Numerical and Experimental Study of Dental Fiber Post Adhesive Bond Strength

Natalia T. Gavryushina
Bauman Moscow State Technical University, Moscow, Russia
Email: n.gavryushina@bmstu.ru

Anna S. Bobrovskaia
A.I. Evdokimov Moscow State University of Medicine and Dentistry, 127473, Moscow, Russia
Email: aggi@yandex.ru

Olga O. Baryshnikova
Bauman Moscow State Technical University, Moscow, Russia
Email: barysh-oo@bmstu.ru

***Abstract*—A numerical and experimental study of the new method for determining the adhesive bond strength of fiber posts, called by the authors the "torque-out" test, is considered. In contrast to the known methods of testing the push-out test and the pull-out test, in which a tensile or compressive load is applied to the sample, the load is produced by the torque. Samples for determining the adhesive strength of a particular post-cement combination can be made in a clinical setting without using of special equipment. Testing of samples is carried out on a compact installation developed by the authors, designed to evaluate the adhesive strength of a joint in clinical conditions according to the magnitude of the limiting torque. The numerical study of the adhesive strength of the connection of fiber posts and luting cements and the comparison of the stress-strain state arising in the samples during the push-out and torque-out tests is performed using mathematical modeling such as the finite element method.**

***Index Terms*—fiber post, adhesive bond strength, finite element method, torque-out test.**

I. INTRODUCTION

In recent years, restoration strengthening by using intracanal dental posts has gained popularity [1, 2, 3]. Fiber posts are luted adhesively in root canals of the teeth with composite cement. However, according to the published data, due to the weakness of the adhesive compound, more than 60% of the failures [4] are associated with construction’s "debonding". A large number of foreign studies [4, 5, 6] are known, devoted to the search for rational post pretreatment and fixation methods. The actual practical task is the development of an accessible technique that allows evaluating the adhesive bond strength of intracanal constructions.

Studies that assess the bond strength of fiber posts usually are carried out in laboratory conditions, and are a fairly complex procedurerequiring special equipment. [5, 6, 7, 8, 9]. Standardized conditions for the assessment and direct measurement of the adhesion value of fiber posts and luting cements fixation have not been developed to date.

Microshear and microtensile tests are the two fundamentally different approaches in studying the adhesive joints strength. When conducting microshear tests, one of the adhesion substrates is fixed immovably, and force acting in the direction of the axis parallel to the contact plane between the substrates is applied to the other. During the test, the maximal force that occurs when the sample is destroyed is determined. The tests of the first group include the so-called micro "push-out" and "pull-out" tests. When implementing a micro push-out test, the fragment of the post is extruded from the prepared sample obtained by horizontal saw cuts of the preparation. When carrying out a pull-out test, the pin previously locked in the prepared preparation is pulled.

Microshear tests are widespread today, but among their main drawbacks, it should be noted a significant frequency of cases of cohesive destruction of the substrate. This is due to the emergence of a complex load distribution scheme during the test and may lead to erroneous interpretation of the results [7].

The second group includes microtensile tests [6, 10, 11], in which force is applied along an axis directed perpendicular to the plane of the adhesive compound. The microten-sile test was originally developed to evaluate the strength of tooth tissues, but was later used to measure the adhesive bond strength to enamel and dentin [3]. In this test, preparation of test specimens requires cutting the sample into "bars" containing a fragment of the post, the fixing cement and the area of the adhesive bonding be-tween them. Then the stretching load is applied to the preparations until the moment of destruction. The small size of the samples provides a fairly even distribution of the load, which limits the possibility of cohesive fractures and helps to evaluate the adhesive bond strength directly [7]. In addition, from one

Manuscript received May 7, 2020; revised February 1, 2021.

doi: 10.18178/ijmerr.10.3.157-162

sample it is possible to obtain several fragments for testing, which leads to a smaller scatter of data. At the same time, it is noted in [3] that 46 (!) specimens out of 50 were subjected to premature failure in the preparation of samples for a microtensile test, which forced the authors to abandon the application of this method. The main disadvantages of these methods are their complexity, a complicated sample preparation methods (procedure, protocols), and the use of special high-precision process equipment, the direct conduct of the experiment requires the use of expensive stationary equipment [12] and practically inaccessible for practitioners.

