The University Of Sheffield.

The Leonardo Tribology Centre

Wear mechanisms in hip prostheses: metals and ceramics

Subsurface microstructural changes in metal-metal and ceramic-ceramic hip joint

Dr Peng Zeng*, Prof W Mark Rainforth (*PDRA, p.zeng@sheffield.ac.uk)

Introduction:

Fig.1 A metal hip resurfacing (top) and an alumina hip joint (bottom) (images from internet).

Metals and ceramics are popular bearings of hip prostheses (Fig.1), however, there remains little quantitative understanding of the surface microstructure changes during tribo-contact, thus the changes of the surface mechanical properties and chemical activity. To prolong the lifespan of artificial hip joints, it is crucial to study the microstructure of hip prostheses.

This project should directly benefit orthopaedic industries, such as JRI Orthopaedic, Smith Nephew, Finsbury Orthopaedic and CeramTec etc. Also, materials used in orthopaedic industry are widely used in other regions (although medical-grade materials are required for orthopaedic application), i.e. aerospace or automobile, and it will potentially benefit them.

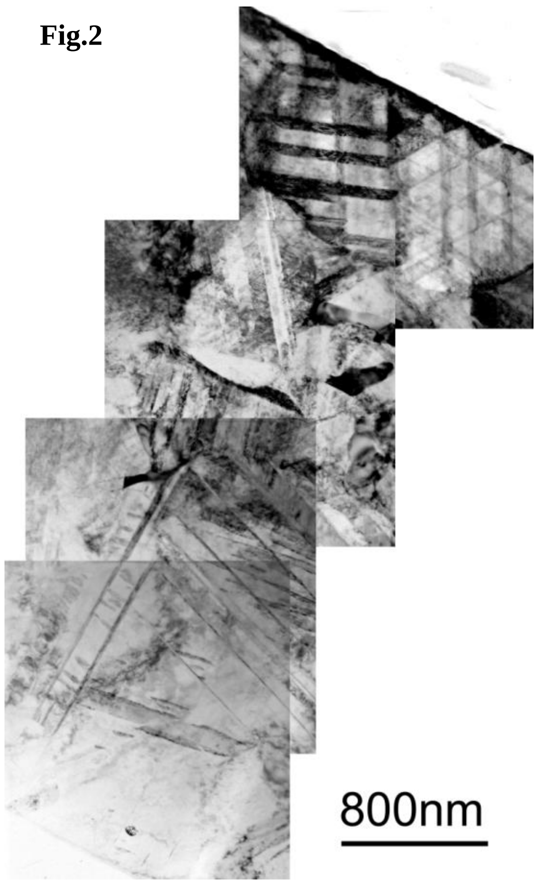
The objectives of current research are: Why do some metal-metal hip prostheses perform inadequately alongside the successful stories of some early implanted metal-metal hip prostheses, which last for more than two decades; What are the wear mechanisms of alumina hip prostheses, thus how to avoid the failure of alumina implants; Finally and most importantly, how to improve the materials used in orthopaedic industries, thus increase the lifespan of artificial hip joints.

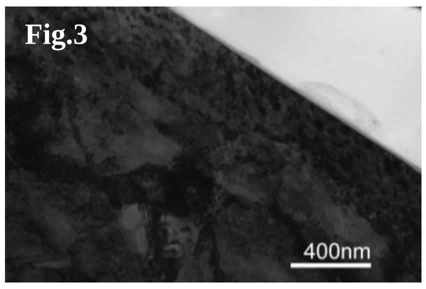
Research Summary:

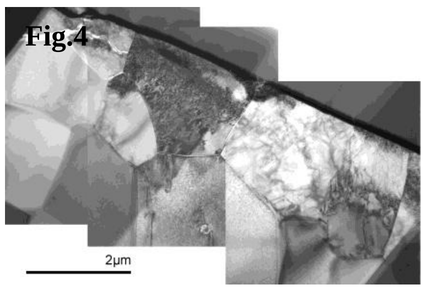
Interests in hard-hard hip prostheses, such as metal-metal and ceramic-ceramic, are increased due to osteolysis and aseptic loosening caused by polymer debris. Advanced electron microscopy is used to investigate the microstructural changes of such bearings, including *in vivo* hip implants and *in vitro* test samples.

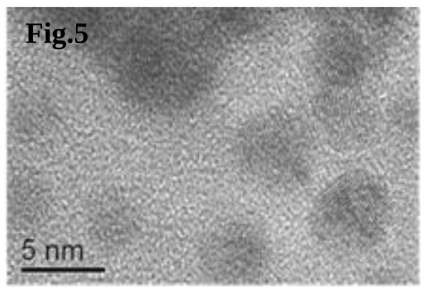
With its superior wear and corrosion resistance, CoCrMo alloys have been widely used for metal hip prostheses. The current work provides a detailed study of sub-surface damage of retrieved CoCrMo hip resurfacing and biomedical CoCrMo after reciprocating wear test. Fig.2 shows a montage of TEM micrographs from a cross section taken outside the high wear region of a retrieved femoral head, and Fig.3 is TEM cross-section of CoCrMo after 4N reciprocating test, showing nanocrystallines and protein layer on the worn surface.

Due to its high wear resistance and consequently the reduced number of wear particles liberated into the body, alumina has been widely used for hip replacement since its introduction in the 1970s. Retrieved alumina orthopaedic hip replacements show characteristic wear regions and the mechanisms associated with such wear are studied. Fig.4 shows TEM cross-section of a retrieved alumina femoral head taken from mild wear to severe wear, showing subsurface changes. Fig.5 is a HRTEM image of the amorphous layer on the retrieved alumina femoral head, suggesting nanocrystalline wear debris.









TEM bright field images of cross sections of worn surface from various hip prostheses: Fig.2 Showing the surface deformation in a retrieved CoCrMo femoral head; Fig.3 Surface damage from *in vitro* reciprocating wear test of CoCrMo at 4N; Fig.4 Retrieved alumina femoral head showing subsurface changes from mild wear to severe wear, with clear evidence of plastic deformation; Fig.5 High resolution image of an amorphous layer with embedded nanocrystalline alumina particles found on a retrieved alumina femoral head.

Methodology and facilities:

- Reciprocal testing on a UMT-2 Tribometer (Bruker, US).
- Surface characterisation by scanning electron microscopy (SEM) and transmission electron microscopy (TEM).
  SEMs: InspectF, Sirion, and Nova (FEI, the Netherlands), Jeol 6400 (JEOL, Japan).
  TEMs: Philips 420 and CM 200 (Philips, the Netherlands), Tecnai (FEI, the Netherlands) and Jeol 2010F (Jeol, Japan).
- Site-specific TEM cross-section sample preparation by Focused Ion Beam (FIB) milling: Quanta 200 3D (FEI, the Netherlands)
- High Resolution Transmission Electron Microscopy (HRTEM) and Electron Energy Loss Spectrum (EELS) to investigate the topmost surface of worn hip joints.