physics. These ratios may become a foundation for creation of supersensitive amplifiers of signals using inherent noises of amplifying elements, and also of photodetectors, discrete antenna arrays. Stochastic amplification naturally underlies analysis techniques on quality of working layers for magnetic and optical data carriers and reduction of damaged data on them. It can be widely used in medicine, for example, in analysis of electrocardiograms, electroencephalograms, organism noises and in other spheres.

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BEARING SURFACES WITH SAPPHIRE FOR TOTAL HIP-JOINT REPLACEMENT

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Abstract. *The results of friction tests and the wear behavior of rubbing couples sapphire against sapphire or tetragonal dioxide of zirconium are shown in this paper. Tribological characteristics of tetragonal dioxide of zirconium (Y, Ce, Hf)-TZP in pair with a counter body from sapphire are essentially better than characteristics of the couple sapphire/sapphire (friction force is 1,3 times lower and the linear wear reduces 1,5 times).*
Keywords: *Endoprostheses of joints, bearing surfaces, ceramics, sapphire, coefficient of friction, wear.*

Introduction

For nowadays in total hip-joint replacement the group of materials is mainly determined for the bearing surfaces with minimally possible amount of the worn products at interface. Such couples of bearing surfaces with excellent wear behavior are friction couples ceramics-ceramics, metal-metal as well as highly cross-linked polyethylene (XLPE) in combination with ceramics or metal [1]. The main unsolved problem in the last decade was elaboration of bearing surfaces that could support higher loads required for young and active people. Due to their encouraging wear behavior ceramic matrix (82% of aluminum oxide, 17% of zirconium dioxide, 0.3% chrome oxide), zirconium dioxide and ceramics in couple with cobalt-chrome alloy are the surfaces that investigated in the laboratory conditions [2-3].

In addition to that the sapphire that is mono-crystal of aluminum oxide, as the material for bearing surfaces has unique properties due to its inertness, including electrolyte passivity, probably the best bio-compatibility among the well-known materials, corrosion resistance and high hardness. Stability of sapphire towards any acids and alkali is incommensurably higher than metals and even aluminum polycrystalline oxide have. Probably, that's why sapphire does not change the immune status of the patient. If for metals and polycrystalline materials used for bearing surfaces uneven wear rate of micro-surfaces leads to the increased coefficient of friction at interface and to elevated wear, then this effect is absent with sapphire.

The results of friction tests and wear behavior of friction couples sapphire against sapphire, sapphire in pair with tetragonal dioxide of zirconium is presented in this paper.

Materials

Tribological tests of biocompatible materials for sliding couple are one of criteria for materials selection for bearing surfaces of prostheses for human hip-joint. With this purpose friction and resistance to wear have been studied for:

– Sapphire with various density of a crystalline lattice in a plane of sliding, in particular the planes 0001, 1010 and 1018;

– Tetragonal dioxide of zirconium that contains 97 molecular % of ZrO_2 and 3 mol % of Y_2O_3 (3Y-TZP) which is widely used for the hip-joint heads;

– Tetragonal dioxide of zirconium with 99% content of nano-sized grains of ZrO_2, Y_2O_3, CeO_2 and HfO_2 ((Y,Ce,Hf)-TZP), therewith the percentage of Y_2O_3 varies from 4,5 to 5,4 %, CeO_2 – 3,0 %, HfO_2 – no more than 2 %.

Some physical and mechanical properties of investigated materials are shown in Table 1.

Table 1

Properties of biocompatible materials

Characteristics	Sapphire	3Y-TZP	(Y,Ce,Hf)-TZP
Flexural strength	>400 MPa	>800 MPa	850 MPa
Fracture toughness, K_{1C}	3.5 $MPa \cdot m^{-1/2}$	>7–9 $MPa \cdot m^{-1/2}$	8–11 $MPa \cdot m^{-1/2}$
Young's modulus	400 GPa	200 GPa	209 GPa
Content of tetragonal phase	–	>98 %	100 %
Density	3.99 g/cm^3	6.01–6.02 g/cm^3	6.03–6.05 g/cm^3
Total porosity	0	0	0
Open porosity	0	0	0
Hardness	19.4–22 GPa	10–12 GPa	10–12 GPa
Content of Y_2O_3	–	3 %	3 %
Autoclave treatment	–	Possible	

Methods of friction and wear tests

Tribological tests of the materials in sliding couple have been carried out under the rotational friction with contact geometry of type ball-on-disc. The plane disc have made from the material to be studied, a ball – of a material of counter body (Fig. 1).

