STRUCTURAL PROPERTIES OF THE FRICTION COUPLE, DENTAL MILLING CUTTER-DENTAL MATERIAL, BEFORE THE WORK PROCESS

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Modeling of the wear phenomenon at dental milling cutters based on the experimental results involves the materials characteristics knowledge in contact for friction couple, dental milling cutter-dental material, in the working process. Analyzes are needed of the materials, because wear process depends both on the dental milling cutter material, but also on processed dental material, respectively the parameters of the working process (speed rotational, pressing force, feed, position etc.). The aim of the paper is knowledge the crystalline structure and of mechanical properties of the materials couple dental milling cutter-dental material, by specific analyzes, with important implications on wear behavior.

Keywords: Dental milling cutter, Crystalline structure, Material properties, Hardness

1. Introduction

The phenomenon of removing dental material with the help of dental milling cutters is a complex phenomenon, like rubbing and wearing materials or even the fine process of cutting milling materials [1-3].

All these phenomena can be statistically-mathematically modeled starting from experimental results obtained in complex and very expensive research. Many experimental data and parameters involved in the process directly influence the accuracy and stability of the model.

Advanced research on dental milling cutters continues to be carried out [4] through complex experimental studies. In ref. [5] are presented interesting results based on the experiments, regarding the working process of dental milling cutters.

The experimental results are values of some parameters from the contact areas, between the cutting tool and the material, regarding their wear, even if not is the active area of a dental milling cutter.

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A systemic image of contact of the dental milling cutters - dental material helps to inventory the process parameters, as a result, and of control this process.

As input parameters of the process can be listed:

- the parameters of the material from which the active part of the dental milling cutter is built: hardness, plasticization limit stresses/tensions (if any), breaking, thermomechanical characteristics, chemical composition, parameters that define the geometry of the cutting edges;

- parameters of the milled material: hardness, breaking stresses/tensions, chemical composition, and other thermomechanical characteristics;

- operating parameters (control parameters): rotational speed and the pressing force of the dental milling cutter on the dental material, contact time, temperature, or the life cycle of the dental milling cutter.

The working process of dental milling cutters being a complex one, many of the basic parameters of the process could be established and quantified only after the mathematical modeling of the phenomenon [6, 7].

The complexity of the work process in the dentistry field, as well as the parameters and factors that act on the process, imposed the approach of experimental research by integrating interdisciplinary fields, based on the following:

a) solving some complex problems encountered in the field of dentistry, before the work process of dental milling cutters, by:

• metallographic and chemical analysis of the dental milling cutters materials;

• determination of the mechanical properties of the active part of the dental cutters;

b) establishing the types of dental material to be processed with the dental milling cutters during experiments, by:

• determination of chemical composition;

• determination of mechanical properties;

• determination of the initial mass;

• establishing the optimal operating conditions (with friction and wear, minimum) in order to make the right choice of dental materials and dental milling cutters;

It is necessary for experiments, regarding the wear behavior of dental milling cutters, to be preceded by metallographic [8, 9] and chemical analyzes [10], but also by mechanical analyzes [11, 12] of the materials used because the wear is a process that depends not only on the material of the dental cutter, but in the same measure, and the processed dental material, as well as the parameters of the working process (rotational speed, pressing force, feed, position, etc.). Therefore, the paper presents analyses (metallographic, chemical, but also mechanical), of the materials of the dental milling cutter couple - dental material before experimental testing at wear to obtain the experiments data necessary for statistical-mathematical modeling of the wear phenomenon. These analyzes are made in order that after modeling there is a possibility to prolong the life of the dental milling cutters, respectively to optimize their operation.

2. Materials and methods

For the research and experimental determinations, a cylindrical-conical dental milling cutter was used [13], shown in Fig. 1 and made of tungsten, having a medium granulation on the active side used for processing Co-Cr alloys, other metals, semi-precious and precious metals, with blue ring for identification (see Fig. 1). This type of dental milling cutter works at speeds up to 35.000 rpm.

