

EXPERIMENTAL RESEARCH OF THE DURABILITY OF UHMWPE IMPLANTS WITH DIFFERENT COATING STRUCTURE AND DURABILITY

Formatted: Font: 18 pt

Andžela Šešok*

Department of Biomechanics, Vilnius Gediminas Technical University, J. Basanavičiaus str.
28, Vilnius, Lithuania

ABSTRACT

~~The article examines structure of implants coatings using scanning probe microscope. Osteolysis, artificial hip joint components, materials, UHMWPE coating other coatings and magnetron sputtering method, which is used to coat UHMWPE, are discussed. The experimental Co+TiO₂, Co-Cr-Mo, Zr and ZrO₂ coatings microstructure research before and after the friction test have been done. During research, has been used 15 % polyvinylpyrrolidone – artificial joint lubricant, the friction test has been carried out in vertical plane and UHMWPE samples was rubbed at the same working conditions. It has been determinate that after the friction test Co+TiO₂ coating has shown the best endurance and greatest abrasion resistance. However, this coating also were considerably after 10 000 cycles. This circumstance may cause formation of favorable conditions for accumulation of worn out granules around the implant. This fact shows that prior to application of coating onto polyethylene, its surface should be duly prepared and modified to change its hydrophilic and adhesive properties.~~

Formatted: 20 - Reziune tekstas, Right: 0.24"

Keywords: implants, coating, scanning probe microscope, durability

1. INTRODUCTION

Development of replacement arthroplasty touched a number of problems. They include a design of the implanted component, a way of its fixation, its properties, rubbing surfaces and their wear resistance. In scientific publications of the last decade, the consequences of wear of articular surfaces, such as osteolysis and survival of mechanical fixing components, are frequently discussed upon. Osteolysis is understood as bone resorption around the implant or massive formation of cystic granuloma. The bone resorption around the implanted hip joint components is one of topicalities of today surgical replacement arthroplasty that predetermine the service life of the mechanical fixtures of the implanted component.

For manufacturing the components of an artificial hip joint, various materials are used; they include metals and their alloys (titanium and its oxides, stainless steel, cobalt-chromium-

* Tel.: +370 61482835

E-mail address: andzela.sesok@vgtu.lt.

molybdenum alloy and so on) [1, 2, 3], ceramics (aluminum oxide, [zirconium-oxide-zirconia](#) and so on) [4] and polymeric materials (PMMA, UHMWPE) [5, 6].

Polymeric materials usable in production of the implants are abundant; however, for over 40 years, Ultra-High Molecular Weight Polyethylene (UHMWPE) is used in production of hip joint endoprostheses. The said material is used for producing an insert of the hip joint socket. It is distinguished for low friction coefficient, good biocompatibility and lubricant properties; however, its break resistance is lower, so it wears rapidly. In addition, particles of worn polyethylene get into the body and cause undesirable reaction of tissues, known as osteolysis [7]. In such a case, the patient is a subject to revision surgery of the hip joint replacement arthroplasty.

At present, the modification of metal or plastic surface of implants is very often explored [8, 9]. The modification of a polymer surface, either by chemical or physical methods, is very important in order to achieve new uses and different properties. This is especially true when referred to inert polymers, as is the case of polyethylene, whose surface needs etching treatments to improve its adhesion with printing or decoration finishes and also its biocompatibility [4-6].

The previous researches [10] have shown that when the elasticity module of the material of hip endoprosthesis socket is small and the stiffness of femoral stem is big, the pressure in contact surfaces is reduced considerably, lubrication conditions are improved and the durability of hip endoprosthesis is increased. The researches [11] have shown that when coating the polyethylene surface of the socket with durable coatings TiO₂ and Co-Cr-Mo on one side the contact surface is hardened but on the other side it is coated on a resilient base and allows to increase the contact surface. Such solution helps to reduce stresses and to considerably improve wear-and-tear resistance. The above combination can be applied in the fields where it is crucial to extend service life of frictional parts and units featured for their restricted lubrication, to undertake damping of vibrations and impacts.

