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COMPARATIVE ANALYSIS OF TWO METHODS OF ASSESSMENT WEAR OF DENTAL MATERIALS

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Abstract: Wear of dental materials used for permanent dental fillings has a significant impact on their lifetime. Wear products generated during chewing process involving direct tribological contact between a composite and tooth enamel can cause damage not only to enamel itself but also to the entire tooth structure thus affecting the patient's the health. It is essential therefore to assess the process of wear rates as well as the usefulness and effectiveness of the method used to measure these values. As there are a number of different methods used to quantify the loss of dental materials subjected to friction, eg.: scanning digital 3D models of dental casts, confocal microscope scanning or profilographometer measurements, the authors chose to analyze two selected research methods using confocal microscopy and profilographometer to assess their effectiveness. Two commercially available composite dental materials, i.e. ES and FFE previously subjected to friction tests in contact with human dental enamel, were used for the analysis.

Key words: Tooth Enamel, Dental Material, Wear, Friction, Profilografometer, Confocal Microscope

1. INTRODUCTION

Research on dental materials, in the context of their tribological properties, has been playing an extremely significant part in prolonging their durability or lifetime. Despite numerous modifications to their composition and emergence of new composite materials on the market, they still fail to match the working properties of natural enamel (Lambrechts et al., 2006). This is the main reason why research is being continued to develop new and better dental materials. Currently fillings of dental hard tissues used for in natural contact with the opposing teeth are subject to abrasion, chipping and even falling out. They can also cause excessive wear of the tooth enamel remaining antagonistically to be filled. As a result the wear products penetrate into the human organism posing a health risk. Research work on the wear of permanent dental filling materials is of substantial importance for the development of effective methods used to measure wear rates (Ferracane, 2006). The materials such as dental composites are characterized by porosity that gives them a certain absorbency of liquids (Malacarne et al., 2006), for example, human saliva in the oral cavity conditions. As we know, absorbency determines the absorption of the material, i.e. the ability to absorb liquids. Thus, for example, the mass methods, which are also used to evaluate the loss of such materials, are not reliable. That is why new research methods are being developed to assess wear values. To determine the usefulness of the applied method, we use specific statistical procedures to analyze the obtained information on dental materials. There are measurements of volumetric loss of dental materials making use of such methods as 3D digital scanning of dental casts (Park et al., 2014), confocal microscope, profilographometer (Paepegaey et al., 2013) and another.

In this paper the authors analyse tribological wear of two composite dental materials: Estelite Sigma and FulFil Extra in contact with human enamel. The volumetric loss of the samples has been measured using a confocal microscope and profilographometer. The accuracy of the applied the methods is evaluated.

2. MATERIALS

In tribological tests samples of dental composite materials shaped in the form of a truncated cone and countersamples made of human dental enamel were used (Fig. 1). The analysis involved two dental materials used for permanent fillings, namely Estelite Sigma (ES) (Tokuyama Dental, Japan) - light-cured composite containing fillers in the form of spherical particles of submicron size (0.2 - 5 μm) and and FulFil Extra (FFE) (DENTSPLY International Inc., USA) – micro-hybrid, light-cured composite with filler of the particle size varying from 0.04 to 5 μm. In all 20 samples of each of the materials were tested. The materials had been previously formed in layers in aluminum-rimmed frames and cured with a polymerization lamp. Next, they were grinded with upward gradation abrasive paper and finally polished using an emulsion containing aluminum oxide.

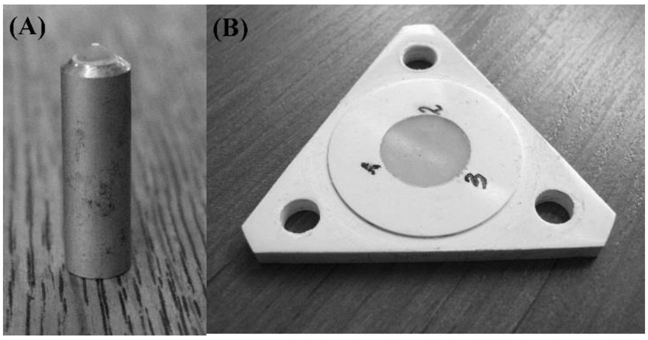

Fig. 1. View of A) countersample, (B) sample

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3. METHODS

The tests were conducted at the Faculty of Mechanical Engineering of the Białystok University of Technology on a specially constructed pin on disc type tribometer designed for studies involving friction in vitro (masticatory simulator) (Fig. 2). The tribometer made it possible to subject the samples to both half-sine cyclic load tests and also reversing movements of the countersample. A detailed description of the device can be found in the authors' another work (Sajewicz and Kulesza, 2007).