II. The Methodology Essence

The proposed new method of measuring the adhesive bond strength of fiber posts proposed by the authors was called the “torque-out” test.

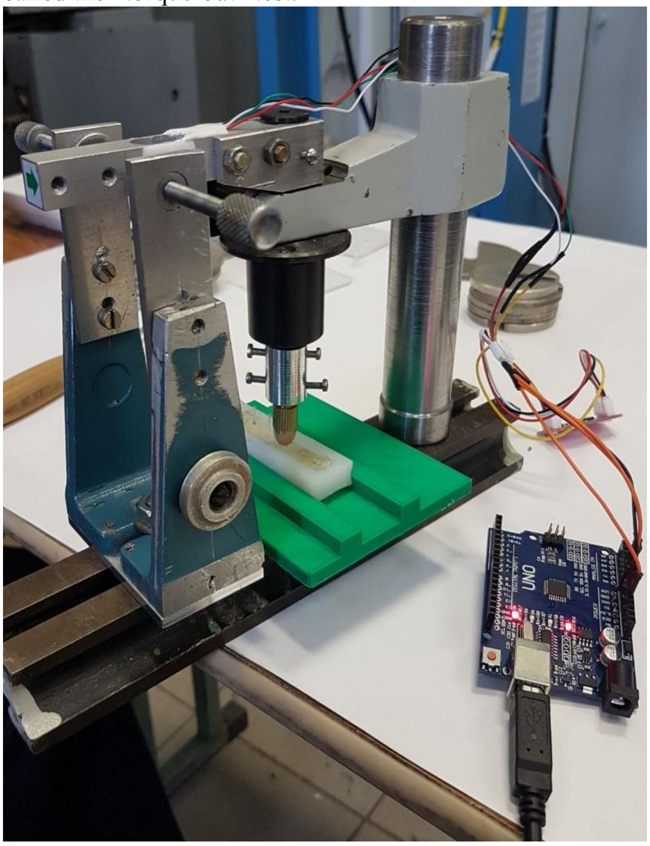

Figure 1. Testing installation for torque-out test.

Unlike the known test methods described above (push-out test and pull-out test), in which a tensile or compressive load is applied to a sample, the samples are loaded with a torque. The description of the compact installation (Fig. 1) designed by the authors for the evaluation of the adhesive strength of the joint in terms of clinical conditions by the magnitude of the limiting torque, as well as the method of sample preparation and carrying out the torque-out test are given in [12]. A patent has been received for the proposed method and the developed installation (Fig. 2).

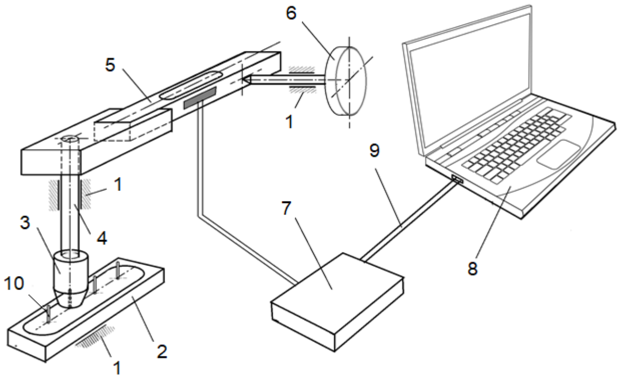

Figure 2. Instalation diagram (frame (1), template (2) for posts (10), collet clamp (3), shaft (4), translating the torque, strain gauge sensor (5), micrometer screw (6), controller (7), personal computer (8) and wires (9)).

The measurement is carrying out this way: posts (10) are installed in the template (2), luting cement is introduced into the recess around the posts for fixation and polymerized according to the manufacturer's instructions. The template is fixed in a special slot on the frame (1) of the device. The test post is fixed by means of a collet clamp (3), wherein the strain gauge sensor (5) is set to its original position, controlled by a micrometer screw (6). Using the program installed on the computer, the torque value is reset. The successive rotation of the micrometer screw (6) affects the strain gauge sensing element (5), connected through the shaft (4) and the collet with the test pin. The torque value is shown in the diagram. Upon reaching the destruction of the maximum torque value is fixed and the loading process stops.

