Citation for published version

Todor, Raluca and Negrutiu, M.L. and Sinescu, C. and Topala, F.I. and Bradu, Adrian and Duma, V.F. and Rominu, M. and Podoleanu, Adrian G.H. (2018) Investigation of firing temperature variation in ovens for ceramic-fused-to-metal dental prostheses using swept source optical coherence tomography. In: 2nd Canterbury Conference on OCT with Emphasis on Broadband Optical

DOI

https://doi.org/10.1117/12.2281892

Link to record in KAR

http://kar.kent.ac.uk/66597/

Document Version

Author's Accepted Manuscript

Investigation of firing temperature variation in ovens for ceramic-fused-to-metal dental prostheses using swept source optical coherence tomography

Raluca Todor[1], Meda-Lavinia Negrutiu*[1], Cosmin Sinescu[1], Florin Ionel Topala[1], Adrian Bradu[2], Virgil-Florin Duma[3], Mihai Romînu[1], Adrian Gh. Podoleanu[2]

[1]School of Dentistry, “Victor Babes” University of Medicine and Pharmacy of Timisoara, 2A Eftimie Murgu Place, Timisoara 300070, Romania
[2]Applied Optics Group, School of Physical Sciences, University of Kent, Canterbury CT2 7NH, United Kingdom
[3]OM Optomechatronics Group, “Aurel Vlaicu” University of Arad, 77 Revolutiei Ave., Arad 310130, Romania

*corresponding author: Meda-Lavinia Negrutiu, email: meda_negrutiu@yahoo.com

ABSTRACT

One of the most common fabrication techniques for dental ceramics is sintering, a process of heating of the ceramic to ensure densification. This occurs by viscous flow when the firing temperature is reached. Acceptable restorations require the alloy and ceramic to be chemically, thermally, mechanically, and aesthetically compatible. Thermal and mechanical compatibility include a fusing temperature of ceramic that does not cause distortion of the metal substructure. Decalibration of ovens used for firing of the ceramic layers for metal ceramic dental prostheses leads to stress and cracks in the veneering material, and ultimately to the failure of the restoration. 25 metal ceramic prostheses were made for this study. They were divided in five groups, each sintered at a different temperature: a group at the temperature prescribed by the producer, two groups at lower and two groups at higher temperatures set in the ceramic oven. An established noninvasive biomedical imaging method, swept source (SS) optical coherence tomography (OCT) was employed, in order to evaluate the modifications induced when using temperatures different from those prescribed for firing the samples. A quantitative assessment of the probes is performed by en-face OCT images, taken at constant depths inside the samples. The differences in granulation, thus in reflectivity allow for extracting rules-of-thumb to evaluate fast, by using only the prostheses currently produced the current calibration of the ceramic oven. OCT imaging can allow quick identification of the oven decalibration, to avoid producing dental prostheses with defects.

Keywords: firing temperature, ceramic-fused-to-metal dental prostheses, nondestructive investigations, swept source optical coherence tomography, quantitative assessment, en-face OCT images

1. INTRODUCTION

One of the most common fabrication techniques for dental ceramics is sintering, a process of heating of the ceramic to ensure densification. This occurs by viscous flow when the firing temperature is reached. Ceramics are inorganic, nonmetallic materials manufactured by heating raw minerals at high temperatures [1]. The problem is that materials like ceramics and glasses are brittle: they display a high compressive strength but a low tensile strength, therefore they may be fractured under a low strain, of only 0.1% or 0.2%. As restorative materials, dental ceramics present disadvantages due mostly to their inability to withstand the functional forces that are present in the oral cavity [2, 3].

Metal ceramic dental prostheses combine both, the exceptional esthetic properties of ceramics and the good mechanical properties of metals [4]. Their technology is mature, and advanced materials are being used in such constructs. However, fracture of the metal ceramic prostheses may occur occasionally [5]. Acceptable restorations require the alloy and ceramic

to be chemically, thermally, mechanically, and aesthetically compatible. Thermal and mechanical compatibility include a fusing temperature of ceramic that does not cause distortion of the metal substructure [6].
Decalibration of ovens used for firing of the ceramic layers for metal ceramic dental prostheses leads to stress and cracks in the veneering material, and ultimately to the failure of the restoration.

