, resin and gold, or resin only.

The heat transfer coefficient is an important parameter in the process of energy transport into teeth. The heat transfer coefficient represents the quantity of energy transferred in a unit time at a fluid-solid interface of a unit area having a unit temperature difference. Its value is a complex function of a flow rate of the fluid, the fluid's physical parameters, and the interface geometry of the solid into which or from which energy is transferred.

A lot of studies have been reported on the optimum design of crowns based on finite element analysis. Spierings *et al.* [1,2] used finite element method (FEM) to transient heat transport problems within axisymmetric models of unrestored and various restored teeth. Due to lack of detailed knowledge concerning the thermal load on teeth caused by a draught of liquid, the ambient temperature imposed by the liquid change was assumed to vary linearly with time [3]. To affirm this assumption, Spierings *et al.* [4] carried out an in vivo experiment to determine the temperature change in the oral cavity when hot or cool beverages are consumed. Toparlı *et al.*, [5] utilised finite element model to stress analysis of the maxillary second premolar tooth under thermal loading due to hot/cold liquid in the mouth.

The objective of this study was to investigate the temperature change of crown tooth in a three dimensional model of maxillary second premolar tooth, by using finite element method.

2. MATERIALS AND METHODS

2.1 Finite Element Modelling

The finite element formulation for computation of the transient temperature distribution T(x,y,z,t) for solids with general surface heat transfer. Consider transient heat transfer in a three-dimensional isotropic solid V bounded by a surface Γ. The problem is governed by the energy equation

$$-\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right)=\rho\, c_p\,\frac{\partial T}{\partial t} \tag{1}$$

where q_x, q_y and q_z are components of the heat flow rate vector per unit area in Cartesian coordinates (x,y,z), ρ is the density, and c_p is the specific heat.

The solution domain V is divided in to M elements of r nodes each. By the usual procedure we expresses the temperature and temperature gradients with in matrix rotation

$$T\ (x,y,z,t)=\left[N\ (x,y,z)\right]\left\{T\ (t)\right\} \tag{2}$$

$$\left\{\begin{matrix}\dfrac{\partial T}{\partial x}(x,y,z,t)\\ \dfrac{\partial T}{\partial y}(x,y,z,t)\\ \dfrac{\partial T}{\partial z}(x,y,z,t)\end{matrix}\right\}=\left[B\ (x,y,z)\right]\left\{T\ (t)\right\} \tag{3}$$

where $[N]$ is the temperature interpolation matrix, $[B]$ is the temperature-gradient interpolation matrix. By Gauss's theorem, which introduces surface integrals of the heat flow across the element boundary Γ. We write the result in the rearranged form by finite element methods.

$$\int_{V^{(e)}}\rho\, c_p\,\frac{\partial T}{\partial t}\,N_i\,dV-\int_{V^{(e)}}\left[\frac{\partial N_i}{\partial x}\quad\frac{\partial N_i}{\partial y}\quad\frac{\partial N_i}{\partial z}\right]\left\{\begin{matrix}q_x\\ q_y\\ q_z\end{matrix}\right\}dV=\int_{\Gamma}(q.n)\,N_i\,d\Gamma \tag{4}$$

where n is the direction cosines of the outward normal to the surface, q is the specified heat flow rate Per unit area and $V^{(e)}$ is the domain for element *(e)*.

Finally, after some manipulation the resulting element equations become

$$[C]\left\{T_{n+1}\right\}=\left\{R_h\right\}\Delta t-\left[\left[K_c\right]+\left[K_h\right]\right]\Delta t\left\{T_n\right\}+[C]\left\{T_n\right\} \tag{5}$$

where,

$$[C]=\int_{V^{(e)}}\rho\, c_p\,[N]^T\,[N]\,dV \tag{6}$$

$$\left[K_c\right]=\int_{V^{(e)}}k\,[B]^T\,[B]\,dV \tag{7}$$

$$[K_h] = \int_{S} h [N]^T [N] \, d\Gamma \tag{8}$$

$$\{R_h\} = \int_{S_2} h \, T_e \, [N] \, d\Gamma \tag{9}$$

The coefficient matrix $[C]$ of the time derivative of the nodal temperatures is the element capacitance matrix. The coefficient matrices $[K_C]$ and $[K_h]$ are element conductance matrices and relate to conduction and convection, respectively. The vector $\{R_h\}$ is surface convection vector. k is the conduction heat transfer coefficient and h is the convective heat transfer coefficient. T_e is the convective exchange temperature.