Samples for research are made with the use of posts and cements in a clinical setting without the use of technological equipment for cutting. The developed compact torque measuring device allows the evaluation of the adhesive strength of the joint without the use of stationary test equipment. The change in the torque value over time is shown in the computer diagram (Fig. 3).

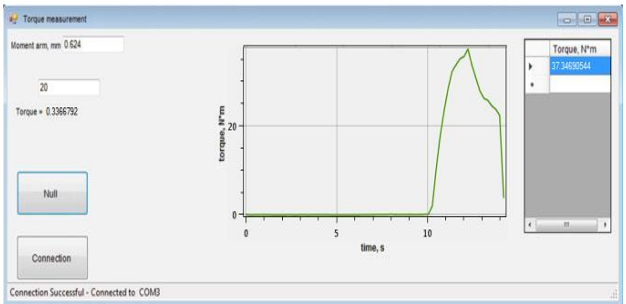

Figure 3. Screenshot of torque-out measurement.

Upon reaching failure of the connection of the pin with the cement, the maximum torque value is fixed.

III. The Methodology Essence

To assess the possibility of using the developed torque-out test, measuring the adhesive strength of fixing fiberglass pins and luting cements, it is necessary to compare it with the methods described in the literature to assess the reliability of measurements and the comparability of the results obtained with literature data. For this purpose, methods of mathematical modeling are used, in particular, the finite element method (FEM) [14, 14, 15, 16, 17, 18, 19], which has been widely used in studies of the strength characteristics of materials and structures [19], which makes it possible to obtain a theoretical justification of the experimental results.

The FEM implements a simple and fairly obvious algorithm for studying the behavior of a structure based on known information about the laws of behavior of its individual parts, called finite elements. In mathematical modeling of tests for approximating the interaction between a fiberglass post and fixing cement, the model is used as a set of individual finite elements. The behavior of each of the finite elements obeys pre-known ratios obtained on the basis of established theoretical or experimental dependencies that describe the process under study.

For the analysis of the stress-strain state of the directly post and fixing cement, the relationships of the deformable solid body mechanics are used. In mathematical modeling, the pin and fixing cement are considered as a three-dimensional medium — a continuum endowed with certain mechanical properties. When a buoyancy force is applied (in the case of a push-out test) or a torque (in the case of a torque-out test), the pin and adhesively bonded cement are deformed, and internal stresses arise in them. In the framework of the traditional approach, it is assumed that for the pin and cement materials it is possible to use the continuity and homogeneity hypotheses generally accepted in materials resistance [20]. Physical and mechanical properties of materials are taken in accordance with the manufacturer.

To describe the stress-strain state of the structure, the classical relations of the elasticity theory are used. The three-dimensional environment is represented as a set of material points, each of which occupies a certain position in space, defined by the initial coordinates (x, y, z) in the Cartesian coordinate system.

When a solid is deformed by an external load, each material point shifts to some neighboring point with coordinates (x', y', z'). The components of the displacement vector are defined as the difference between the coordinates of the point before, and after the load is applied:

$$\{u\} = \{u, v, w\}^T \tag{1}$$

Displacement of a set of material points leads to a change in the geometric shape of the body as a whole. The measure of shape change in a small neighborhood of the point in question is the longitudinal $\varepsilon_x, \varepsilon_y, \varepsilon_z$ and shear deformations γ_{xy}, γ_{yz}, γ_{zy}. Small deformations are associated with displacements by Cauchy dependencies. In matrix form, the Cauchy relations are written as follows.

$$\{\boldsymbol{\varepsilon}\} = [R]\,\{u\} \tag{2}$$

The deformation vector $\{\boldsymbol{\varepsilon}\} = \{\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zy}\}^T$ t is expressed in terms of the displacement vector {u} using the matrix of differential operators [R] of size (6x3). Note that three displacements uniquely determine six deformations, which indicates the necessity of the existence of three additional relations, known as the Codazzi-Gauss equations.