UHMWPE is coated to improve its mechanical properties & durability and to reduce its wear herewith the number of fragments that cause host reaction to the artificial hip joint [11]. However, only primary tests on durability of the said coatings were carried out in the above-mentioned works - 2500 friction cycles only. This number is too low, because the joints on their movement pass considerably higher number of cycles; in addition, using of various coatings is possible. At present, zirconium and [zirconia-zirconium-oxide](#) are increasingly often used in replacement arthroplasty. Zirconium is distinguished for good biocompatibility and its modulus of elasticity is close to modulus of elasticity of human bones.

In the present research, we plan to apply coatings of UHMWPE with other materials (such as zirconium, [zirconium-oxide-zirconia](#), titanium oxide and cobalt-chromium-molybdenum alloy), to carry out friction tests on a stand, to examine the microstructure of the coatings by a scanning probe microscope (SPM) after application of the coatings and after the friction tests and to identify what coating withstood 10 000 working cycles in the best way.

2. MATERIAL AND METHODS

For formation of the coatings, the magnetron sputtering method was chosen. The method was chosen because application of coatings takes place at 70°C, so the properties of polyethylene do not change (its melting temperature varies between 144°C and 152°C). [Magnetron sputtering technology is characterized by: oxide coatings can be sputtered \(reactive sputtering\), excellent layer uniformity, very smooth sputtered coatings \(no droplets\). Magnetron sputtering technology has some disadvantages: slow deposition speed and](#)

* Tel.: +370 61482835

E-mail address: andzela.sesok@vgtu.lt.

[adhesion of coatings is lower and density of the sputtered layers may be lower.](#) 3-source magnetron sputtering SCM was used.

In course of the works [11], on the base of the carried out tests and their results, we selected the coating that showed them the best on the primary tests: Co-Cr-Mo, Co+TiO₂; in addition, we used Zr and ZrO₂, coatings, because they increasingly often are applied in production of implants.

In the works, special UHMWPE usable for medical applications (*Chirulen* (ISO5834-2, from *POLY Hi Solidur MediTECH* company) was used. UHMWPE was coated with Co+TiO₂, Co-Cr-Mo, Zr and ZrO₂. The thickness of the said coatings is 2 µm.

The surface of samples has been measured by scanning probe microscope (SPM) Dimension 3100 produced by company Digital Instruments. In comparison with profilometer, microscope is characteristic of much larger resolution in respect of X and Y axes (0,1-3 nm) and Z axis (0,01 nm). Measures have been taken by microscope set for tapping mode. This mode is applied when larger horizontal resolution is necessary. The needle of the microscope vibrates at frequency close to resonance and touches the surface of the sample periodically. The amplitude of needle vibration comes up to 20-100 nm. Information on the surface of the sample is obtained upon combination of data related to the movement of a piezo scanner at the direction of Z axis and the change in probe vibration phase.

Coatings have been tested for their steadfastness and durability. For this purpose a special rubbing [stand-device](#) generating friction effect has been designed and manufactured (Fig. 1).

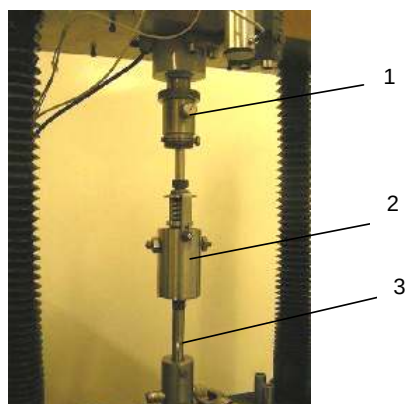


Figure 1. [Stand of the experiment](#): 1– FP-10 tensioning equipment; 2 – special device; 3 – rod

The device for the stand is intended for operation in the German-made FP-10 tensioning equipment. The stand is used for simulation of real movements taking place in the human hip joints. One cycle is back-and-forth motion of the stand's rod 3. Within such a cycle, a sample inserted in the fixture 2 is loaded from 0 to the maximum force (400 N) and rotated at a certain angle. Within one cycle, the sample performs a complex movement, i.e. it is pressed and rotated, thus simulating motions and load of a hip joint. For lubricating, 15 % polyvinylpyrrolidone was used.

