Introduction: Aseptic loosening in cemented hip prosthesis is still prevalent, constituting 63% of revision procedures performed in the UK in 2006[3]. The integrity of the cement-bone interface is vital to the long term performance of a cemented hip prosthesis[2]. Examination at the microstructural level would aid further understanding in the complex load transfer from cement to bone, whether bone or cement fails first and the effect of the quality and geometric bone microstructure on the strength of the interface. Due to the difficulty in obtaining the properties of the interface experimentally, micro finite element (μFE) methods can be used as a powerful technique for evaluating the interfacial behaviour at the microstructural level. In this study, μFE models of a cement-bone analogue specimen subject to four point bend loading conditions have been created. Regions of high stress were identified. Additionally, the specimen was subjected to four point bend testing experimentally and monitored using acoustic emissions (AE) until events representative of damage were located. CT images of the samples were used to evaluate these damage areas. Damage occurred within the interdigitated cement/bone region and was directly related to stress raisers and recesses in the cement. These experimental observations correlated well with the finite element model.

Materials and Methods: Cement-cancellous bone analogue specimens were manufactured and tested in four-point bending. Duocel aluminium foam (ERG, Ca) was used as a cancellous bone analogue to eliminate problems with specimen variability. CMW1 cement (CMW Ltd, Blackpool, UK) was mixed and pressurised into the foam to produce cement/cement-foam (composite)/foam tri-layer specimens with cement penetration depths of approximately 3mm and cement mantle thicknesses of 2mm, similar to values reported in the literature[3]. The specimens were machined into four point bend specimens with dimensions of 10 x 12 x 50mm following guidelines suggested by BS ISO 12108:2002[4]. The samples were subjected to incrementally increased loading and AE was used to continually monitor and detect the onset of permanent damage. Testing was suspended when critical damage was observed[3]. This corresponded to acoustic emission events with high amplitude (>70dB), high energy (>102eu) and high durations accompanied by medium rise times. Damage was evaluated using CT at a resolution of 40μm before and after testing. This process of testing and imaging was repeated to examine propagation of damage.

A smooth surface tetrahedral FE mesh, using the CT images of the sample were created with the marching cubes algorithm implemented in Amira 4.0 (Mercury Systems)[6,7]. Pores in the cement mantle were not included in the mesh. Boundary conditions representative of a four point bend test were applied in MSC Marc. A linear elastic analysis was performed. Damage and contact was not modelled. The interface between materials was assumed to be fully bonded. Tissue moduli of 70GPa and 2GPa were used for aluminium and cement respectively.

Results: Damage progression was monitored using complimentary non destructive techniques. Acoustic emission was able to locate damage before it was discernable by 40μm resolution CT images of the sample. Cracks initiated at the interface in the cement-foam composite region 25-30mm from the 1st sensor and did not propagate into the cement region. Cracks form in regions of stress raisers as a result of the geometry of the foam and recesses in the cement due to flow of the cement into the intra-trabecular spaces as shown in Figure 1.

Figure 2 shows the equivalent von Mises stress for a sample in four point bending. There are regions of high stress at the aluminium foam, where the nodes are constrained corresponding to deformation of the foam around the rollers. The stress is higher on one side of the sample where greater acoustic activity was recorded.

Discussion: Excellent correlation was observed between damage location identified by AE and actual damage location seen by CT. Damage occurred in the interdigitated region where Race et al[3] found damage is likely to initiate. Cracks may be difficult to examine using CT after loading due to crack closure. The synthesis of these techniques confirms AE as an effective tool for examining propagation of damage for validation of μFE element models.

The high resolution μFE model of the interface was able to predict regions of deformation of the sample in the aluminium but was unable to identify the exact region of failure. This may be due to the omission of damage and contact parameters in the simulation. The stress transfer will change across the interface with inclusion of contact, modelling debonding and modelling damage of the aluminium.


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