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A role of surface treatment in modification of the useable properties of the medical tools

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ABSTRACT

Purpose: of this paper is to discuss a division of the surgical tools according to the different criteria and to indicate the dominant wear processes of the medical tools. Moreover, the paper gives some guidelines on improvement in wear resistance of the medical tools by the surface treatment.
Design/methodology/approach: Objectives were achieved thanks to the frictional and wear tests carried out on the T05 test stand ("ring-block" tester). An influence of the different surface treatments carried out for Ti6Al4V titanium alloy on its wear resistance was examined. Moreover, "scratch test" was done.
Findings: In the course of the work it was found that the application of nitrogen titanizing process can increase wear resistance of the titanium alloys several times. This can expand the application range of titanium alloys for elements, which are subjected to intensive wear.
Research limitations/implications: Wear tests belong to the long-lasting tests, so it is the main research limitation.
Practical implications: Surface treatment discussed in the paper is partially used for production of the titanium medical tools (some kinds of forceps). An application of the titanium surgical tools is advisable because of their high mechanical strength and low weight.
Originality/value: A part of the tests was carried out for the frictional pair: "titanium alloy+surfacing – animal bone". Such tests allow for better determination of the wear resistance occurring during surgical operations, i.e. during the direct contact between the surgical tool and bone tissue.
Keywords: Surface treatment; Surgical tools; Wear; Durability

1. Introduction

Different medical operations need the application of the suitable surgical tools. High requirements placed to the surgical tools are the reason that only highly specialised firms produce such tools. It is necessary to emphasise that the more complicated operation is the more expansive surgical instrumentarium is used.

The growing amount of the surgical operations, also operations carried out by highly specialised clinic or hospitals departments, such as: cardiosurgery, neurosurgery, ophthalmology etc., causes the increase in demand for surgical instrumentarium.

Surgical tools can be divided regarding the following criterions [1]:

1. regarding their application we can distinguish:
- universal surgical tools,
- special surgical tools e.g. orthopaedic, cardiosurgical, gynaecological, dental tools etc.,
- veterinary tools,
- anatomic tools (for autopsy).
2. regarding kind of action we can distinguish:
- cutting device, e.g scalpels, saws etc.,
- gripping device,
- prickly device,
- striking device, ect.
3. regarding tribological aspect we can distinguish:
- tools collaborating with soft tissue,
- tools collaborating with bone tissue,
- tools collaborating with metal e.g. wire cutter.

The tool division regarding multiplicity of their use also seems important. Considering this criterion we distinguish disposable tools and tools of multiply usage.

Surgical tools should be characterised by [1,2]:
- geometry, which enable to perform a specific operation,
- proper mechanical properties,
- corrosion resistance to tissue fluid,
- ergonomic shape,
- high wear resistance,
- susceptibility to sterilization.

Complexity of the performed surgical operations, such as: endoprostheses implantation or cardiosurgical operations, requires the use of the special, very expensive tool sets. It is characteristic that each implant kind (e.g. hip or knee endoprosteses) needs the special set of the tools. Therefore, durability and reliability of the surgical tools are very essential. An increase in wear resistance is connected not only with the tool durability and costs but also has a medical aspect. It results from the fact that the metal wear products, remaining in the human being can cause unforeseen negative effects [3, 4].

In Figure 1 and 2, for example, the sets of surgical tools used for implantation of the hip and knee endoprostheses are shown.

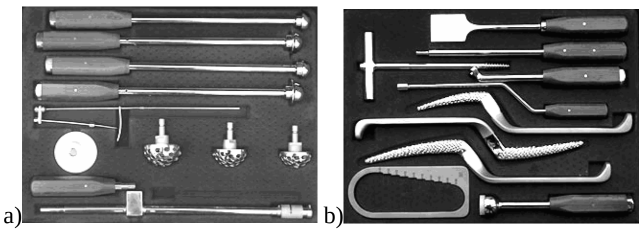

Fig. 1. Tool kit for implantation of the hip endoprostheses – Benoska s.r.o. a) acetabular cup, b) stem [5]