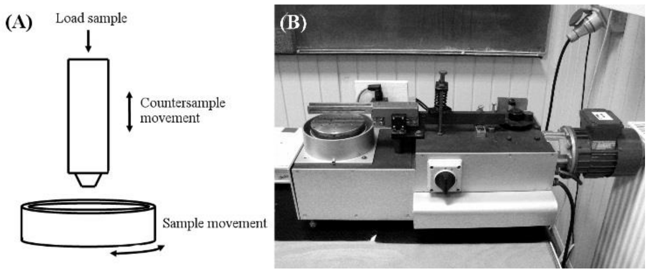

Fig. 2. View of (A) sample and countersample movements, (B) tribometer type of pin on disc

3.1. Evaluation of Wear with Profilografometer

In order to assess the wear rate of the researched material, a special method of measuring the loss in the material was used. The measuring device Surftest SJ-500 (Fig. 3) manufactured by Mitutoyo was mounted on a solid granite basis with a column.

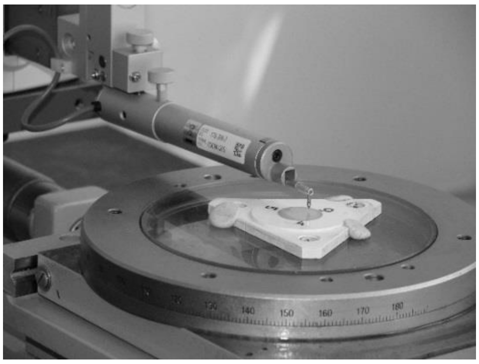

Fig. 3. Profilografometer Surftest SJ-500 Mitutoyo with visible micrometer table and mounted sample of dental material

Surftest SJ-500 is a very high-precision instrument for measuring surface texture. The accompanying software-Formtracepack made it possible to control the device and setup measurements to ensure efficient automation of the measurements. During the tests the needle deflection was measured with respect to the precision drive track. Because the profilographometer's arm moves only in X and Z directions, it was necessary to use additional equipment in the form of a micrometer table, which made it possible to perform a manual shift towards Y. During the measurements the tested material was rigidly mounted on the micrometer table. First a great number of measurements of sample profiles with a step 0.05mm was carried out (Wróblewska, 2014). Due to the fact that the profilographometer performs no automatic operations in the Y-axis, every single record of a profile in Formtracepack program has the Y coordinate equal zero. To avoid profile overlapping and obtain spatial data, it is required to replace zero coordinates on Y axis with the actual manual shift values. Thus the adopted step is added to the Y value in the program's text editor, increasing the value by 0.05 for each subsequent profile. In order to compress data of one wear track (for many profiles) in one file, they were imported into CATIA software using digitized shape editor environment. Next the data were saved in the IGES format. The obtained data in the form of a point cloud were imported into the Rhinoceros program in which the patch operation from the menu was used. The patch, with suitably chosen parameters, was laid over the point cloud so that the created surface did not differ too much from the profiles. Next the file was saved in the IGES format and opened in Solid Works software .Here a base surface was created on the vertices of the imported surface. Then another surface was created, this time by moving it by 0.1mm from the base surface. Next a sketch on the edges of the base area was drawn and base adding operation was performed choosing the direction: to the surface (select the surface imported from tree operation). Then another sketch on the edges of the base area was created using the command of extruded cut in two directions: A – 0.1mm and B – 0.098mm towards the imported surface (the set value should make it possible to see the wear track). The imported surface was covered to see which part was left after cutting out (Fig. 4). Finally the volume of material loss was calculated using the option: measure from the menu.

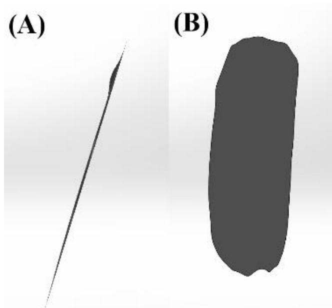

Fig. 4. View of (A) profile of wear trace in the material realized in SolidWorks, (B) top view

