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Sub-surface investigation of fretted Co28Cr6Mo and Ti6Al4V alloys

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Introduction: Cobalt-Chromium-Molybdenum (CoCr) and Titanium-Aluminium-Vanadium (Ti) alloys are the most commonly used alloys used for Total Hip Replacement due to their excellent biocompatibility and mechanical properties. However, both are susceptible to fretting corrosion In-vivo. The objective of this study was to understand the damage mechanism of both combinations through a sub-surface assessment of damage to the alloys at various fretting amplitudes using the Transmission Electron Microscopy (TEM – CM200 FEGTEM). The TEM was used to attain a cross sectional view of the alloys in order to see the effect of high shear stress on the grain structure.

Methods: The two combinations were fretted at a maximum contact pressure of 1 GPa in a Ball – on – Plate configuration for displacement amplitudes of ±10μm, ±25μm, ±50μm and 150μm. The contact was lubricated with 25% v/v Foetal Bovine Serum (FBS), diluted with Phosphate Buffered Saline (PBS). The material loss as a result of wear and corrosion from the fretting contact were quantified using the Visual Scanning Interferometry (VSI). The TEM samples were obtained using the Focused Ion Beam (FIB – FEA Nova 200 Nanolab). Samples were obtained from regions of high stress (shaded in red) [Figure 1] for both the CoCr flat and Ti flat from the CoCr – CoCr and CoCr – Ti respectively.

Result: The TEM images of CoCr alloy (denoted as CC) reveal a progressive damage to the topmost surface of the alloy and loss of nano-crystalline layer. Evidence of severe grain damage from the topmost surface can also be seen at 50μm. On the other hand, the Ti alloy (denoted as CT) at 25μm reveal some recrystallization at the topmost surface and a progressive recrystallization of the bulk alloy was observed at 150μm. Damage to the surface was also visible at this displacement amplitude which initiated a crack as circled in red in the image CT – 150μm.

Discussion: Fouvry et al[1] discussed the effect of the interfacial shear work done (dissipated energy) on a fretted material; this energy is mainly expended on material structure transformation (as observed in Ti alloy) and/or wear generation (as observed in CoCr alloy) [Figure 2]. This intermediate damage mechanism helps to identify that CoCr – CoCr follows a wear dominated mechanism while CoCr – Ti preferably exhibits a fatigue behaviour until large displacement amplitudes are applied leading to accelerated wear of the top surface (seen at CT - 150μm). The recrystallization was observed over 2μm below the surface at 150μm. Consequentially, this could modify the metallurgy of the Ti alloy and may contribute to the clinically observed phenomena whereby, the softer Ti wears the harder CoCr component[2].

Conclusion: TEM micrographs reveal large granular damage on the CoCr alloy and deep bulk recrystallization of the Ti alloy as a result of interfacial shear stress. This suggests that the Ti alloy may experience a change in its mechanical behaviour. On the other hand, it is identified that a CoCr – CoCr couple experiences a wear dominated mechanism.

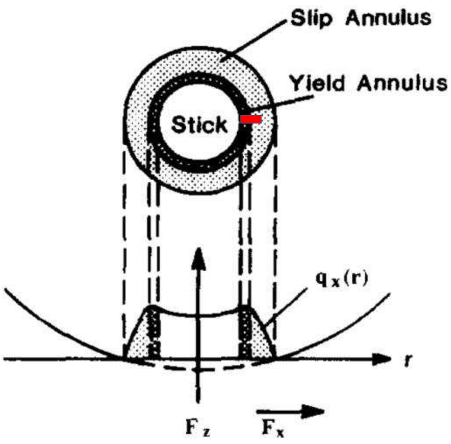

Figure 1: Schematic of extracted TEM sample region. Diagram obtained from Vingsbo et al 1988.

