THE INFLUENCE OF MATERIAL KIND AND LOAD ON STRAIN AND STRESS DISTRIBUTION IN THE SYSTEM: «HEAD – ACETABULAR CUP»

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Abstract: Implantation of hip and knee endoprostheses for injured human joints is more and more common surgical operation. Extremely high wear resistance of materials used for movable elements of endoprostheses is required. There is also a distinct effect of wear products on the disease changes in system: osseous tissue – acetabular cup. Hardening of top layer by ion implantation is one of the methods increasing the wear resistance. Results of the accounts of stress and strain distribution in the system: "head – acetabular cup" have been presented. Influence of the load (body weight) on stress and strain distribution has been shown.

Key words: implantation, hip and knee endoprostheses, wear, head – acetabular cup system

Introduction

For the last 10 years the amount of people who need implantation of hip or knee endoprostheses in place of the natural joints has considerably increased. Some of the main reasons that cause injury of human natural joints (biobearings) are:

- unhealthy changes of joints as a result of rheumatism,
- excessive load of limbs caused by improper load lifting,
- mechanical injury of limbs caused for example by car crash.

The amount of these last cases is still growing.

In spite of great achievements of the west companies in the field of new endoprostheses constructions as well as the application of more perfect materials showing great biocompatibility and biotolerance, many problems still need to be solved. Failures occurring during the surgical procedures of patients with an injury of joints prove that not all problems have been properly solved so far. The most common problem occurring in using endoprosthesis is looseness of acetabular cup or stem of endoprosthesis caused by inflammable states. The life of endoprostheses, estimated for 8-10 years, is also not satisfying.

The investigations carried out in many scientific centres dealing with endoprostheses are focused on:

- finding new, more suitable materials being similar in a way of strength to natural human osseous tissue,
- geometry optimisation of endoprosthesis stem and acetabular cup,
- selection of materials for a frictional pair: "head – acetabular cup" providing minimal friction and wear,
- surface treatment of stem and acetabular cup.

Material aspects of endoprostheses

The knee and hip joints belong to the most loaded human osseous systems [1,4]. Thus materials used for the endoprostheses have to fulfil many mechanical requirements. The most frequently mentioned properties of materials used for endoprostheses are [1,2]:

– biotolerance,
– corrosion resistance,
– good static and dynamic strength,
– wear resistance.

It is essential to remember that endoprostheses are used to replace the osseous substance, so their mechanical properties should be similar to natural osseous tissue. Traditional CoCrMo alloys have been (partly) replaced by Ti6Al4V alloys as a result of searching for materials with optimal properties. Titanium alloys have more advantageous properties than CoCrMo alloys. An insufficient information about carbon materials does not give full assessment of them.

Tribological aspects of material selection

The mechanical and first of all tribological properties of materials determine durability of endoprosthesis.

The tests carried out in the special simulators can give many valuable information about wear processes occurring in frictional pair: “head – acetabular cup”. Three simulators for tests of hip and knee endoprostheses have been constructed and made at the Institute of Metal Forming and Plastics of Technical University of Częstochowa.

Tests carried out at the Institute are aimed at:

1) quality and quantity assessment of wear processes occurring in moveable contact “head - acetabular cup” and wear products,
2) fatigue strength assessment of endoprosthesis stem,
3) selection of surface treatment methods focused on increasing cup durability (a weak element).

According to the tests friction coefficient in the contact: “head – acetabular cup” mainly depends on two factors: material kind of frictional pair and surface roughness. Frictional resistance in the frictional pair influences on the intensity of material wear and the amount and form of wear products.

The values of friction coefficient for tested frictional pair: “head – polyethylene acetabular cup” were as following:

– CoCrMo - PE $\mu = 0.085$ 🕑 0.126,
– Ti6Al4V – PE $\mu = 0.0771$ 🕑 0.124,
– Ti6Al4V – TiN $\mu = 0.055$ 🕑 0.098,
– Al_2O_3 - PE $\mu = 0.047$ 🕑 0.094,
– ZrO_2 - PE $\mu = 0.062$ 🕑 0.12,

while friction coefficient of natural human joint is $\mu = 0.001$ 🕑 0.05.

Mechanical load in head and acetabular cup

The acetabular cup is a weak link of the used endoprostheses. The numerous clinical tests and observations confirm that damage of acetabular cups is the most frequent. Considering the above aspects an analysis of stress distribution in the contact: “head – acetabular cup” has been carried out.

Calculations have been made with ADINA program using the finite element method.