* Tel.: +370 61482835

E-mail address: andzela.sesok@vgtu.lt.

After the wearing tests, the microstructure of the coatings was examined again by a scanning probe microscope. Finally, an analysis of the obtained results was carried out.

3. RESULTS AND DISCUSSION

The results of the tests are provided in Figs 2 and 3. In Fig. 2, the photos of the microstructure of Co+TiO₂, Co-Cr-Mo, Zr and ZrO₂ coatings applied onto UHMWPE by magnetron sputtering are provided; they were made by a scanning probe microscope before friction tests. In course of analysis of the photos of the surface of coatings made by a scanning probe microscope (Fig. 2), it was found that the largest agglomerates of granules are formed in Co-Cr-Mo coating (about 2 μm long, 7 μm wide and 10 nm high). The roughness of Zr coating is the minimum; however, it includes large agglomerates of granules (1.5×1.7 μm). Zirconium is known as a crystal structure comminuting agent and shows particularly good granular structure refinement effect. The roughness of ZrO₂ coating is relatively low (3.2×2.5 μm); however, the structure of the coating consists of large granules. Co+TiO₂ coating is of a moderate roughness with 4.5×4.5 μm granular agglomerates.

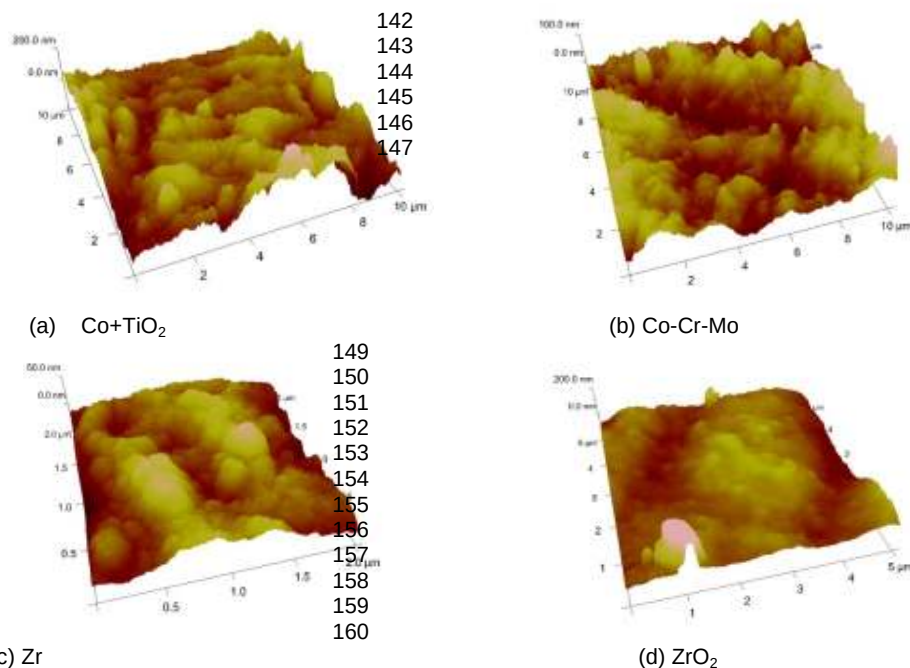


Figure 2. Coatings Co+TiO₂ (a), Co-Cr-Mo (b), Zr (c) and ZrO₂ (d) SPM morphology images before friction test

It was found that after application of Co+TiO₂ coating by magnetron sputtering the sizes of granules are from 50 nm to 200 nm, so the surface is rough enough. The sizes of granules in Co-Cr-Mo coating vary between 20 nm and 100 nm; the granules are oval with striking sharp inequalities. The sizes of granules in Zr coating vary between 8 nm and 50 nm; it is a

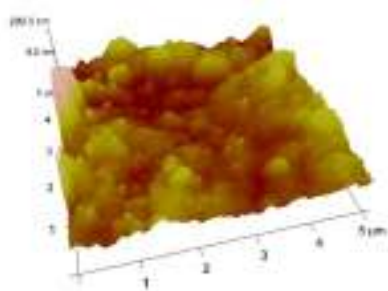
surface of the minimum grain and roughness. The sizes of granules in ZrO₂ coating vary between 85 nm and 200 nm, and the surface is rough enough.

