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Development of a wear model for lubricated metal-on-metal hip joints

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Outline

1. Introduction and motivations
2. Hip joint loading and motions
3. Hip joint mixed lubrication modelling
4. Hip joint wear prediction
5. Results
6. Conclusions

1. Introduction and Motivations



2nd generation Metal-on-Metal

Ceramic-on-Metal

Ceramic-on-Ceramic

Ceramic-on-Polyethylene

Metal-on-Polyethylene (UHMWP, XPE)

1st generation Metal-on-Metal



Fig.1 History development of artificial hip joint replacements

- A hip implant is often the difference between *walking* and a *wheelchair;*
- Demand is huge but the implants' life time is not satisfied;
- Wear is the main cause of failure (loosening, infection, worn out, etc.) of the implants;

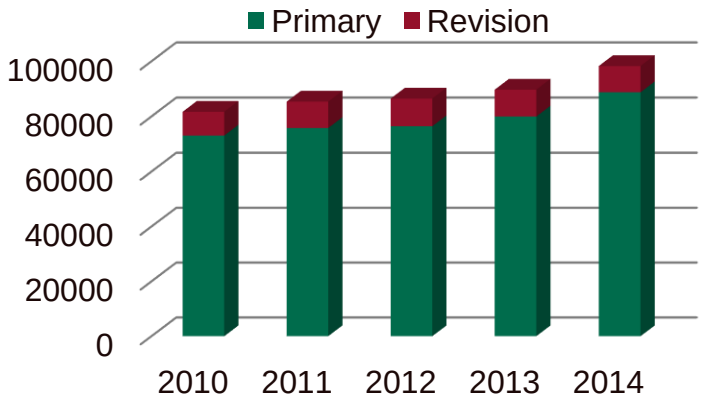


Fig.2 Total hip replacement procedures performed in UK in the past 5 years [1]

[1] UK National Joint Registry Annual Report 2010 to 2015.