2.2 Tooth Model

The finite element method was used to calculate temperature changes in a maxillary second premolar crown tooth. The geometry of the tooth was taken from the textbook [6] and its finite element model is shown in Fig. 1. The model was completed from elements having 8 nodes (hexahedral element). Total number of elements was 840 with 1032 nodes.

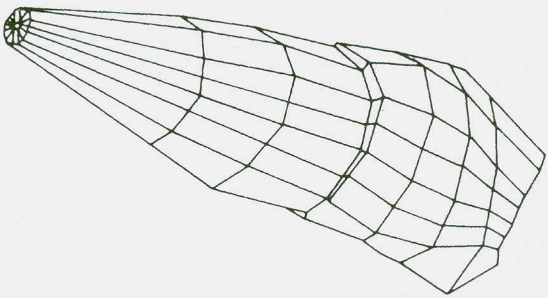

Fig. 1. Three dimensional finite element model of tooth

In this study Au-alloy and porcelain as crown materials were studied. As shown in Fig. 2 the tooth model was coated with Au-Ag Pd alloy and porcelain. The crown thickness was 1.3 mm in the palatinal and vestibule region. Data of the thermal properties of these material and dentin are presented in Table 1. Heat transfer coefficient was taken 4.10 x 10^{-4} (cal/mm^2.s.^{o}C).

Table 1. Data of thermal properties of the material

Material	Thermal conductivity (cal/mm.s.^{o}C)	Density.heat capacity (cal/mm^2.^{o}C)
Au-AgPd alloy	0.300 x 10^{-1}	0.435 x 10^{-3}
Porcelain	0.250 x 10^{-3}	0.754 x 10^{-3}
Pulp	0.100 x 10^{-11}	0.100 x 10^{-9}
Dentin	0.150 x 10^{-3}	0.588 x 10^{-3}

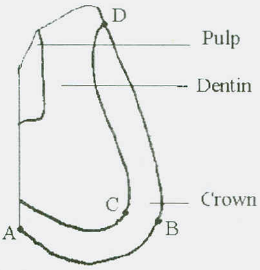

Fig. 2. Calculated temperature distribution at nodes A, B, C and D on the tooth

The computer program has been organized to calculate node temperature. In order to minimize the temperature error interval (Δt) has been calculated to use the appropriate smallest value in equation 5.

Tooth temperature has been initially selected as 36 °C. This study has been carried out for two different temperatures. These are hot (60 °C) and cold (15 °C) liquid. These values were selected from literature [4,7]. It was assumed that cold and hot liquid was held 1 second in the mouth, this means that the mouth temperature was thought to have reached 36 °C in 1 second.

Temperature changes with time were selected A, B, C and D nodes (Fig. 2). These nodes were regarded as critical ones.

3. RESULTS

Fig.3 illustrates the changes in temperature with time at points A, B, C and D caused by hot liquid when porcelain was used. The highest temperature value takes place at point B. The corresponding maximum temperatures for node B were achieved between 1.0 s and 2.4 s. Temperature values at point C is not change. Maximum temperature changes occur at the surfaces of porcelain. Maximum and minimum temperatures are 60 °C and 36 °C at points B and C, respectively.

As seen in Fig.4 temperature changes are almost the same at all points when Au- AgPd alloy was used. The calculated maximum and minimum temperature for Au alloy is 41°C at point B and 39.5 °C at point A.

Fig.5 shows temperature changes with time at points A, B, C and D caused by cold liquid when porcelain was used. The temperature at points A and D are nearly the same. The temperatures at point C are seen no change with time. The temperature at this point is 36 °C. The corresponding minimum temperatures for node B were achieved 15 °C between 1.0 s and 2.4 s.

