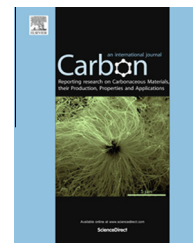


Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/carbon

Friction pair evaluation of cartilage–diamond for partial joint repair

Huaping Xiao ^{a,1}, Sunghan Kim ^a, Xingliang He ^a, Dongsheng Zhou ^b, Chengming Li ^c, Hong Liang ^{a,*}

^a Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, USA

^b Shandong Provincial Orthopaedic Hospital, Jinan, Shandong 250014, China

^c School of Materials Science and Engineering, University of Science Technology Beijing, Beijing 100083, China

ARTICLE INFO

Article history:

Received 22 April 2014

Accepted 29 August 2014

Available online 6 September 2014

ABSTRACT

Alternative approaches to replace total joint replacement are desirable to reduce the massive loss of healthy tissues. The tribological performance of the cartilage–diamond contact in deionized water and calf bovine serum environments was investigated in this study. To optimize lubrication, hydrogen and ammonia treatments were applied on diamond surfaces. Adhesion and wettability on the same were evaluated to determine the impact of functionalization on surface properties. It was found that the friction between the cartilage and diamond decreased with an increase in the load. This is related to the interaction between two contacting surfaces. Under dry conditions, the hydrogen treatment enabled a reduction in friction while the ammonia treatment increased it. The lubricated friction, however, is determined by two effects: the surface area covered by the lubricant and their interactions. Our results show that the microcrystalline diamond without functionalization provided the lowest friction (coefficient of 0.02–0.03) while sliding against cartilage in serum. The reason is that microcrystalline diamond attracts more molecules that dominate the lubricating performance. This research demonstrated that diamond materials could be suitable as implants as well as to locally repair them.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The extended life span and aging generation often involve a high incidence of osteoarthritis [1–3]. The most common cause of osteoarthritis is the tissue damage of cartilage or joint bone. For example, hip joint fracture caused by osteoarthritis is a major clinic concern [2]. Total or partial joint replacement is one of the most widely used approaches to reduce patients' pain and recover the disabilities induced by joint fracture. Hemiarthroplasty is usually applied to treat

patients when there is a fracture in the femoral neck of a hip joint or damage in the knuckle or shoulder joint [4,5]. In hemiarthroplasty, the problem side of the joint is replaced by an implant, generating a cartilage/artificial material interface. Compared to total joint replacement, hemiarthroplasty involves less intensive surgical operation, needs minimal time to recover, and causes less harm to the patient's body [6–8].

The performance of the implant is determined by the properties of the materials at the interface. Alloys, ceramics,

* Corresponding author.

E-mail address: hliang@tamu.edu (H. Liang).

¹ Current Affiliation: College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing 102249, China.

<http://dx.doi.org/10.1016/j.carbon.2014.08.095>

0008-6223/© 2014 Elsevier Ltd. All rights reserved.

and polymers are common materials used as replacements in hemiarthroplasty. Metallic alloys are utilized due to their excellent mechanical properties, such as ductility and hardness, and wear resistance [9,10]. Polymers showed chemical stability and a low coefficient of friction (COF) when they were used as contacting surfaces in physiological environments [11,12]. Ceramics, such as TiN, Al_2O_3 , and ZrO_2 , are usually used as the backbone or coating materials in implants [13]. In the case of long-term use, however, these materials may fail before the designed service life. The corrosion induced by the dissolution of a passivation film on the metal surface in the presence of Cl^- , SO_4^{2-} , and HCO_3^- in the physiological liquid is responsible for the failure of some metallic alloys [10]. The toxicity of cobalt in some alloys also limits their usage [14]. The wear debris generated from polymers may lead to harmful effects, such as the inflammation of tissue around the implant [15].

As a promising material for biomedical application, diamond has attracted great attention due to its high hardness, chemical inertness, low friction, and high wear resistance [16–18]. These properties make diamond a promising candidate as coatings on the artificial joint. Compared to the bare metal-on-metal contact, diamond-like carbon (DLC) coating on metal ($\text{Co}_{28}\text{Cr}_6\text{Mo}$) surfaces was found to effectively reduce the volumetric wear [19]. The wear rate of tetrahedral amorphous carbon (ta-C)-coated metal-on-polyethylene mating pair was 10^5 – 10^6 times lower than the metal-on-metal or metal-on-polyethylene joint, and the corrosion rate greatly decreased as well [20]. The service time of the artificial joint has been significantly increased by coating a ta-C film on both the metal surface and the polymer surface for an ultra-high-molecular-weight polyethylene and Co–Cr–Mo contact [21].