3.2. Evaluation of Wear with Confocal Microscopy

The fundamental principles of confocal imaging were patented by Marvin Minsky in 1961. In the confocal microscope the laser light reflects off a dichroic mirror. From there it hits the scanning mirrors and is focused by the lens at one point. The laser beam excites a dye-marked sample, which results in the emission of a longer light wave. Then the light returns along the same path through the scanning and dichroic mirrors hitting a diaphragm with a small hole in it. Finally, the focused beam reaches the detector where it is converted by the analog-to-digital converting device is and analyzed by computer (Cox, 2002). Confocal microscopy compared with conventional optical microscopy has a high resolution and contrast. The light that is excited in the regions lying outside the focus is eliminated by a system of pinholes and is not involved in creating the image. The result is an image containing no components from other than the focal plane. Confocal microscopy makes it possible to reconstruct 3D images and allows us to record images of the sample's thin layers at its different depths. Modern confocal microscopes enable us to analyze the topography of any surface with

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high accuracy. Advanced optical devices are used for the observation of very thin layers of material (with a thickness of 1 μm even) in extremely high resolution and contrast. This is possible by using a laser as a light source. The achievable resolution is getting better generated images (resolution below 35 nm in XY), increasing the sensitivity of the light detection (detection of even single photons), and getting faster to create images of the samples tested (scanning speed of up to several tens of optical sections per second) (Korczyński, 2013) .

In the research microscope OLS 4000 Lext Olympus with 20-fold magnification was used (Fig. 5). The microscope produced topographical 3D images of the investigated surfaces. The samples were placed on the microscope stage, leveled and scanned by a laser beam. As a result, it was possible to obtain the data of the sample's selected area in the form of a spatial topography map of the wear track (Fig. 6). The LEXT software, compatible with the microscope, made it possible to fully analyze the acquired images.

Fig. 5. Confocal microscope Olympus OLS 4000 Lext

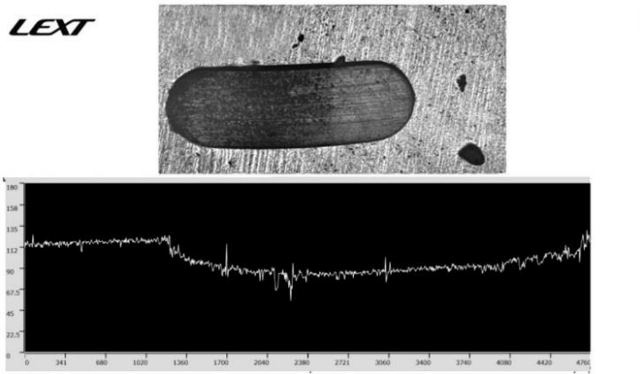

Fig. 6. Program LEXT report of the surface of the sample (visible trace of friction, wear values, longitudinal profile of trace friction)

4. RESULT

Figs. 8 and 9 present the values of volumetric wear of the dental materials subjected to friction in the friction couple composite – enamel. The two methods were used to compare the results obtained for each material. The measurement results are presented in the function of friction work. The data show slight differences in the method of evaluating the wear, as far as the matching of the linear regression model is concerned. There are a number of different diagnostic statistics methods used to assess the matching of the model to experimental data. The most commonly used is the determination coefficient denoted by R^2. Its value, approaching 1, indicates a better matching of the regression curve. The coefficient R^2 is a measure of the quality of matching of the model. It takes values from the range (0, 1). The closer the values come to 1, the better the matching of the model to the data is. The regression curves for the two methods are not identical and indicate higher wear rates obtained using the profilographometer.

As can be seen by comparing the curves, there is a much better matching of the regression curve for the measurements of wear rates for FFE material using confocal microscopy rather than the profilographometer. The determination coefficient assumes a value of 0.894, and is higher by 0.194 than that of the profilographometer. However, in the case of ES, these differences disappear so it is hard to say which of the two methods offers greater effectiveness (R^2 coefficient for profilographometer measurements is equal to 0.832 and for the confocal microscope 0.815).

In addition, the values of Pearson correlation coefficient r (Tab. 1) were calculated. The correlation analysis is used to test if there is a relation between two variables thus providing information on the strength and direction of the relation and whether the result is statistically significant. The correlation coefficient always takes values in the range (-1,1). The higher the absolute value of the coefficient, the higher the linear relation exists between the variables. In our case the sign of correlation coefficient is positive, which means that the relation between the variables is positive, i.e. if the wear increases, the value of the work done also increases. The values of the r coefficients confirmed the presence of a strong positive correlation between the specific wear energy and the value of wear for the ES and FFE materials using different measurement methods. According to A. Stanisz (2006), wear measurements for ES using confocal microscope and for ES using profilographometer and also for FFE using confocal microscope for $r \geq 0.9$ there is almost a complete correlation, while for FFE using profilographometer (for $r < 0.7, 0.9$) the correlation is very high.

