THERMAL DIFFUSIVITY MEASUREMENT OF ENAMEL AND DENTIN AS A FUNCTION OF TEMPERATURE OBTAINED BY INFRARED CAMERA.

Thiago Martini Pereira[1], Claudia Bianchi Zamataro[1], Denise Maria Zezell[1],
1 - Centro de Lasers e Aplicações - Instituto de Pesquisas Energéticas e Nucleares

RESUMO

O objetivo neste trabalho foi desenvolvido um software que calcula o valor da difusividade térmica em função da temperatura. foram utilizados dados de temperatura para ajustar a uma função encontrada por meio da equação de calor. A câmera termográfica foi calibrada para captar temperaturas entre 185ºC e 1300ºC,e frequência de 300Hz.Foram utilizados 10amostras de esmalte bovina e 10 amostras de dentina bovina, com dimensões de4x4x2mm. A irradiação foi feita de forma pontual com o laser pulsado de Er:Cr;YSGG(λ=2,78μm), por 10s. O registro das temperaturas atingidas nas amostras iniciou 2s antes da irradiação laser e continuou por mais 2s após seu término. As imagens foram processadas no software desenvolvido durante este trabalho, que gerou os dados da difusividade térmica em função da temperatura. O resultado médio de difusividade térmica obtido para o esmalte dental neste trabalho foi 0,0084$\pm$ 0,001cm^2/s para a região de temperatura de 220-550ºC. Este valor é aproximadamente constante até a temperatura de 550ºC.O valor médio de difusividade térmica obtido para a dentina foi de 0,0015$\pm$0,0004cm^2/s na região de temperatura de 300-360ºC. Conclui-se que o software desenvolvido junto com camera termografica, apresenta-se como um método preciso e adequado para a determinação da difusividade térmica em função da temperatura.

Descritores: propriedades termicas,dentina, esmamlte, termografia na infravermelho

ABSTRACT

The goal of this present study was developed a software that calculates automatically, the thermal diffusivity value as a function of temperature in materials. The temperature data were used to adjust a temperature function obtained from the homogeneous heat equation. For that, an infrared camera was calibrated to detect temperature ranging from 185ºC up to 1300ºC at acquisition rate of 300 Hz. It was used, 10 samples of bovine dental enamel and 10 samples of bovine dentin, with 4x4x2mm. These samples were irradiated with an Er:Cr:YSGG pulsed laser (λ=2,78μm). The resulting temperature changed were recorded 2s prior, 10s during irradiation and continuing for 2 more seconds after it. The thermal images were processed in the software, creating a file with the data of thermal diffusivity as a function of temperature. The mean result of thermal diffusivity obtained for enamel was 0.0084$\pm$0.001cm^2/s for the temperature range of 220-550ºC this value is approximately constant for the temperatures up to 550 ºC. The mean value for thermal diffusivity obtained for dentin was 0,0015$\pm$0,0004cm^2/s in temperatures up to 360ºC. According to these results, it was possible to conclude that the use of infrared thermography, associated with the software developed in this work, is a preside and suitable method to determine the thermal diffusivity values as a function of temperature.
Key Words: Thermal diffusivity,enamel,dentin,infrared termography

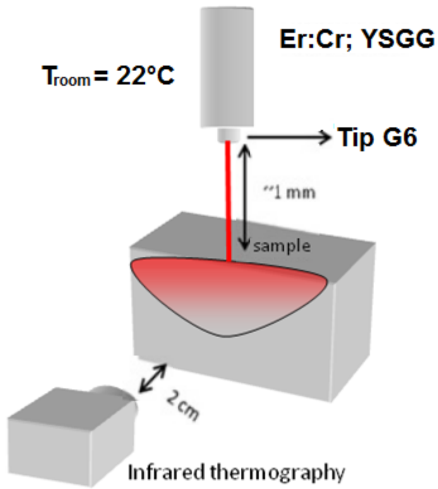

Figure 1: Scheme of laser irradiation of dentin and enamel samples

INTRODUCTION

The heat conduction phenomenon is a great point of interest in laser applications in dentistry and medicine[1] in order to determine safe irradiation parameters, for the biological structures, such as collagen and proteins, that are highly susceptible to thermal damages. The laser wavelengths that are highly absorbed by a specific tissue, the heat conduction phenomena is the main factor for determining the thermal damage area.

The thermal diffusivity is the most important thermal parameter when heat conduction is studied. This thermophysical parameter represents the rate between conduction and the material ability to keep the heat[2]. Several photothermal and photoacoustic techniques have been proposed for measurement of the thermal diffusivity.

This work proposed the infrared thermography as an alternative effective method to measure thermal diffusivity parameter. The main advantage of this method is related to the possibility of obtaining time and special resolution analysis of a plane distribution temperature of the whole sample[3], while other photothermal techniques are restricted only to a few points.

Several studies investigating the thermal parameters and their influence on dental hard tissues have been performed [4,5,6,7]. However, the thermal diffusivity as a function of temperature is still not well established in the literature.