2. Hip joint loading and motions

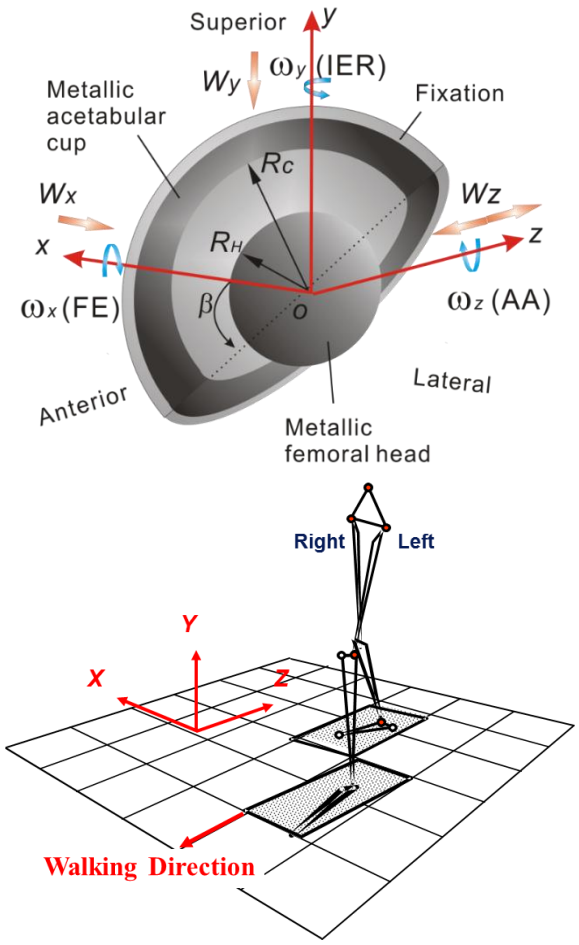


Fig.3 Loading and motions applied on the hip bearings during walking

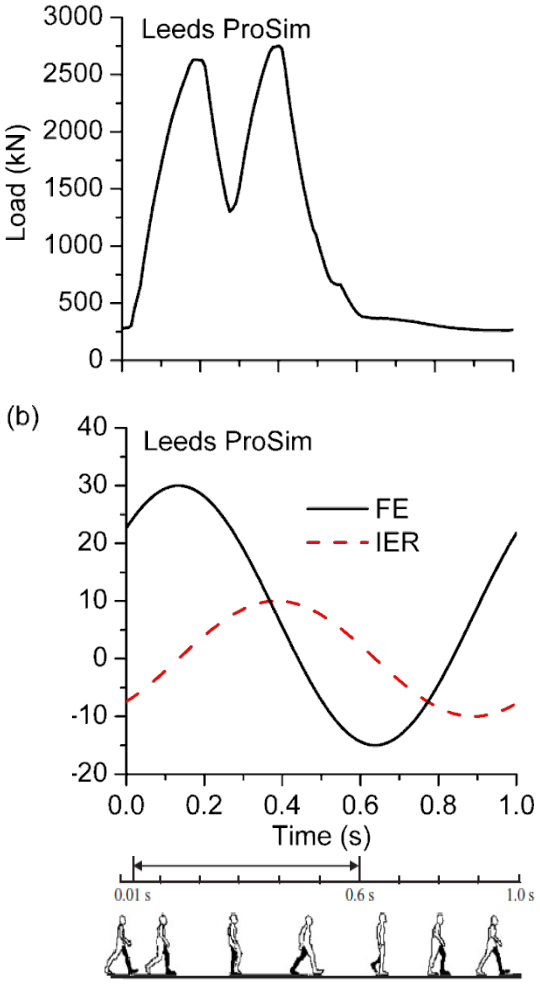


Fig.4 Simplified load and motion in hip simulators

3. Lubrication regime of hip implants

- Three types of lubrication regimes
- Lambda ratio (λ) = film thickness/surface roughness

