ESRF	**Experiment title:** Observation of fatigue failure processes within conventional and advanced PMMA-based orthopaedic bone cements	**Experiment number:** ME-1083
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Report: Total hip replacement (THR) is seen as a successful surgical practice in terms of patient outcome. In the UK for example, approximately 40,000 total hip joint replacements are performed annually. Some 18% of all total hip joint replacement operations are revision procedures (replacement of 'failed' implants), at an estimated annual cost of £32 million (UK Dept. of Health, 1996). It has been demonstrated that aseptic loosening represents the most common cause implant failure, being linked to a number of complex interacting factor, including material choice, implant shape, surface finish, and operative technique. Amongst these factors, loosening of the femoral component of THR's has been specifically associated with fatigue failure of the cement mantle and/or the stem-cement interface. A major uncertainty in understanding and optimising bone cement performance is found in the uncertainties in monitoring the evolution of internal defects that are though to dominate *in vivo* failure. The current experiments particularly sought to synthesise high resolution imaging with complementary damage monitoring methods (particularly acoustic emission and ultrasonic scanning). As such, evidence of the chronology of failure may be obtained whilst making efficient use of the synchrotron facilities as critical damage locations within samples will be known prior to scanning. Several material were prepared for the experiment: post-cured model implant constructs (stems cemented into bone analogues in the laboratory), fatigue loaded materials taken either to final failure or halted after initial damage detection via acoustic emission, and ex-planted cement, retrieved from a failed implant in an elderly patient. Additionally, fatigued coupons of novel cements containing multi-walled carbon nanotubes (MWCNT) were investigated.

A key result of the experiment has been the successful synthesis of micro-tomography with prior damage monitoring. Figure 1 shows ultrasound scan results and corresponding micro-tomographic reconstruction of defects in a region exhibiting high acoustic emission activity in the early stages of fatigue loading. Previous work has shown failure to progress from internal porosity within such cements, although the earliest stages of this process have been impossible to observe. Whilst relatively large fatigue cracks were identified and analysed in a number of the present micro-tomography samples, close examination of the region highlighted in Figure 1 was significant in revealing the earliest stages of failure, see Figure 2. In Figure 2(a) it is evident that cracking occurred close to an apex in the pore morphology, formed by the intersection of pre-polymerised beads required for clinical use of the material. Sections through the crack suggest that it did not form at the root of this stress concentrating feature, but in a $BaSO_4$ rich region of matrix immediately ahead of the notch, i.e. it is initially discontinuous with the pore. Such behaviour is of interest in its parallel with previous work on pore initiated fatigue cracking in Al-Si metallic samples [1], where it is noted that it is the combined influence of pore stress concentrators and stress/strain mismatch between constituent phases that may control damage initiation.

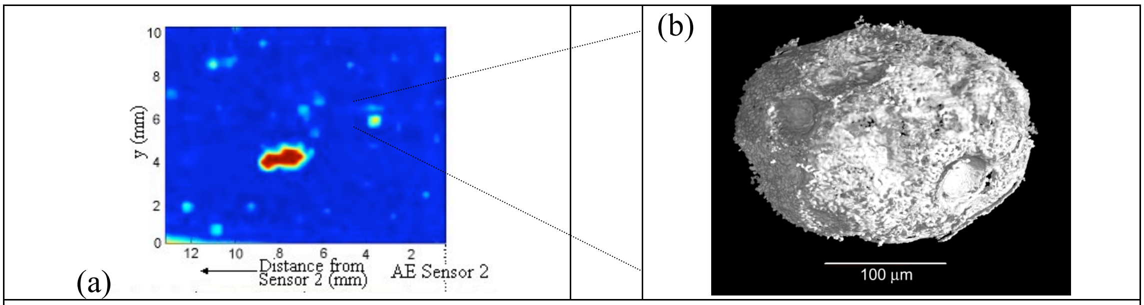

Figure 1: (a) Ultrasound image and (b) 3D tomographic reconstruction of porosity in a region exhibiting high acoustic emission activity during fatigue.

