Appropriate Input Parameters for Computational Wear Models of UHMWPE under High Contact Stress Conditions

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Introduction

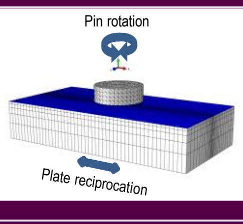
Computational models have been used extensively for preclinical wear prediction and optimization of total joint replacements [1,2]. In most cases, the input wear parameters (wear factors and coefficients) to the computational models have been experimentally measured under average contact stresses to simulate standard activities [3,4]. These wear studies are not therefore applicable for more adverse conditions that could lead to edge loading and high stress conditions, including higher levels of activities and severe loading conditions.

Aim

To investigate the multidirectional pin-on-plate wear performance of moderately cross-linked ultra-high molecular weight polyethylene (UHMWPE) under high applied nominal contact stresses and different levels of cross-shear at the articulating surfaces, to be used as inputs to computational models investigating adverse high stress conditions.

Materials

Moderately cross-linked UHMWPE (GUR 1020, 5Mrad gamma irradiation) pins articulating against cobalt–chrome alloy (CoCr) plates (polished to an average surface roughness Ra of 0.01μm).



Methods

Table 1: Load and kinematic test conditions:

Pin diameter [mm]	Load [N]	Stress [MPa]	Stroke length [mm]	Rotation angle [degrees]	Cross-shear ratio	Time [weeks]
5	80	4	28	±30	0.087	3
5	216	11	28	±30	0.087	3
4	252	20	28	±30	0.087	3
3	212	30	28	±30	0.087	3
3	283	40	28	±30	0.087	3
2	252	80	28	±30	0.087	3
5	216	11	28	0	0.0	2
5	216	11	10	±10	0.01	2
5	216	11	12	±15	0.022	2
5	216	11	26	±45	0.18	2

Six pins were tested per each set and each set was run for at least 2 weeks (660,000 cycles, 1Hz) in 25% bovine serum as a lubricant, in a multidirectional pin-on-plate wear simulator (Fig. 1).

Measurements: Gravimetric wear.

Calculations: Wear factor = (volumetric wear/(load x sliding distance)).

Wear coefficient = (volumetric wear/(contact area x sliding distance)).

Statistical analysis: One way ANOVA (significance at 0.05) & Tukey's test .

Figure 1: Multidirectional pin-on-plate wear simulator.

Results and Discussion

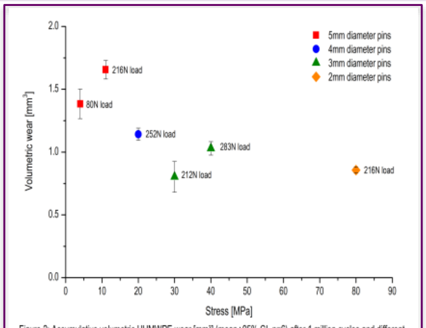


Figure 2: Accumulative volumetric UHMWPE wear [mm³] (mean±95% CI, n=6) after 1 million cycles and different pin diameter - applied load combinations.

For the same level of motion at the articulating surfaces, the two main parameters that significantly contributed to the volumetric wear were the applied load and contact area (Fig. 2).

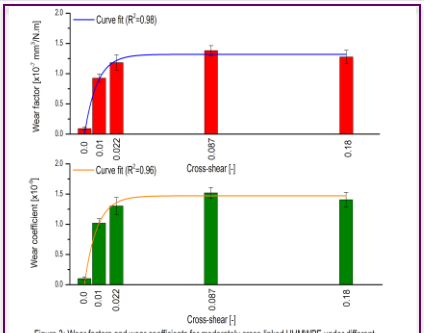


Figure 3: Wear factors and wear coefficients for moderately cross-linked UHMWPE under different cross-shear (mean±95% CI, n=6), stress = 11MPa.

Changing the cross-shear level from zero to 0.01 significantly increased the wear factor and the wear coefficient (p<0.001). Further increase in the cross-shear to 0.18 significantly increased the wear factor and the wear coefficient (p<0.001) (Fig. 3).

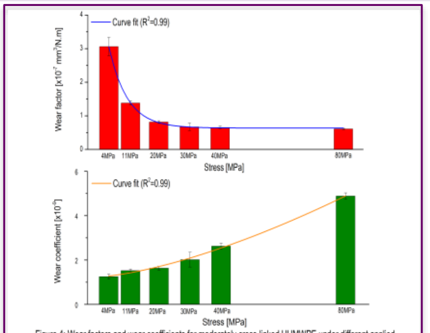


Figure 4: Wear factors and wear coefficients for moderately cross-linked UHMWPE under different applied nominal contact stresses (mean±95% CI, n=6), cross-shear = 0.087.

Increasing the stress level from 4 to 30 [MPa] significantly decreased the wear factor (p<0.001). Any further increase in the stress level did not affect the measured wear factor (p=0.44). The measured wear coefficient significantly increased (p<0.001) while increasing the stress from 4 to 80 [MPa] (Fig. 4).

The measured wear parameters were significantly dependent on the applied nominal contact stress and the degree of cross-shear at the articulating surfaces. The measured wear parameters will be adopted in future computational wear models of total joint replacements to simulate higher levels of activities and severe loading conditions.

Significance

The contact stress and cross-shear significantly affected the wear parameters of moderately cross-linked UHMWPE in this pin-on-plate configuration. Computational wear models of total joint replacements should therefore account for these effects when considering adverse high stress conditions.

References:
[1] Abdelgaied et al., J Biomech, 2011.
[2] Knight et al., J Biomech, 2007.
[3] Kang et al., J Biomech, 2008.
[4] Abdelgaied et al., J IMechE, 2013.

Disclosure

John Fisher is a paid consultant to DePuy Synthes, Invibio, Tissue Regenix, Simulation Solutions; a share holder of Tissue Regenix; a senior investigator to DePuy Synthes, Invibio, Corin, Mathys, Biocomposites, Tissue Regenix.

Louise M. Jennings is a senior investigator to Invibio, DePuy Synthes, Mathys, Biocomposites.

Acknowledgement

This study was supported by the EPSRC, DePuy Synthes (Leeds, UK), and EPSRC Centre for Innovative Manufacturing in Medical Devices.

EPSRC Engineering and Physical Sciences Research Council

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