The stress state at a body point is recorded using 6 independent components of the stress state tensor, which can be conveniently represented in the form

$$\{\sigma\} = \{\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx}\}^T \tag{3}$$

In accordance with Hooke's law for an isotropic material, the relationship between the deformation vector $\{\boldsymbol{\varepsilon}\}$ and the stress vector is written as

$$\{\boldsymbol{\sigma}\} = [\boldsymbol{D}]\{\boldsymbol{\varepsilon}\} \tag{4}$$

where [D] is the matrix of the elastic properties of the material.

The equilibrium conditions of an elementary parallelepiped cut in a neighborhood of the point in question can be written as

$$\{\boldsymbol{R}\}^T\{\boldsymbol{\sigma}\} + \{\boldsymbol{b}\} = \boldsymbol{0}, \tag{5}$$

here $\{\boldsymbol{\sigma}\} = \{\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx}\}^T$ is the stress vector,

{b} = {bx, by, bz} T is the vector of external forces distributed over the body volume.

To obtain a closed system of equations, relations (5) are supplemented by boundary conditions given on the boundary of the body.

As a rule, on part of the surface Su the boundary conditions are specified in the kinematic form

$$\{\boldsymbol{u}\} = \{\boldsymbol{u}\}^* \tag{6}$$

here {u} * is the vector of specified displacements. On the remaining part Sp of the surface of the body, the boundary condition is specified in a static form:

$$\{\boldsymbol{p}\} = [\boldsymbol{C}]\{\sigma\} = \{\boldsymbol{p}\}^* \tag{7}$$

where {p} * is the vector of specified voltages, [C] is the matrix of the direction cosines of the normal at the current point on the body surface.

The basic relations of the finite element method in the form of the displacement method can be obtained on the basis of the variational principle of the minimum of the total potential energy of the system, according to which the body is in equilibrium if the total potential energy of the system takes a stationary value. Using the variational principle allows one to write the equilibrium conditions of a finite element with the number - "e" in the form:

$$[\boldsymbol{K}]^{(e)}\{\boldsymbol{a}\}^{(e)} = \{\boldsymbol{f}\}^{(e)} \tag{8}$$

where the matrix $[\boldsymbol{K}]^{(e)}$ is the finite element stiffness matrix, $\{\boldsymbol{a}\}^{(e)}$ is the vector of unknown displacements at the finite element nodes, $\{f\}^{(e)}$ is the nodal force vector for the element with the number "e".

The stiffness matrix and the vector of nodal forces for an ensemble of finite elements are obtained by summing the corresponding values for individual finite elements. The finally resolving relations of the FEM are represented in the form of a system of high-order linear algebraic equations:

$$[\boldsymbol{K}]\{\boldsymbol{a}\} = \{\boldsymbol{f}\} \tag{9}$$

When conducting a numerical study, the modulus of elasticity of the first kind and the Poisson ratio for the pin were taken to be equal to the characteristics of dentin [16, 17]: E1 = 18.6 GPa and ν1 = 0.31. The corresponding parameters for cement were E2 = 5.1 GPa, and ν2 = 0.27. Materials assumed to be homogeneous and isotropic.

The finite element method [14, 19] carried out a numerical simulation of the proposed torque-out test (Fig. 4) and the well-known push-out test (Fig. 5).

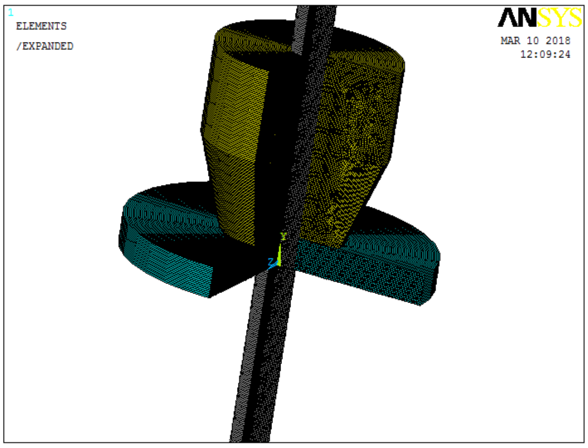

Figure 4. Finite element model for torque-out test.