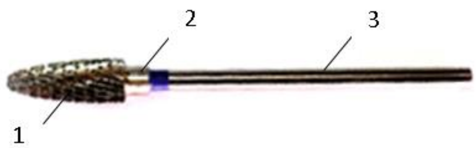


Fig. 1 Cylindrical-conical dental milling cutter:
1 - the active part of the dental milling cutter, 2 – milling cutter neck, 3 – milling cutter leg

To perform the metallographic, chemical, and mechanical analyzes, the sampling, and preparation of the samples were performed first [14]. The metallographic analysis was made at the macro-microscopic level on samples taken from dental cutters of the type shown in Fig. 1, using an Olympus metallographic microscope equipped with camera and image processing software Stream Essentials (Olympus NTD Inc., USA). For this, dental milling cutters samples were sectioned, using a 76 x 1.0 x 10 mm Bosch Multi Wheel cutting machine with disc and Labotom-5 manual actuation from Struers Inc., USA.

To be studied and handled easily at the microscope and subsequently to be subjected to a hardness test, the samples from the active part of the sectioned dental cutters being small were fixed and then embedded in a resin matrix with a hardener, mixed in a special bowl Struers - Denmark. Because, during embedding, a thin film of resin was deposited over the material-sample area from the analyzed dental milling cutters (Fig. 2), it was necessary to remove the resin film (Fig. 3), in order to perform the micro-macroscopic analysis in good conditions. The resin film was removed by sanding with the help of an automatic sanding and polishing machine - Tegramin 25, from Struers Inc., USA.

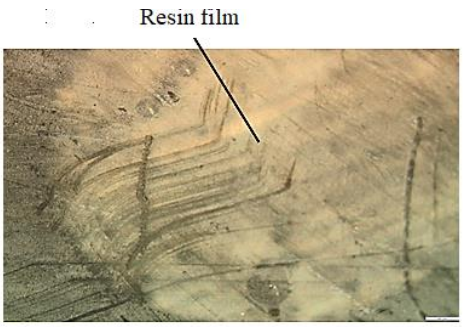


Fig. 2 Resin film over the analysis area of the dental milling cutter

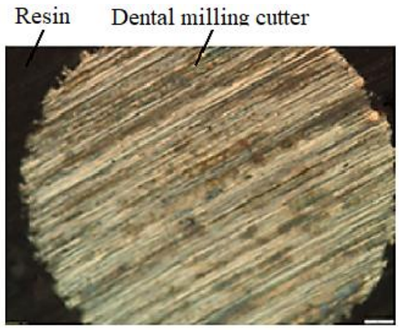


Fig. 3 Removing the resin layer

Then, proceeded to sand and polishing the metallic-sample material from the dental milling cutter, and this operation was performed, also with the Tegramin 25 sanding and polishing machine, using the predefined program from the machine's database. The metallographic attack is the final stage of the preparation of the samples for the metallographic analysis and has the role of highlighting the crystalline structure [14, 15]. The polished surface is washed with water, dried, and then attacked with reagents that dissolve or color the components to make them stand out.

A chemical X-ray fluorescence (XRF) spectrometer (Olympus NTD Inc. USA), which is a portable energy dispersion spectrometer, was used for the chemical analysis of the active part of the dental milling cutter. The XRF spectrometer determines the elemental composition of a material, identifies the components of a substance, and quantifies the amount of elements present [16].

Finally, an Innovatest type hard meter (Ireland) was used to measure Vickers micro hardness, with the possibility of converting into Brinell, Rockwell units, respectively into breaking strength units. For research were registered Vickers HV hardness and breaking strength R_m (σ_r), in MPa, at compression stress/tension.

3. Results and discussions

For the experimental tests were considered two dental cutters of the same type (cylindrical-conical, marked with F1 and F2), having the same characteristics, used in dentistry, with the same dimensions and the same shape (see Fig. 1). For the microscopic analysis of the active part of the dental milling cutter, samples were sectioned from the two dental milling cutters, F1 and F2, after the plans xOy (through the foot of the milling cutters) and x'O'y '(through the active part of the dental cutters), Fig. 4. The samples taken are cylindrical (Fig. 4), with the diameter of the active part 4.2 mm, respectively the diameter of the foot 2.2 mm of the dental milling cutters in the sectioning planes (x’O’y’ and xOy) and presented in Fig. 5.

