279. Research of artificial joints coatings obtained by using a magnetronic method

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(Received 15 May 2007, accepted 15 June 2007)

Abstract: The article analyses the possibility of using a magnetronic method of coating for the formation of more durable ceramics (TiO_2) and metal or metal alloy (Ag, Co, Co-Cr-Mo, Zr) coatings of endoprostheses on a polyethylene implant. Chirulen (ISO5834-2, POLY Hi Solidur MediTECH), special design (for medical purposes) high molecular weight polyethylene has been used for investigation. The coatings are applied either directly onto the polyethylene or by using a bond, e.g., Ag, Co. Materials used in tests are suitable for medical implants. Three types of implant surface have been made in order to investigate the friction coefficient reducing possibilities. In the paper was analyzed which of surface forms is tend to wear less after tests. The pilot studies carried out in this way showed that the best adhesives and durability characteristics have Co+TiO_2 coating of nanostructure. When using Zr, Ag+Co+TiO_2, Ag+Co-Cr-Mo and Ag+TiO_2 the coatings are less durable and tend to wear more quickly due to poor adhesion. Appointed, that smooth implant surface tends to wear more quickly.

Keywords Artificial joints, polyethylene, coating, nanostructure, ceramic, magnetronic, durability

1. Introduction

Joint replacement surgeries that ease the life of a number of people are performed worldwide. According to the data of the European Commission more than 500 thousand artificial knee and hip joints per year are implanted in the EU states. Materials used in the production of endoprotheses must be distinguished for inertness, good biocompatibility with the tissues of human body, perfect mechanical and tribological features. Such materials as titanium, Co-Cr-Mo, polyethylene, TiO_2 are frequently used in the manufacturing of endoprotheses [1, 2, 3]. However, it was noticed that artificial polyethylene joints marked for good compatibility with the tissues of organism are nondurable and more suitable for elderly patients. One of the promising groups of materials for the production of artificial joints is ceramic oxide coatings. The previous researches [4, 5] have shown that when coating the polyethylene surface of the socket with durable coatings TiO_2 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 increasing the contact surface. Such solution helps to reduce stresses and to considerably improve wear-and-tear resistance. The above mentioned 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.

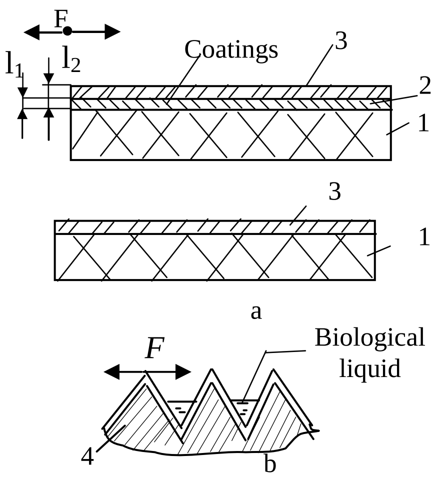
Purposes of the work: to evaluate the influences of implant surface forms and biological lubricants to the durability of the implant and reduction of friction coefficients.

2. Methods

Chirulen (ISO5834-2, POLY Hi Solidur MediTECH), special design (for medical purposes) high molecular weight polyethylene has been used for investigation purposes. Coatings were obtained by using a magnetronic method. When coating polyethylene with ceramics and metals by using a magnetronic method the process takes place under low temperatures (less than 70°C). These coating combinations have been obtained: $Ag+Co+TiO_2$, $Co+TiO_2$, TiO_2; Ag+Co-Cr-Mo; Co-Cr-Mo; $Ag+TiO_2$; Zr.

Coatings have been tested for their steadfastness and durability. For this purpose a special rubbing stand generating friction effect has been designed and manufactured [5]. 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 performed by the human knee and hip joints. During experiments a number of cycles have been repeated at first 1,500 times and later 2,500 times. One cycle – recursive-stepping motion of rod. During this cycle the sample placed into the device 2 is loaded by 0 to maximum force (up to 1000 N) and turned at a certain angle. During one cycle the sample makes a complex motion, i.e. it is pressed and turned by imitating the motions and load of the hip joint. The loading has been subject to cyclic variations within 0 and 240 N range.

For explanation of reduction possibilities of friction coefficients three types of implant surface was made: 1) smooth surface (Fig. 1 a); 2) triangular form (Fig. 1 b); 3) special form (Fig.1 c). Supposedly, friction forces acting in the smooth surface (Fig. 1 a) will try to tear off the coated layer in all its length and will allow to wear more quickly. In this instance tension conditions will be worse because there is no place for accumulation of biological lubricants. Fig. 1 b and c show cavities in the grooves at the surfaces where biological lubricants can accumulate and abrasive particles form ceramic coated surface can gather up. These particles are able to intensive destruction of the surface. These cavities should improve lubrication and reduce friction coefficient during work. In occasions presented in Fig. 1 b and c forces will act to elementary area of the implant, but not in all its length. Comparing advantages and limitations of all three surfaces (Fig. 1 a, b and c) can be a priori noticed, that Fig. 1 b coating layer at the top of the surface will be not strong and will tend to wear quickly. Consequently for the first stage it is necessary to ascertain which of three types of surfaces is more durable and has the least friction coefficient.



