Journal of Theoretical and Applied Mechanics, Sofia, 2016, vol. 46, No. 2, pp. 27–36

DE GRUYTER
OPEN

DOI: 10.1515/jtam-2016-0008

ROUGHNESS MEASUREMENT OF DENTAL MATERIALS*

Assen Shulev, Ilia Roussev, Simeon Karpuzov,
Georgi Stoilov, Detelina Ignatova
*Institute of Mechanics, Bulgarian Academy of Sciences,
Acad. G. Bonchev St., Bl. 4, Sofia 1113, Bulgaria,*
e-mails: {assen, ilia, gstoilov, ignatova, simeon}@imbm.bas.bg

Constantin von See, Gergo Mitov
Steiner Landstraße 124 A-3500, Krems-Stein, Austria
e-mails: {gergo.mitov, Constantin.See}@dp-uni.ac.at

[Received 11 December 2015. Accepted 20 June 2016]

Abstract. This paper presents a roughness measurement of zirconia ceramics, widely used for dental applications. Surface roughness variations caused by the most commonly used dental instruments for intraoral grinding and polishing are estimated. The applied technique is simple and utilizes the speckle properties of the scattered laser light. It could be easily implemented even in dental clinic environment. The main criteria for roughness estimation is the average speckle size, which varies with the roughness of zirconia. The algorithm used for the speckle size estimation is based on the normalized autocorrelation approach.
Key words: Roughness, speckle, light scattering, zirconia ceramics; normalized autocorrelation.

1. Introduction

There are various factors, affecting dental enamel and crown ceramic mutual wear, which leads to changes in mechanical, microstructural, physical, chemical, and surface characteristics with unpleasant and dangerous consequences [1]. Exteriorly, the wear results in changes of the surface's roughness,

*Corresponding author e-mail: assen@imbm.bas.bg
This work is supported by the Bulgarian National Science Foundation grant B02/25 (2014) for the project "Clinical Wear Investigation of New Zirconia Dental Ceramics by Optical and Laser Techniques".

initially determined by ceramics' surface grinding and polishing and the actual dental surface condition are investigated. The surface roughness of the used ceramics and its long term changes carry important information for the ceramics' quality and for development of new crown materials.

The effect of surface roughness on ceramics in dentistry and place of zirconia between others crown materials is comprehensively reviewed in [2]. To evaluate the effect on the roughness, controlled clinically simulated intraoral grinding and polishing of two types zirconia crowns have been applied [3].

Numerous measurement technics have been used for roughness study in enormous quantity of works over a large periods of time, which itself speaks for the importance of this research area. Important types of contact, non-optical, and optical instrumentation for surface metrology are reviewed in [4]. Among non-contact methods, most used are optical white light and laser ones. Apart from all known microscopes for direct surface examination, for surface topology study almost all known optical measurement techniques with relevant digital hardware facilities and image processing software are used. A lot of measurement techniques rely on a pattern projection and its modulation, caused by the surface's roughness, structure of the generated speckle pattern, and the intensity of the scattered light. To mention some of them briefly citing exemplary publications:

Three-dimensional profiles of surface roughness are well revealed by the fringe projection technique [5], as well as by fringe projection moiré [6]. Interference fringes analysis is used in [7, 8], and electronic speckle pattern interferometry – in [9], speckle-pattern correlation and visibility [10].

Light scattering from rough surfaces is the more often utilized phenomenon [11–15]. Different methods are used for obtaining quantitative information from the scattered light. The Fourier spectrum of the scattered light is examined in [16], the wavelet transform – in [17], goniometry – a contact angle technique – in [18], changes in the state of polarization of light – ellipsometry – in [19].

Recently, a comparison between three optical methods for characterizing surface roughness on nanoscale via two scatterometers (laboratory and commercial), and a confocal optical profiler have been performed [20]. Contrast, correlation, energy, and homogeneity features are studied with respect to surface roughness of paper through gray-level co-occurrence matrix of the produced speckle patterns [21].

In this work a simple optical technique is applied for surface roughness measurement of several differently polished surfaces of zirconia material for dental crowns. The roughness was measured initially by a commercially available device Zeta-20 manufactured by Zeta Instruments and the obtained results have been used as reference data.