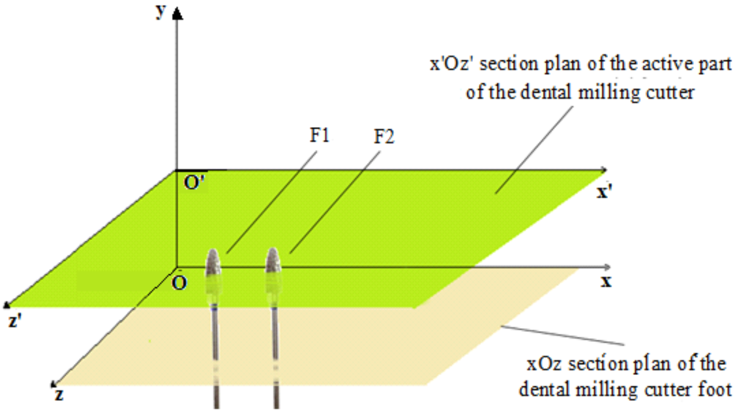


Fig. 4 Dental milling cutters studied

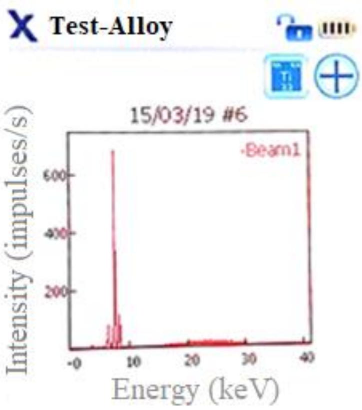
Fig. 5 Final sectioning of the F1 sample

These dimensions are relative, for the active part of the dental milling cutters and depend on the chosen section planes, the thickness/length and the type of the sample, while for the foot of the dental milling cutters they are the same, resulting the samples to be analyzed under a microscope and with the spectrometer X-ray fluorescence (XRF).

The analysis at microscope and XRF was done after material sanding and polishing, the metallic-sample from the dental milling cutter, with the Tegramin 25 machine, using the predefined program from the machine's database. For the choice of the program, it was taken into account that the milling cutters are made of tungsten, having a medium granulation on the active side, so in the chemical composition of the milling cutter there are tungsten metal carbides, respectively chromium, according with Fig. 6 a.

Element	%	+/-
W	58.14	0.41
Fe	19.07	0.31
Cr	6.52	0.26
Mn	6.17	0.22
Co	4.55	0.16
Cu	3.17	0.12
Zn	2.04	0.13
Ni	0.34	0.08

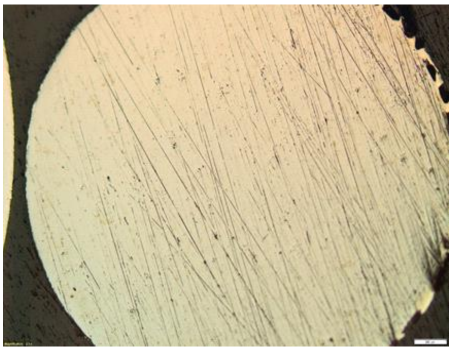
a)



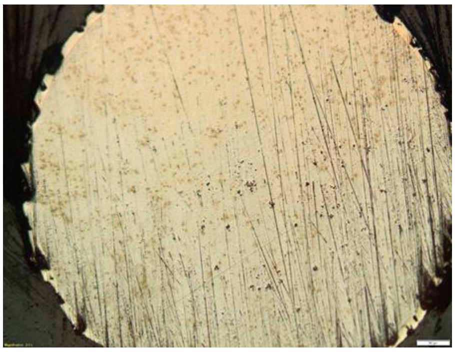
b)

Fig. 6 Chemical composition using XRF (a) and X-ray fluorescence energy spectrum used to determine composition (b)

The energy spectrum of the X-ray fluorescence is also presented (Fig. 6 b), because an element is defined by the characteristic wavelength of the emitted X-rays, or of energy (*keV*). The amount of an element present in the substance is determined by measuring the intensity of the diffraction line (*impulses/sec*), characteristic. In a first step, a macroscopic analysis of the polished samples was performed, Fig. 7 a, and b, and thus a series of information was obtained regarding the appearance of the polished surface of the samples from the dental milling cutters F1 and F2. From the macroscopic analysis it was found that on the surface of the sample material there are a series of very small inclusions determined by the presence in the structure of some Fe carbides (Fe_3C), but also by the presence of copper.



a



b

Fig. 7 Appearance of the polished surface: a - sample from F1 and b - sample from F2

The Fe_3C inclusions, observed and shown at an enlarged scale are visible in the images in Fig. 8 - the sample from F1, and Fig. 9 - the sample from F2, respectively in Fig. 10, and the copper inclusions can be seen in the enlarged microstructure and shown in Fig. 11.