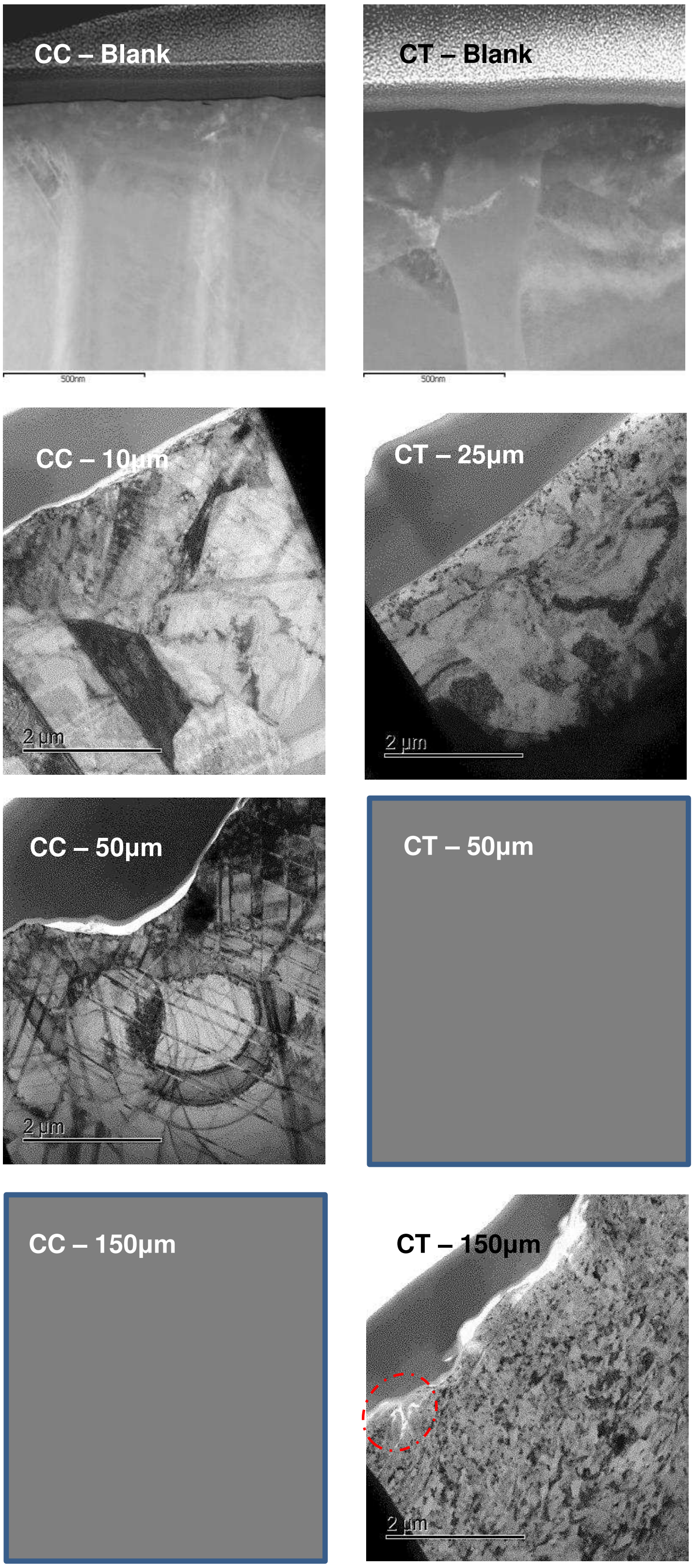

Figure 2: TEM micrographs of CoCr and Ti alloys. Missing images are yet to be obtained.

Reference:

1. FOUVRY, S., PHILIPPE KAPSA, AND LEO VINCENT. Quantification of fretting damage. Wear, 1996, 200(1), pp.186-205.
2. MOHARRAMI, N., D. J. LANGTON, O. SAYGINER, AND S. J. BULL. Why does titanium alloy wear cobalt chrome alloy despite lower bulk hardness: A nanoindentation study? Thin Solid Films, 2013, 549 pp.79-86.