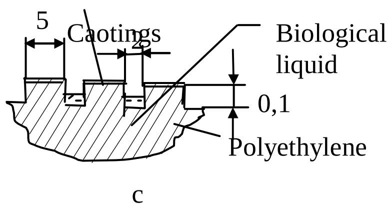


Fig. 1. The structure of different layers (a) and surface roughness (b), (c): 1 – polyethylene; 2 – Ag; 3 – ceramics or Co-Cr-Mo alloy; 4 – rough surface (containing grooves); *F* – acting frictional force

Rectangular form areas have been received by milling grooves (Fig. 1 c) of the polyethylene surface (Fig. 2). An example of the implant presented in Fig. 2. But any form of implants suitable for artificial joints form can be made by the same way.

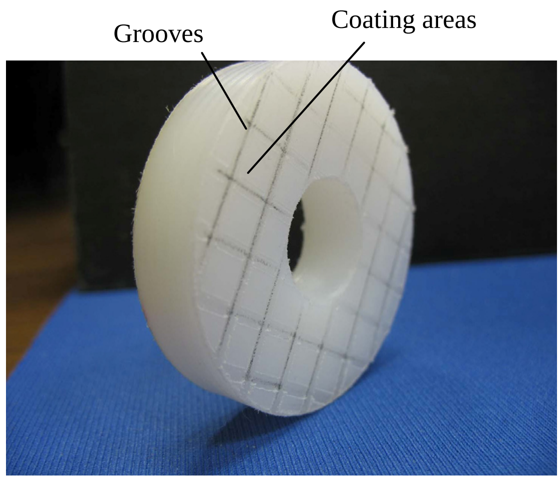


Fig. 2. Polyethylene implant with grooves

The influence of biological lubricant to reduction of friction coefficients was researched in the literature source [4]. Three different liquid lubricants have been used during investigations: blood serum, Fermathron sodium hylaurinate and 15% solution of polivinylpyrrolidone. Research has shown that the most reduction of the friction coefficient (from 1.2 to 1.3 times) was achieved by using 15% solution of polivinylpyrrolidone, which will be used in the further research. Therefore 15% solution of polivinylpyrrolidone will be used in the further research.

Five different form samples have been used for the evaluation of the influence of implant surface form to coating durability.

As different surfaces have shown their different durability level the surfaces attrition was measured by different methods. For evaluation of surfaces shown in Fig. 1 a and b the 7 times magnifying microscope was used and scanning probe microscope Dimension 3100 produced by company Digital Instruments for the surface shown in Fig. c. The roughness of coatings' surfaces was analyzed with digital profiler DEKTAK 6M.

3. Results

The researches showed that different metal and ceramic coatings obtained using a magnetronic method have different stability and durability.

Analysing the primary research results after 2500 cycles it can be noticed that Co+TiO_2 and Co-Cr-Mo coatings are least worn while Ag+Co+TiO_2 is fully worn and only the remains of coating may be seen. After 2500 cycles Ag+Co-Cr-Mo coating has worn analogically. Late finding imply that the adhesion of these coatings and polyethylene is poor.

The pilot studies carried out and showed that the best adhesives and durability characteristics have by Co+TiO_2, i.e. coatings where layer of cobalt is between the polyethylene and ceramics. For the further stage the influence of polyethylene surface coated with Co+TiO_2 to implant durability. In Fig. 3 presented photos of polyethylene coated with Co+TiO_2 when it has the smooth surface (prepared due to Fig. 1 a).

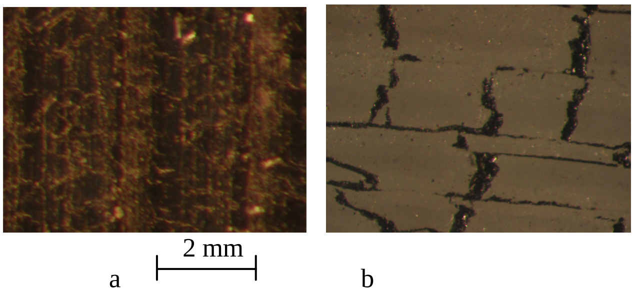


Fig. 3. Photos of polyethylene surface coated with Co+TiO_2, surface is smooth: a – until tests, b – after 2500 cycles, load force 240 N. (X7 magnification)

Photos of a polyethylene surface coated with Co+TiO_2, when triangular grooves are made (according Fig. 1 b) are shown in Fig. 4.