The following material data in calculations have been assumed:

– material of the head – ceramics Al_2O_3 $E = 3.8 \cdot 10^5$ MPa,

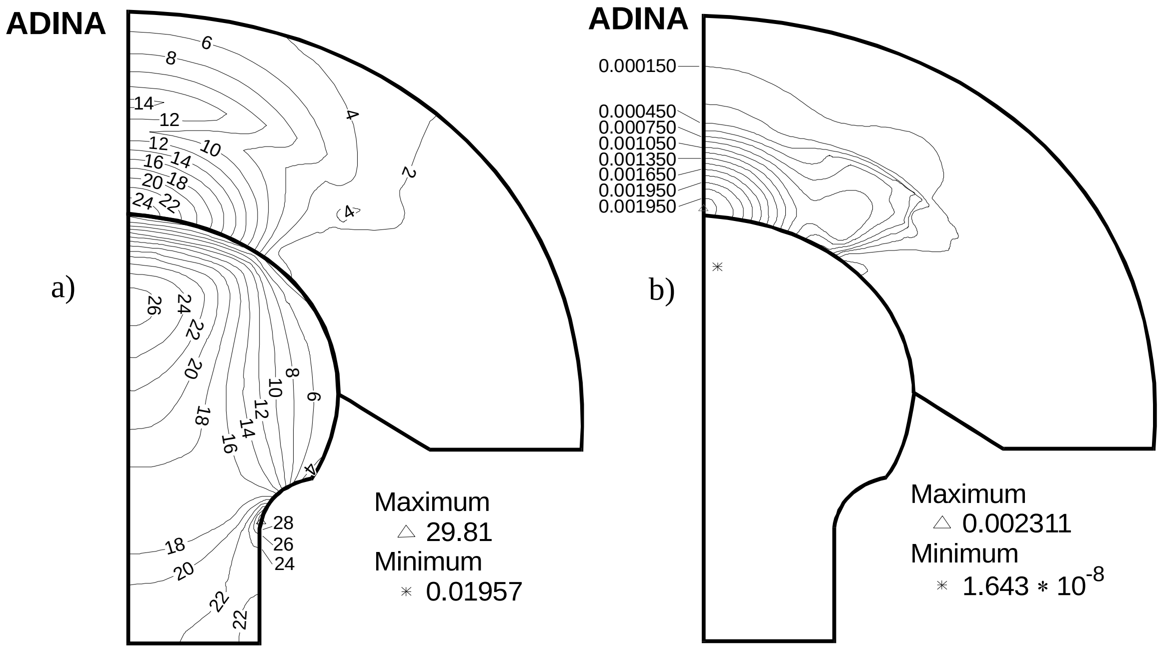

Fig. 1. Distribution of effective stress and strain in the system: "head–acetabular cup": a) stress, b) strain.

– material of acetabular cup – polyethylene $E=1\cdot10^3$ MPa,
– osseous cement $E=2.1\cdot10^3$ MPa,
– bone $E=1.5\cdot10^4$ MPa.

Calculations have been made for two kinds of friction: $\mu=0.00$ and $\mu=0.24$. The load of endoprostheses were $P_1=700$ N and $P_2=2000$ N.

In Fig.1, an example of effective stress and strain in the system: “head – acetabular cup” is presented.

In Fig.2, influence of the load on the stress and displacement distribution in a cup is presented.

In Fig.3, values of maximal stresses and displacement of the cup have been compared. According to the calculations a threefold increasing of load of the system: “head – acetabular cup” results in 1.7-times growth in stresses and strains of the cup. The increasing of a frictional resistance causes a movement of a point of the maximal effort inside the cup. A cup deformation, being sometimes observed in practice, is a result of such load of the system: “head – acetabular cup”.

The surface treatment of endoprostheses

Three kinds of surface treatment play significant part in endoprosthesis production:

– finishing (polishing) which gives high smoothness of co-operating surfaces “head – acetabular cup”,

– coating layers facilitating union of endoprosthesis stem with osseous tissue (for this aim endoprosthesis stems are coating with hydroxyapatite),

– purifying top layer of the friction elements to achieve increase wear resistance.

The third kind of surfacing based on ion implantation (carbon, nitrogen, boron, etc.) can be treated as a future surfacing, especially in relation to the polyethylene elements. The research on improving tribological properties of polyethylene by the ion implantation method started in the Technical University of Częstochowa in co-operation with the Institute of Nuclear Physics in Cracow.