The adjustment of the oven thermal regimes can be made by the dental technician by remarking the outcome of the procedure. Experienced ceramists often achieve this by evaluating the parameters of translucency and texture of the ceramic when firing a sample of the clearest porcelain powder in the system. However, such a method relies completely on the subjective judgment of the operator.

The most modern computerized ceramic ovens go through a self-diagnostic process to check the quality of the electronics, muffle, and vacuum so the user can be sure that the oven is operating at optimum levels.

Periodic calibration at large time intervals (e.g., at six months) of dental ovens is not sufficient to prevent such consequences that can affect a large number of prostheses produced. Evaluation methods based on firing supplemental control samples are subjective, time consuming, and they rely entirely on the skills of the dental technicians.

The aim of this paper is to approach this issue by using an established biomedical imaging technique, optical coherence tomography (OCT). This technique, based on the principles of low coherence interferometry [7], presents millimetre depth penetration and micrometer resolution [8, 9]. It is also non-invasive, in comparison with other investigation methods for teeth and dental constructs, such as radiography and Cone Beam Computer Tomography. Out of the many methods to perform OCT, the swept source (SS) OCT method is chosen here, which offers the highest achievable acquisition speed and the best sensitivity [10].

2. MATERIALS AND METHODS

25 metal ceramic prostheses were made for this study (Fig.1). They were divided in five groups, each sintered at a different temperature: a group at the temperature prescribed by the producer, two groups at lower and two groups at higher temperatures set in the ceramic oven: **Group 1**, for which the ceramic layers were sintered according to the producer's indications (i.e., at 930°C); **Group 2**, for which the ceramic layers were sintered at 30°C below the recommended temperature (i.e., at 900°C); **Group 3**, for which the ceramic layers were sintered with 100°C under the recommended temperature (i.e., at 830°C); **Group 4**, with ceramic layers sintered with 30°C above the recommended temperature (i.e., at 960°C); **Group 5**, with ceramic layers sintered 50°C above the recommended temperature (i.e., at 980°C). The samples were stored in special boxes, previously marked and prepared for imagistic investigation.

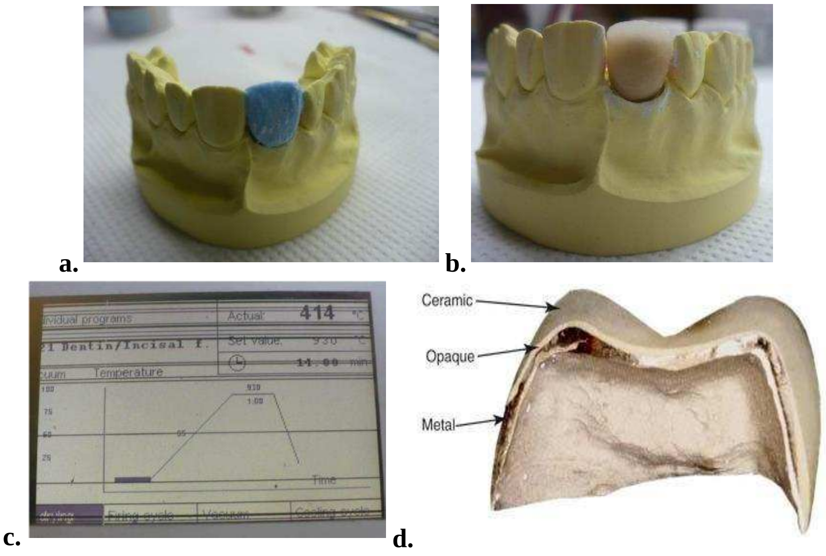


Fig. 1. Aspects from the preparation of the samples: (a) adding the ceramic material on the copings;
(b) sample after its sintering in the oven; (c) temperature chart displayed by the dental ceramic oven; (d) the various layers of a metallo-ceramic crown

Each of these temperature variations were meant to simulate a certain degree of decalibration in the ceramic oven in order to evaluate the possibility of detecting it by OCT.