2. Zirconia specimen preparation

Three different axial surfaces of a zirconia cube (Fig. 1) were finished with instruments, used widely for intraoral grinding and polishing (Table 1). The unprepared surface Glazed Zirconia (GZ) was sandblasted for 30 s with 100-μm Al_2O_3 particles at 2 bar and glazed, using a commercial glazing agent (Vita Akzent VM9, Vita Zahnfabrik, Bad Säckingen, Germany) according to the manufacturer's instructions for glazing glass ceramics. The finishing procedures for the groups Zircona prepared with *Red Ring* 30-μm diamond bur (8879.314.016) (RR) and Zircona prepared with *Green Ring* 100-μm diamond bur (S6879.314.016) (GR) were accomplished, using a high-speed handpiece. Five back and forth strokes were performed at the maximum operating speed for the handpiece of 200,000 $\min^{-1}$for the RR and GR surfaces and 10,000 $\min^{-1}$for the Zirconia prepared with *Soft-Lex XT* polishing and contouring Disc (SL) surface.

Fig. 1. Zirconia cube finished with different dental instruments

3. Optical set-up

The optical zirconia roughness measurement set-up is presented schematically in Fig. 2. A He-Ne laser is used as a source of coherent light. The laser beam goes trough a spatial filter and the collimated light illuminates the speci-

Table 1. Description of the test surfaces

Test surface	Group code
Glazed Zirconia	GZ
Zirconia prepared with *Soft-Lex XT* polishing and contouring Disc**	SL
Zircona prepared with *Red Ring* 30-μm diamond bur (8879.314.016)*	RR
Zircona prepared with *Green Ring* 100-μm diamond bur (S6879.314.016)*	GR
*Brasseler, Savannah, GA, USA **3M ESPE, Seefeld, Germany	

men's surface at an angle of $\pi/4$ rad. The intensity image of the scattered light is captured by a CMOS camera with 10 Mpix sensor and pixel size of 1.67 μm x 1.67 μm, and transferred into a computer for further processing.

The average speckle size of the captured image depends on the lens aperture and magnification, light wavelength, and the distances between those elements. It has been found that the speckle size also depends on surface properties and particularly on its roughness [10]. The white light fiber illumination is used only for surface inspection and fine focusing of the specimen's surface.

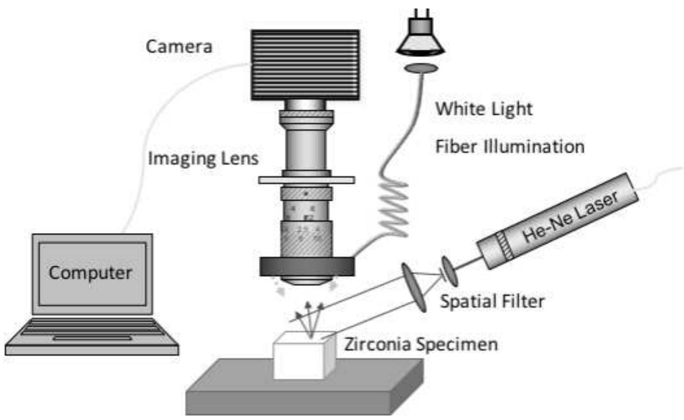

Fig. 2. Roughness measurement optical set-up

Captured white light and coherent images of the different specimen's surfaces are shown in Fig. 3 on the first and the second row, respectively. It could be seen from the coherent image that the contrast varies with the roughness.

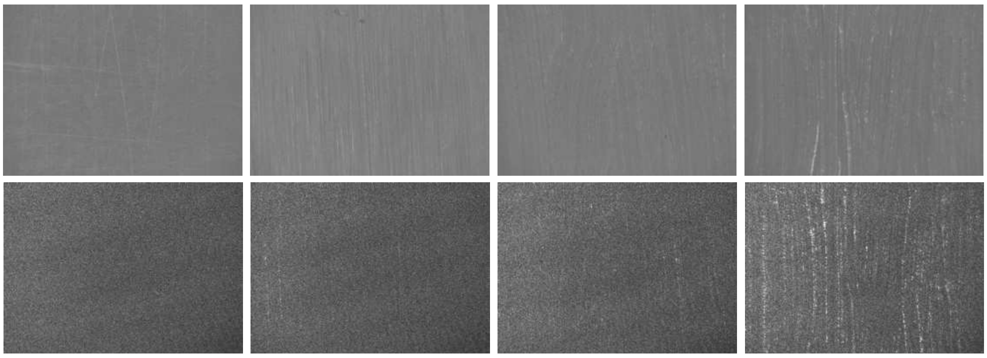

Fig. 3. Intensity images of the zirconia surfaces GZ – first column, SL – second column, RR – third column, GR – forth column, in white light – first row, in coherent light – second row

4. Speckle size estimation

It has been shown, that the average speckle size could be estimated from the first fall to zero of the normalized autocorrelation function of the speckle pattern [22]. The normalized two dimensional autocorrelation of an intensity image might be presented by the following equation:

$$A(u,v) = \frac{\Sigma_{x,y}(f(x,y) - \overline{f_{u,v}})(f(x-u,y-v) - \overline{f_{u,v}})}{\sqrt{\Sigma_{x,y}(f(x-u,y-v) - \overline{f_{u,v}})^2 \Sigma_{x,y}(f(x,y) - \overline{f_{u,v}})^2}} \tag{1}$$

where $f(x,y)$ is the image intensity, and $\overline{f_{u,v}}$ is the mean value of the intensity.