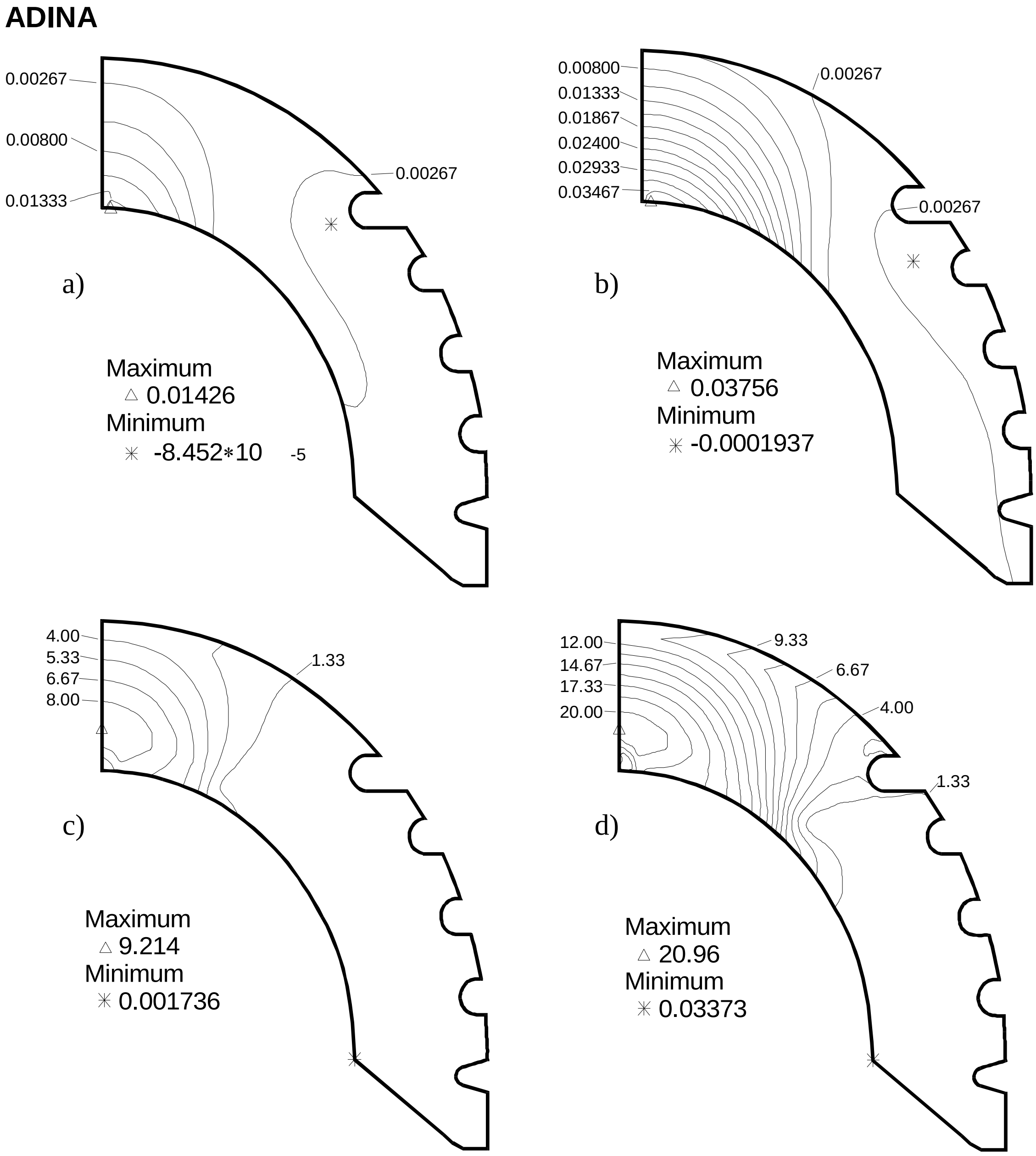

Fig. 2. Influence of the load on the stress and displacement distribution in a cup
a) the displacement distribution for the load P = 600 N,
b) the displacement distribution for the load P = 2000 N,
c) the stress distribution for the load P = 600 N,
d) the stress distribution for the load P = 2000 N.

