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ScienceDirect
J China Univ Mining & Technol 18 (2008) 0606–0612
JOURNAL OF CHINA UNIVERSITY OF MINING & TECHNOLOGY
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Biotribological behavior of ultra high molecular weight polyethylene composites containing bovine bone hydroxyapatite

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Abstract: Wear particles of ultrahigh molecular weight polyethylene (UHMWPE) are the main cause of long-term failure of total joint replacements. Therefore, increasing its wear resistance or bioactivity will be very useful in order to obtain high quality artificial joints. In our study, UHMWPE composites filled with the bovine bone hydroxyapatite (BHA) were prepared by the method of compression moulding. A ball-on-disc wear test was carried out with a Universal Micro-Tribometer to investigate the friction and wear behavior of a Si_3N_4 ceramic ball, cross-sliding against the UHMWPE/BHA composites with human plasma lubrication. At the same time, the profiles of the worn grooves on the UHMWPE/BHA surface were scanned. The experimental results indicate that the addition of BHA to UHMWPE had a significant effect on the biotribological behavior of UHMWPE cross-sliding against the Si_3N_4 ceramic ball. The addition of BHA powder enhanced the hardness and modulus of elasticity of these composites and decreased the friction coefficients and wear rates under conditions of human plasma lubrication. When the added amount of BHA powders was up to 20%~30%, UHMWPE/BHA composites demonstrated the designed performance of the mechanical properties and biotribological behavior.
Key words: UHMWPE; hydroxyapatite; biotribology; composite material

1 Introduction

Ultra high molecular weight polyethylene (UHMWPE) is an organic polymer widely used as an acetabular component in hip and total knee joint replacements, because of its excellent mechanical properties, biocompatibility and stability in the human body[1–2]. However, in recent years it has been recognized that the wear debris of UHMWPE may be a limiting factor for the long-term success of prostheses. At Present, most clinical results have revealed that aseptic loosening is the primary cause of failure of total hip replacements (THRs) and accounts for almost three-quarters of all revision operations[3–6]. Aseptic loosening has been strongly linked with UHMWPE wear debris-induced osteolysis and since the occurrence and severity of osteolysis appears to be related to the size and concentration of wear particles, it follows that reducing the amount and rate of generation of wear particles should reduce the occurrence of long-term aseptic loosening[7–8]. Therefore, it is believed that two effective methods to reduce aseptic loosening are the following:

1) improving the wear resistance to reduce the concentration of wear debris.

2) increasing the biocompatibility and bioactivity to decrease adverse biological reactions.

Since the wear resistance of UHMWPE appears to be related to its mechanical properties, especially those on the surface, it follows that an increased enhancement of its mechanical properties should improve the wear resistance of UHMWPE. Many authors have reported that the mechanical properties of UHMWPE composites can be improved by introducing reinforced second phases of ceramics ($A1_2O_3$, TiO_2, quartz, wollastonite, etc.), metals or polymers (polyurethane, phenyl *p*-hydroxyzoate, etc.)[9–15]. The results show that these reinforced second phases may improve not only the mechanical properties but also the wear performance of UHMWPE-based composites. But, most of these filling materials have no or at best poor biocompatibility and bioactivity.

Hydroxyapatite (HA) is currently used as a biomaterial for many applications in biomedicine, because it can form a real bond with the surrounding bone tissue when implanted[16]. Several studies on UHMWPE/HA composites have been reported. Reis et al. investigated the impact behavior of a HA/UHMWPE composite[17]. Cunha et al. studied the effect of processing conditions on the mechanical

Received 07 April 2008; accepted 12 June 2008
Projects 50535050 supported by the National Natural Science Foundation of China and NCET-06-0479 by the New Century Excellent Talents in University
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behavior of the HA/UHMWPE composite using injection and compression molding[18]. However, few of these efforts are related to the natural bone hydroxyapatite, which has been used as bone implant material due to its improved bioactivity, structure and components, similar to that of human bones. Knets et al. produced an annealed compact bone tissue reinforced UHMWPE composite, but few processing details were given[19].