In Fig. 4, the central part of the normalized autocorrelation of the intensity image of the GZ surface is shown. It has been demonstrated [23], that more reliable approach for the speckle size estimation is to evaluate the full width at half maximum of the normalized autocorrelation function, instead of searching for the first fall to zero around the correlation peak.

The intensity speckle image is divided into several blocks in order to estimate the average speckle size from the width of the two dimensional autocorrelation peak. For each block, the full width at half maximum along x and y directions have been evaluated and averaged after that.

5. Measurement results

The roughness of specimen's surfaces has been measured by commercial equipment Zeta-20, possessing resolution of 13 nm in z direction. A 3D profile

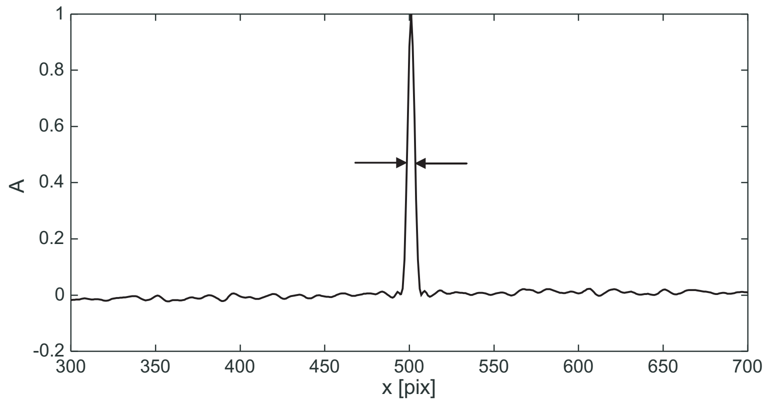

Fig. 4. Plot of the normalized autocorrelation function along x direction. The arrows depict the full width at half maximum corresponding to the speckle size

of these surfaces is shown in Fig. 5 and the obtained results for the Root Mean Square (RMS) roughness Sq are given in Fig. 6 – left. The RMS roughness error is less than 12 %. Calculated results for the average speckle size are presented in Fig. 6 – right.

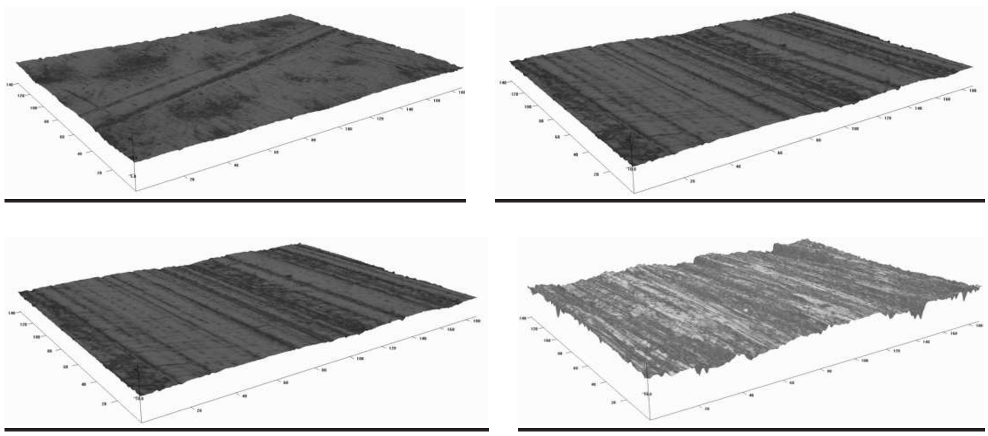

Fig. 5. 3D scan of the specimen's surfaces by Zeta-20: GZ – upper left, SL – upper right, RR – lower left, GR – lower right

Both RMS roughness and estimated speckle size data are shown in Fig. 7. The adjacent points are connected by straight lines, just to lead the eye. It

