Using FIB-SIMS to understand tribological changes in an Al-Si automotive alloy subject to transient start-stop velocities

Worldwide vehicle ownership is predicted to exceed 2 billion vehicles by 2030, with cars and vans responsible for around 45% of global CO_2 emissions from the transport sector. This has resulted in a significant drive within the automotive sector to mitigate the environmental impact from our vehicles of the future. New technologies such as innovative light-weight materials, hybrid and electrical vehicles have all progressed from advanced concept to mainstream consumer models. There has also been a greater emphasis on drive efficiency – the need to reduce mechanical and frictional losses to obtain the maximum amount of mileage whilst minimising fuel consumption.

Whilst individually these technologies all aim to reduce the environmental impact of our vehicles, when combined, the synergistic result is perhaps less well understood. Take for example the surface interactions of the piston ring again the cylinder wall. For effective hydrodynamic lubrication in the mid-stroke region, the ring must be in continuous motion. However with the introduction of a hybrid start-stop cycle, velocity interruptions are much more frequent and as a consequence boundary lubrication and surface contact much more prevalent. This could potentially be a problem in engines that use aluminium-silicon as the cylinder wall material, as aluminium is poor tribologically and prone to scuffing and adhesive wear. In order to investigate if this was the case, a series of laboratory tests were conducted on a hyper-eutectic Al-Si alloy, as shown in Figure 1. A segment from a cast iron piston ring was oscillated against a honed Al-Si surface under lubricated conditions, similar to that experienced in a real engine. One set of tests was conducted under continuous reciprocation whilst a second set was repeatedly interrupted at one minute intervals.

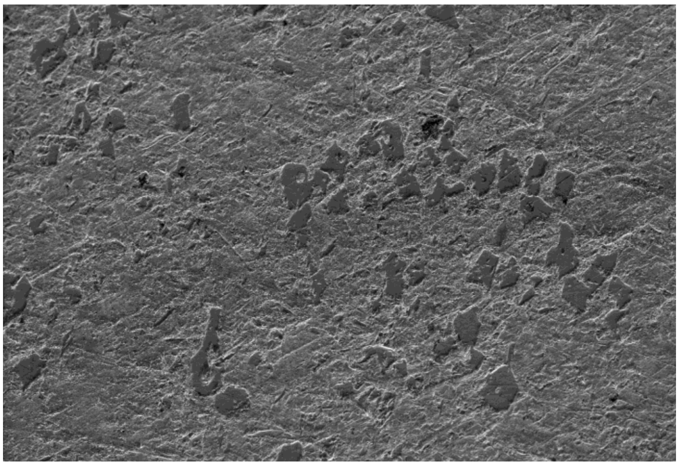

Figure 1. Honed Al-Si surface showing aluminium matrix and silicon particles

Each test surface was investigated using a Zeiss NVision40 dual beam focused ion beam – scanning electron microscopy (FIB-SEM). The equipment, based at the University of Southampton's Nanofabrication Centre is equipped with a Hiden Analytical EQS quadrupole secondary ion mass spectrometer (SIMS). This allowed chemical mapping of ions sputtered from the surface of the Al-Si as well as dynamic SIMS depth profiles. For Al-Si alloys to be effective tribologically, the Si particles are engineered to stand proud of the aluminium and bear the load. It can be seen from the images in Figure 2 that formation of friction modifying additives containing Molybdenum (e.g. MoS_2) from the lubricating oil had formed a low friction layer on the aluminium matrix. Chemical analysis from the SIMS mapping showed how Zinc based anti-wear additives were forming preferentially on the silicon particles, as expected.