Most of the previous studies focused on the contact composed of two synthetic materials. To make it possible to repair one of the two rubbing components, that is, hemiarthroplasty, we focus on the contact surfaces between a human tissue, such as cartilage, and diamond as the contacting surface. In this study, the tribological performance of diamond sliding on a human cartilage was investigated. This study generates understanding in the tribological behavior of diamond materials used as implants in hemiarthroplasty.

2. Experimental

Human cartilage was collected after a surgery by one of the authors (Zhou). The specimens were cleaned with alcohol and stored in a refrigerator (-4°C) before testing. Six diamond samples were studied, including nanocrystalline diamond (NCD), ammonia-treated NCD (NCD-NH_3), hydrogen-treated NCD (NCD-H_2), microcrystalline diamond (MCD), ammonia-treated MCD (MCD-NH_3), and hydrogen-treated MCD (MCD-H_2). MCD and NCD are polycrystalline diamonds with grains in micro- or nanoscale. The MCD has a larger grain size and lower density of boundaries than other samples [22,23]. More carbon atoms are tetrahedrally arranged in MCD, leading to a larger ratio of sp^3 bonding to sp^2 bonding. This means the properties of MCD are closer to those of tetrahedral amorphous carbon in the ternary phase diagram for DLC [24]. The thickness of the diamond coating on the silicon substrate

is $\sim 5\ \mu\text{m}$. The NCD was deposited on the silicon surface using the microwave plasma chemical vapor deposition (CVD) method with argon-rich $\text{CH}_4/\text{H}_2/\text{Ar}$ plasmas. The MCD was prepared by means of direct current (DC) arc jet CVD in a circulating $\text{CH}_4/\text{H}_2/\text{Ar}$ environment. The as-deposited MCD was then polished with diamond grinding wheels. The hydrogen treatment was carried out at 750 – 800°C for 15 min while the ammonia treatment was carried out at 300°C for the same time. More details about the sample preparation can be seen in Refs. [25,26].

The sample surfaces were characterized using atomic force microscopy (AFM) and Raman spectroscopy techniques. The contact angle of deionized water (DI water, $10\ \mu\text{l}$) on different diamond surfaces was measured. The adhesion force between the diamond and the AFM tip (standard Si_3N_4 tip) was evaluated. Ten measurements were obtained for each sample. The two lowest and two highest results were eliminated and the averaged value of the remaining six measurements was taken as the effective adhesion force.

The COF between the cartilage and the diamond was measured using a pin-on-disk tribometer (CSM Instruments). Fig. 1 shows the schematic of the experimental setup for tribological measurements. The cartilage was attached to a steel rod with a diameter of 1 cm using super glue as shown in Fig. 1. The diamond-coated silicon specimens were square shaped with a size of $1 \times 1\ \text{cm}$. The diamond sample was attached to a linear stage that reciprocally moves with a length of 3 mm. During frictional experiments, some drops of DI water and as-received commercial calf bovine serum (Thermo Fisher Scientific Inc.) were added into the contact as a lubricant. The authors made sure that the contact was fully covered by the lubricant. The reason we used DI water was to pinpoint interfacial interactions during spectroscopic characterization. During experiments, a piezoelectric sensor recorded the frictional force and the COF between the cartilage and the diamond. The COF under different conditions was measured. The sliding speed was changed from 2 to 6 mm/s with an increment of 1 mm/s, while the applied load was increased from 0.5 to 1.5 N with an increment of 0.25 N, with applied pressure from 50 to 150 kPa, respectively. Each test lasted for 1 min and the presented COF is the average value. These conditions were set based on simple calculation to mimic a human hip joint. The COF of

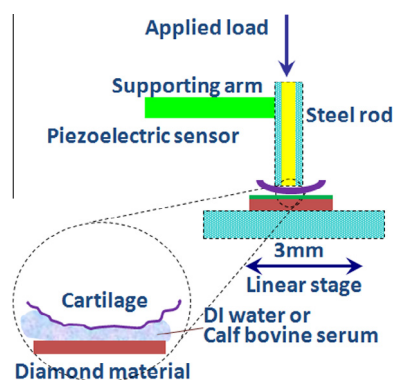


Fig. 1 – Schematic expression of tribological experiment. (A color version of this figure can be viewed online.)

Download English Version:

<https://daneshyari.com/en/article/1413753>

Download Persian Version:

<https://daneshyari.com/article/1413753>

[Daneshyari.com](https://daneshyari.com)