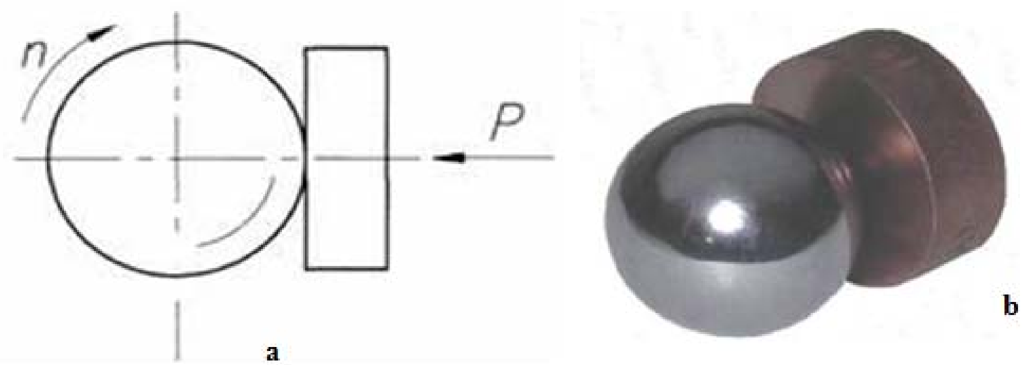
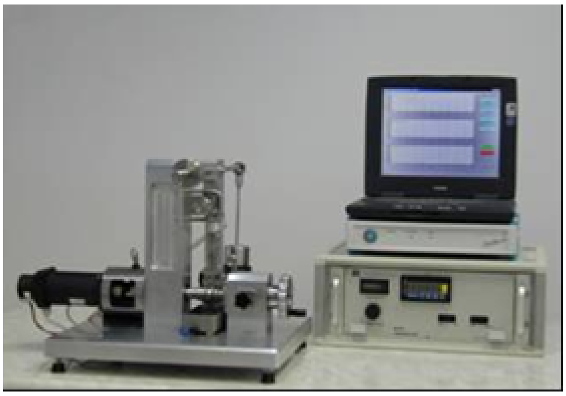


Fig. 1. The layout of rotational friction – a, and the example of counter bodies-b

Tribological tests were conducted on T-20 device of "ball-on-disk" type tribo-system (Fig.2). The tribo-system consists of immovable flat disk of the tested material and ball of the counter body material rotating with the specified speed n. The disk is pressed to the ball with a definite load P. During the tests the friction force and the linear wear of the disk have been measured. The process temperature was not fixed but it was kept constant. The lubricant was fed by means of drop on the surface of the rotating ball. The lubricant composition (Ringer's solution) is shown in Table 2.



Test Condition:

Normal load	10 N
Frequency of movement	1 cycle /sec
Lubricant	Ringer's solution
Number of cycles	1×10^6 cycles
Test temperature	37 °C
Interval of data logging	5×10^4 cycles

Fig. 2. General view of T-20 tester

Table 2

Composition of used Ringer's solution

No.	Component of solution	Concentration [g/l]
1.	NaCl	0,75
2.	$CaCl_2$	0,125
3.	KCl	0,0075
4.	$NaHCO_3$	0,0125
pH=7,0		

Results of tests

The obtained dependences of friction force for the couples sapphire-sapphire and sapphire-ruby against the time of testing (amount of cycles) have mainly un-monotone spasmodic character (see Figs.3-4). Three stages of wear can be seen, namely:

– running-in wear – creation of work roughness and necessary back-up surface on friction surfaces. At the beginning of tests the contact of bodies happens at the point where the specific load is sufficiently high that leads to the abrupt growth of the friction force and as a result the wear of the material is speedy.

– normal wear – after achievement of the wear land of surfaces at which the optimal values of bearing surface are reached and a stable friction process of bodies with gradual reduction of the friction force have place.

– catastrophic wear – in the friction process of counter bodies the worn products gradually fill the pockets at interface and due to a weak (drop) feeding of Ringer's solution into the friction area the wear products are accumulated filling the whole free spaces of the pockets and consequently acting as a free abrasive in the process of wear of the surfaces under the test.

As it is seen from Fig.3-4 the above-mentioned stages of wear can have different extent in time or not attend the wear process generally. The characteristic example of presence of all three stages of wear of the investigated materials is Fig.5. On the rest layouts the change of the friction force includes one (first) or any two stages of the wear process. Thus, with great probability can be confirmed that for achievement the catastrophic wear a considerably bigger amount of cycles that is foreseen by tribological tests will be necessary.

