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Hinge-type knee prosthesis wear tests with a mechanical load and corrosion properties monitoring

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ABSTRACT

The primary goal was to compare model replacements with and without DLC layer. Components were made of the Ti6Al4V alloy and coated with a DLC layer, the sliding sleeve made of a PEEK polymer. Testing was done in the saline physiological solution (9 g/L NaCl). The measuring system was supplemented with the corrosion behavior monitoring.

The results show that the applied DLC coating significantly increases the service life of the implant. Based on the results it is possible to state that an accurate mechanical load together with corrosion behavior monitoring shifts testing in the given field to a qualitatively higher level.

1. Introduction

The hinge type of total knee replacement stands away from the main stream of related research due to its non-anatomic joint movements, yet it is the only possible option for some medical indications. A great part of implantations are conducted on patients after a bone tumor operation in the vicinity of the knee joint. Given the ever growing rate of success in the field of tumor treatment, mechanical and tribological requirements on implants are increasing accordingly. Similarly as in the case of anatomic replacements, younger patients in particular wish to preserve their active life style in spite of the seriousness of their illness, and perform their everyday activities with the aid of total replacement. From patients' point of view, joint replacement implantation represents a radical medical intervention in their body followed by convalescence. Consequently, their logical and justified requirement is for the implant to fulfill its function in the body as long as possible even after the primary illness has been cured. In vitro simulations may serve as an important tool in predicting the abrasive behavior of the implant and/or of new materials applied in the implant contact pair. Since a simulation cannot provide for entirely identical conditions as those of the joint dynamic movement after implantation, in vitro testing of implant components is conducted with some sets of movement and load parameters simplified [1]. However, this modification must not decrease the informative value of experiments with regard to the clinical practice [2].

Mechanical load may significantly affect the properties of materials applied in orthopedic implants. Consequently, scientists search for ways allowing for the use of current materials, well-tested in a number of other biological applications, in highly loaded implants as well. DLC layers (Diamond-Like-Carbon layers) represent a suitable choice for bio-tribological applications due to their high wear resistance [3]. Another reason for using these layers in biomedical applications rests in their bio-inert character, low friction coefficient, high hardness, and good wear and corrosion resistance. DLC coating may be obtained by way of various coating technologies [4–6]. Lasting interest is devoted to assessing the efficacy of DLC coating and the mechanisms of its wear.

While testing real components, it is usually impossible to fix the time of the damage initiation and then interrupt the test in order to evaluate the implant state and search for its cause. It is therefore desirable to supplement the obtained set of monitored values with a quantity that would sensitively react to the implant surface conditions/corrosion behavior. Corrosion resistance of

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titanium and its alloys is based on their ability to passivate, which ensues from the existence of the passive layer. In the given case it is a thin (thickness in the order of nanometers) oxide layer which forms very quickly in the air or in electrolytes containing oxygen [7]. Coating with a DLC layer, aimed primarily at improving tribological properties, has a neutral or positive effect on the corrosion properties of a coated Ti-DLC system. The DLC layer takes over part of the cathodic process (oxygen reduction), thus increasing the passive state stability in layer pores.

Corrosion behavior of metallic materials, or layers deposited on a metallic base, can be monitored by way of a number of methods providing good-quality information about corrosion behavior as well as corrosion rate quantification. Open circuit potential monitoring is the simplest method of examining passive materials. Its changes (decrease) at a passive layer breakdown may range in the order of several hundreds of millivolts. The instrumental part of such monitoring system is relatively simple. Its outcome is the open circuit potential time dependence, on which the passive layer degradation manifests itself by a gradual decrease in the measured value or, in case of a local breakdown, by jumps of the potential. Similarly, electrochemical noise measurement method also provides rather qualitative information about the state of the passive layer. This method consists of scanning the oscillation of the same quantity as in the preceding case, i.e. the open circuit potential (frequency in the order of 10^1 Hz and lower), around its mean value. Passivity breakdowns are indicated by increasing electrochemical noise. More quantitative information about the rate of corrosion processes, even in systems with a changing mechanical load, can be provided by polarization resistance measurement [8]. However, application of the last mentioned methods requires more sophisticated instrumentation.

The presented study is aimed to assess the DLC layer effect on the tribological properties of a model knee joint prosthesis, and to ascertain applicability of open circuit potential measurement in identifying an early stage of damage.