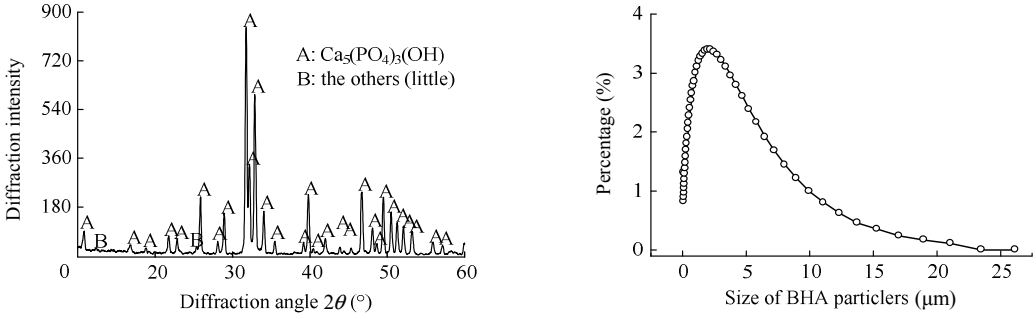
In order to improve the wear resistance and bioactivity of UHMWPE and reduce aseptic loosening, bovine bone hydroxyapatite (BHA) powders (<10 μm) obtained from natural compact bones were filled in UHMWPE. In our study, we prepared UHMWPE/BHA composites by a method of formation pressing. The present investigation focused on mechanical surface properties and the biotribological behavior of Si_3N_4 ceramic cross-sliding against these composites under conditions of human plasma lubrication.

2 Material and methods

2.1 Raw and processed material

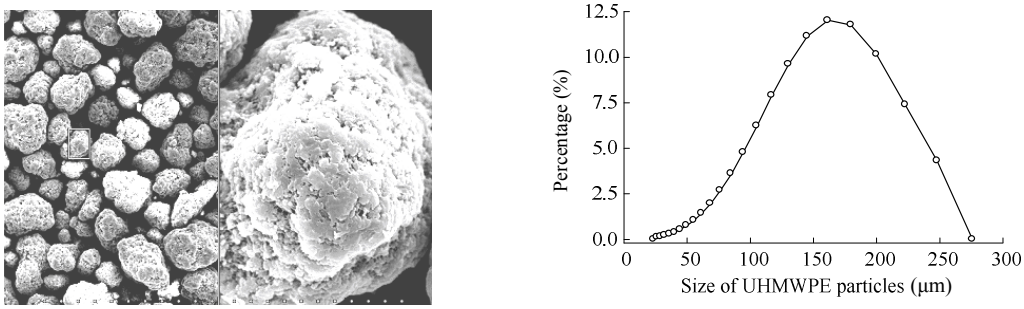
The middle compact bone was selected from fresh bovine femoral bones as our experimental material, from which the parenchyma and marrow were removed thoroughly. After drying at room temperature for two weeks, this bone material was smashed and reduced to powder with particle sizes less then 10 μm. The bovine powders were disinfected in a $NaHCO_3$ solution at high pressure for 30 min and then washed by distilled water several times and dried at 80 °C for 24 h. The dried powder was sintered at 800 °C for 2 h and cooled in a stove to room temperature. XRD spectra of the bovine powder, as shown in Fig. 1a, indicated that hydroxyapatite (HA) was the main mineral component, which agreed with HA standard spectra provided by JCPDS-ICDD. The size distribution curve of BHA powder in Fig. 1b shows that the median diameter (D50) was about 1.58 μm and the specific surface area 3023.17 m^2/kg.

Fig. 2 shows the analytical results of UHMWPE powder with a molecular weight of 5.4×10^6 g/mol (Lingen Chemicals Co., Ltd, China). The median diameter (D50) was about 157.21 μm and the specific surface area 16.53 m^2/kg (Fig. 2b). Prior to milling, the BHA powder was coated by the coupling agent KH-550 and dried in a vacuum oven at 80 °C for 12 h. The ball milling was conducted in a rotary ball mill with adjustable rotation speed up to 35 r/min. The mill container volume was 1.0 L and the agate ball diameter was about 8 mm. The mill container and ball were cleaned by rinsing in an analytical grade ethanol before ball milling. The coated BHA powder was compounded with the UHMWPE powder by ball milling in ethanol for 8 h. Then the mixture was dried in a vacuum oven at 80 °C for 24 h. Finally, it was hot pressed at 190 °C to form 6 mm thick UHMWPE/BHA composite discs of 50 mm diameter.



(a) XRD spectra (b) Size distribution curve

Fig. 1 XRD spectra of bovine bone powder and size distribution curve of bovine hydroxyapatite powder



(a) SEM micrograph (b) Size distribution curve

Fig. 2 SEM micrograph of UHMWPE particles and size distribution curve of UHMWPE powder