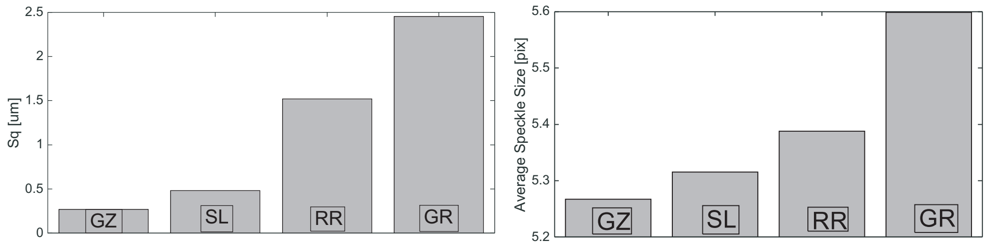

Fig. 6. Root mean square roughness assessed by the Zeta-20 profilometer for the different surfaces – left, and estimated average speckle size for the same surfaces – right

might be seen, that there is a correspondence between the average speckle size and the surface roughness. These results show that the proposed technique can be successfully used for qualitative roughness estimation of zirconia ceramics.

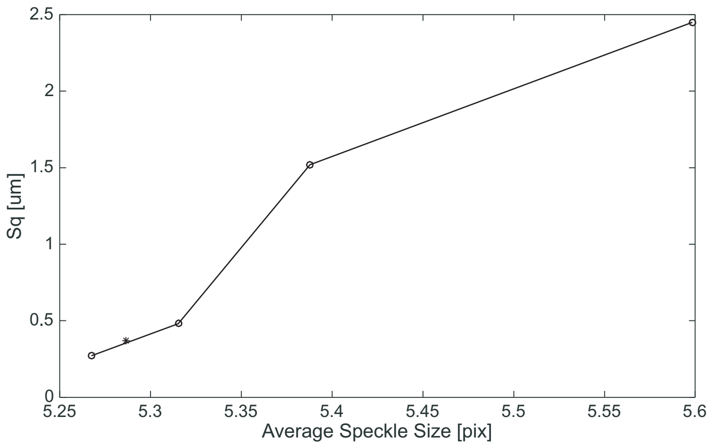

Fig. 7. Average speckle size vs. RMS roughness, measured for the different surfaces of the zirconia specimen

The glazed surface GZ of the zirconia specimen has been slightly touched with one of the finest dental polishing tools to verify the sensitivity of this method, just to introduce few more scratches. Both images of the same glazed surface, before and after this fine polishing hint, are shown in Fig. 8 on the left and the right side, respectively.

The measured average speckle size, after the additional fine scratching made by the polishing disc SL, has been found to be 5.286 pix, while the initial

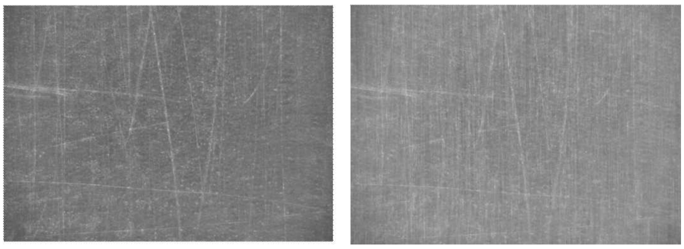

Fig. 8. Glazed zirconia surface GZ – left, and the same surface after fine additional polishing – right

size was 5.267 pix. The roughness of the additionally polished surface was measured again by Zeta-20 profilometer. A value of 0.37 μm was acquired for the RMS roughness and depicted together with the corresponding speckle size with starlet in Fig. 7. Therefore, we demonstrated that this approach has a potential to estimate the roughness of zirconia ceramics, caused even by the finest polishing, used in dentistry.

6. Conclusion

The proposed method for roughness measurement of dental zirconia ceramics is simple, sensitive, reliable, and it does not require expensive imaging lenses with high resolution and other sophisticated components. It is based on the variation of the speckle statistics of the scattered light from surfaces with different roughness, and in particular the speckle size variation. Therefore, an approach for the average speckle size estimation, based on full width at half maximum of the normalized autocorrelation function was applied. The obtained roughness results were compared to measurements realized by state of the art equipment for roughness evaluation. The sensitivity of the method, even to the finest dental manipulation, has been demonstrated. Simple optical set-up might be used in clinical environment, allowing dentists to estimate the roughness of zirconia ceramic crowns or implants.

REFERENCES

[1] Oh, Won-Suck, R. Delong, K. Anusavice. Factors Affecting Enamel and Ceramic Wear: A Literature Review. *The J. of Prosthetic Dentistry*, **87** (2002), No. **4**, 451–459.