2. Material and methods

The tested implants were coated with a DLC layer using Hauzer Flexicoat 1200 equipment (chamber volume 1000l). Prior to deposition, the implants were degreased in an ultrasound alkaline bath, rinsed in deionized water and dried in vacuum. Ti6Al4V (Ti Grade 5 ELI) was used for the implants. Then the implants were cleaned in argon plasma and coated with an adhesive interlayer with a gradient composition changing from Ti to Ti-C:H. The interlayer was deposited by way of nonequilibrium magnetron sputtering from Ti (99.5) targets in Ar (99.999% purity) and C_2H_2 (99.6% purity) atmosphere. The upper layer a-C:H was deposited using the PACVD (Plasma Assisted Chemical Vapor Deposition) method, with a pulsed bias 50 kHz applied on the substrates holder and peak voltage 200 V. Deposition temperature was 200 °C, C_2H_2 flow 500 sccm, base pressure 2.10^{-3} Pa and exposition pressure 1.0 Pa.

The measurement of the layers mechanical properties was carried out on metallographically polished DIN X153CrMoV12 steel specimens hardened to 62 HRC. They were placed in the same positions as the coated implants. The thickness of the deposited layers was determined using a calotest method, the layers adhesion to the coated material was tested on CSEM Revetest equipment using the standard scratch test method. A second adhesion measurement, Mercedes test, was conducted for comparison. The surroundings of the stab created by the hardness measuring device with a diamond Rockwell tip at a load of 150 kg (HRC) was optically assessed, and evaluated using a parameter from 1 to 6. The Fischer PICODENTOR® HM500 device was used to measure the layers hardness. The measurement was carried out at a load of 20 mN. HV values corresponding to the standard Vickers hardness were calculated.

The simulator—KKK ELO 2007 (Fig. 1) was developed for the testing according to the ISO standard for knee joint prostheses [9]. The knee joint simulator was designed so as to simulate flexion, AP movement (forward–backward) and IE rotation (internal–external). This means that the simulator had three controlled kinematical degrees of freedom. The component movements were controlled by one linear and two torsion independent motors. The exposed component was placed in a cell closed with a flexible latex element coated with a layer of silicon rubber. Saline solution containing 9 g/L sodium chloride was used as the testing medium at 37.0 ± 0.2 °C. The cell diagram is shown in Fig. 1. The hinge, the femoral section and the tibial components of the studied implants were made of the Ti6Al4V alloy (Ti Grade 5). The pair of sliding sleeves placed in the tibial component was made of PEEK polymer.

In terms of the load kinematics and dynamics, the experiment was designed in agreement with requirements on the real range

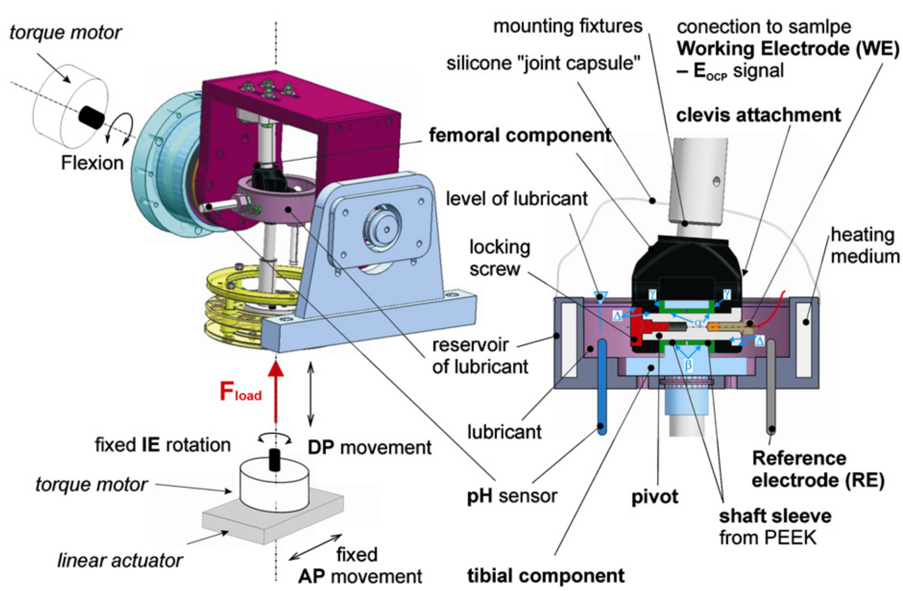

Fig. 1. Exposure system diagram.