Tab. 1. Values of coefficient of Pearson correlation r (p – significance level, N - importants)

Methods	r	p	Valid n
ES - confocal microscope	0.903	0.907	13
ES - profilographometer	0.9123	0.907	13
FFE - confocal microscope	0.9456	0.265	11
FFE - profilographometer	0.8367	0.265	11

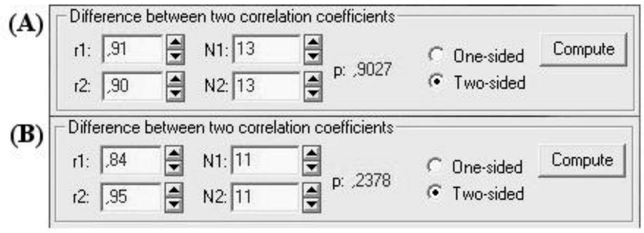

Fig. 7. Window with the results of the test for two correlation coefficients: A) ES ; B) FFE

Moreover, a test was performed to compare the statistical significance of differences between two Pearson correlation coefficients for each material (Fig. 7). Significance level p for ES was equal to 0.90 and for FFE $p = 0.24$, which confirms the previous

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statistical interpretations that the correlation coefficients for the two methods used for both ES and FFE materials are the same. Thus, there are no significant differences in the wear values measured with the use of either confocal microscopy or the profilographometer.

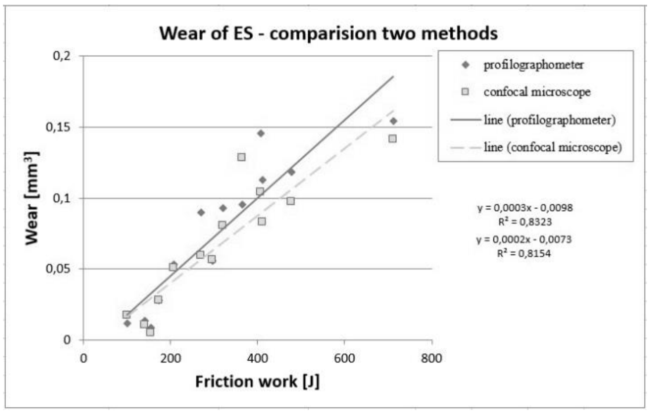

Fig. 8. Wear of ES materials in contact with the enamel in the function of friction work for two measuring methods

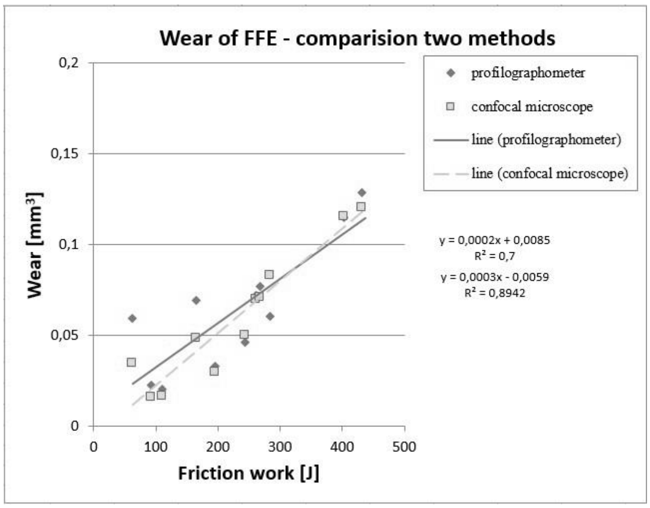

Fig. 9. Wear of FFE materials in contact with the enamel in the function of friction work for two measuring methods

In the research values of specific wear energy were calculated for each measurement (Sajewicz, 2007). Their averages are presented in Tab. 2. As the wear values of the investigated composites calculated with the prifilogrphometer were higher than those obtained with the use of the confocal microscope, specific wear energy, which is essential in the study of wear intensity of dental materials, assumed smaller values for the profilographometer measurements.

The paper also provides data concerning the standard deviation, which determines the degree of dispersion of results around the specific work energy. As can be seen in Table 2 the standard deviation for the FEE composite calculated with either method, i.e. confocal microscopy or the profilographometer is practically identical and amounts to 1409 and 1498 respectively. In the case of the ES material the standard deviation is twice the value for the microscopic measurements than profilographometer measurements, and amounts approx. to 8.000. This indicates that individual results obtained by confocal microscopy are farther from the average making them less typical. Thus, more accurate result are obtained for wear measurments in the case of the FFE material.