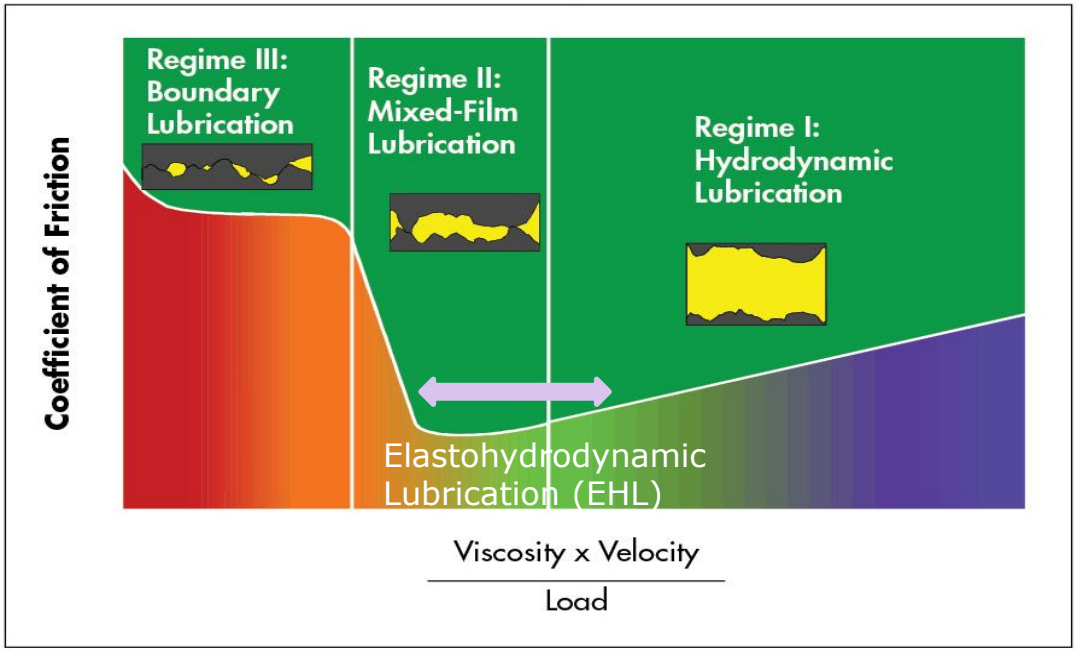


Fig. 5 Stribeck curve

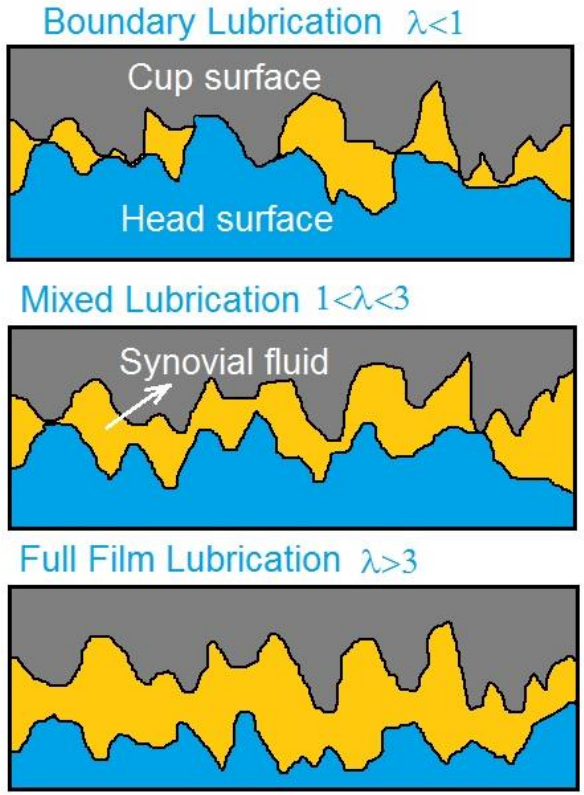


Fig. 6 Lubrication regimes

Hip Lubrication modelling

- Thin film lubrication model
- Ball in socket geometry allows cup inclination and 3D load and motion
- Elastic deformation of both cup and head materials
- Realistic rheology (shear-thinning) of the joint synovial fluid

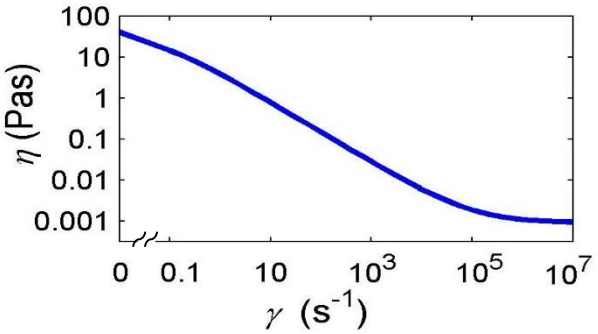


Fig.7 Viscosity variations against shear-rate [2]

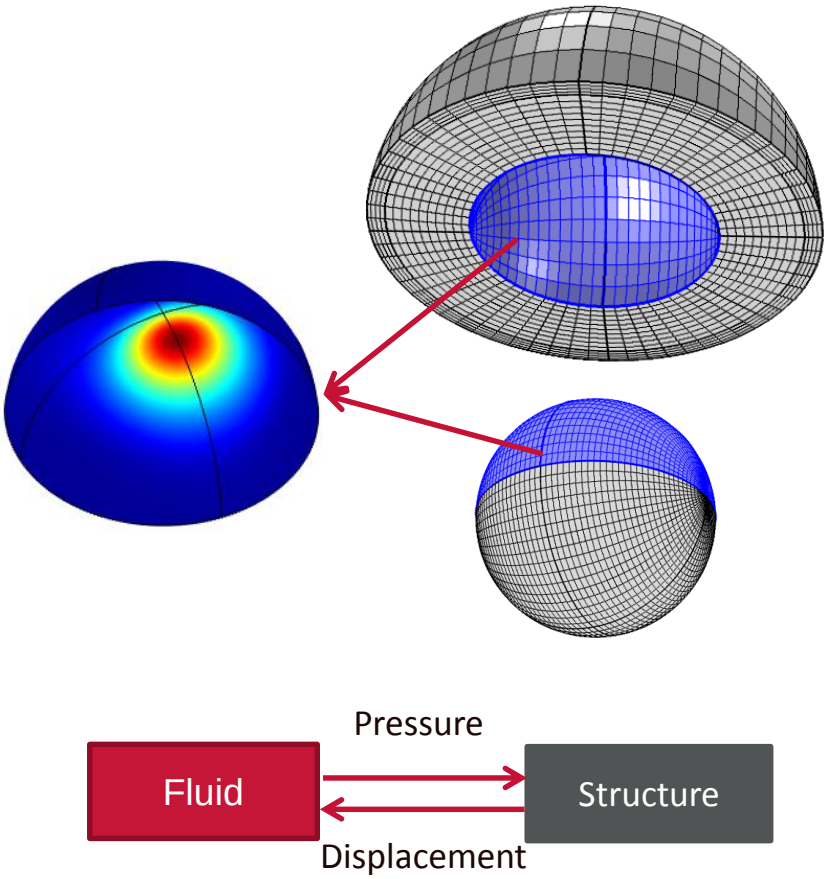


Fig.8 EHL model of hip joint replacements

[2] Gao et al., Tribology International, 2016; **93**: 486-494.