An established non-invasive biomedical imaging method, swept source (SS) optical coherence tomography (OCT) was employed [11], in order to evaluate the modifications induced when using temperatures different from those prescribed for firing the samples.

For investigations, C-scan (en face) images, obtained from similar depths in all samples were generated. The control of the depth was made possible by analyzing the B-scan OCT image for each sample, obtained with OCT [12]. This depth was approximately $z_{en\text{-}face}$= 0.375 mm from the position corresponding to an optical path difference (OPD) of 0 mm considered at the top of each sample in the B-scan image. In all cases, the vestibular surface of the sample was imaged.

The outer surface of all the samples was positioned at the same depth ($z_{surface}$) measured from the plane corresponding to a zero OPD; then the en-face images were rendered from the same depth position ($z_{en\text{-}face}$). In this way, as the reference and sample optical powers were kept constant, we ensured that changes in the brightness of the images are only due to changes of the optical properties of the samples. Moreover, placing the samples as explained before ensure keeping the same lateral resolution in all the en-face images. Figure 2 depicts the way in which the en-face images were rendered from the volumetric dataset.

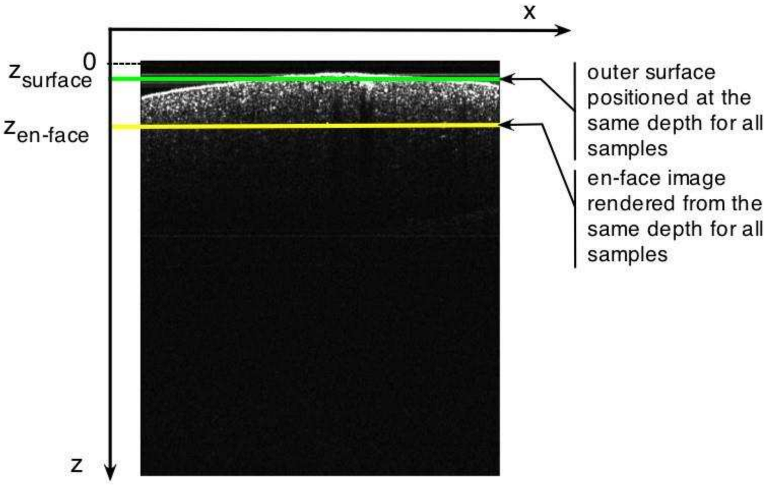


Fig. 2. Illustration of the method used to render en-face images from the volumetric dataset. All the samples were positioned in order to have their outer surface placed at $z_{surface}$, while the en-face image was rendered from the $z_{en\text{-}face}$ depth in all cases.

3. RESULTS AND DISCUSSIONS

The non-invasive investigations revealed specific aspects for each of the groups considered. All the imagistic modifications could be evaluated on the en-face images. As the production of the en-face images cannot be done in real time, in order to position the samples at the correct depth position we took advantage of the capability of the OCT instrument to produce high-speed B-scan images.

Samples sintered at the temperatures indicated by the producers: a normal distribution of the reflectivity could be noticed (Fig.3 a).

Samples sintered at temperatures below the one indicated by the producers (i.e. below with 30°C): decrease of the reflectivity, an alternation between reflective and less reflective areas (Fig.3 b).

Samples sintered at temperatures above the one indicated by the producers (i.e. above with 30°C): increase in the reflectivity, air accumulation and defects inside the ceramic layer (Fig. 3 c).

Figure 3 shows specific aspects for some of the considered groups evaluated on the en-face OCT images.

