Effect of Roughened Counterpart on Behaviors of Vitamin E Infused Ultra-High Molecular Weight Polyethylene

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Introduction:

Ultra-high molecular weight polyethylene (UHMWPE), granted as a successful prosthetic biomaterial, has been widely used in total joint replacements. However the longevity of prostheses is greatly limited by the delamination wear due to the oxidative degradation of UHMWPE components. It has been addressed clinically and was reproduced in laboratories as UHMWPE components were sterilized by the gamma irradiation in air [1]. To eliminate free radicals caused by irradiations, vitamin E is employed to stabilize UHMWPE. In the literatures some investigations demonstrated the massive reduction in wear [2]. The aim of the present study is to address the behaviors of vitamin E infused UHMWPE (E1) as articulating against roughened counterpart.

Methods:

Two groups of samples were prepared, E1 and UHMWPE (GUR1050 Ticona) direct-compression moulded at the temperature of 175°C for 30 minutes. The material combination of flat-ended metallic indentors loaded against polyethylene plates was constructed. At the first stage of wear tests the counterparts with smooth bearing surfaces were used, which had the roughness less than 0.03μm. At the second stage the counterparts were ground to have the roughness of 1.307 ± 0.205μm (mean ± standard deviation). Wear tests were carried out using a Durham four-station multi-directional pin-on-plate machine, which generated both reciprocating and rotating motions simultaneously (Fig. 1). Their frequencies were pre-set as 1Hz. The articulating surfaces were lubricated using 25% diluted bovine serum (protein content 17.5g/L). The load applied in present study was 40N. The stroke length was 20mm. Wear tests were conducted up to three million cycles (MC) at each stage. The machine was stopped every 0.25MC to clean samples and record masses gravimetrically. The mass losses of worn plates were corrected by soaking controls.

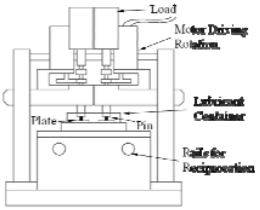
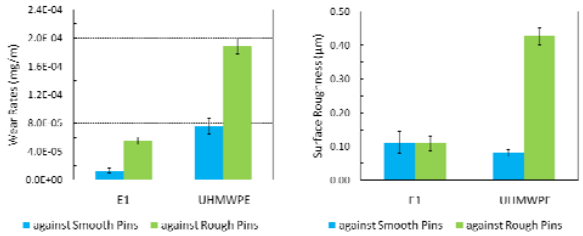


Figure 1 Schematics of pin-on-plate machine

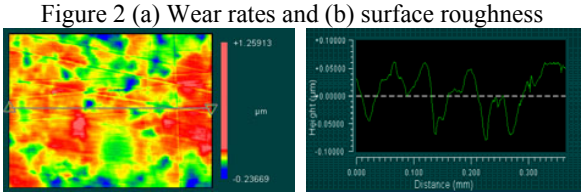
Results:

Figure 2 compares the wear rates of polyethylene plates and surface roughness recorded after wear tests. The wear-resistant ability of UHMPWE is greatly improved as the vitamin E is applied during processing. Sliding against counterparts with smooth surfaces, E1 produces the wear rate of $1.340\times10^{-5}\pm0.035\times10^{-5}$mg/m (mean ± standard deviation), which is approximately 82.2% lower than that of conventional UHMWPE. As expected the roughened counterparts result in massive wear generation for both types of materials. The increases are 75.9% for E1 and 59.9% for conventional UHMPWE. As illustrated in Fig. 2 the roughened counterparts lead to increases of both wear rate and surface roughness for conventional UHMWPE. Interestingly it is noticed that there is less change for E1, which remains in the magnitude of approximate 0.10μm. Using non-contact profilometer Zygo View 100, the topographical analyses show the presence of inter-particle boundaries in E1 worn surfaces as displayed in 2-D contours in Fig. 3 and Fig. 4. The line profiles through the central lines of 2-D plots show the variations like waves. Further examination indicates that bands of ripple-like patterns form in E1 worn surfaces at the stage of sliding against roughened counterparts. They consist of a series of alternative ridges and valleys and occur only at the peaks of the line profile in Fig. 4b.



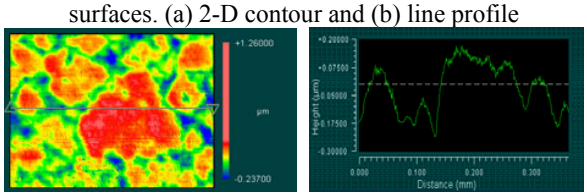
(a) (b)

Figure 2 (a) Wear rates and (b) surface roughness



(a) (b)

Figure 3 Features of E1 aginst indentors with smooth surfaces. (a) 2-D contour and (b) line profile



(a) (b)

Figure 4 Features of E1 aginst indentors with roughened surfaces. (a) 2-D contour and (b) line profile

Conclusions:

The wear debris accumulating around joint prostheses increase the risks to make bearing surfaces roughened. In present study the counterparts with rough surfaces increase wear generation of E1 to some extent. But in contrast to conventional UHMWPE, vitamin E infused UHMWPE is proven to have the excellent wear-resistance ability. Moreover the roughened counterpart has less effect on roughness of E1.

References:

1. (Bell CJ. J Arthrop. 1998; 13:280-290.)
2. (Oral E. Biomaterials. 2009; 30:1870-1880.)