Combined Non-Destructive Evaluation of Cement Shrinkage Effects in a Total Hip Replacement Model

Mark N. Mavrogordato1, Mark Taylor, Andrew Taylor2, Martin Browne1

1Bioengineering Science Research Group, University of Southampton, Southampton, United Kingdom; 2Finsbury Development, Leatherhead, United Kingdom

mm100@soton.ac.uk

Introduction: Failure to identify early stages of aseptic loosening of cemented components can lead to revision operations that are unnecessarily complicated and more likely to fail [1]. Several authors have demonstrated that the magnitude of strains induced in bone cement during polymerisation due to the volumetric shrinkage and thermal contraction is sufficient to cause damage [2][3]. Using one Acoustic Emission (AE) sensor they were able to show signs of activity indicative of cracking and de-bonding. Various other studies have looked at the potential to exploit the AE technique for use in orthopaedics, however, the true sources of the acoustic activity detected in these studies has often been the subject of debate [4] due to the difficulty in correlating any acoustic activity to real damage. This paper combines acoustic and radiographic methods to monitor damage accumulation during the polymerisation of a bone cement like material. The source of located acoustic events has been correlated to visual flaws such as cement cracking, porosity and de-bonding, demonstrating the potential of AE for in situ monitoring.

Materials and Methods: AE sensors were developed in-house and linked to a Vallen Systeme AMSY-5 acoustic emission analyzer and software package. The CT images were produced from an X-TEK Systems Ltd Benchtop CT 160Xi micro CT scanner at 30-40micron resolution. To demonstrate the technology, a solid square section tapered stainless steel stem was inserted into an acrylic based polymer (Technovit - Heraeus Kulzer GmbH) filled Tufnol tube with four AE sensors mounted along the length of the Tufnol tube. The location capability of the sensors was verified using a Hsu-Nielson source to induce acoustic activity within the construct at known locations. Following initial insertion, the construct was left for 60 minutes to allow the Technovit to polymerize and cool following exotherm. AE activity was recorded throughout this time. The cured Technovit was bathed in a solution of Zinc Iodide which acts as a radiopaque penetrant and was found to effectively highlight regions of damage and porosity on the subsequent CT images. This procedure was repeated five times.

Results: Similar to the work of Roques et al [2], acoustic activity was observed in the form of bursts of high activity followed by periods of silence. This burst type activity was observed in all five specimens and the waveform characteristics showed evidence of both crack type behaviour (events showing short rise-times and long durations) together with events characteristic of debonding (events with relatively long rise-times and durations). However, the main focus of this work was to locate and correlate acoustic activity to the CT images. The micro-CT images show clearly the different types of damage that can occur during the polymerization of Technovit. Specimen 1 tended to locate events around the distal tip of the cement mantle, and the CT images showed the majority of damage to have formed in this region. Subsequent specimens showed a distinct proximal dominance for located AE events (Fig 1), and again the CT images reflect this to be the case (Fig 2). The exact location of the defects within the Technovit layer remained undetermined until the radiographic images were reconstructed into a 3-D volume and segmented such that only the zinc iodide appeared visible (Fig 2).

Discussion: Present in vitro and in vivo methods of detecting damage accumulation in implanted constructs are limited by resolution and frequency of review. The results from this work demonstrate the capability of the acoustic emission technique to detect different forms of damage accumulation in situ and in real time. Excellent correlation between AE activity and actual located damage was observed in all specimens. Direct correlation of damage observed via AE and micro-CT has highlighted the potential value of AE for assessing the state of the bone cement layer and its interfaces without the need for test interruption.


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