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Short communication

Sliding wear characteristics of the diamond-like carbon films on alloy substrates

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Abstract

This study used an un-balanced magnetron sputtering system to deposit different thickness of diamond-like carbon (DLC) film on Co–Cr–Mo and Ti–6A1–4V alloy substrate. Wear test, Raman spectroscopy analysis, nano-indentation test and morphology of contact surface were conducted to evaluate the tribological performance of these films for bio-medical applications. The ring-on-disk wear testing shows that the thicker film leads to the lower friction coefficient and higher wear resistance. In the testing process, the fluctuating friction coefficient of DLC coated Co–Cr–Mo substrate was less than that of DLC coated Ti–6Al–4V substrate. Raman spectroscopy analysis and nano-indentation test provide the underlying mechanism for the enhancement of the wear resistance. The DLC coated Co–Cr–Mo substrate provides better wear resistance than the DLC coated Ti–6Al–4V substrate owing to better adhesion of DLC film to the Co–Cr–Mo substrate.

Keywords: Diamond-like carbon (DLC); Nano-indentation test; Raman spectroscopy

1. Introduction

The function of an artificial joint is to restore smooth articulation between the bones of the joint. The total hip arthroplasty consists of a femoral component with a head and stem and an acetabular component with a metal backing and acetabular cup. Medical grade ultra high molecular polyethylene (UHMWPE) that articulates well against alloy (typically Co–Cr–Mo) is generally used in total joint replacements. The clinical performance of the cup mode of UHMWPE is well accepted except for its wear behaviour.

Over the years, the improvement of the wear resistance of UHMWPE has not met the expectation [1]. Thus, the current trend is to replace the weaker component UHMWPE, with a relatively harder counter-face. That results in the new generation of total joint replacements with metal-on-metal (MOM) sliding pairs, in which Co–Cr–Mo and Ti–6Al–4V alloy are the key materials. Metal-on-metal joint bearings are gaining more acceptance as an alternative to conventional metal-on-polyethylene (MOP) bearings due to its excellent wear resistance [2,3]. However, in addition to the tribological behaviour of this metal-on-metal sliding pair, surface modification of Co–Cr–Mo and Ti–6Al–4V alloy with an inert coating such as high quality DLC may prolong the life of the component and also reduce the release of ions.

Diamond-like carbon (DLC) coatings have been of interest as a protective coating in biomaterials ever since clinical studies showed successful results for DLC-coated artificial mechanical heart valve (AMHV) [4,5]. Lappalainen et al. [5] showed that amorphous diamond coating is able to improve the wear and corrosion resistance compared to uncoated materials. McNamara et al. [6] specifically identified the adhesion strength properties of diamond-like coating and its dependence on process parameters for applications to orthopaedic steels, alloys and polymer substrates. Some researchers have investigated the wear rate of UHMWPE against DLC-coated stainless steel and reported that the DLC coating reduces the wear of the polymer by approximately seven times, and the DLC coating improves the frictional and wear characteristics of DLC coated Ti–6Al–4V sliding against UHMWPE [7,8].

The investigation of the wear of biomaterials conducted by Kim et al. [9] showed that the DLC coating dramatically improved the wear performance of Ti and Ti–6Al–4V, and protected the substrates from corrosion and wear. Sheeja et al. [10]

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reveal that the tribological behaviour of uncoated Co–Cr–Mo and DLC coated Co–Cr–Mo sliding pairs clearly shows that the friction of the Co–Cr–Mo sliding pair can be significantly reduced by the DLC coating on the sliding surface. The wear depth and the roughness of the transfer layer prove that the uncoated sliding pairs exhibit a larger wear than that of the DLC coating.

The present work is to investigate tribological behavior of DLC coated on Co–Cr–Mo and Ti–6Al–4V alloy disks against Co–Cr–Mo rings. The characteristics of DLC of different thickness were measured using atomic force microscopy (AFM) and nano-indentor. Wear test was conducted to show the effect of DLC on tribological behavior of different alloy against Co–Cr–Mo ring.