Material of a Metal-on-Metal (CoCrMo) hip implant

Table 1 Materials and geometrical parameters of a MoM hip implant	
Head radius	18 mm
Radial clearance	25 mm
Cup wall thickness	9.5 mm
Equivalent support thickness	2 mm
Young's modulus of metal	210 GPa
Young's modulus of equivalent support	2.27 GPa
Poisson's ratio of metal	0.3
Poisson's ratio of equivalent support	0.23

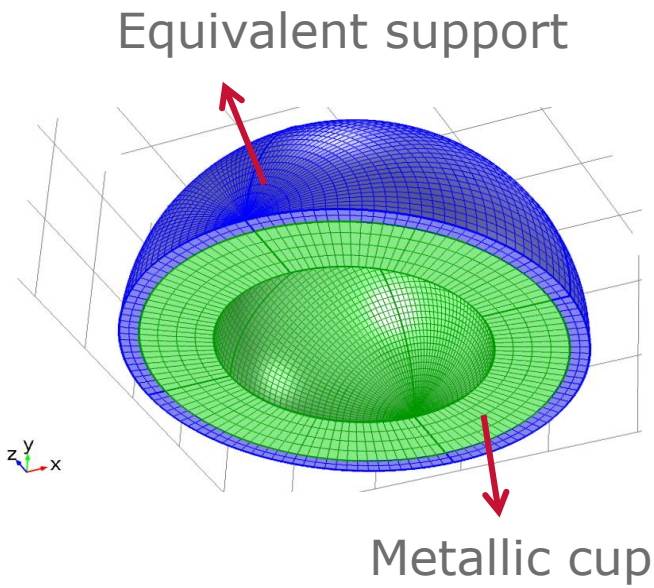


Fig.9 Material composition of the cup

Example of EHL solutions

The minimum film thickness variations in a walking cycle

Film thickness and pressure contours at 21% time of a walking cycle*

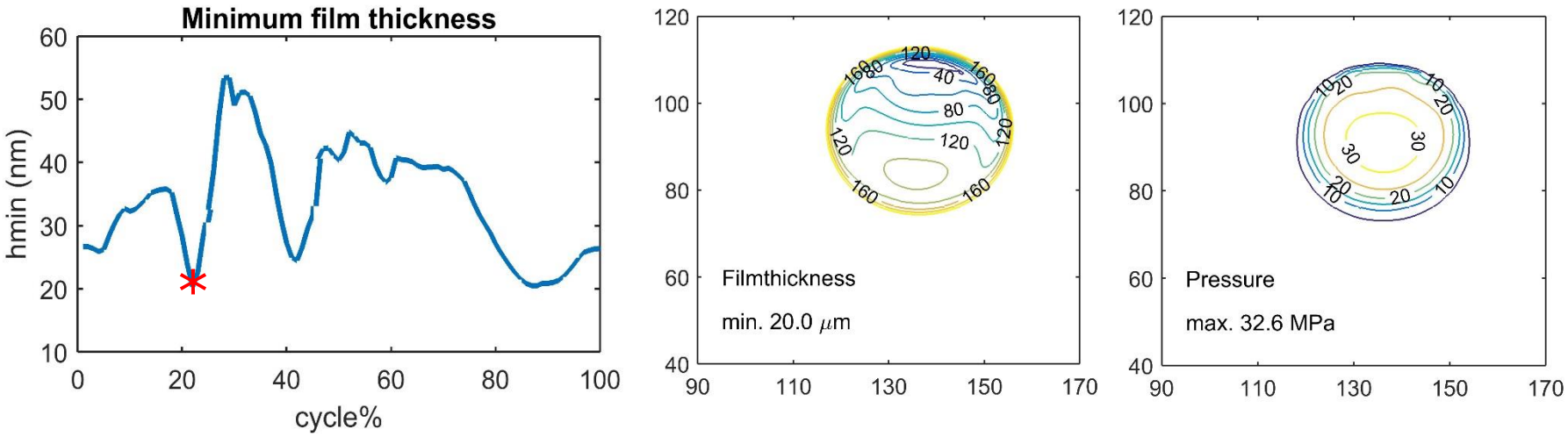


Fig.10 EHL solutions of an MoM hip joint replacement

4. Hip Joint Wear Modelling

- Typical wear trend of physical hip simulators
- Archard law and adapted Archard law
- Dry contact wear model
- Wear model with lubrication addressed
- Some results

Typical Wear of hip joint implants

The typical wear results of artificial hip bearings from physical hip simulator shows:

- Two stage wear trend
- Initial bedding-in (running-in) wear, followed by steady wear with reduced wear rate
- Despite of different material combinations, included hard-on-hard or hard-on-soft.