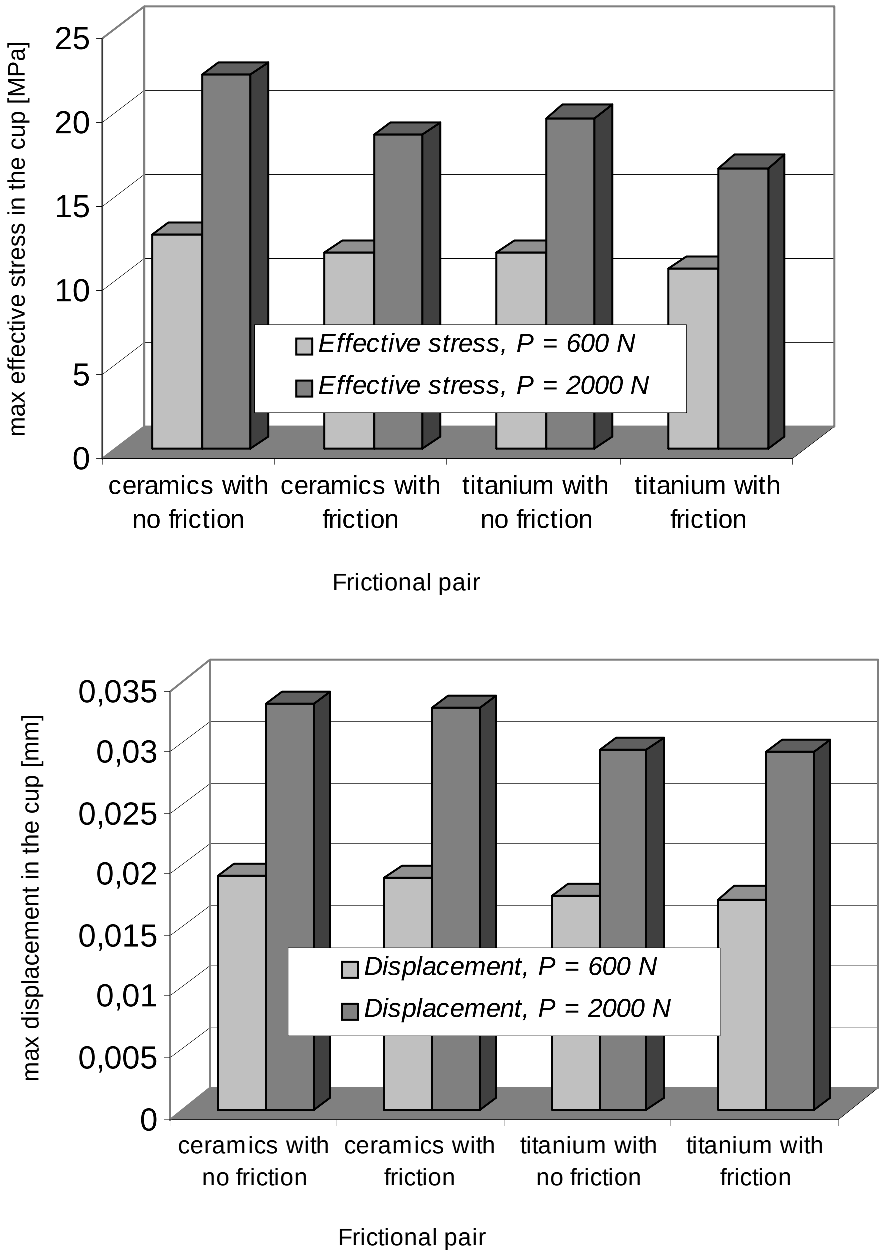

Fig. 3. Influence of the cup load on stress and displacement.

Conclusions

1. The wear limitation (decrease) of frictional pair: “head – acetabular cup” lets to achieve two aims:
   – increase the durability of endoprosthesis,
   – decrease the amount of wear product harmful for health.
2. The surface purifying by ion implantation is one of the methods of increasing endoprosthesis wear resistance.

Acknowledgements

The work has been performed of the KBN project, No 7T08C 038 09.

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ВЛИЯНИЕ ВИДА МАТЕРИАЛА И НАГРУЗКИ НА РАСПРЕДЕЛЕНИЕ ПОЛЕЙ НАПРЯЖЕНИЙ И ДЕФОРМАЦИЙ В СИСТЕМЕ «ГОЛОВКА ЭНДОПРОТЕЗА – ВЕРТЛУЖНАЯ ВПАДИНА»

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Имплантация эндопротезами поврежденных тазобедренного или коленного суставов становится повседневной хирургической операцией. Особенно износостойкий материал требуется для изготовления отдельных элементов эндопротеза. Также имеет место бесспорное влияние продуктов износа на болезненные изменения в системе “костная ткань - вертлужная впадина”. Одним из методов повышения сопротивления износу является упрочнение поверхностного слоя путем использования имплантации ионов. В статье представлены результаты вычисления распределения полей напряжений и деформаций в системе “костная ткань - вертлужная впадина”. Показано влияние нагрузки (веса тела) на распределение полей напряжений и деформаций. Библ. 5.

Ключевые слова: имплантация, эндопротезы, износ, система “головка – вертлужная впадина”

Received 18 November 1999