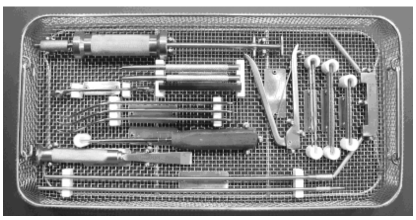

Fig. 2. Tool kit for implantation of the knee endoprostheses – Benoska s.r.o. [5]

2. Peculiarity of the surgical tool wear

A correct course of the surgical operation depends both on the doctor's qualifications and the proper technical state of the tools. So far little attention has been paid to a wear problem of the surgical tools. Tool kit producers usually do not give any information about tool durability, even in estimated way. Generally, the surgical instrumentarium consists both of the tools, which wear less intensively (collaborating with soft tissue) and tools, which wear severely (collaborating with bone tissue). The dominant destructive processes deciding the tool durability are as follows:
- abrasive wear processes, which affect the cutting edges become blunt (e.g. destroying of the milling cutters, drills, saws etc.),
- fatigue wear processes manifesting as microspalling,
- corrosive processes.

In Figure 3, for example, a view of the worn surface of the milling cutter and surgical chisels, which were used for implantation of the hip endoprostheses is shown. The visible marks of abrasive wear and microspalling are seen.

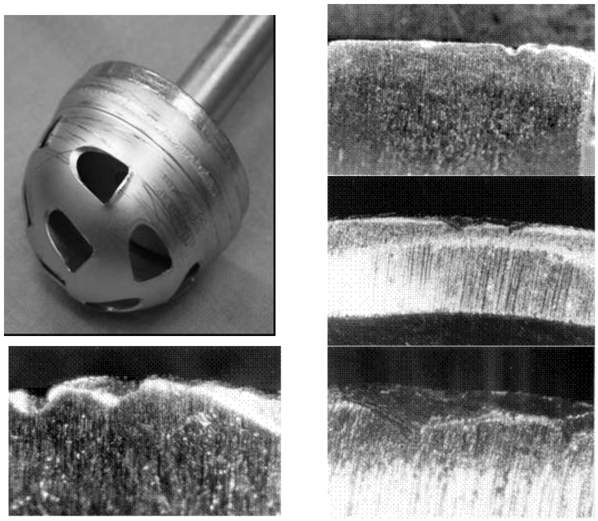

Fig. 3. Worn surfaces of some surgical tools

Mean durability of the milling cutters and drills, which are used for making holes in pelvis and thigh bones is estimated for 10÷15 operations. Cutting edges of the scalpels, laparoscope scissors or knives naturally become blunt as a result of abrasive wear. Operation with the dull tools is troublesome both for the doctors and patients because making holes with the blunt tools causes significant destruction (crushing) of the bone. Additionally, holding parts of the tools often get damaged during the sterilisation process. Such damage mainly results from the improper selection of the material (plastic).

Furthermore, the proper tool functionality and durability strongly depend on the tool construction. Figure 4, for example, shows the simulation results of the laparoscope scissors with the area of the local stress concentration [6]. Sometimes, elimination of the area with high stress concentration is impossible respecting the tool function. In that case, it is necessary to apply the proper heat or surface treatment. Therefore, the numerical simulations of the tool load during its work are very useful both for the tool constructor and process engineer.

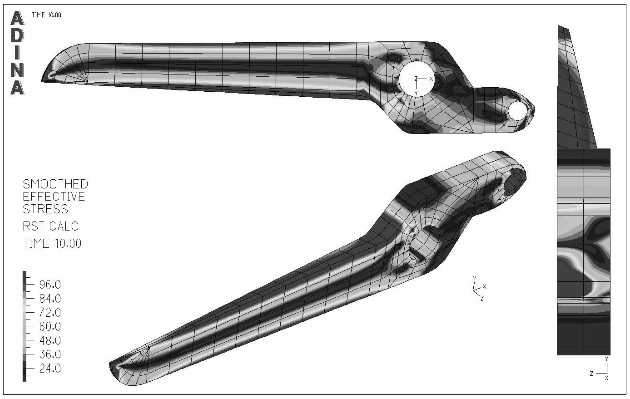

Fig. 4. Stress concentration in the laparoscope scissors determined by the numerical simulation [6]

3. Production technology of some surgical tools. Selection of the surface treatment

For many years surgical tools have been made of martensitic, ferritic and austenitic steels. Recently, titanium alloys are used for the tools, which are designed for precise operations. The combination of high strength and low weight makes titanium alloys a very useful constructional material. However, low wear resistance is its disadvantageous. It can be improved by surface treatment [7, 8, 9, 10, 11].