From the curves in Fig.5 it follows that the best results in relation to the friction force towards the loading force shows the friction couple sapphire-sapphire with orientation of the crystalline lattice on plane 0001, linear wear – of friction couple of sapphire-sapphire with orientation of crystalline lattice on plane 0001 and sapphire-ruby.

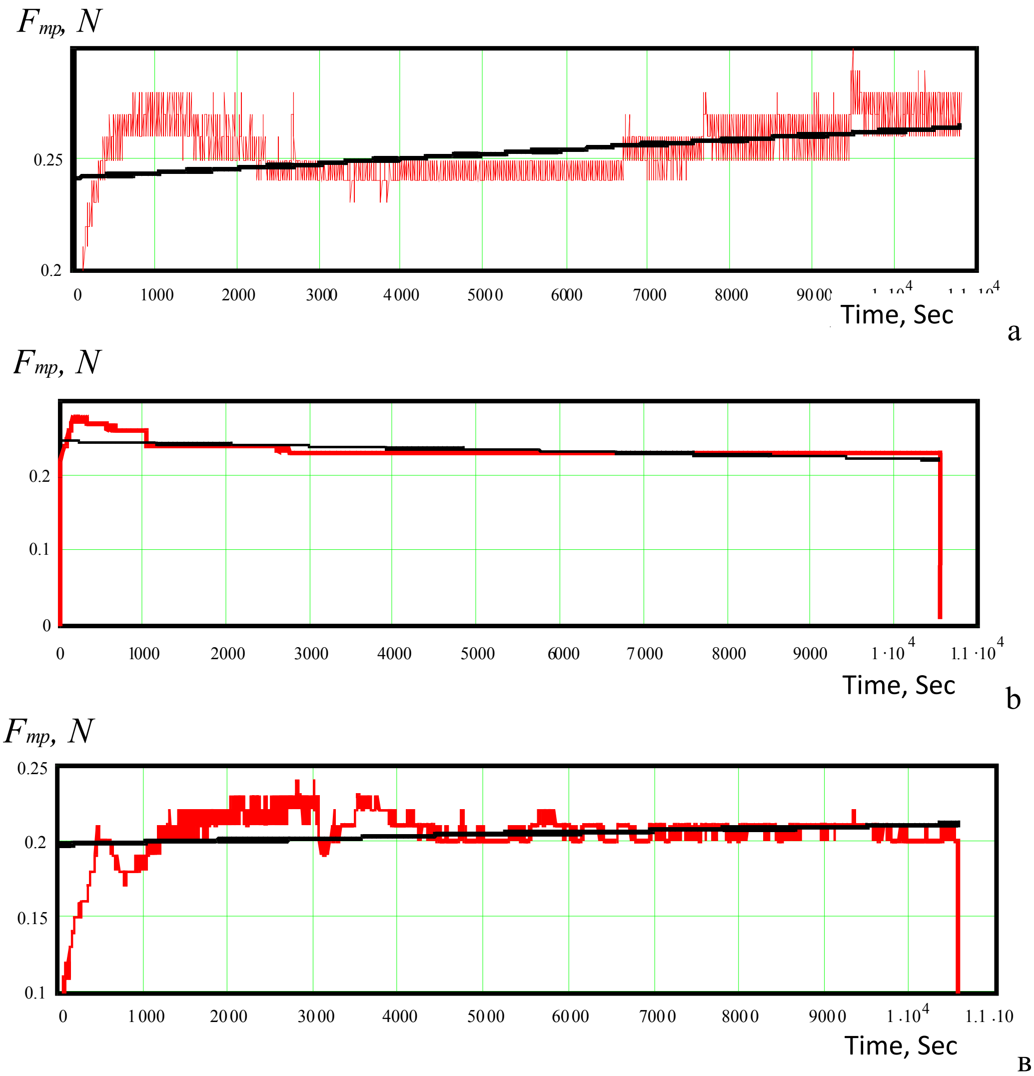


Fig. 3. Experimental curves of the friction force for the sapphire-sapphire couple against the time and its approximation by straight line: plane 1018 – a, plane 1080 – b, plane 0001 – c.