When Au- AgPd alloy was used instead of porcelain for crown, temperature changes caused by cold liquid are almost the same at all points, where the temperature changes are relatively smaller (Fig.6). Maximum and minimum temperature changes take place at the crown/dentin interface (i.e. at point B) and the surface of crown (i.e. at point A), respectively.

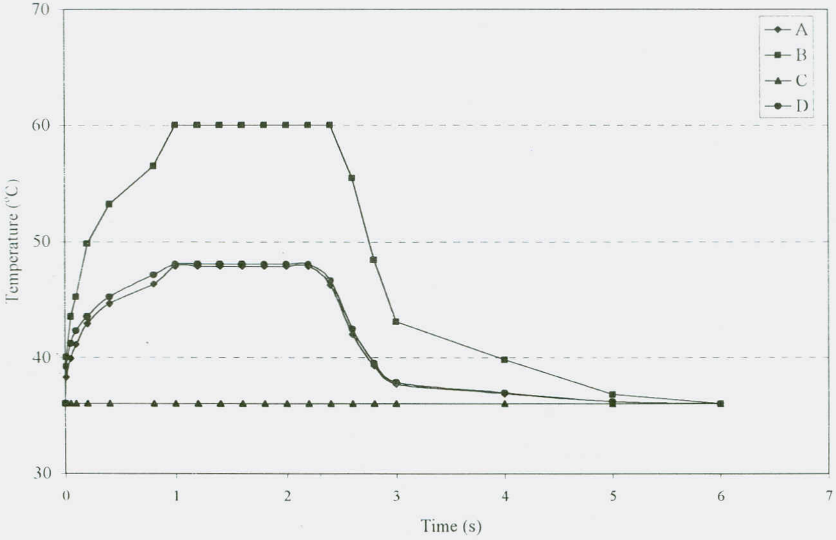

Fig. 3. Temperature changes with time at nodes A, B, C, and D caused by hot liquid when porcelain was used.

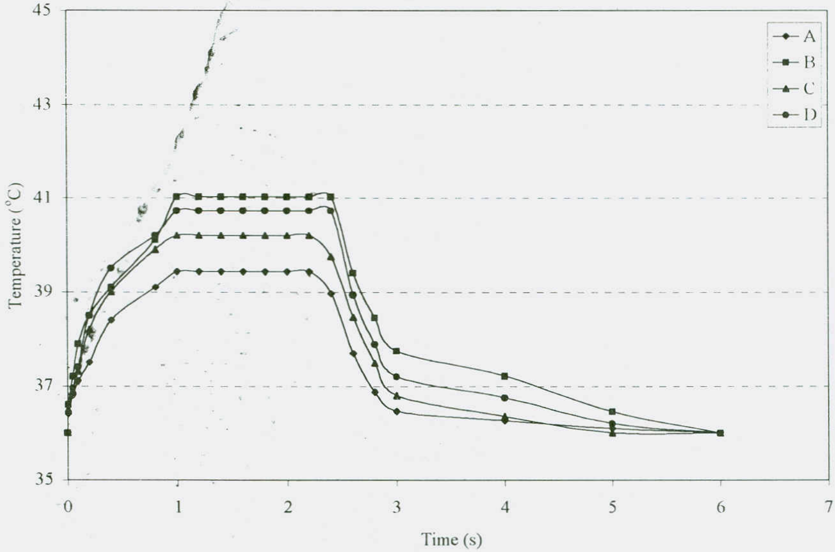

Fig. 4. Temperature changes with time at nodes A, B, C, and D caused by hot liquid when Au-AgPd alloy was used.