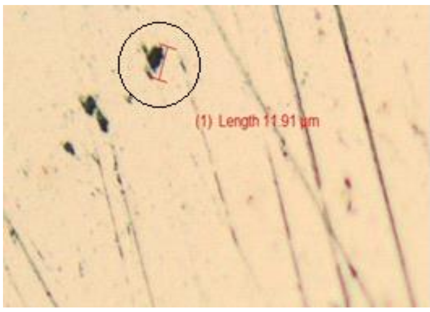


Fig. 8 Inclusions (Fe3C) - sample from F1

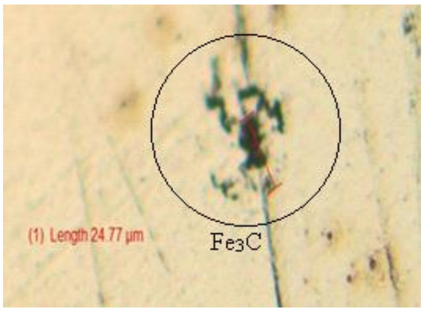


Fig. 9 Inclusions (Fe3C) - sample from F2

All these images were captured using an Olympus metallographic microscope equipped with a camera and Stream Essentials image processing software (Olympus NTD Inc. USA).

Finally, the metallographic attack was necessary to highlight the crystalline structure. The polished surface is washed with water, dried and then attacked with reagents that dissolve or color the constituents to make them stand out. Given the fact that the nature of the material was not known, it was resorted to attacking the samples with Nital 2%. The microstructures of Fig. 10 - the sample from F1 and Fig. 11 - sample from F2 (magnification scale 500x).

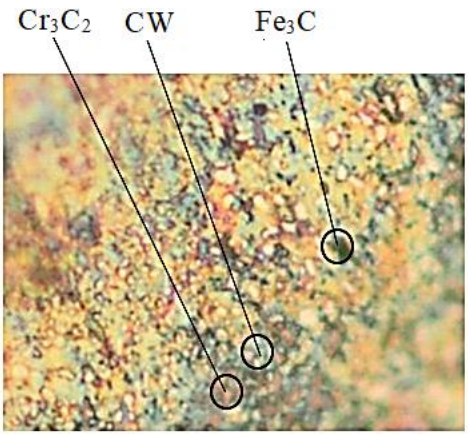


Fig. 10 F1 sample microstructure (500X)

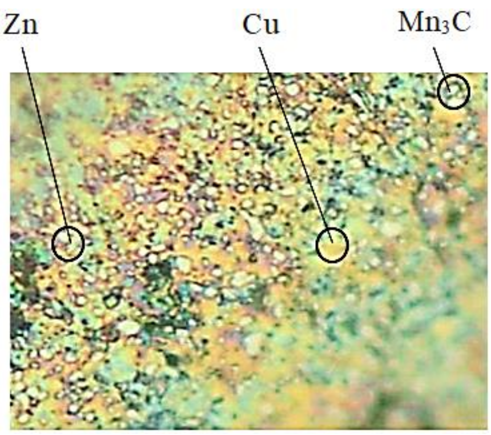


Fig. 11 F2 sample microstructure (500X)

To make a proper analysis of the microstructure of the sample-materials from the dental milling cutters F1 and F2, it was necessary, in addition, to know their chemical composition. Thus, following the chemical analysis, it was found that the sample-material is a mixture of carbides of W, Cr, Mn, Fe, and in order to obtain it by sintering, a series of other metallic elements Cu, Zn, Co were added, which have the role of gluing metal carbides particles. From the analysis of the microstructures shown in Fig. 10 and 11 it was found that there were large amounts of carbides. Regarding the microstructure of Fig. 11 larger areas of Zn (gray-bluish color) are observed. This can be explained by the fact that in the microscopically analyzed area there may be separate Zn that did not form compounds together with Cu, such as brass or bronze. Also for the chemical analysis of the active part of the dental milling cutters studied, X-ray fluorescence (XRF) analysis was used because it determines the elementary composition of the sample material, identifies the components and quantifies the amount of elements present, in the analyzed material.