The average sizes of granules are provided in Table 1 below.

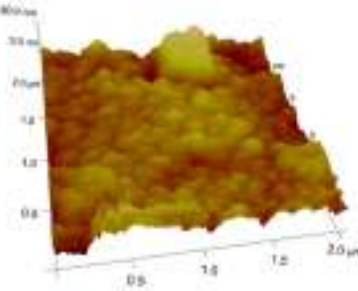
Table 1. The values of average sizes of granules, nm

Coating							
Co+TiO ₂		Co-Cr-Mo		Zr		ZrO ₂	
Sizes of granules, nm							
min	max	min	max	min	max	min	max
50±2.5	200±5.2	20±1.8	100±4.2	8±1.2	50±3.2	85±3.5	200±6.4

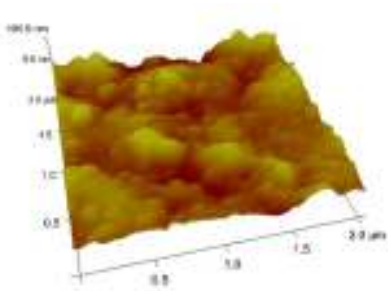
On durability and wearing tests, 10 000 cycles were applied upon the load of 400 N. On the analysis of the photos of Co+TiO₂, Co-Cr-Mo, Zr and ZrO₂, coatings made by a scanning probe microscope (SPM) after the tests on friction stand, it was found that Co+TiO₂ coating was distinguished for the best mechanical properties, because the changes of its grain and the shape of its granules were inconsiderable. ZrO₂ showed the worst mechanical properties: it may be seen from the SPM photo that the surface of this material wore to the maximum extent and residue on UHMWPE was the smallest. After the friction tests, the grain and roughness of the above-described Zr coating increased and the shape of its granules changes considerably. This change was caused by wear of the coating. The surface of Co-Cr-Mo coating wore by 20 %. The shape of granules in Zr and Co-Cr-Mo coatings became rounded, because the sharp inequalities abraded on traction. Thus, the roughness of the surface was reduced.



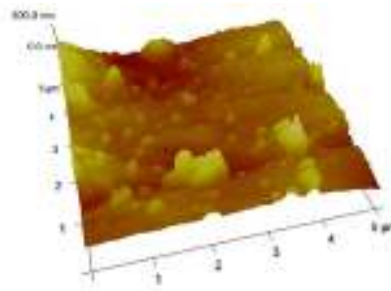
(a) Co+TiO₂



(b) Co-Cr-Mo



(c) Zr



(d) ZrO₂

* Tel.: +370 61482835

E-mail address: andzela.sesok@vgtu.lt.

Figure 3. Coatings Co+TiO₂ (a), Co-Cr-Mo (b), Zr (c) and ZrO₂ (d) SPM morphology images after completed friction test

The average sizes of granules after friction test are provided in Table 2 below.

Table 2. The values of average sizes of granules after completed friction test, nm

Coating							
Co+TiO ₂		Co-Cr-Mo		Zr		ZrO ₂	
Sizes of granules, nm							
min	max	min	max	min	max	min	max
50±3.0	200±5.8	20±2.4	80±5.6	20±2.2	100±2.5	140±4.5	250±7.2

So, after comparing the morphological photos of the structure of coatings made by a scanning probe microscope prior to the friction tests and after them, we can state that Co+TiO₂ coating had demonstrated the best durability and the highest abrasion resistance; however, this coating wore considerably. The last circumstance may cause formation of favorable conditions for accumulation of worn out granules around the implant. The results of the test showed that adhesion of a majority of coatings to polyethylene is insufficient and the coatings were worn out soon. This fact shows that prior to application of coating onto polyethylene its surface should be duly prepared and modified to change its hydrophilic and adhesive properties.

