ELASTO-PLASTIC MATERIAL MODELS INTRODUCE ERROR IN FINITE ELEMENT POLYETHYLENE WEAR PREDICTIONS

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Introduction

Polyethylene wear of joint replacements can cause severe clinical complications, including; osteolysis, implant loosening, inflammation and pain. Wear simulator testing is often used to assess new designs, but it is expensive and time consuming. It is possible to predict the volume of polyethylene implant wear from finite element models using a modification of Archard's classic wear law [1-2]. Typically, linear elastic isotropic, or elasto-plastic material models are used to represent the polyethylene. The purpose of this study was to investigate whether use of a viscoelastic material model would significantly alter the predicted volumetric wear of a mobile-bearing unicompartmental knee replacement.

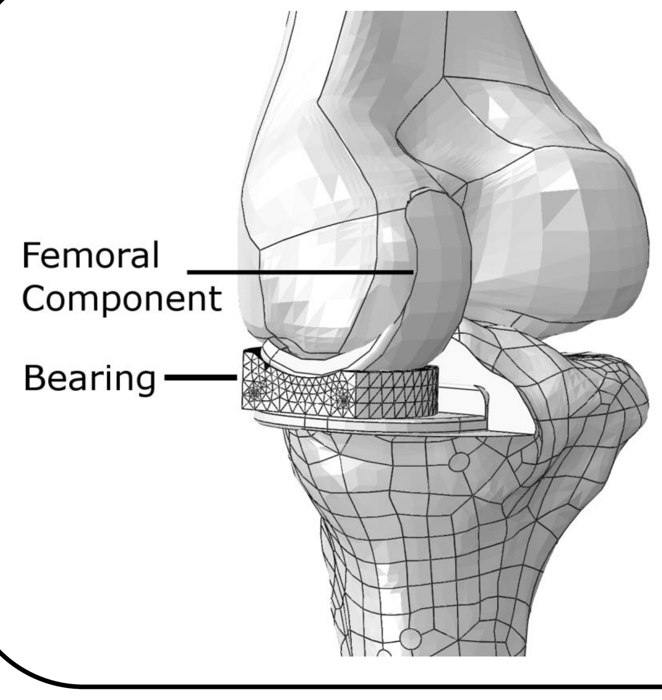


Fig 1: Illustration of the finite element model of a mobile bearing unicompartmental knee replacement

Materials & Methods

Tensile creep-recovery experiments were performed to characterise the creep and relaxation behaviour of the polyethylene (moulded GUR 4150 samples machined to 180x20x1 mm). Samples were loaded to 3 MPa stress in 4 minutes, and then held for 6 hours, the tensile stress was removed and samples were left to relax for 6 hours. The mechanical test data was used fit to a validated three-dimensional fractional Maxwell viscoelastic constitutive material model [3].

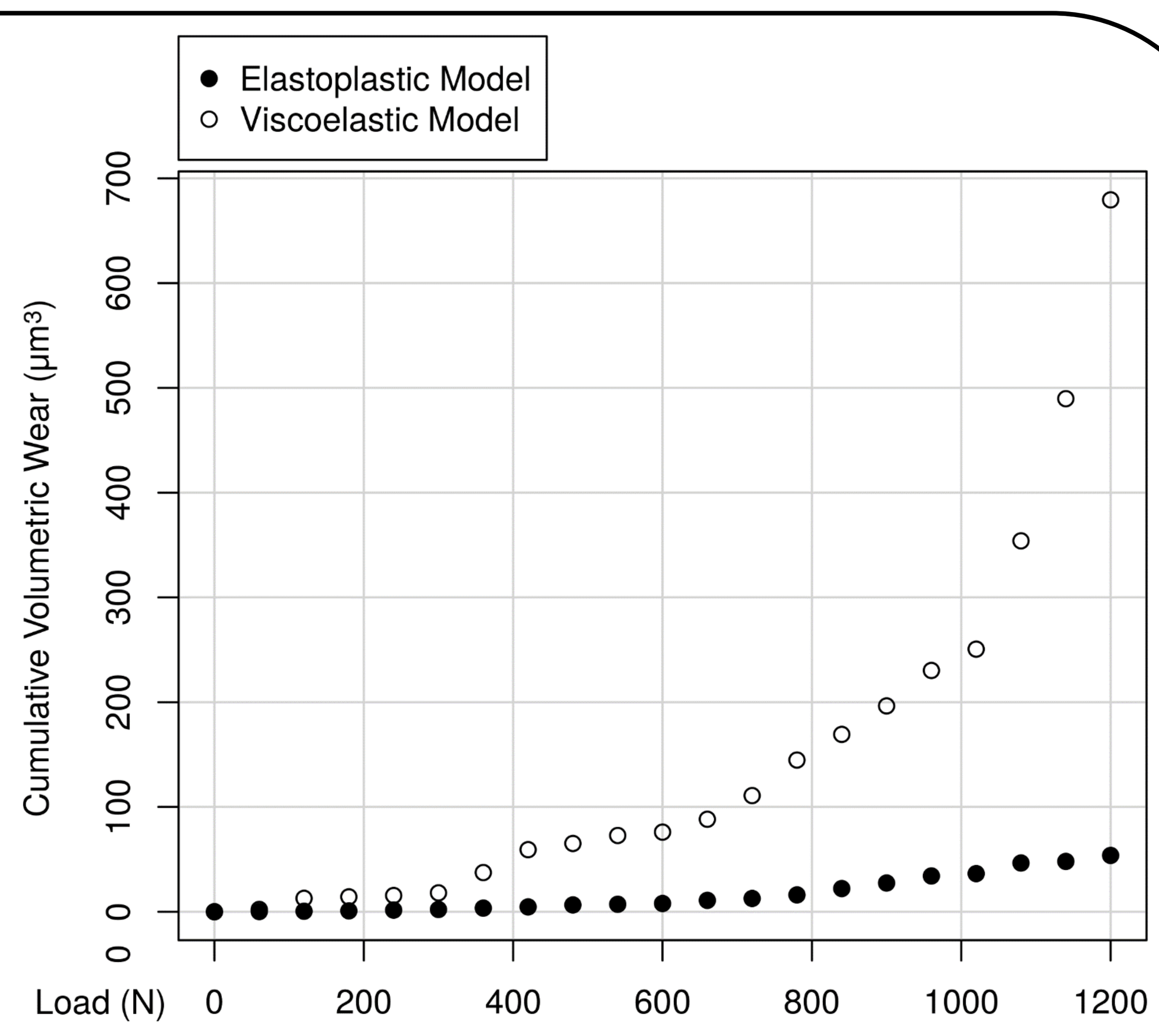
Fig 2: Viscoelastic characterisation of the UHMWPE