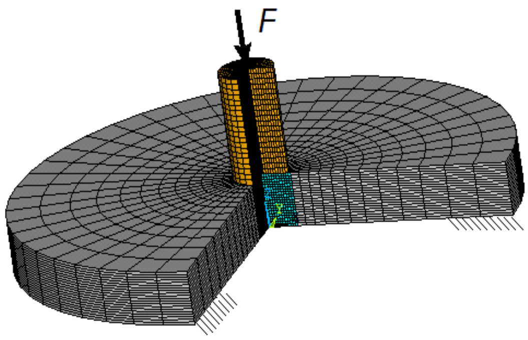

Figure 5. Finite element model for push-out test.

Figs. 6 and 7 show color graphic diagrams of the equivalent stresses distribution according to the Huber-Mises theory [15], Figs. 7 and 8 show graphs of the distribution of equivalent stresses along the height of the cement layer. The samples were loaded with a torque of M = 6 N * mm and an ejection force equal to 10 N, respectively.

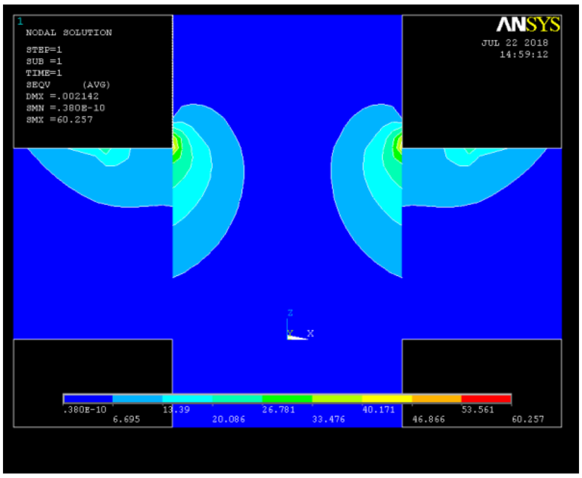

Figure 6. Color graphic chars of the equivalent stresses distribution for torque-out test.

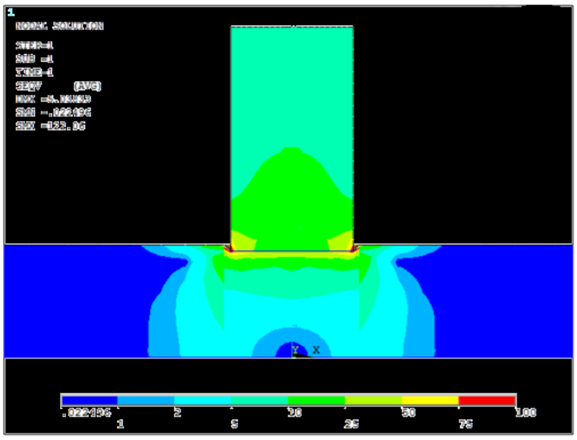

Figure 7. Color graphic chars of the equivalent stresses distribution for push-out test.

To compare the results of the analysis of the stress-strain state, we used the averaged value of shear stresses. With respect to the push-out test, the averaged tangential stress level was estimated using the formula:

$$\tau_{yz} = \frac{F}{\pi D h}$$

Where D is the diameter of the pin, h is the thickness of the cement layer.

With respect to the torque-out test, the average level of tangential stresses was estimated using the formula:

$$\tau_{xz} = \frac{2M}{\pi D^2 h}$$

Equating the average level of the tangential stresses of the tests under consideration, we can establish an approximate correspondence between the load parameters:

$$M = \frac{FD}{2}$$

Graphs of the equivalent stress distribution over the height of the cement layer are shown for torque-out test

(Fig. 6) and for push-out test (Fig. 7). The results of calculation are compared with experiments held by methods in [20, 21].

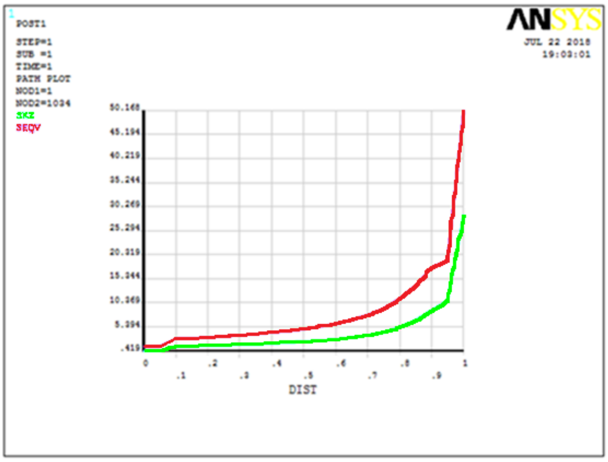

Figure 8. Graph of the equivalent stresses distribution along the height of the cement layer for torque-out test.