For a complete analysis, Vickers micro-hardness was also measured with the Innovatest hardness meter (Ireland). For the research in question, the Vickers *HV* hardness and the breaking strength R_m (σ_r), in MPa, at compression stress/tension was important to remember. Three measurements were made on both samples from dental milling cutters in two areas: in the middle of the cross section and at its edge, very close to the cutting edge of the cutter. The obtained results are centralized in Table 1. The pressing force was 5 N, and the maintaining time of the penetrator was 10 seconds.

Table 1

Vickers hardness and breaking strength forcompression request

Measuring area	*HV*	Middle *HV* (MPa)	R_m (MPa)	Middle R_m (MPa)
Middle	292.3	291.96	939.2	937.7
	293.4		943.4	
	290.2		930.5	
Margin	378.8	375.9	1216.4	1207.73
	370.5		1191.6	
	378.4		1215.2	

It is observed that both Vickers hardness values, as well as the breaking strength, are larger in the marginal area and smaller in the middle (see Table 1).

The graphical presentation of the variation of Vickers hardness and breaking strength for compressive stress/tension is given in Fig. 12, where it is observed that for the same area the variation is very close (it can be considered approximately linear, both for Vickers hardness and for breaking strength), followed by a relatively small jump for hardness but higher for breaking strength, when moving from the middle to the edge.

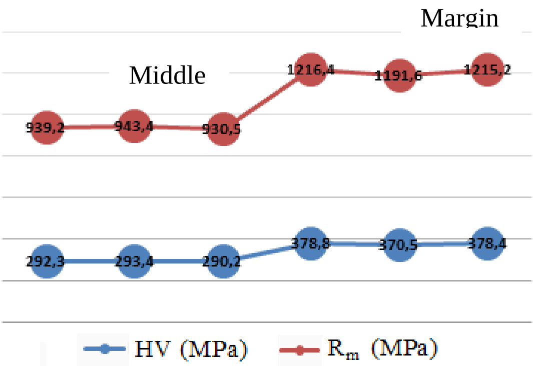


Fig. 12 Variation of Vickers hardness and breaking strength for compressive stress/tension

Higher breaking strength when switching from the middle to the edge is desirable, because it gives the dental milling cutter a good tribological behavior (a minimal friction and wear), so an extension of the life span. Also, we can say that the lower values in the middle ensure a tenacity of the dental milling cutter.

6. Conclusions

Some complex problems encountered in the dentistry field were solved by metallographic and chemical analysis of the material of the dental milling cutters tested and of the dental material (Ni-Cr alloy) processed during the experiments, respectively the determination of the mechanical properties, of the active part of the dental milling cutters investigated. From the metallographic analysis of the material of the dental milling cutter, no material gaps were found following the sanding/polishing process, even if in the material oxides were found as inclusions, but of very small dimensions, determined by the presence in the structure of some Fe carbides (Fe_3C), but also by the presence of copper.

XPF analysis was also required to determine the elemental composition of the sample material, to identify the component elements and to quantify the amount of elements present in the analyzed material. Then, from the spectrophotometric analysis with the X-ray analyzer it was found the presence of a large number of chemical elements (W, Fe, Cr, Ni, Co, Mn, Cu, Zn) in the composition of the material of dental cutters.

To highlight the crystalline structure, the metallographic attack was used with Ni 2%, because the nature of the material was not known. It was noticed a fine granular structure of the material of the dental milling cutters researched. For a complete analysis, the Vickers micro-hardness, *HV* and the breaking strength R_m (σ_r), at the compression stress/tension, were also measured. The samples of material taken from the two categories of dental cutters studied have increased hardness values (over 280 HV) and a very high resistance to compression stress/tension (over 900 MPa), the hardness increasing to the marginal area of the active part of the cutters by about 28.70%.

It was observed that, both Vickers hardness values, and the breaking strength are higher in the marginal area and lower in the middle, with the specification that the breaking strength is higher when switching from the middle to the edge area. This is desirable, because it gives the dental milling cutter a good tribological behavior (minimal friction and wear), so an extension of the life span, and the lower values in the middle ensure a tenacity of the dental milling cutter.