OBJECTIVE

The goal of the present study was to develop a software that calculates automatically the thermal diffusivity value as a function of, temperature, in materials.

MATERIAL AND METHODS

Experimental Procedure

Bovine incisor teeth were used in this study and, until the beginning of the experiment, the teeth were stored in water under refrigeration to avoid dehydration. blocks of 5x5x1.3 mm for enamel and 5x5x2 mm for dentin were obtained by teeth sectioning using a diamond saw (Accutom 5, Struers, UK).

The high intensity Er,Cr:YSGG laser (Milennium, Biolase, USA) was used in this study. This laser emits at wavelength of 2.78 µm, with pulse duration of 150 µs and repetition rate of 20Hz.the energy per pulse was 41,7 J/cm^2 for enamel and dentin. The sapphire tip G6 used in this experiment has 600µm of diameter. The experimental setup is detailed in figure 1.

These samples were irradiated during 10 s. The resulting temperature was recorded 2 s prior, 10 s during irradiation and continuing for 2 more seconds after it.

Data Processing

The heat equation was solved on polar coordinates previously. The solution of heat equation, obtainable using Fourier, Hankel, and inverse Laplace integral transforms, result in:

$$T(r,t) = \frac{8IoR^2}{R^2+8\alpha t} e^{-\frac{2r^2}{R^2+8\alpha t}} \quad (1)$$

where α is the thermal diffusivity, R^2 is radius laser beam, t is the time, r is the radial coordinate and Io is the intensity of laser at the center of the beam.

The proposed method for obtaining the thermal diffusivity is to find the best fitting at each frame. The solution of the equation (1), shows that the temperature profiles depends only on radial coordinate. The spatial fitting at each time after irradiation was made with the temperature dots along the line that pass through the center of the radius laser beam.

A linear fitting was adjusted by using the Gaussian coefficients and time of each frame. The slope (8α) from the linear regration leads to the thermal diffusivity.

RESULTS

The figure 2 shows the average of thermal diffusivity of enamel as a function of temperature.

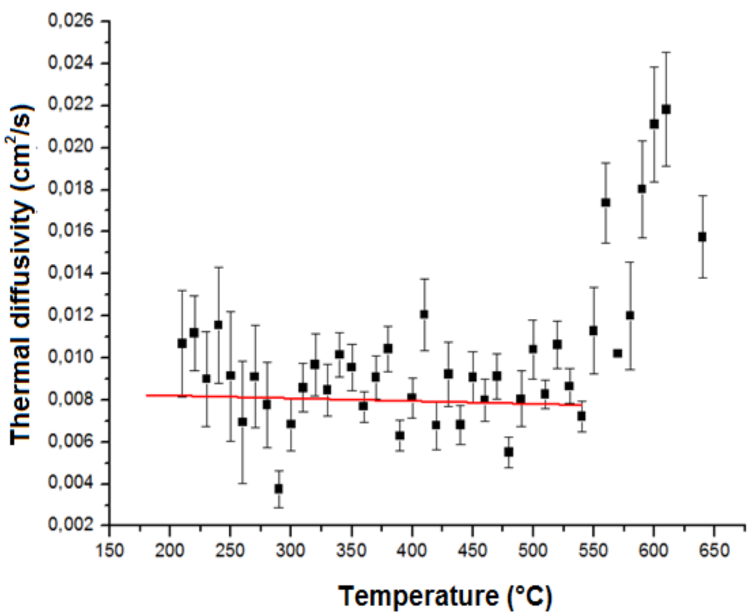

Figure 2: Averages of thermal diffusivity for 10 enamel samples as a function of the temperature. Bars are the variance

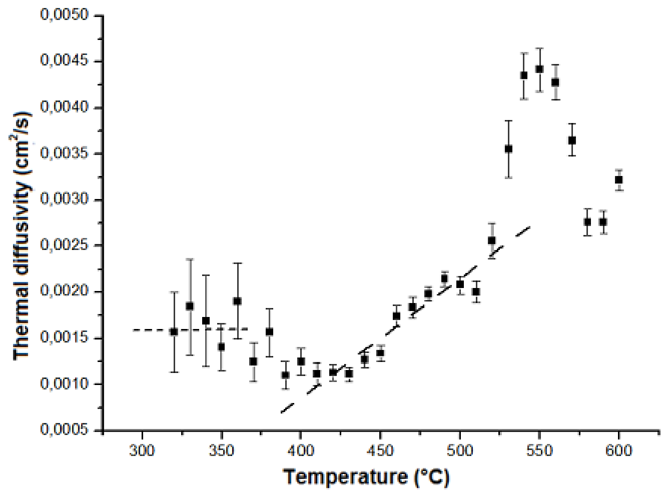

Figure 3: Averages of thermal diffusivity for 10 dentin samples in function of temperature. Bars are the variance

There is no significant changed in the thermal diffusivity values ($8.4\pm0,1.10^{-3}$ cm^2/s) of enamel in temperatures above 550 ^oC.

Figure 3 shows thermal diffusivity as a function of the temperature and variance. The thermal diffusivity values increase from 420°C.