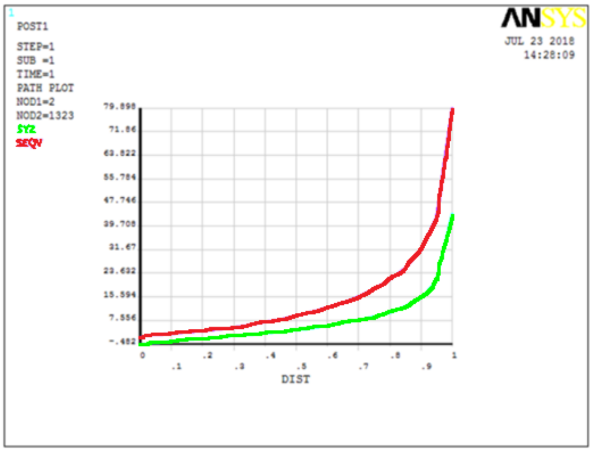

Figure 9. Graph of the equivalent stresses distribution along the height of the cement layer for push-out test.

The nature of the stress distribution allows us conclude that there is a qualitative coincidence of these dependencies for torque-out and push-out tests, which makes it possible to compare the experimental data.

IV. Conclusion

1. The developed technique, called the torque-out test, makes it possible to evaluate the adhesion strength of dental posts and fixing cements and to make an informed choice of the restoration method in a specific clinical case.
2. The results of numerical simulation have shown that it is possible to compare the test-to-test data with other known techniques for determining the adhesive bond strength.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A. S. Bobrovskaia analyzed the data, developed the model, stated the recommendations.

N. T. Gavryushina conducted the experiment and analyzed experimental results.

O.O. Baryshnikova made a conclusions and wrote the paper.

All authors accepted the paper.

References

[1] D. Dietschi, O. Duc, I. Kreici, A. Sadan, "Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of literature," Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). - Quintessence International, no. 39, pp. 117-129, 2008.

[2] B. Duret, M. Reynaud, F. Duret, "A new concept of corono-radicular reconstruction," *The Composipost (2). Le Chirurgien-dentiste de France*, vol. 60, no. 542, pp. 69–77, 1990.

[3] C. Goracci, S. Grandini, M. Bossu, E. Bertelli, M. Ferrari, "Laboratory assessment of the retentive potential of adhesive posts: a review," *J. Dent.*, vol. 35, pp. 827–835, 2007.

[4] R. Mosharraf and P. Ranjbarian, "Effects of post surface conditioning before silanization on bond strength between fiber post and resin cement," *J. Adv. Prosthodont*, no 5, pp. 126-132, 2013.

[5] C. S. Castellan, P. C. F. Santos-Filho, P. V. Soares, C. J. Soares, P. E. C. Cardoso, "Measuring bond strength between fiber post and root dentin: A comparison of different tests," *J. Adhes. Dent*., vol. 12, pp. 477–485, 2010.

[6] H. Sano, T. Shono, H. Sonoda, T. Takatsu, B. Ciucchi, R. Carvalho, D. H. Pashley, "Relationship between surface area for adhesion and tensile bond strength–evaluation of a micro-tensile bond test," *Dent. Mater*. vol. 10, no. 4, pp. 236–240, 1994.

[7] M. Sumitha, R. Kothandaraman, M. Sekar, "Evaluation of post-surface conditioning to improve interfacial adhesion in post-core restorations," *J. Conserv. Dent*. vol. 14, pp. 28–31, 2011.

[8] C. V. Reddy, P. R. Babu, R. Ramnarayanan, "Effect of various filler materials on interlaminar shear strength (ILSS) of glass/epoxy composite materials," *Int. J. Eng. Manuf. (IJEM)*, vol. 6, no. 5, pp. 22–29, 2016.

