Filiform corrosion of Al-alloys has important commercial implications (e.g. in Al car body sheet). It is known that that filiform corrosion is related to thin (a few microns) fine surface layers on the hot rolled surfaces. However, similar layers induced by cold rolling do not enhance filiform corrosion rates: this situation has not been understood. Work at Sheffield as part of IMMPETUS has been the first to accurately simulate the surface layers generated in the industrial product through laboratory rolling simulations [1] which have allowed, for the first time, the correlation of the evolution of surface structure as a function of each process step. The prior view was that the surface layer arises primarily as a result of transfer from the work piece to the roll and back again. However, with the aid of FIB-prepared cross-sections of these fragile surface structures, we have shown that the surface layer is a result of reverse shear during rolling (and therefore directly related to the state of lubrication, and the strain imposed at each stand), with transfer apparently being minor. Moreover, we have been able to show that the fine scale of the structure and the abrupt interface between surface layer and substrate (see Fig. 1) arises from Zener pinning of subgrains from oxides and carbides, introduced during reheating, not during rolling. This detailed mechanistic understanding, only possible through the use of FIB sample milling, has therefore brought about a completely different approach to modifying the industrial process in order to minimise the development of these damaging layers.

The wear of hip-joints is a significant clinical problem, which causes adverse tissue reactions leading to bone absorption and consequent loosening of the fixation. Artificial hip joints retrieved after use and tested on simulators typically exhibit a small region of excessive wear, associated with intergranular fracture (referred to as ‘stripe’ wear), whereas the majority of the component exhibits mild wear. We have used FIB microscopy to investigate the sub-surface damage mechanisms in worn alumina hip-joints for the first time to understand the process of stripe wear formation, both from laboratory simulations (in association with Prof Fisher’s group at Leeds University) and from explanted human hip prosthetics. We have shown that, in the region adjacent to the severe stripe wear, extensive dislocation activity occurs. 3-D analysis of the fracture path within and adjacent to the stripe wear region has been undertaken by FIB studies of corresponding selected micro-areas: this has allowed the quantification of the crack density (see

Fig. 1. a) Secondary electron image of a hot rolled aluminium alloy, showing the location of the FIB cut. b) Bright field TEM image of a FIB generated sample of the surface of a hot rolled aluminium alloy, showing the heavily deformed and mechanically mixed surface layer that is responsible for filliform corrosion.

Fig. 2. a) SEM secondary electron images within the severe ‘stripe wear’ region. (b) secondary electron image from an FIB section through the stripe wear zone showing the subsurface intergranular cracking (arrowed).
The build up in dislocation density is believed to provide residual stresses that are additive to the applied stress and also increase with time to the point that intergranular fracture occurs. Interestingly, the wear debris is nanocrystalline $\alpha$-Al$_2$O$_3$, not the amorphous wear debris that previous work suggests.

Although extensive research has been undertaken into the dry sliding wear of aluminium alloys, virtually no work has been reported on the lubricated sliding, surprising given that this is the industrially relevant condition. We have been developing novel Al-alloy metal matrix composites (e.g. AA2124+MoSi$_2$) that have at least as good wear resistance as Al-SiC MMCs, but that do not impart so much abrasive wear damage to the counterface. Interestingly, fragmentation of the MoSi$_2$ leads to an increase in volume fraction of reinforcement at the worn surface, improving wear resistance. We have used site specific FIB to determine the reasons for wear differences. For the MoSi$_2$, the re-embedded particles form a strong bond with the underlying matrix (Fig. 3). In contrast, the SiC is so hard it simply abrades the surface. The dynamic surface topography was then found to be a result of three factors: surface deformation, local detachment of reinforcement and re-incorporation of the fragments back into the surface [3,4].

![Fig. 3](image)

**Fig. 3.** a) Secondary electron image showing the wear scar of a novel Al-alloy-MoSi$_2$ composite. b) Corresponding TEM image from a FIB cut through the region protected by Pt, showing particle fragmentation and compaction into the work surface.

**References:**