The method proposed in this study to calculate thermal diffusivity, by using infrared thermography, allows the acquisition of a large amount of data of temperature distribution in real time, which is difficult to be obtained by other methods. In this way, the infrared thermography provided good data to be adjusted by the theoretical function used and then can be used for obtaining the thermal parameters of anisotropic materials.

Table 1 shows a comparison of the thermal diffusivity values obtained in this work with the values from the literature to dental enamel obtained by different methods for the room temperature. It is possible to evidence that the thermal diffusivity value obtained at present study for temperatures up to 500ºC is $8,4.10^{-3}$ cm^2/s, higher than those determined in literature by other methods, such as photoacoustic, Angstrom´s method and flash laser.

Table 1: Comparison of thermal diffusivity values of enamel obtained by this study and those reported on literature.

reference	**Temperature (^{o}C)**	**Thermal diffusivity (cm^2/s)**
Craig Peyton [8]	~ amb	0,0048
Braden [6]	~ amb	0,0047
Panas [4]	~ amb	0,0041
This work	220-550°C	0,0084±0,0010

The thermal diffusivity value for dentin tissue obtained at present study is in agreement with those determined in the literature (Table 2) for temperatures between 300-360 °C. However, the diffusivity value increases on temperatures above 400 ºC. The reason for that is the conditions of laser irradiation promotes loss of water and decomposition of organic material at temperatures up to 400 ºC [9]. There is a wide range of thermal diffusivity values of dentin than enamel because the dentin has more water and organic material than enamel.

Table 2: Comparison of thermal diffusivity values of dentin obtained by this study and those reported on literature.

reference	Temperature (°C)	Diffusivity value (cm^2/s)
Craig Peyton [8]	~ amb	0,0018
Braden [6]	~ amb	0,0024
Panas [4]	~ amb	0,0022
This study	300-360 °C	0,0015±0,0004
This study	500 °C	0,0020±0,0004

CONCLUSIONS

The values of thermal diffusivity for the enamel is 8.4×10^{-3} 0.1 cm^2/s in the temperature range 200-525 °C and for the dentin is $1.5 \times 10^{-3} \pm 0.4$ cm^2/s in the temperature range 300-360 °C and $2 \times 10^{-3} \pm 0.4$ for the temperature of 500 °C.

According to the results obtained in this study, it is possible to conclude that the experimental methodology used, together with the digital tool developed, was able to determine the values of thermal diffusivity of dental hard tissues as a function of temperature, presenting itself as a promising technique to determine the behavior of thermal diffusivity as a function of the temperature of other materials, in an automated and efficient way.

ACKNOWLEDGEMENT

CNPq (135162/2007-6), CAPES Procad (0349/05-4), FAPESP (05/51689-2), CNPq (573.916/2008-0)

REFERENCES

[1] PICHARDO-MOLINA, J.L.; GUTIERREZ-JUAREZ, G.; HUERTA-FRANCO, R.; VARGAS-LUNA, I.; CHOLICO, P.; ALVARADO-GIL, J.J. , Open photoacoustic cell technique as a tool for thermal and thermo-mechanical characterization of teeth and their restorative materials, INT J THERMOPHYS,v. 26, n. 1, p. 243-253, 2005.

[2] INCROPERA, F.P.; DEWITT, D.P. Fundamentals of heat and mass transfer. New York N.Y. John Wiley, 1996.

[3] CERNUSCHI, F.; RUSSO, A.; LORENZONI, L.; FIGARI, A. In-plane thermal diffusivity evaluation by infrared thermography. *REV SCI INSTRUM*, v. 72, n. 10, p. 3988-3995, 2001.

[4] PANAS, A.J.; ZMUDA, S.; TERPILOWSKI, J.; PREISKORN, M. Investigation of the thermal diffusivity of human tooth hard tissue. *INT J THERMOPHY*. v. 24, n. 3, p. 837-848, 2003.

[5] PANAS, A.J.; PREISKORN, M.; DABROWSKI, M.; ZMUDA, S. Validation of hard tooth tissue thermal diffusivity measurements applying an infrared camera. *INFRARED PHYS TECHN*, v. 49, n. 3, p. 302-305, 2007.

[6] BRADEN, M. Heat Conduction in Teeth + Effect of Lining Materials. J DENT RES, v. 43, n. 3, p. 315-322, 1964.

[7] BROWN, W.S.; DEWEY, W.A.; JACOBS, H.R. Thermal Properties of Teeth. *J DENT RES*, v. 49, n. 4, p. 752-759, 1970.

[8] CRAIG, R.G.; PEYTON, F.A. Thermal Conductivity of Tooth Structure, Dental Cements, and Amalgam. *J DENT RES*, v. 40, n. 3, p. 411-418, 1961.

[9] BACHMANN, L.; DIEBOLDER, R.; HIBST, R.; ZEZELL, D.M. Changes in chemical composition and collagen structure of dentine tissue after erbium laser irradiation. *J CELL PHYSIOL,* v. 61, n. 11-12, p. 2634-2639, 2005.