Many surgical tools are traditionally produced by metal working processes such as: blanking, bending, stamping, forging; machining and heat treatment. Surface treatment also fulfils an important role in tool production. Two kinds of surface treatment can be mentioned here:

- surfacing aiming at improvement of the surface smoothness i.e. mechanical polishing, electropolishing, polishing in the special barrels etc.
- surfacing aiming at improvement of the wear resistance by creation of the diffusion layers in such processes as: nitriding, nitrogen titanizing etc.

Taking into consideration more and more common application of the titanium alloys for tool production, in the paper a special attention was paid to the surface treatment of the titanium alloys.

4. Tests

4.1. Microstructure

Laboratory tests were aimed at:

- preliminary selection of the surface treatment aiming at the increase in wear resistance of the titanium alloys,
- determination of the wear curves for the titanium alloys after hardening treatment collaborating with the bone tissue,
- determination of the scratch resistance for the applied layers,
- final selection of the surface treatment in order to apply it to titanium tool production.

4.2. Materials and methods

The widely used Ti6Al4V titanium alloy underwent the tests. The following surface treatments were applied:

- high temperature anodizing in order to create Ti(ON) layer – process 659,
- nitrogen titanizing by PVD method,
- ion nitriding in order to create composite layer.

By contrast Ti6Al4V alloy with no surfacing was also examined.

4.3. Test stands

Frictional and wear tests were carried out on T05 Tester with the following parameters:

- load force P=600N
- area contact F=100mm^2
- mean unit pressure p=6N/mm^2
- rotational speed of the ring v=0,91 rot./s
- kind of lubrication Ringer's liquid
- kind of contact surface contact (semicup – ring)

The following frictional pairs were tested:

- sample (ring) – titanium alloy Ti6Al4V with and without surfacing,
- counter-sample – animal (ox) bone.

Scratch resistance of the applied layers were carried out on the "Scratch tester" at the Institute of Terotechnology in Radom.

4.4. Test results

Frictional and wear test results are presented in Figure 5.

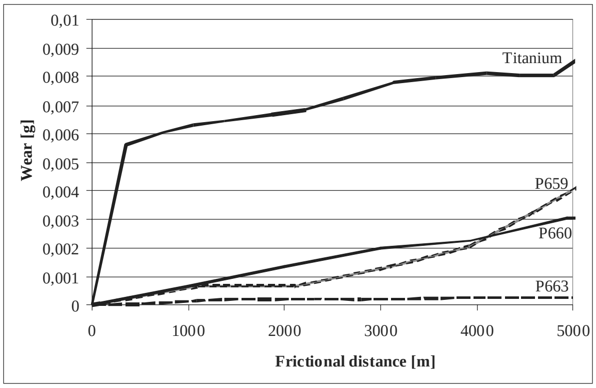

Fig. 5. Wear curve for the frictional pair: Ti6Al4V+ surfacing - animal bone

According to the carried out tests it can be stated that the proper surface treatment increases wear resistance of the titanium alloy to several times. Ion nitriding (process 663) gives the best results. The obtained layer is very hard and resistant to wear.

Ion nitriding was carried out at the Faculty of Materials Science and Engineering at the Warsaw University of Technology according to the technology invented by T.Wierzchnoń [6].

Scratch resistance is an important characteristic of the layers obtained during surface treatment of the implant and surgical tools.

In Figure 6 a diagram, which illustrates the mean value of the force causing scratch of the tested layers, is shown.

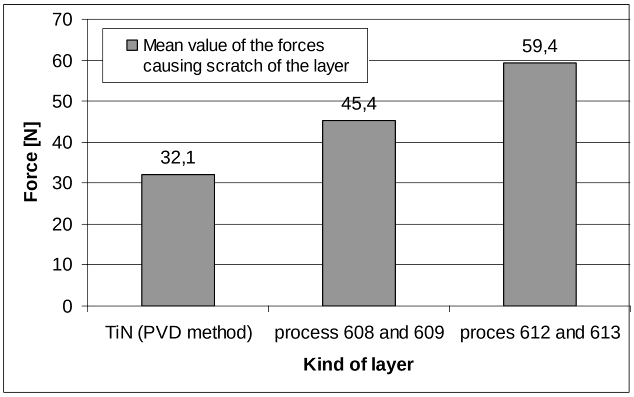

Fig. 6. Scratch resistance for the tested layer created on Ti6Al4V titanium alloy

According to the test results the highest scratch resistance was obtained for the layer after ion nitriding.