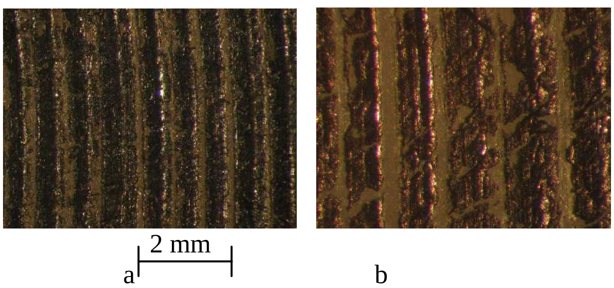


Fig. 4.. Photos of polyethylene surface coated with Co+TiO_2, when grooves are triangular: a - until tests, b - after 2500 cycles. (X7 magnification)

In Fig. 5 presented photos of polyethylene coated with Co+TiO_2 with made rectangular grooves (due to Fig. 1 c). These photos were received by scanning probe microscope Dimension 3100.

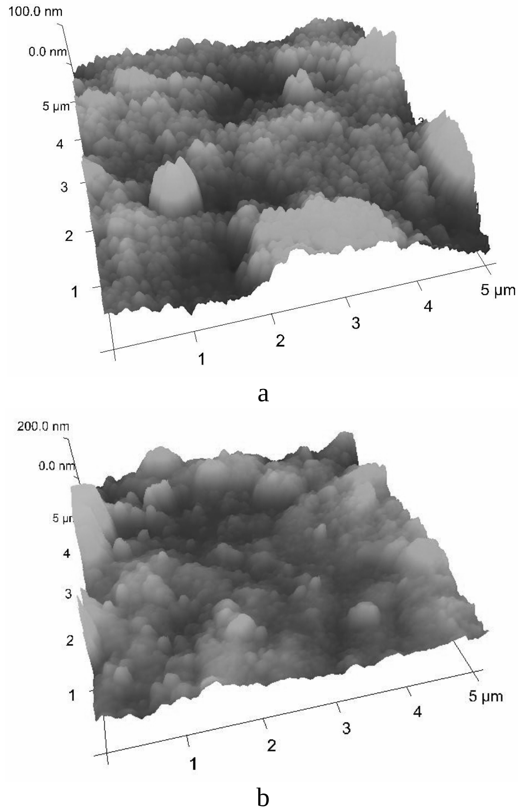


Fig. 5. Photos of polyethylene surface coated with Co+TiO_2, when rectangular areas are formed at the surface: a – until tests, b – after 2500 cycles.

Fig. 6 shows the dependence of roughness parameter R_a of coatings on the number of load cycles.

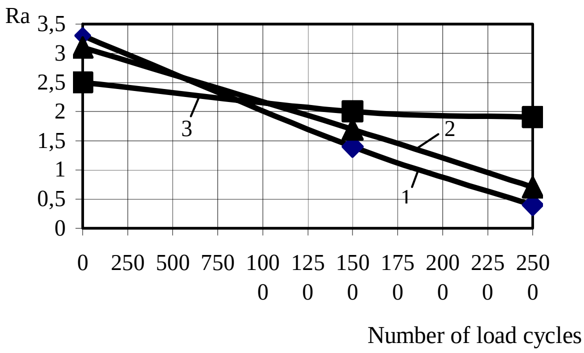


Fig. 6. The dependence of roughness parameter R_a of coatings on the number of load cycles: 1 – smooth surface; 2 – triangular form; 3 – rectangular area form.

The research results (Fig. 6) indicate that the wear of Co+TiO_2 rectangular area form (curve 3) coatings is minor. In other cases (curves 2, 3) the wear is big enough.

By analyzing the structure of different variants (Fig. 3, 4 and 5) it has been noticed that in smooth surface (Fig. 3) clearly seen cracks of ceramic coatings. When polyethylene surface include triangular form grooves (Fig. 4) coating layer at the top of surface tend to quick wear that is to say top of the surface worn completely and remain only the polyethylene. Observed that polyethylene surface with rectangular areas (Fig. 5) was less distorted after tests, so it is more durable. Biological lubricant and nano sized abrasive particles, which affect smooth surface as abrasive and increase wearing, accumulate at rectangular grooves.

Analysis and comparison of Fig. 3, 4 and 5 allows one to draw the conclusion that $Co+TiO_2$ cover with specific grooves has shown the least wear (Fig. 5), i.e. that it is the most enduring.

Conclusions

1. There were estimated, that smooth implant surface coated with ceramics tends to wear more quickly in comparison with the specially prepared surface. Consequently for the increase of durability it is necessary to form appropriate type grooves on the surface;
2. The most durable and hard surface was implant surface with rectangular areas. Biological lubricant and broken away abrasive particles, which affect smooth surface as abrasive and increase wearing, accumulate at these grooves.

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