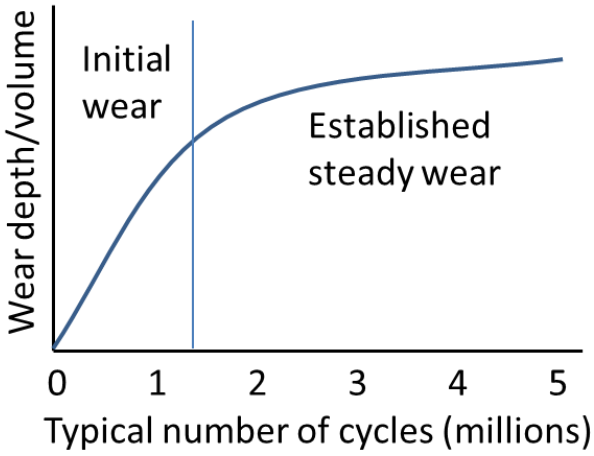


Fig. 11 Representation of typical physical simulator wear results [3]

[3] Bowsher JG, et al. J Biomed Mater Res B. 2009;91B:297-308.

Archard law and adapted Archard law for wear modelling

- Dry contact wear model of hip implants using Archard law [4]:

$$w_L = k_w p s$$

k_w: wear coefficient
p: contact pressure
s: sliding distance

  - Two stage wear was obtained using two different wear coefficients, e.g.
  - $k_w = 1 \times 10^{-9} \mathrm{mm}^3/(\mathrm{Nm})$ at 1st MC, and $1 \times 10^{-8} \mathrm{mm}^3/(\mathrm{Nm})$ afterwards [5].

- Adapted wear formula[6] with lubrication explicitly addressed

$$w_L = k_w p s \left(\frac{R_a}{h}\right)^n \quad \text{if} \quad \lambda < 3$$

$k_w = 5 \times 10^{-9} \mathrm{mm}^3/(\mathrm{Nm})$
$R_a = 14.1$ nm
$n = 2.24$[6]

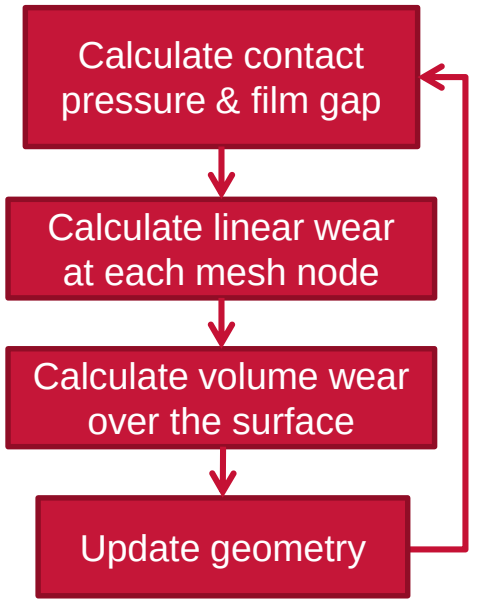


Fig.12 A brief wear modelling procedure

[4] Archard JF, Journal of Applied Physiology, 1953 (24): 981–988
[5] Liu F et al., Journal of Biomechanics, 2008; 41: 686–694
[6] Sharif KJ et al., IMechE-Part J, 2006 (220): 295-306

5. Results: dry contact V.S. lubricated wear model

- Dry contact wear model of hip implants using Archard law [4]:

$$w_L = k_w p s$$

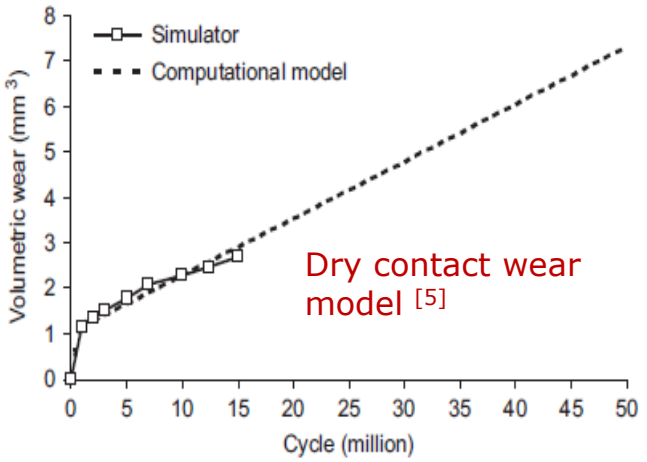
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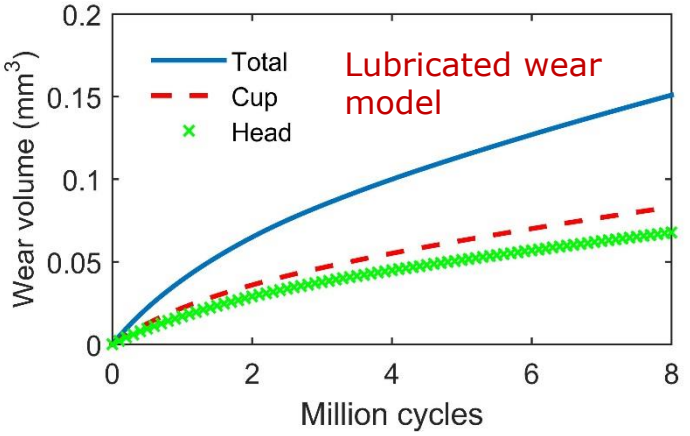
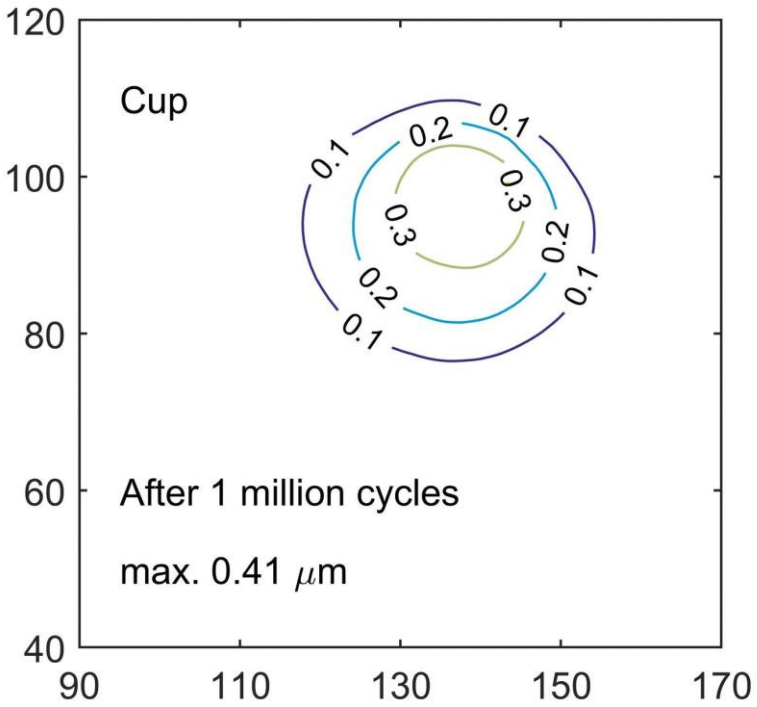


Fig.13 Wear predictions of hip replacement

[4] Archard JF, Journal of Applied Physiology, 1953 (24): 981–988
[5] Liu F et al., Journal of Biomechanics, 2008; 41: 686–694
[6] Sharif KJ et al., IMechE-Part J, 2006 (220): 295-306