The bone cement and Al-Si alloy are analogous in this respect, in that the secondary phase contain part of the microstructure will necessarily lie at the most convex/small local radius regions of the pores that are present. It may be seen in 3D reconstruction of Figure 2(b) that the crack is closely correlated with a ridge in the side of the pore formed by the location of five pre-polymerised beads; the ridge is approximately perpendicular to the loading direct, consistent with an enhanced stress concentration effect. A combined initiation influence of pore stress concentrations and secondary phase particles supports recent literature findings regarding the performance nano-scale $BaSO_4$ containing cements, although this point will require further experimental analysis and validation.

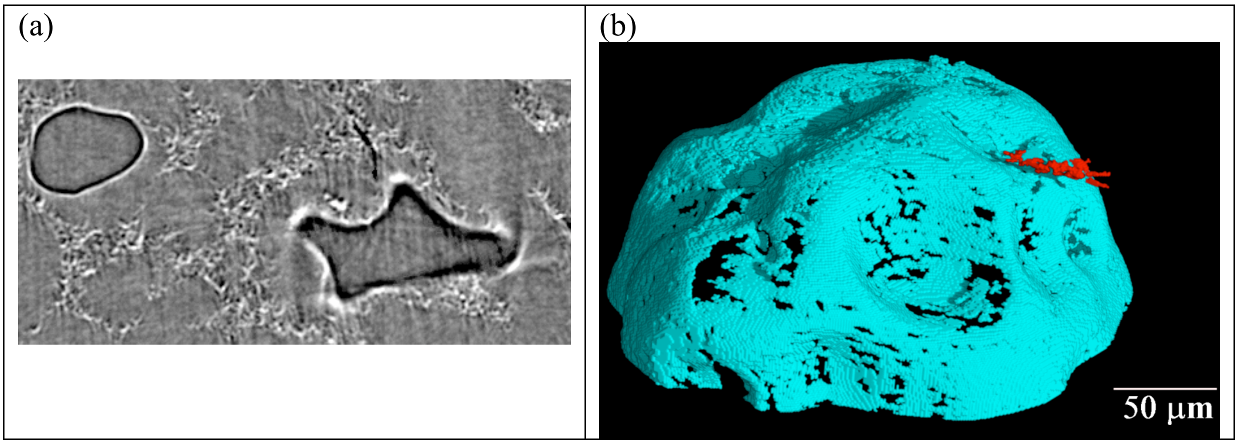

Figure 2: (a) Tomographic slice through a crack initiated in the vicinity of a pore demonstrating the discontinuous nature of the crack and pore, and (b) 3D representation of the crack (red) in relation to the overall void morphology (blue). N.B. loading direction is horizontal in (a), and approximately vertical in (b).

Similar analysis of carbon nano-tube containing cement showed evidence of a change in crack initiation mechanism, highlighting an increased rôle of debonding between the matrix and pre-polymerised beads. A change in mechanism was also implied by the acoustic emission signature of the material, and is initially attributed to the necessarily inhomogeneous distribution of nanotubes, being present in the matrix material only (subject to ongoing assessment).

Investigation of ex-planted samples proved to be unsuccessful in this experiment, as the available samples were found to contain very high levels of porosity (consistent with the era of their implantation). As such, exact crack locations could not be discerned in radiographic projections: features that appeared to be cracks during projection turned out to be artefacts of closely spaced voids. Improved location of damage in such clinical materials is expected to be the subject of a future beamtime proposal.

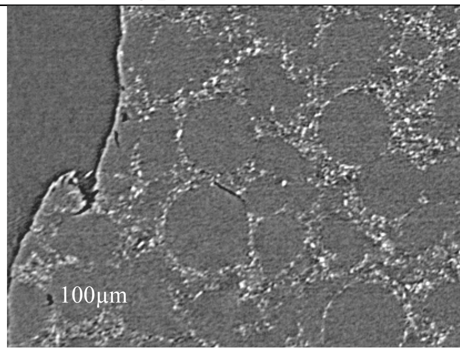

Figure 3: Interfacial crack initiation identified in MWCNT containing cement.

[1] J-Y. Buffiere, S. Savelli, P.H. Jouneau, E. Maire, R. Fougeres, (2001), 'Experimental study of porosity and its relation to fatigue mechanisms of model Al –Si7–Mg0.3 cast Al alloys' Materials Science and Engineering, A316,115–126.