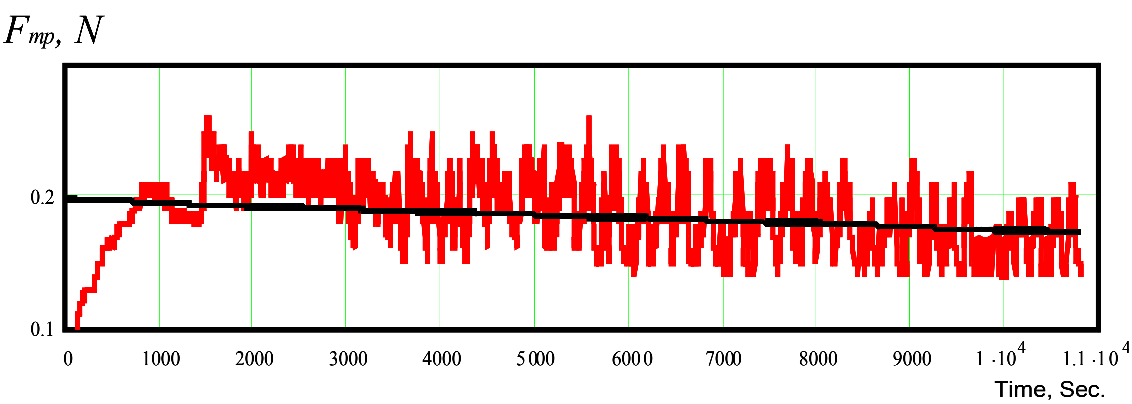


Fig. 4. Experimental curves of the friction force of the sapphire-ruby couple against the time and its approximation by straight line.

The results of tribological tests are shown in Fig. 6-7 as lay outs of curves of the ratio of friction force to loading force and linear wear of disks for the investigated materials in course of 3 hours of friction. In Fig.8 are shown the pictures of the wear spots on the surface of disk of sapphire, tetragonal dioxide of zirconium 3Y-TZP and (Y,Ce,Hf)-TZP.

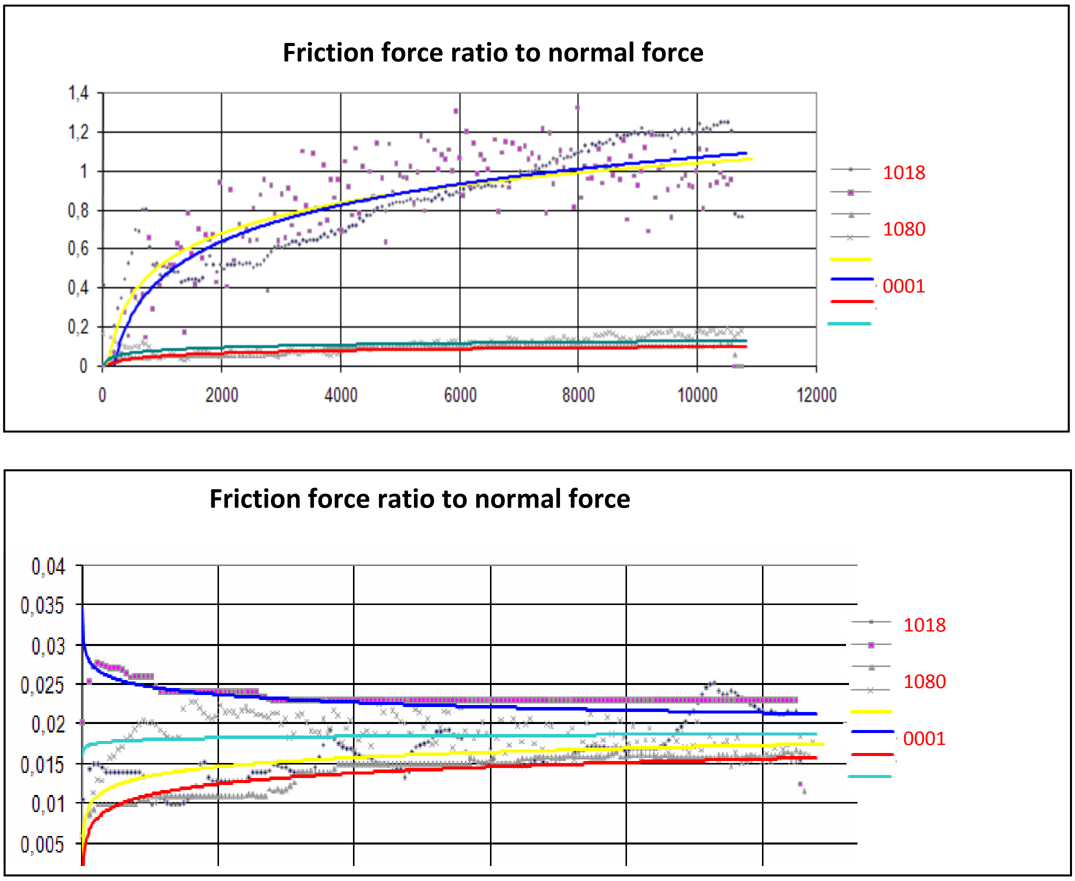


Fig. 5. Curves of change the coefficient of friction and the linear wear of sapphire in pair with ruby against the time.