Wear scar development

Cup bearing surface



Head bearing surface

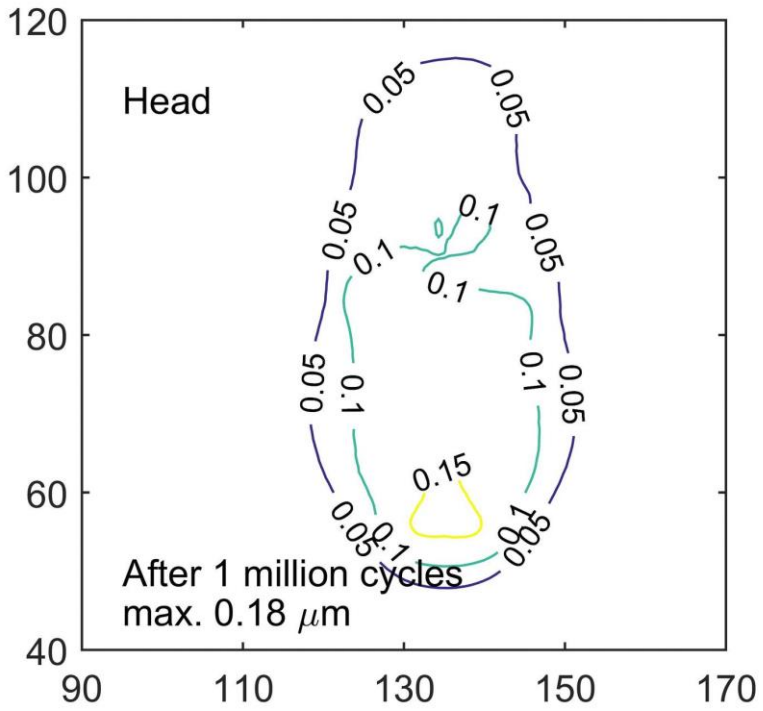


Fig.14 Wear scar development on bearing surfaces

Why the predicted wear is reduced against time?

- Local gap in main loading area is increased, i.e. the loading area is flattened, and
- resulted in a decreased peak pressure distributing in a larger area

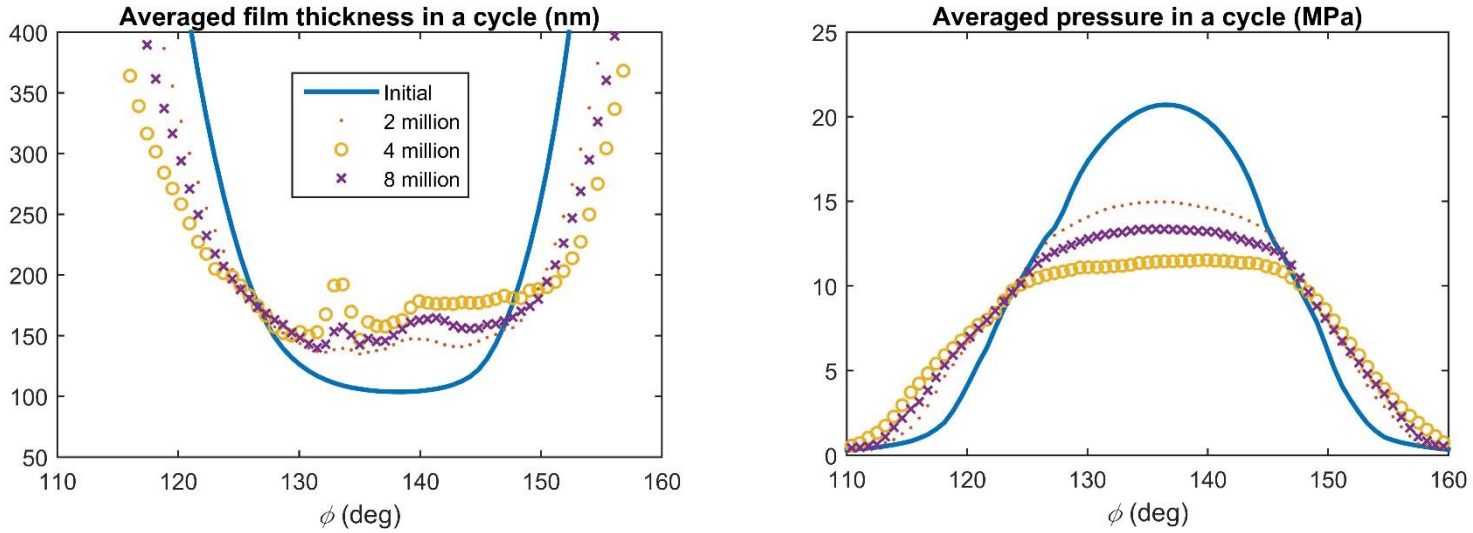


Fig.15 Time averaged pressure and film thickness distribution along the cross-section of bearing surface

6. Conclusions

- Lubrication plays an important role in the wear of hip joint implants, which operate in the mixed lubrication regime.
- When the film thickness is low, the wear most likely occurs.
- This model provides a useful tool to predict the wear performance of hip joint replacements.
- Hip joint replacements may potentially benefit from properly designed geometry, such as surface texturing and non-spherical profiles.

Acknowledgement

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Thank you!

Questions?