R E F E R E N C E S

[1]. *Chetan, A. Narasimhulu, S. Ghosh and V. R Parchuri*, Study of Tool Wear Mechanisms and Mathematical Modeling of Flank Wear During Machining of Ti Alloy (Ti6AI4V), Journal of Institution of Engineers (India): Series C, **vol. 96**(3), 2014, doi: 10.1007/s40032-014-0162-9.

[2]. *S.Chinchanikar and S-K.Choudhury*, Characteristic of wear, force and their inter-relationship: In-process monitoring of tool within different phases of the tool life, Procedia Materials Science, **vol. 5**, 2014, pp.1424-1433, doi.org/10.1016/j.mspro.2014.07.461.

[3. *J. Taylor*, The tool wear-time relationship in metal cutting, International Journal of Machine Tool Design and Research, **vol. 2,** Issue 2, 1962, pp.119-152.

[4]. *R. Yin, Y-S Jang, M-H Lee and T-S Bae*, Comparative Evaluation of Mechanical Properties and Wear Ability of Five CAD/CAM Dental Bloks, Materials (Basel), **vol. 12**(14), 2019: 2252, doi:10.3390/ma12142252.

[5]. *J-A. Arsecularatne, N-R Chung and M. Hoffman,* An in vitro study of the wear behaviour of dental composites, Biosurface and Biotribology, **vol. 2**(3), 2016, pp.102-113, doi: 10.1016/j.bsbt.2016.09.002.

[6]. *I. Okokpujie, O-M Ikumapayi, U-C Okonkwo, E-Y Salawu, S-A Afolalu, J-O Dirisu,O-N Nwoke and O-O Ajayi*, Experimental and Mathematical Modeling for Prediction of Tool Wear on the Machining of Aluminium 6061 Alloy by High Speed Steel Tools, Open Engineering, **vol. 18**, 2018, pp. 1196-1203, doi.org/10.1016/j.dib.2018.04.003

[7]. *N. Qehaja and F. Abdullahu*, Mathematical Modelling of the Influence of Cutting Parameters and Tool Geometry on Surface Roughness During Drilling Process, Scientific Proceedings XIV International Congress "Machines. Technologies. Materials.", 2017.

[8]. *E. Akca and E. Trgo*, Metallographic Procedures and Analysis – A review, Periodicals of Engineering and Natural Sciences, **vol. 3**, no. 2 (2015). 3(2):9-11, doi:10.21533/pen.v3i2.51.

[9] Pace Technologies Educational Web page at http://www.metallographic.com/Basics.htm.

[10]. *E. Akca and A. Gursel,* “A review on superalloys and IN718 Nickel-based INCONEL superalloy,” Periodicals of Engineering and Natural Sciences, **vol. 3**(1), 2015, pp. 15-27, doi: 10.21533/pen.v3i1.43.

. [11]. *E. Akca, and A. Gursel*, “The Effect of Diffusion Welding Parameters on Mechanical Test Results of Titanium Alloy and Aluminum Couples,” 4th International Conference on welding technologies and exhibition, **vol. 4**, 2016, pp. 21-33.

[12]. *P. Pedrosa, P. P. R. Filho, T. S. Cavalcante, S. Cavalcante, V. Hugo, V.H.C. Albuquerque, J. M. R. S. Tavares and P. João,* Brinell and Vickers Hardness Measurement Using Image Processing and Analysis Techniques, Journal o, Testing and Evaluation, **vol. 38**(1), 2020, doi: 10.1520/JTE102220.

[13]. https://www.dentotal.ro/.

[14]. *K. Geels*, “Metallographic and Materialographic Specimen Preparation, Light Microscopy, Image Analysis and Hardness Testing,” ASTM International, 2006.

[15. *G.F. Vander Voort*, “Metallography: Principles and Practice,” ASM International, Materials Park, OH, 1999.

[16]. *M. T. Chang, P. Suraneni, O. B.Isgor, D. Trejo and W. J. Weiss,* Using X-ray fluorescence to assess the chemical composition and resistivity of simulated cementitious pore solutions, Int J Adv Eng Sci Appl Math, **vol. 9**, 2017, pp. 136–143, doi: 10.1007/s12572-017-0181-x.