Improvements on Wear Performance of Ultra-High Molecular Weight Polyethylene through Precise Temperature-Time Moulding Conditions

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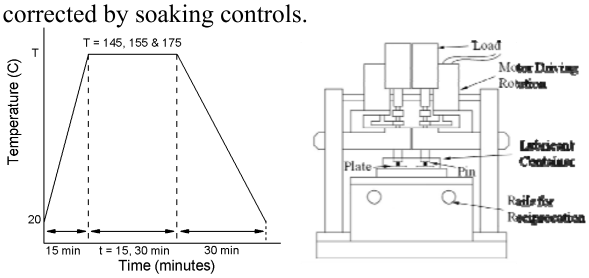
Introduction:

Ultra-high molecular weight polyethylene (UHMWPE) has been the preferred biomaterial used in total knee replacements (TKR) for decades because of its high impact strength, proven excellent wear-resistance ability and biocompatibility. However for the growing demands in young and active patients, the long-term concerns still remain regarding to wear debris, which triggers the occurrence of osteolysis [1]. As one of factors leading to delamination wear, fusion defects were reported to be contained in both explanted and non-implanted UHMWPE components [2]. Their origin in UHMWPE has been investigated [3]. The present study aims to enhance material integrity and reduce the probability of material failure. Wear tests were carried out to examine the hypothesis that there is a correlation between material failure of UHMWPE components and the precise temperature-time history employed during fabrications.

Methods:

UHMWPE plates were direct-compression moulded at a variety of temperature-time consequences (Fig. 1a) using GUR1050 powder (Ticona). These were considered to form different degrees of inter-particle diffusions in plates. The material combination of flat-ended metallic indentors loaded against UHMWPE plates was constructed to mimic conformal contact conditions in knee prostheses. 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. 1b). 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. The tests were conducted up to three million cycles (MC). 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.



(a) (b)

Figure 1 (a) Temperature-time histories of UHMWPE plates; (b) Schematics of pin-on-plate machine

Results:

Figure 2 illustrates the wear rates of UHMWPE moulded at temperatures of 145°C, 150°C and 175°C for dwell times of 15 and 30 minutes. The averaged values over four stations are presented with standard deviations. Among four groups of UHWMPE plates, the graph shows a descending trend of wear rates apparently. For a temperature of 175°C and a dwell time of 30 minutes, the minimum wear rate is achieved, which has the magnitude of $7.520\times10^{-5} \pm 1.256\times10^{-5}$ mg/m (mean ± standard deviation). In contrast to those at 145°C for 15 minutes, the wear rate drops about 39.4%. It well depicts that the moulding condition with high temperatures and long dwell time strengthen inter-particle cohesion.

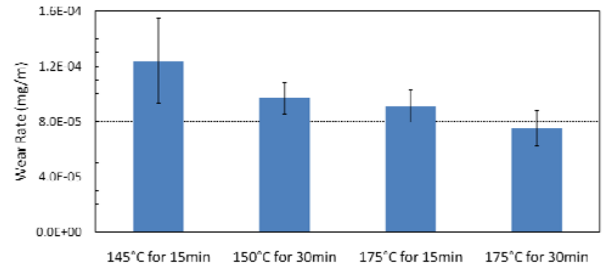
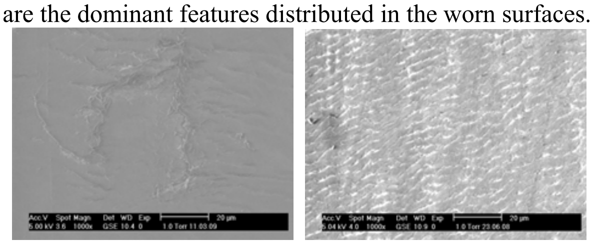


Figure 2 Wear rates of UHMWPE moulded at a series of temperature-time sequences.

The structural analyses, using non-contact profilometer Zygo View 100, indicate that the moulding surfaces of all plates have the similar roughness varying in the range of 0.150~0.225μm. For the temperature of 145°C, the voids due to incomplete consolidation are observed in the surfaces initially. After 3MC wear test it is noticed that micro-cracks take place in one of plates. ESEM image in Fig. 3a shows that material ruptures occur along the interfaces. Cracks originate from the interfaces and align perpendicular to the principle sliding direction. The application of high moulding temperature greatly reduces the occurrence of defects. For the temperature of 175°C, ESEM image in Fig. 3b reveals that ripple-like patterns are the dominant features distributed in the worn surfaces.



(a) (b)

Figure 3 ESEM images of UHMWPE moulded at 145°C for 15 minutes (a) and at 175°C for 30 minutes (b)

Conclusions:

For long-term success of TKR, optimization on wear performance of UHMWPE components is greatly concerned since material failure is associated with fusion defects. The present study finds that the enhanced mechanical integrity of UHMPWE benefits from precise temperature-time consequences during processing.

References:

1. (Wright TM. Clin Orthop Relat Res. 2005; 440:141-148.) 2. (Wrona M. Clin Orthop Relat Res. 1994; 299:92-103.) 3. (Wu JJ. Biomaterials. 2002; 23:3773-3783.)