[9] D. Cecchin, A. P. Farina, R. P. Vitti, R. R. Moraes, A. Bacchi, A. O. Spazzin, "Acid etching and surface coating of glass-fiber posts: bond strength and interface analysis," *Brazilian Dental Journal*, vol. 27, no. 2, pp. 228-233, 2016.

[10] J. Aksornmuang, R. M. Foxton, M. Nakajima, J. Tagami, "Microtensile bond strength of a dual cure resin core material to glass and quartz fiber posts," *Journal of Dentistry*, no. 32(6), pp. 443-450, 2004.

[11] S. Bouillaguet, S. Troesch, J. C. Wataha, I. Krejci, J. M. Meyer, D. H. Pashley, "Microtensile bond strength between adhesive cements and root canal dentin," *Dental Materials*, no. 19, pp. 199-205, 2003.

[12] A. S. Bobrovskaia, S. S. Gavriushin, A. V. Mitronin, "Evaluation of adhesive bond strength of dental fiber posts by "Torque-out" test / Advances in Artificial Systems for Medicine and Education II," *Advances in Intelligent Systems and Computing*, vol. 902, pp. 261-270, 2018.

[13] S. J. Soares, F. R. Santana, C. G. Castro, P. C. F. Santos-Filho, , P. V. Soares, F. Qian, S. R. Armstrong, "Finite element analysis and bond strength of glass post to intraradicular dentin: Comparison between microtensile and push-out tests," *Dent. Mater*. vol. 24, pp. 1405–1411, 2008.

[14] O. C. Zienkiewicz, *The Finite Element Method*, 3rd ed, p. 483. McGraw-Hill, London, 1977.

[15] S. S. Gavriushin, O. O. Baryshnikova, O. F. Boriskin, *Numerical Analysis of Structure's and Device's Elements*, M, BMSTU Publishing (2014). 479 p. (in Russian)

[16] J. Tong and Y. He, "Vane design which based on finite element analyzing method," *Int. J. Educ. Manage. Eng. (IJEME)*, vol. 2, no. 10, pp. 72–81, 2012.

[17] E. Asmussen, A. Peutzfeldt, A. Sahafi, "Finite element analysis of stresses in endodontically treated, dowel-restored teeth," *J. Prosthet. Dent.* vol. 21, pp. 709–715, 2005.
[18] A. I. Matveeva, V. A. Kanatov, S. S. Gavryushin, "Application of numerical modeling in the improvement of prosthodontic treatment of the end dentition defects," *Dentistry 1*. 48 (1990). (in Russian)
[19] A. I. Matveeva, A. G. Ivanov, R. S. Gvetadze, S. S. Gavryushin, A. V. Karasev, "Improving the efficiency of patient prosthodontic treatment based on mathematical modeling of perspective implant designs. Dentistry," vol. 76, no. 5, pp. 44, 1997. (In Russian)
[20] N. V. Valishvili, S. S. Gavriushin, "Strength of materials and structures," *M, Urait*, (2017), 429 p. (in Russian)
[21] A. D. Terenteva, "Increase the accuracy of automated control for technical measurements," *IJMERR*, vol. 9, no. 4, 2020.
[22] A. D. Terenteva, M. E. Limorenko, E. O. Podchasov, "Development of systematical biases exclusion methods for technical measurements," in *Proc. 2018 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, 2018

Natalia Gavryushina was born at 1948. In 1972 she graduated from the Bauman Moscow State Technical University. Currently associate Professor of the Department "Applied mechanics". Direction of scientific activity — strength calculations of various materials and structures.

Anna Bobrovskaia was born at 1989. In 2011 she graduated from the Evdokimov Moscow State University of Medicine and Dentistry. She is associate Professor. In 2019 she defended her thesis. Dentist, private practice. Research interests – restoration of destroyed teeth, treatment of dental caries and its complications.

Olga Baryshnikova was born on September 28, 1967. In 1989 she graduated from the Irkutsk Polytechnic Institute, received the qualification of engineer - mechanic. From 1993 to 1996 she was a post-graduate student of the Department of Applied mechanics at BMSTU. Since 1996 she has been working at the Department of "Theory of mechanisms and machines" of BMSTU, associate Professor. Research interests – calculation of flexible elastic elements and development of devices and devices on their basis.