5. Conclusions

According to the test results the following conclusion can be drawn:

1. Wear of the samples made of titanium alloy without any surfacing is very high, what is in agreement with the literature information on the unfavourable tribological properties of titanium alloys.
2. The proper surface treatment allows for the increase in wear resistance of the titanium alloys to several times. The layers after ion nitriding show the highest wear resistance among the tested layers.
3. Surgical tools such as: drills, milling cutters, which are designated for the operations making on the bone, should have surface strengthening in the working parts. Such strengthening allows for the effective increase in their durability.
4. Application of the titanium alloys for medical tools is advisable considering their high resistance and low specific gravity. These tools should undergo surface treatment aiming at strengthening of the top layer. Diffusion treatment e.g. nitrogen titanizing is advisable.

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References

[1] Z. Paszenda, J. Tyrlik-Held, Surgical instruments, Printing House of the Silesian University of Technology, Gliwice 2003 (in Polish).

[2] J. Marciniak, Z. Paszenda, M. Kaczmarek, J. Szewczenko, M. Basiaga. M. Gierzyńska-Dolna, P. Lacki, Wear investigations of tools used in bone surgery, Journal of Achievements in Materials and Manufacturing Engineering, 20 (2007) 259-262.

[3] M. Gierzyńska-Dolna, Biotribology. Printing House of the Częstochowa University of Technology, Częstochowa, 2002 (in Polish).

[4] J. Marciniak, Biomaterials. Printing House of the Silesian University of Technology, Gliwice, 2002 (in Polish).

[5] Tool catalogs: Beznoska s.r.o., Manufacturer of surgical and medical Instruments CHIRMED.

[6] M. Gierzyńska-Dolna, P. Lacki, J. Marciniak, Z. Paszenda, W. Chrzanowski, Numerical analysis of the laparoscope tools, Problems of the Exploitation 3 (2006) 21-30 (in Polish).

[7] M. Gierzyńska-Dolna, T. Wierzchoń, J. Adamus, P. Lacki, A role of surface treatment in creation of properties of implants made of titanium alloys, Engineering of Biomaterials 28 (2003) 17-20.

[8] T. Wierzchoń, E. Czarnowska, D. Krupa, Surface engineering in creation of titanium biomaterials, Printing House of the Warsaw University of Technology, Warszawa, Poland, 2004 (in Polish).

[9] X. Lu, Y. Leng, Electrochemical micromachining of titanium surfaces for biomedical applications, Journal of Materials Technology 169 (2005) 173-178.

[10] W. Chrzanowski, Corrosion behaviour of Ti6Al7Nb alloy after different surface treatments, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 67-70.

[11] L.A. Dobrzański, E. Hajduczek, J. Marciniak, R. Nowosielski, Physical metallurgy and heat treatment of tool materials, WNT, Warsaw, 1990 (in Polish).

[12] M. Gierzyńska-Dolna, J. Adamus, P. Lacki, Tribological properties of biomaterials and hardening layers used in joint arthroplasty, International Journal of Applied Mechanics and Engineering 9 (2004) 263-268.

[13] P.J. Prendergast, S.A. Maher, Issues in pre-clinical testing of implants, Journal of Materials Processing Technology 118 (2001) 337-342.

[14] K. Kubiak, J. Sieniawski, Development of the microstructure and fatigue strength of two phase titanium alloys in the process of forging and heat treatment, Journal of Materials Processing Technology 78 (1998) 117-121.

[15] S. Król, Z. Zalisz, M. Hepner, Comparison of the friction and wear properties of titanium and oxidised titanium in dry sliding against sintered high speed steel HS18-0-1 against C45 carbon steel, Proceedings of 13th International Scientific Conference on “Achievements in Mechanical and Materials Engineering” AMME’2005, Gliwice-Wisła, 2005, 371-374.