Tab 2. Average values of specific wear energy of tested composite materials and standard deviations

Materials	Specific wear energy (J/mm^3); average values, standard deviations		
Estelite Sigma	Confocal microscope	7 491.365	8 015.584
	Profilographometer	6 006.887	4 331.477
FulFil Extra	Confocal microscope	4 264.377	1 498.094
	Profilographometer	3 890.394	1 408.803

For a more detailed comparative analysis of the two methods STATISTICA computer program was employed. Using the option of descriptive statistics, an average value of volume wear, standard deviation as well as standard error were calculated (Tab. 3). Higher measurement values using the profilographometer were observed, i.e.: for ES the average values are higher by 0.009mm^3, and for FFE by 0.0043mm^3. The standard deviation shows higher values for ES measurements. The standard error specifying the degree of accuracy with which the value of the arithmetic mean is determined, appears to be roughly the same for all measurements, yielding the highest values for ES materials. (confocal microscopy – 0.0123, profilographometer – 0.014). A smaller standard error for FFE proves better predictability of the measurement.

Tab. 3. Sheet results for descriptive statistics

Variable	Descriptive statistics			
	Valid n	Mean	Std. dev.	Std. error
ES confocal microscope	13	13	0.0663	0.0442
ES profilographometer	13	13	0.0754	0.0507
FFE confocal microscope	11	11	0.0597	0.0362
FFE profilographometer	11	11	0.0640	0.0346

In order to provide a more detailed comparative analysis of the two wear measurement methods a non-parametric Mann-Whitney U test available in STATISTICA was used (Tab. 5). The immediate reason for carrying out the comparison were some observations of the results. Namely it was observed the data scatter diagram from experiment for ES and FFE material (Fig. 8-9) strongly deviates from the normal distribution (i.e. the assumption of t-test is not fulfilled), which may indicate a lack of significant difference in arithmetic averages. So in this case, zero hypothesis assumes that the tested groups come from the same population, i.e. data distributions of the analyzed groups do not differ significantly.

Tab. 4 above provides in the header the adopted probability level of the test. The results are significant for $p < 0.05$. As shown in Tab. 4 p-value for ES material is high ($p = 0.343$), and, as a result, on this significance level, there is no good reason for rejecting the output (zero) hypothesis on equal impact of the two methods on the results. The results of the analysis ($p = 0.343$) lead to the conclusion that the research methods have a statistically insignificant effect on the value of the volumetric wear of the tested composites.

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Tab. 4. Sheet results for Mann-Whitney U test for the data of experiments using material ES anf FFE

Variable	Mann-Whitney U test by variable method Marked tests are significant at $p < 0.05$ Methods: I – confocal microscope, II – profolographometer				
	Rank sum I	Rank sum II	p	Valid n I	Valid n II
ES	194	157	0,3428	13	13
FFE	134	119	0,6224	11	11

For the FFE composite the Mann-Whitney U test indicates the significance levelequal to 0.622 (Tab. 4), and also $p > 0.05$. So there is no justification to reject the hypothesis that the observed difference is accidental.

5. SUMMARY AND CONCLUSIONS

Evaluation of the wear of dental materials is crucial in view of their wear resistance in contact with tooth enamel. Susceptibility to wear determines the quality of dental materials and hence their cautious choice for permanent dental fillings determines the success of damaged tooth reconstruction. Because the wear values of tooth enamel exposed to friction are very small, of the order 10^{-2} (Sajewicz, 2007; Wojda et al., 2015), selection of an appropriate measurement method is extremely important for obtaining accurate and reliable results. In the present study two measurement methods assessing the loss of dental materials, i.e. confocal microscopy and profilographometer are analyzed. The statistical analysis of the results has clearly shown that the two methods do not show any significant differences as far as measurement accuracy is concerned. Hence both methods can be used interchangeably for the measurement of volumetric wear of dental materials. Guidelines for choosing of a specific method are certain advantages in the way of its application, namely availability of required equipment, graphics programs, the time needed for measurements, ease of taking measurements and use of software compatible with the measurement device.

In view of the research conducted by the author, it was the confocal microscopy method that proved to be easier and faster. The procedure requires placing the analyzed sample on the microscope stage and subjecting it to laser beam scanning. The data are automatically entered into the compatible software. At this stage, determining the value of wear requires uncomplicated knowledge of the program and it only a matter of minutes to obtain the needed data for further analysis. Unlike confocal microscopy, the profilographometer method requires a time-consuming measurements of investigated surface profiles involving manual-shift of the micrometer table and laborious further processing with the use of such computer tools as Catia, Rhinoceros or SolidWorks.

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