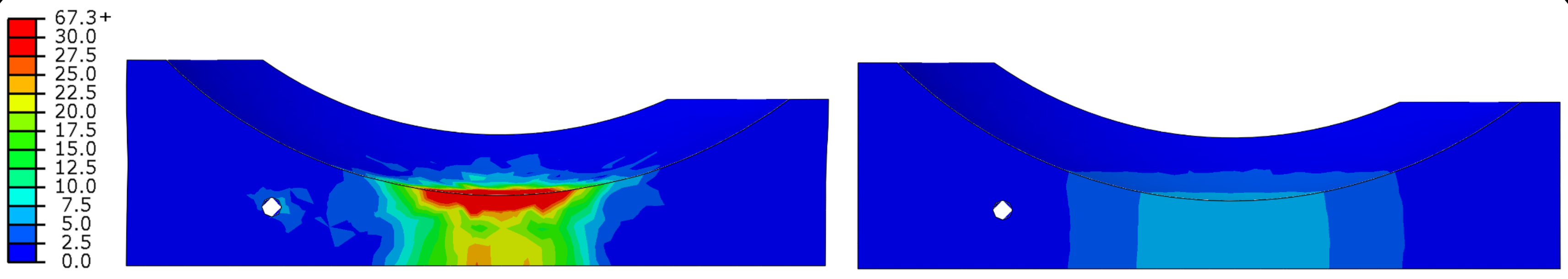
An explicit finite element model of a mobile-bearing unicompartmental knee replacement was created (Fig. 1), which has been described previously [4]. The medial knee replacement was loaded to 1200 N over a period of 0.2 s. The bearing was meshed using quadratic tetrahedral elements (1.5 mm seeding size based on results of a mesh convergence study), and the femoral component was represented as an analytical rigid body. Wear predictions were made from the contact stress and sliding distance using Archard's law, as has been described in the literature [1-2]. A wear factor of 1.06 x 10^{-6} mm^3/Nm was used based upon the work by Maxian et al. [1]. All models were created and solved using ABAQUS finite element software (version 6.14, Simulia, Dassault Systèmes).

Results

The fractional viscoelastic material model predicted almost ten times as much wear for one loading cycle compared to the elasto-plastic model (Fig 3). The higher wear prediction was due to both an increased sliding distance and higher contact pressures in the viscoelastic model (Fig 4).

Fig 3: Cumulative wear calculated for one loading cycle for two different material models.





(a) (b)

Fig 4: Cross-sectional view of the stresses within the centre of the bearing for (a) the viscoelastic model and (b) the elastoplastic model.

Discussion

These preliminary findings indicate the simplified elasto-plastic polyethylene material representation can underestimate wear predictions from numerical simulations. Polyethylene is known to be a viscoelastic material which undergoes creep clinically, and it is not surprising that it is necessary to represent that viscoelastic behaviour to accurately predict implant wear. However, it does increase the complexity and run time of such computational studies, which may be prohibitive.

References

[1] Maxian, T. A. et al. “A sliding-distance-coupled finite element formulation for polyethylene wear in total hip arthroplasty. ” (1996) J Biomech 29, p687-692.

[2] Netter, J. et al. “Prediction of wear in crosslinked polyethylene unicompartmental knee arthroplasty” (2015) Lubricants 3 p381-393.

[3] Alotta, G., et al. “On the behaviour of a three-dimensional fractional viscoelastic constitutive model” Manuscript submitted to Meccanica (2016).

[4] Pegg, E.C. et al. “Fracture of mobile unicompartmental knee bearings: A parametric finite element study”. (2013) Proc IMechE Part H: Journal of Engineering in Medicine 227 p1213-1223.

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