Journal of Dental Applications

Open Access

Austin Publishing Group

Mini Review

Thermal Properties of Selected Group of Dental Materials

Borut Kosec[1*]; Mateja Vodlan[2]; Aleš Nagode[1]; Alenka Pavlič[3]; Igor Kopač[3]; Matija Zorc[1]; Hennry Taubmann[4]; Igor Budak[5]; Tatjana Puškar[6]; Blaž Karpe[1]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia

[2]LEK d.d., Verovskova 57, 1526 Ljubljana, Slovena

[3]University of Ljubljana, Faculty of Medicine, Korytkova 2, 1000 Ljubljana, Slovenia,

[4]C3 Prozess und Analysentechnik Gmbh, Peter Henlein Str. 20, Munich, Germany

[5]University of Novi Sad, Faculty Technical Sciences, Trg D. Obradovića 6, 21000 Novi Sad, Serbia

[6]University of Novi Sad, Faculty of Medicine, Hajduk Veljkova 6, 21000 Novi Sad, Serbia

***Corresponding author: Borut Kosec**
University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia.
Phone: +386 1 2000410, Fax: +386 1 4704560
Email: borut.kosec@ntf.uni-lj.si

Received: April 17, 2023
Accepted: May 11, 2023
Published: May 18, 2023

Abstract

The thermal properties of dentine and tooth enamel affects the rate of response of the tooth nervous system to the temperature changes to which the tooth is exposed on a daily basis.

Today almost all manufacturers of dental materials in their certificates of material quality describe material chemical composition, mechanical properties, process ability and aesthetic characteristics, while information about thermal properties (thermal conductivity, thermal capacity and temperature diffusivity) are not available.

Within the interdisciplinary teamwork, thermal properties of five selected dental materials were measured and analyzed by modern Transient Plane Source (TPS) method in accordance with the standard ISO 22007-2. Thermal properties were measured at temperature interval between 0°C and 50°C.

Keywords: Dental materials; Thermal properties; TPS: Transient plane source; Method; Measurement

Introduction

The thermal properties of dentine and tooth enamel affects the rate of response of the tooth nervous system to the temperature changes to which the tooth is exposed on a daily basis. In addition to strength and aesthetic requirements, artificial dental materials must also provide a similar thermal protection for the tooth pulp. Likewise, implants and artificial tooth crowns must transfer similar heat flow to the bone as is transferred by a natural tooth, which has a strong influence on the patient's general acceptance of the foreign body [1,2].

Manufacturers of dental materials in their certificates of material quality describe chemical composition, mechanical properties, machinability and aesthetic characteristics, while thermal properties of the material are rarely given [3].

The reported values of human teeth thermal properties show significant discrepancies, with data for thermal conductivity of dentine between 0.11 to 0.98 $Wm^{-1} K^{-1}$, and 0.7 to 0.8 $Wm^{-1} K^{-1}$ for tooth enamel, while temperature diffusivity varies between 0.058 to 0.269mm^2/s and 0.092 to 0.42 mm^2/s for dentin and enamel respectively. The significant discrepancy between the reported results may be attributed to several challenges associated with the measurements, like tooth heterogeneous microstructure and associative anisotropic thermal properties, difficulties at establishing suitable thermal contact or lack of precise emissivity data when axial heat flow or laser flash measuring methods are applied [4].

Thermal Properties Measurement

Thermal conductivity, specific heat and thermal diffusivity are basic thermal properties of material that determine the heat transfer in the system under consideration. Despite the remarkable progress of measuring methods and techniques, it is still difficult to determine them with an error of less than ±2%, even for bulk materials.

Citation: Kosec B, Vodlan M, Nagode A, Pavlič A, Kopač I, et al. Thermal Properties of Selected Group of Dental Materials. J Dent App. 2023; 9(1): 1119.

In our research, we used one of the most advanced instruments for measuring the thermal properties, Hot Disk TPS 2200, a product of Hot Disk AB company, Gothenburg, Sweden [5]. The instrument can be used for determining thermal properties of various materials including pure metals, alloys, minerals, ceramics, plastics, glasses, powders and viscous liquids with thermal conductivity in the range from 0.01 to 500 W/mK, thermal diffusivity from 0.01 to 300mm^2/s and heat capacity up to 5 MJ/m^{3}K. Measurements can be performed in a temperature interval between -0 up to 750°C [6].

Hot disk measuring method is a Transient Plane Source (TPS) technique. Based on the theory of TPS, instrument utilizes a sensor element in the shape of 10µm thick double spiral, made by etching from pure nickel foil. Spiral is mechanically strengthen and electrically insulated on both sides by thin polyimide foil (Kapton ®Du Pont) for measurements up to 300°C or mica foil for measurements up to 750°C. Sensor acts both as a precise heat source and resistance thermometer for recording the time dependent temperature increase (Figure 1).