4. CONCLUSION

1. Taking into account the results of the carried out analysis of the materials usable for hip joint replacement arthroplasty, we can conclude that using UHMWPE causes problems related to operational life of components of the hip joint prosthesis.
2. The durability and the service life of coatings applied by magnetron sputtering are different for various combinations of metal and ceramic coatings. ~~It was found that the coatings obtained were nanocrystalline.~~
2. After the analysis of the morphological photos of the structure of coatings made by a scanning probe microscope prior to the friction tests and after them, we can state that Co+TiO₂ coating had demonstrated the best durability and the highest abrasion resistance.
3. ~~However, this coating also wore considerably after 10 000 cycles. Eksperimento metu dangės nemažai nusitrinė. During the experiment, the vast majority of coatings wore considerably.~~ This circumstance may cause formation of favorable conditions for accumulation of worn out granules around the implant. This fact shows that prior to application of coating onto polyethylene, its surface should be duly prepared and modified to change its hydrophilic and adhesive properties. So, application of coatings of other materials onto polyethylene requires deeper investigation.

REFERENCES

1. Bombac, D., Brojan, M., Krkovič, M., Turk, R., A. Zalar, A. Characterization of titanium and stainless steel medical implants surfaces. Journal of Materials and Geoenvironment. 2007;54-2:151-164.
2. Bragolan, C. R., O'Coner, D. O., Lowenstein, J. D., Jasty, M., Biggs, S. A., Harris, W. H. A New Pin-on-Disk Wear Testing Method for Simulating Wear of Polyethylene

* Tel.: +370 61482835

E-mail address: andzela.sesok@vgtu.lt.

Formatted: Font: Arial

- 236 on Cobalt-Chrome Alloy in Total Hip Arthroplasty. *Journal of Arthroplasty*. 2001;16-
237 5: 658-665.
- 238 3. Leeds, P., Dearnley, A. A review of metallic, ceramic and surface-treated metals
239 used for bearing surfaces in human joint replacements, *Proceedings/Institution of*
240 *Mechanical Engineers*. 2001;213 (H): 107-135.
- 241 4. Rahaman, M. N., Yao, A. Ceramic for Prosthetic Hip and Knee Joint Replacement.
242 *Journal of American Ceramic Society*. 90[7], 2007:1965-1988.
- 243 5. Rieker, C. B. Tribology in Total Hip Arthroplasty – Historical Development and
244 Future Trends. *Journal of Bussiness Briefing: Global Surgery*. 2003:1-3.
- 245 6. Tuller, M. B., Bellare, A. A study of the nanostructure and tensile properties of Ultra-
246 high molecular weight polyethylene. *Journal of Biomaterials*. 2004;25: 3389-3398.
- 247 7. Dumbleton, H. J., Manley, M. T., Edidin, A. A. A literature review of the association
248 between wear rate and osteolysis in total hip arthroplasty. *Journal of Arthroplasty*.
249 2002;17, 5: 649-661.
- 250 8. Desmet, T., Morent, R., Geyter, N. D., Leys, C., Schacht, E., Dubruel, P. Nonthermal
251 Plasma Technology as a Versatile Strategy for Polymeric Biomaterials Surface
252 Modification: A Review. *Biomacromolecules*. 2009; Vol. 10, 9:2351-2378
- 253 9. Shrojal, M. Desai, Singh, R. P. Surface Modification of Polyethylene. Long Term
254 Properties of Polyolefins. *Advances in Polymer Science*. 2004; Volume 169:231-
255 294.
- 256 10. Mariūnas, M., Karavackaitė, J. Investigation of biological lubricants influence on the
257 durability of endoprotheses, *Lecture Notes of the ICB Seminars Biomechanics:*
258 *Customized Endprothese – Design, manufacture and Clinical Application*. Warsaw,
259 2003: 59-63.
- 260 11. Mariūnas, M., Šešok, A., Lisauskas, V. Investigation of Possibilities for Ceramic
261 Coating of Biological Polyethylene Implants. *Solid State Phenomena*. 2006;Vol.
262 113:549-555.