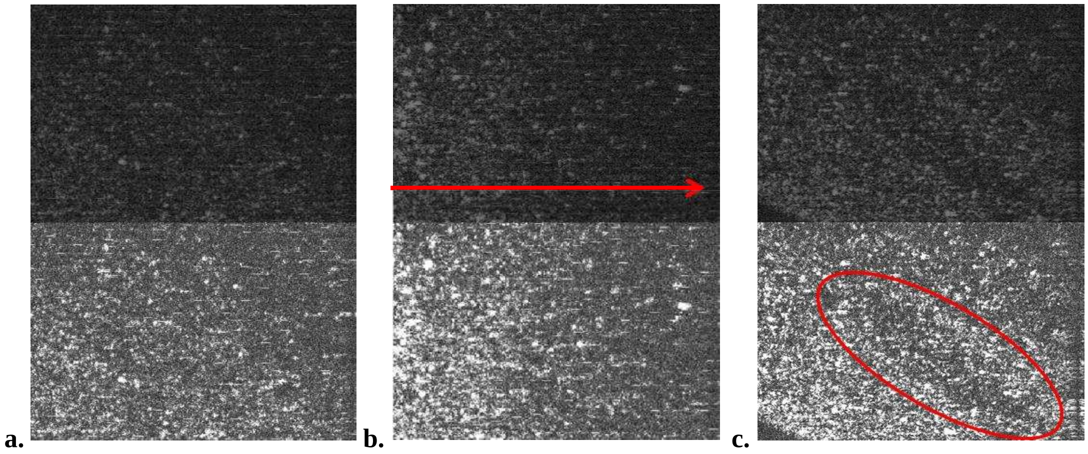
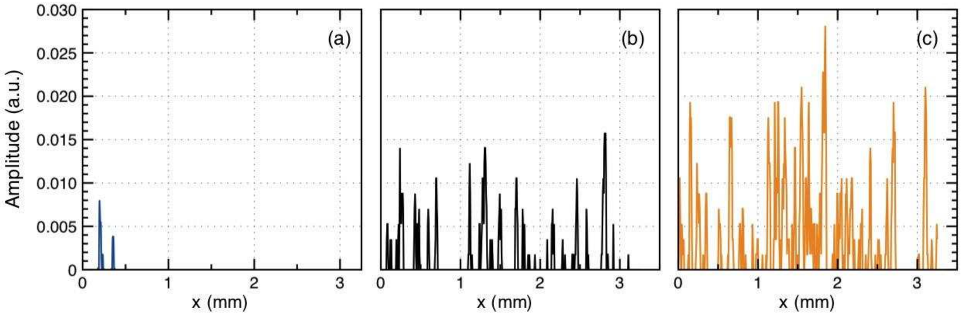


Fig . 3. C-scan en-face OCT images, slice 34/89 0,382 mm depth in air: (a) sample sintered at the temperatures indicated by the producer - normal distribution of the reflectivity, normal granulation; (b) sample sintered at a temperature below the one indicated by the producer (i.e. below with 30°C) - decrease of the reflectivity, an alternation between reflective and less reflective areas; (c) sample sintered at temperature above the one indicated by the producer (i.e. above with 30°C) - increase in the reflectivity, air accumulation and defects inside the ceramic layer.

The results confirm reflectivity increase corresponding to increase in the granulation from Group 3 (sintered at 830°C) towards Group 1 (sintered at 930°C, the normal temperature) and Group 4 (sintered at 960°C) - This results can also be seen in the MATLAB image processed after obtaining a mean value of the OCT investigation (Fig. 4).



.

Fig . 4. Average of 500 horizontal lines of the en-face binary images, corresponding to sintering temperatures of (a) Group 3 (sintered at 830°C) towards (b) Group 1 (sintered at 930°C, the normal temperature) and (c) Group 4 (sintered at 960°C). The number of peaks in each plot indicates the number of "bright particles," while their width indicates their size.