During measurement of solids, encapsulated Ni-sensor is sandwiched between two halves of the sample and constant precise pre-set heating power is released by the sensor, followed by 200 resistance recording in a pre-set measuring time, from which the relation between time and temperature change is established. Based on time dependent temperature increase of the sensor, thermal properties of the tested material are calculated [7].

Experimental Work

- In our study, we measured thermal properties of five important dental materials, used in dental praxis at the Department of Dental Prosthesis of the Medical Faculty, University of Ljubljana, and Medical Faculty, University of Novi Sad. Tested materials were Yttrium stabilized Zirconium ceramics (3Y-TZP),
- Polymer material PMMA,
- 99 % pure titanium,
- Titanium alloy TiAl6V4, and
- CoCr alloy.

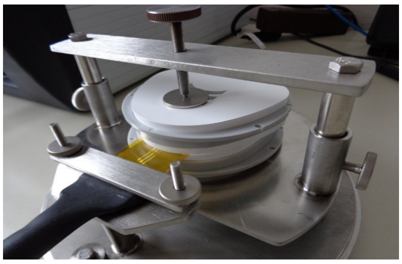

Figure 1: Sensor element (yellow-Kapton) sandwiched between two halves of a sample during measurement.

Figure 2: Measurements in the Laboratory for measurements, Chair of Thermal Engineering, Faculty of Natural Sciences and Engineering, University of Ljubljana.

Thermal properties were measured in the temperature interval that teeth are most frequently exposed, 0°C to 50°C.

Measurements and analysis of thermal properties of selected dental materials were performed in accordance with ISO 22007-2 standard in the Laboratory for measurements, Chair of Thermal Engineering, Faculty of Natural Sciences and Engineering, University of Ljubljana (Figure 2).

A few decades ago, Yttria (Y_2O_3) stabilized zirconium oxide ceramics (3Y-TZP (3 mol.% yttrium tetragonal zirconia polycrystals)), with significantly improved mechanical properties compared to silicate ceramics and glass ceramics was introduced into dental medicine. 3Y-TZP is available in dentistry for the fabrication of dental crowns and fixed partial dentures. Its flexural strength reaches 900–1200 MPa and fracture strength about 9–10 MPa(m)$^{1/2}$.

Dental crowns are processed either by soft machining of pre-sintered blocks followed by subsequent sintering, or by hard machining of fully sintered blocks. Thermal properties were measured on pre-sintered blocks, so an approximately 10% higher values can be expected when fully sintered, due to density increase. Differences of thermal properties at various temperatures were below normal error (±2%) of the measuring method (Table 1).

The first use of Polymethyl Methacrylate (PMMA) as a dental material was for the fabrication of complete denture bases. Today's practise use multilayered CAD/CAM milling disks for long-term temporary restorations, short-term provisionals and as a prototype for implant restorations. Our tested PMMA material is intended for the production of temporary crowns and bridges or provisional units. Compared to 3Y-TZP ceramics, it is better insulating material. Measurements show no significant change of thermal properties in the temperature interval from 0°C to 50°C (Table 2).

Table 1: Thermal properties of 3Y-TZP pre-sintered blocks.

Measurement	**Thermal conductivity [Wm^{-1}K^{-1}]**	**Thermal diffusivity [mm^{2}s^{-1}]**	**Thermal capacity [MJm^{-3}K^{-1}]**
Average	0.5022	0.3457	1.4532
SD	0.0037	0.0054	0.0238

SD: Standard Deviation

Table 2: Thermal properties of PMMA blocks.

Measurement	**Thermal conductivity [Wm^{-1}K^{-1}]**	**Temperature diffusivity [mm^{2}s^{-1}]**	**Thermal capacity [MJm^{-3}K^{-1}]**
Average	0.1986	0.1119	1.7836
SD	0.0029	0.0086	0.1136

Table 3: Thermal properties of pure Ti disks (impurities<1%).

Measurement	**Thermal conductivity [Wm^{-1}K^{-1}]**	**Thermal diffusivity [mm^{2}s^{-1}]**	**Thermal capacity [MJm^{-3}K^{-1}]**
Average	22.5461	6.7196	3.3625
SD	0.3566	0.2652	0.1234

Table 4: Thermal properties of TiAl6V4 disks.

Measurement	**Thermal conductivity [Wm^{-1}K^{-1}]**	**Temperature diffusivity [mm^{2}s^{-1}]**	**Thermal capacity [MJm^{-3}K^{-1}]**
Average	6.6683	2.8093	2.3759
SD	0.0511	0.0838	0.0732

Titanium and its alloys are used in dentistry because of their resistance to electrochemical decomposition, excellent compatibility with live tissues, easily combine with bone (osseointegration), are relatively light (4,61g/cm^3) and have high tensile (450 MPa) and yield (275 MPa) strength. Titanium forms a very persistent oxide layer on the surface, formed in a few nanoseconds. Because of this oxide layer, it is corrosion-resistant and biocompatible. It is used for manufacturing of dental implants, crowns, braces, bridges, partial prostheses and orthodontic wires. Commercially pure titanium (impurities < 1%) disks were measured in the temperature interval between 0°C and 50°C, and as expected, changes of thermal properties were negligible (Table 3).