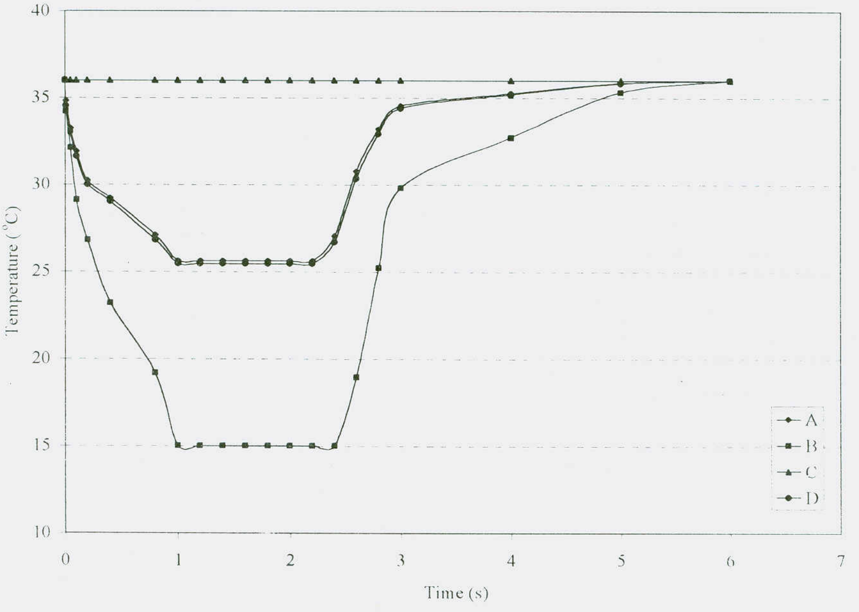

Fig. 5. Temperature changes with time at nodes A, B, C, and D caused by cold liquid when porcelain was used.

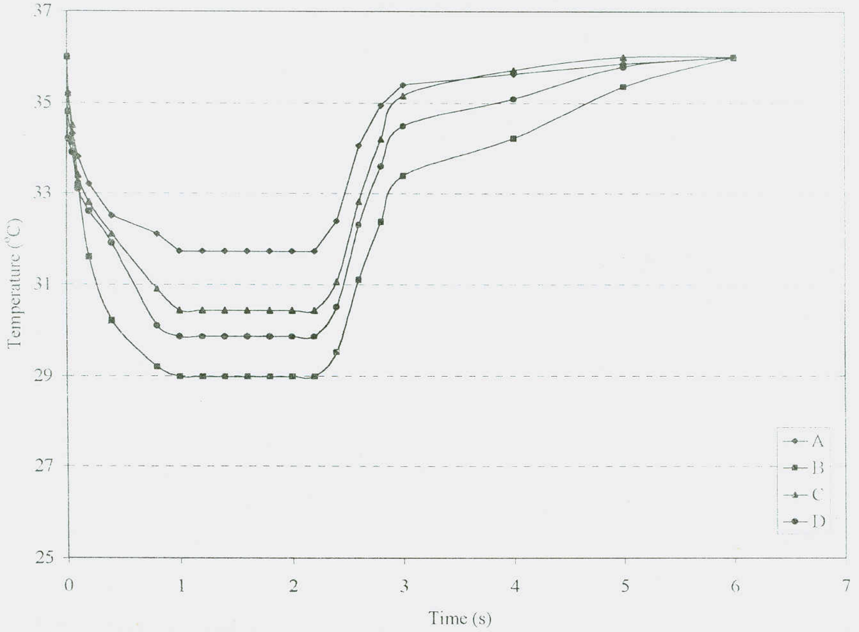

Fig. 6. Temperature changes with time at nodes A, B, C, and D caused by cold liquid when Au-AgPd alloy was used.

4. DISCUSSION

The hot and cold liquid drink in mouth cause temperature changes because of the different thermal properties of different materials on the crowned tooth. These temperature changes occurred on the crowned tooth depend on many factors, such as the conduction heat transfer coefficient, density and specific heat capacity, between dentin and crown materials. A finite element model was developed to calculate temperature distribution in a Porcelain and Au-AgPd alloy.

The process of deglutition is itself a variable factor which causes the direction of the liquid flow to vary as well. According the Boehm [8], the ambient temperature, humidity and dryness of the oral cavity affect the temperature field of the cavity when mouth is opened.

Under the given conditions, the maximum temperature changes were found in a dentin/crown interfaces when Au-AgPd alloy was used. Porcelain was used instead of Au-AgPd alloy temperature distribution was not changed in a dentin/crown interface. Because the conduction heat transfer coefficient for porcelain is smaller than Au-AgPd alloy.

The temperature at the subgingival cervical outer surface is assumed to be stable. Therefore for a porcelain and Au-AgPd alloy crowned tooth model, it should be taken in the account that this theoretical model does not correspond with the biological reality.

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