4. CONCLUSIOSN

This study demonstrates the capability of optical coherence tomography (OCT) to achieve a simple and non-invasive monitoring of the temperature variation inside a ceramic oven, used to obtain metal ceramic dental prostheses. On an every-day basis, the dental technician can evaluate by OCT the ceramic layer at some depth inside the material, here approximately 0.375 mm used . The entire imagistic evaluation is based on inspection of C-scan (en-face) images only. Similar interpretation as suggested here can be based on using B-scans as well, however the C-scan mode is more illustrative for patterns. The B-scan images were used here to impose some rigorous control of the depth of the investigation. It was concluded by example that a variation of 43 % in the reflectivity of the material should trigger an immediate temperature re-calibration of the oven. Other rules of thumb were discussed to allow for the monitoring a process .

The procedure suggested, if followed, can prevent the thermal stress of the ceramic layer. Otherwise, such stress would lead to materials defects and then to fractures inside the ceramic layers of the prostheses manufactured and inserted in the oral cavity.

5. ACKNOWLEDGMENTS

This work was supported by a Partnership grant of the Romanian National Authority for Scientific Research, CNDI–UEFISCDI project PN-II-PT-PCCA-2011-3.2-1682 (http://3om-group-optomechatronics.ro/) and by COST ACTION MP 1005. C. Sinescu acknowledges the support of the PIII-C2-PCFI-2015/2016 project – UMF VICTOR BABES TIMISOARA. A. Bradu and A. Podoleanu acknowledge the support of the European Research Council (http://erc.europa.eu), Grant 249889. A. Podoleanu is also supported by the NIHR Biomedical Research Centre at Moorfields Eye Hospital NHS Foundation Trust, and UCL Institute of Ophthalmology. The authors declare no potential conflicts of interest with respect to the authorship and publication of this article.

REFERENCES

[1] Rosenblum, M.A. and Schulman, A, "A review of all ceramic restorations," J. Am. Dent. Assoc. 128, 297–307 (1997).

[2] Rizkalla, A.S. and Jones, D. W., "Indentation fracture toughness and dynamic elastic moduli for commercial feldspathic dental porcelain materials," Dent. Mater. 20, 198–206 (2004).

[3] Rizkalla, A.S. and Jones, D. W., "Mechanical properties of commercial high strength ceramic core materials," Dent. Mater. 20, 207–212 (2004).

[4] Arango, S. S., Vargas A. P., Escobar, J. S., Monteiro, F. J., Restrepo, L. F., Medellin: Dyna. Ceramics for dental restorations - An Introduction," 77(163), 2636 (2010)

[5] Sinescu, C., et al., "Quality assessment of dental treatments using en-face optical coherence tomography," J. of Biomedical Optics 13 (2008).

[6] Sinescu, C., Topala, F. I., Negrutiu, M. L., Duma, V.-F., and Podoleanu, A. Gh., "Temperature variation in metal ceramic technology analyzed using time domain optical coherence tomography," Proc. SPIE 8925, 89250T (2014). [7] Huang, D., Swanson, E. A., Lin, C. P., Schuman, J. S., Stinson, W. G., Chang, W., Hee, M. R., Flotte, T., Gregory, K., Puliafito, C. A., and Fujimoto, J. G., "Optical coherence tomography," Science 254(5035), 1178-1181 (1991).

[8] Drexler, W. and Fujimoto, J. G., Optical Coherence Tomography, Springer-Verlag, Berlin Heidelberg (2008).

[9] Podoleanu, A. Gh., „Optical coherence tomography," J of Microscopy 247, 209–219 (2012).

[10] Wojtkowski, M., "High-speed optical coherence tomography: basics and applications," Appl. Opt. 49, D30-D61 (2010).

[11] Podoleanu, A. Gh. and Bradu, A., "Master–slave interferometry for parallel spectral domain interferometry sensing and versatile 3D optical coherence tomography," Opt. Express 21, 19324-19338 (2013).

[12] Marcauteanu, C., Bradu, A., Sinescu, C., Topala, F. I., Negrutiu, L. M., and Podoleanu, A. Gh,. "Quantitative Evaluation of Dental Abfraction and Attrition using Spectral Domain Optical Coherence Tomography," J. of Biomedical Optics 19(2), 021108 (2013).