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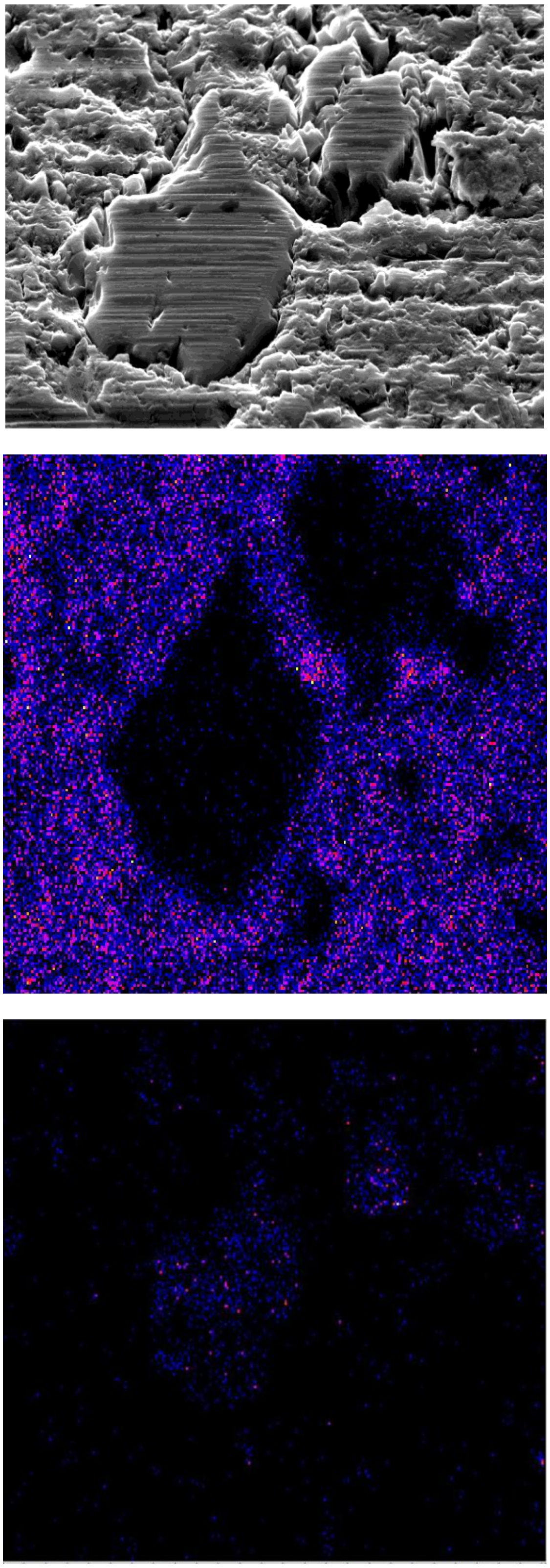

Figure 2. Secondary electron image from worn Al-Si surface and SIMS chemical maps of Molybdenum and Zinc, respectively

Dynamic SIMS depth profiles of the zinc and molybdenum signals from the surface of the silicon particles, Figure 3, indicated that the surface tribo-films, so critical to the frictional and wear performance of the cylinder wall, appeared to be thinner as a result of the interrupted start-stop sliding.

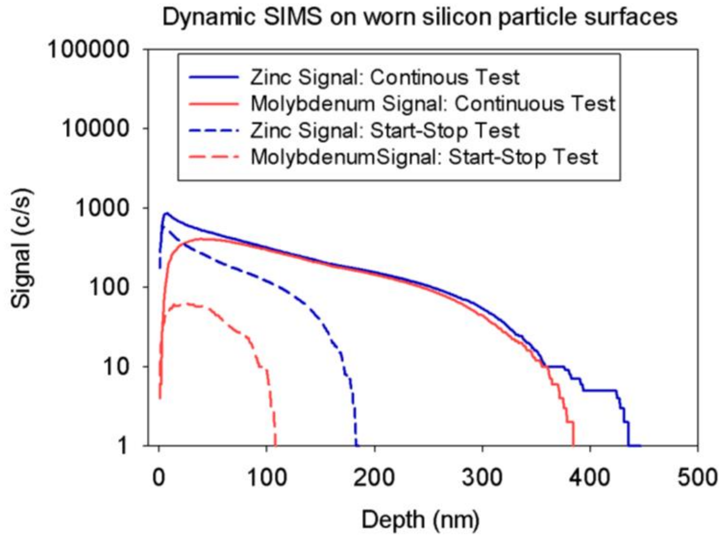

Figure 3. Dynamic SIMS depth profiles on silicon particle surfaces subject to continuous and start-stop sliding

Although the films had not been compromised, this work was good evidence for the need to maintain a good chemically functional lubricant supply throughout the lifecycle of start-stop hybrid vehicles.

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