[2] Rashid, H. The Effect of Surface Roughness on Ceramics used in Dentistry: A Review of Literature. *Europ. J. of Dentistry*, **8** (2014), No. **4**, 571–579.

[3] Hmaidouch, R., W.-D. Müller, H.-Ch. Lauer, P. Weigl. Surface Roughness of Zirconia for Full-contour Crowns after Clinically Simulated Grinding and Polishing. *International Journal of Oral Science*, **6** (2014), No. **4**, 241–246.

[4] Whitehouse, D. J. Surface Metrology – Review Article. *Measurement Science and Technology*, **8** (1997), 955–972.

[5] Windecker, R., S. Franz, H. Tiziani. Optical Roughness Measurements with Fringe Projection. *Appl. Optics*, **38** (1999), No. **13**, 2837–2842.

[6] Ezazshahabi, N., M. Tehran, M. Latifi, K. Madanipour. Surface Roughness Assessment of Woven Fabrics using Fringe Projection Moiré Techniques. *Fibres & textiles in Eastern Europe*, **23** (2015), No. **3**, 76–84.

[7] Kumar, S., G. Kumar. Surface Roughness Characterization using Interference Fringe Analysis. *IGIRSET*, **2** (2013), No. **1**, 563–573.

[8] De Azevedo, A., H. Panzeri, et al. Assessment *in Vitro* of Brushing on Dental Surface Roughness Alteration by Laser Interferometry. *Braz Oral Res.*, **22** (2008), No. **1**, 11–17.

[9] Gülker, G., K. Hinsh. Detection of Surf Microstructure Changes by ESPI. *Optics and Lasers in Engineering*, **26** (1997), No. **2**, 165–178.

[10] Nicklawy, M., A. Hassan, M. Bahrawi, N. Farid, A. Sanjid. Characterizing Surface Roughness by Speckle Pattern Analysis. *J. of Scientific & Industrial Research*, **68** (2009), No. **2**, 118–121.

[11] Wang, Sh., Y. Tian, Ch. Tay, Ch. Quan. Development of a Laser-scattering-based Probe for On-line Measurement of Surface Roughness. *Applied Optics*, **42** (2003), No. **3**, 1318–1324.

[12] Wax, A., V. Beckman. Biomedical Applications of Light Scattering, The McGraw-Hill Companies, Inc., 2010.

[13] Manallah, A., M. Bouafia. Application of the Technique of Total Integrated Scattering of Light for Micro-roughness Evaluation of Polished Surfaces. *Physics Procedia*, **21** (2011), 174–179.

[14] Martinez-Fuentes, V., I. Dominguez-Lopez, A. L. Garcia-Garcia. Surface Texture Changes Followed-up in Real Time during the Initial Wear Transient of Dry Sliding of Steel against Several Metals using Laser Light Scattering. *Wear*, **271** (2011), Nos **5–6**, 994–998.

[15] Cochran, P. T. Fibre Optic Surface Roughness Measurement, Thesis, New Zealand, University of Waikato, Department of Physics, 2004.

[16] Pernick, B. J. Surface Roughness Measurements with an Optical Fourier Spectrum Analyzer. *Applied Optics*, **18** (1979), No. **6**, 796–801.

[17] Stępień , K. Research on a Surface Texture Analysis by Digital Signal Processing Methods. *Tehnichki vjesnik*, **21** (2014), No. **3**, 485–493.

[18] Stacy, R. Contact Angle Measurement Technique for Rough Surfaces, Thesis, Michigan Technological University, 2009.

[19] Svitasheva, S. Experimental Study of Polarization Properties of Rough Surface. *Electrical and Electronic Engineering*, **2** (2012), No. **6**, 403–408.

[20] Feidenhans, N., P.-E. Hansen, et al. Comparison of Optical Methods for Surface Roughness Characterization. *Meas. Sci. Technol.*, **26** (2015), 085208.

[21] Pino, A., J. Pladellorens. Measure of Roughness of Paper using Speckle. *Proc. of SPIE*, **7432** (2009), 74320E – 1–9.

[22] Goodman, J. W. Statistical Properties of Laser Speckle Patterns. Ch. 2 in Laser Speckle and Related Phenomena, pp. 9-75, series Topics in Applied Physics, **9** (ed. J. C. Dainty), Berlin – Heidelberg – New-York, Springer-Verlag, 1975.

[23] Piederrière, Y., J. Cariou, Y. Guern, B. Le Jeune, G. Le Brun, J. Lotrian. Scattering through Fluids: Speckle Size Measurement and Monte Carlo Simulations Close to and into the Multiple Scattering. *Optics Express*, **12** (2004), No. **1**, 176–188.