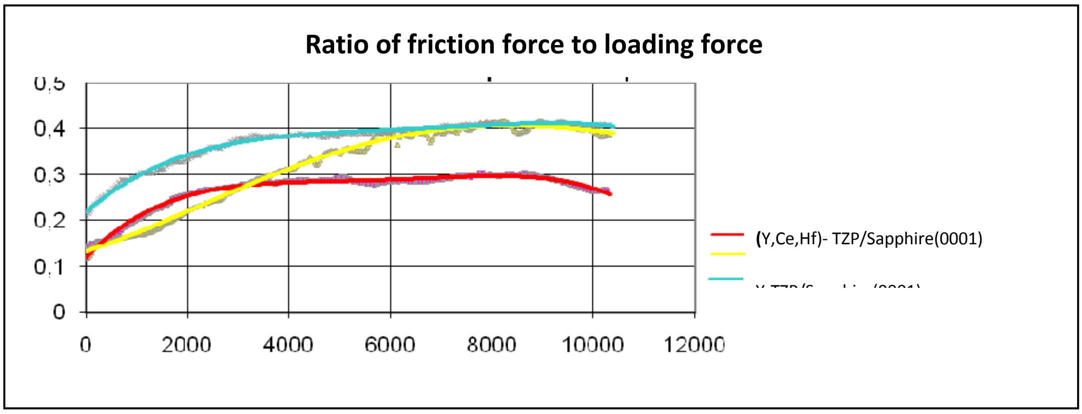


Fig. 6. Experimental curves of change the friction force ratio to loading force of sliding couples with ball of sapphire after 3 hours of tests

Discussion of the results

Depending on the orientation of the crystalline lattice the best results of the friction force relatively to loading force is shown by the friction couple sapphire-sapphire on flat 0001 and sapphire-ruby.

Tribological characteristics of tetragonal dioxide of zirconium (Y, Ce, Hf)-TZP in couple with the counter body is essentially better than characteristics of sapphire-sapphire couple (friction force is lower 1.3 times, linear wear is lower 1.5 times).

Fig. 7. Experimental curves of change in the linear wear of sliding couples with ball of sapphire 0001 after 3 hours of tests

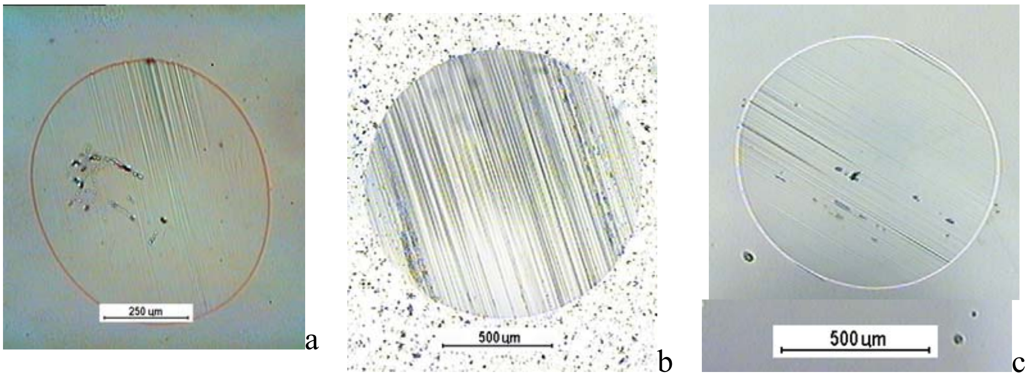


Fig. 8. The pictures of wear spots on surface of disk of: sapphire 0001 – a, 3Y-TZP – b, (Y,Ce,Hf)-TZP – c.

Dimension of the wear spot in the direction of friction on the sapphire disk 0001 (800μm) is less than that of disks of tetragonal dioxide of zirconium: (Y,Ce,Hf)-TZP –1.1 times (900 μm), 3Y-TZP – 1.5 times (1200 μm).

Conclusions

1. Tribological behavior of the ZrO_2-ceramics made at IPMS in couple with sapphire counter body is essentially better than behavior of pair sapphire/ sapphire (friction force is 1,3 times lower and the linear wear is 1,5 times lesser).

2. In a friction direction the size of a spot of wear on a disk of sapphire 0001 (800 μm) is less, than at ZrO_2-ceramics disks: IPMS – in 1.1 times (900 μm), 3Y-TZP – in 1.5 times (1200 μm).

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