

MEASURING FRACTURE TOUGHNESS OF SMALL BONE SAMPLES BY MEANS OF THE “WHITENING-FRONT TRACKING” METHOD

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Introduction

Assessment of toughness behaviour is an emerging means for quantifying bone quality. This is generally done by determining the *fracture toughness* or the *crack-growth toughness* of the material [Ritchie et al., 2008]. The experimental procedure for determining these measures requires monitoring of the crack extension during mechanical testing of a pre-cracked specimen. This, using conventional microscopy methods, is not always feasible when it comes to millimetre-size bone samples as the developed crack is often too small and/or not visible. However, during crack propagation, a pronounced “whitening” area is developed around the crack-tip, which has been associated with increased light reflection on the surfaces of newly formed microcracks [Thurner et al., 2007]. In this study, we present a semi-automatic videography method capable of generating crack-extension resistance curves by tracking the whitening-front propagation.

Methods

Single-edge notched SE(B) specimens of 0.8 - 0.9 mm width - height and 10 mm long were machined from human femora and tested in three-point bending. The experiments were recorded with a video-camera and a custom Matlab® algorithm was used for tracking the whitening-front propagation and generating the propagation resistance curves (R-curves). The algorithm was based on the subtraction of the first video frame, where no whitening had been developed yet, from each frame of video. Correlation between the crack and the whitening propagation was examined using notched whole rat tibiae on which both the crack and the whitening were evident. Finally, tomographic scans of partially cracked specimens were obtained using SRμCT (I13,Diamond Light Source Ltd, Didcot, Oxfordshire, UK) in order to investigate origin of the whitening. This work has been approved by the NHS, Health Research Authority; NRES Committee South Central - Southampton A.

Results

Correlation analysis showed that the whitening - front is located 300 – 400 μm ahead of the crack-tip ($r = 0.97$, $p < 0.001$) and propagates in a self-similar manner with it. Figure 1 shows the whitening localization of the whitening-front (arrow) as it propagates through the specimen. This information combined with the load – displacement data can then be used for the generation of the R-Curve (cf Figure 1). Finally, SRμCT experiments revealed that in fact the whitening is related to extensive microcracking within the bulk of the specimen which is often not evident in the surface of the sample.

Discussion

Here we show that strain-induced whitening can be used for the generation of full crack-growth resistance curves of millimetre-sized bone specimens in a simple and fast manner. Based on the SRμCT analysis, we propose that “whitening” can be conceived as an impression of “true” crack propagation, which often occurs in the bulk of the material. Importantly, the novel method will enable fracture toughness testing of small samples obtained from biopsies or machined from rodent bones.

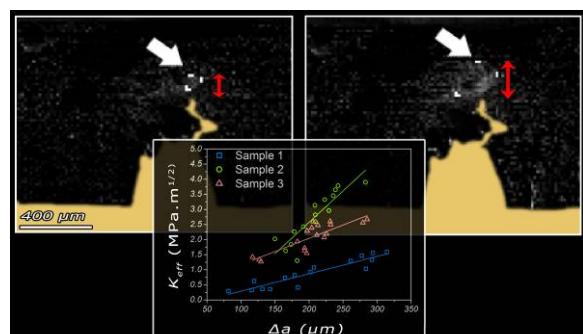


Figure 1: Whitening-front localization on the calculated difference image and representative examples of generated R-curves.

References

Ritchie et al, Bone 43: 798-812, 2008; Thurner et al, Eng Fract Mech, 74: 1928-1941, 2007