2. Experiments

2.1. DLC coating and specimen preparation

The deposition of DLC was conducted in un-balanced magnetron (UBM) sputtering system of a Teer Coating Ltd. UPD-450. The sputtering graphite and titanium targets was used to deposit different thickness (0.3, 0.6 and 1.2 μm) DLC film on Co–Cr–Mo (ASTM F-75) and Ti–6A1–4V (ASTM F-136) alloy substrates. Table 1 list the deposition parameters of the DLC, such as pressure, sputtering time ... et al. Before the coating deposition, the disks were ground and polished to obtain mirror-like smoothness. The grinding and polishing were done in many stages. First step of grinding was done with 150 grit abrasive paper, followed by 400, 600, 1000, 1500 and 2000 grit abrasive papers. Subsequently, the grounded surfaces were polished with 0.05 μm alumina solution to get mirror-like smoothness. The dimensions of the prepared ring and disk are shown in Fig. 1. The polished substrates were cleaned with acetone, alcohol and water in an ultrasonic bath tank to remove any chemical residue and attached Al_2O_3 particulate or debris [6] for the adhesion enhancement of DLC. The samples were then analysed for its roughness using the surface profiler and optical microscope. The averaged surface roughness R_q (root mean square) values of the

Table 1
DLC film deposition parameters

Parameters	Values		
Sputtering sources	Un-balanced magnetron sputtering system		
Substrate materials	Ti–6Al–4V and Co–Cr–Mo		
Chamber pressure (mTorr)	3		
Target		Ti	C
Magnetron current (A)		0.5	2
Thickness (μm)	0.3	0.6	1.2
Coating times (h)	0.5	1	2

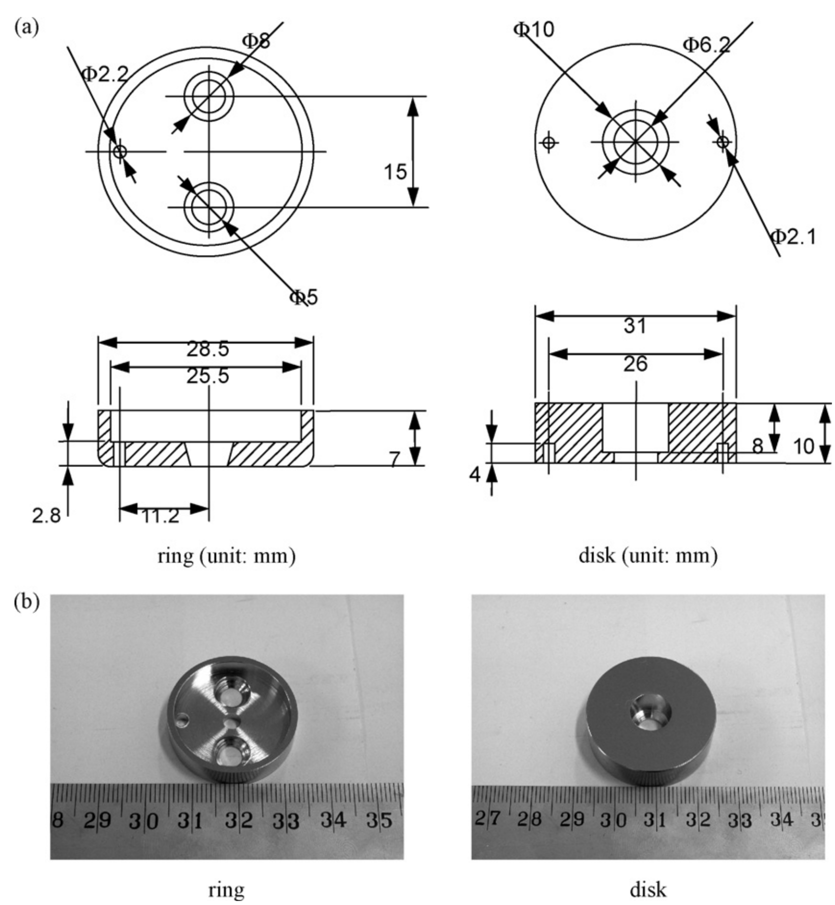

Fig. 1. Ring and disk prepared before deposition: (a) dimensions; (b) real ones.