TiAl6V4 (Grade 5: 6% Al, 4% V, 0.25%>Fe and 0, 2%>O (balance Titanium)) is the most commonly used titanium alloy in dentistry. It is significantly stronger (R_m>895 MPa, $R_{p0,2}$>828 MPa) than commercially pure titanium while having the same stiffness. This grade is an excellent combination of strength, corrosion resistance, weldability and machinability, and has good osseointegration properties. Alloying elements reduce thermal conductivity and diffusivity considerably compared to commercially pure titanium. In the temperature interval between 0 and 50°C thermal properties can be considered as constant (Table 4).

Co-Cr alloys exhibit material properties considered suitable for dental reconstructions, such as high tensile (900-1000 MPa) and yield (640–700 MPa) strength, high modulus of elasticity (>200 GPa), and high corrosion resistance, and are the most common base-metal alternative for patients known to be allergic to nickel. They are relatively inexpensive compared to noble alloys and somewhat easier to manipulate than titanium alloys [8].

In dentistry, Co-Cr alloys are commonly used for the fabrication of metallic frameworks of removable partial dentures, as metallic substructures for the fabrication of porcelain-fused-to-metal restorations and implant frameworks. The increased worldwide interest in utilizing Co-Cr alloys for dental applications is related to their low cost, excellent biocompatibility and adequate mechanical properties [9,10]. Chemical composition of tested sample is complex including 63% Co, 24% Cr, 8% W, 3% Mo, 1% Si, ≈1% Nb and trace elements <0.1%. As with other samples, thermal properties can be considered as constant in measuring temperature interval (Table 5).

Table 5: Thermal properties of CoCr dental alloy.

Measurement	Thermal conductivity [$Wm^{-1}K^{-1}$]	Thermal diffusivity [mm^2s^{-1}]	Thermal capacity [$MJm^{-3}K^{-1}$]
Average	10.7352	2.8283	3.7978
SD	0.0112	0.0636	0.0834

Conclusions

Measurements and analysis of the thermal properties of selected characteristic dental materials were performed using the Hot Disk method on the Hot Disk TPS 2200 in accordance with the standard ISO 22007-2 in the Laboratory for measurement of the Chair of Thermal Engineering, Department of Materials and Metallurgy, Faculty of Natural Sciences and Engineering, University of Ljubljana.

The teeth and dental supplements are most often exposed to temperatures at an interval between 0°C and 50°C, which was the reason why we selected this temperature interval to perform our measurements. We found that for all dental materials there are no significant difference in thermal properties in this temperature interval and can be considered as constant. As expected, metallic materials transmit heat much faster than tooth structure, while Polymethyl Methacrylate (PMMA) have thermal properties similar to teeth. With the performed measurements, we have completed the existing material quality certificates of dental materials with their thermal properties.

References

1. JJ Manappallil. Basic Dental Materials, Jaypee Brothers, New Delhi. 2003.
2. JF McCabe, AWG Walls. Applied Dental Materials, Blackwell Publishing, Oxford. 2008.
3. I Budak, B Kosec, M Sokovic. Application of contemporary engineering techniques and technologies in the field of dental prosthetics, Journal of Achievements in Materials and Manufacturing Engineering. 2012; 54: 233-241.
4. C Scheller-Sheridan. Basic Guide to Dental Materials, Wiley-Blackwell. Dublin, 2010.
5. Internal script Hot Disk AB; Hot Disk Thermal Constants Analyser, Instruction Manual, Revision date 2019-03-27.
6. B Kosec, B Karpe. Instrument for thermal properties analysis Hot Disk TPS 2200, IRT3000. 2017; 70: 67.
7. AB Auklend Kroh. Measurement of conductivity of intumescing materials (Degree of Master of Science). University of Bergen, Faculty of Mathematics and Natural Sciences, Bergen, 2009.
8. Lj Slokar, T Matkovic, P Matkovic. Alloy design and property evaluation of new Ti-Cr-Nb alloys. Materials & Design. 2012; 33: 26-30.
9. D Stamenkovic, M Popovic, R Rudolf, M Zrilic, K Raic, et al. Comparative study of the microstructure and properties of cast-fabricated and 3D-printed laser-sintered Co–Cr alloys for removable partial denture frameworks, Materials. 2023; 16: 3267.
10. T Matkovic, Lj Slokar, P Matkovic. Structure and properties of biomedical Co-Cr-Ti alloys, Journal of Alloys and Compounds. 2006; 407: 294-298.