Effect of fatigue-induced microdamage on the compressive properties of trabecular bone

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Introduction: Understanding the failure mechanisms and effect of microdamage accumulation in bone is important for treatment and prevention in degenerative diseases such as osteoporosis. The common sites of fracture in osteoporotic patients – arm, vertebra, hip – have large proportions of trabecular bone, which makes them of particular interest [1]. Degenerative bone diseases disrupt bone's natural remodeling ability, meaning the microdamage which is normally repaired begins to accumulate, increasing a patient's risk of fracture. The current study aims to investigate the effect of microdamage accumulation on subsequent monotonic compressive tests-to-failure using cored bovine trabecular bone samples.

Methods: Trabecular bone samples were cored using a 4.67mm inner diameter metal bond diamond core drill (Starlite Industries Inc., PA, USA). Embedded in end-caps and wrapped in saline-soaked gauze, the samples consisting of a 2:1 aspect ratio were subjected to cyclic compressive loading at a displacement rate of 1.0mm/min between 0 N and a load corresponding to a normalized stress value of σ/E_0=0.0035 (where σ is the applied stress and E_0 is the initial modulus) on a MT3KCT loading device (Deben UK Ltd, West Sussex, UK). Each sample was tested to a predetermined number of cycles, thus allowing a nominal reduction in Young's modulus to be attained, and then subjected to a compressive test-to-failure using the same displacement rate of 1.0mm/min.

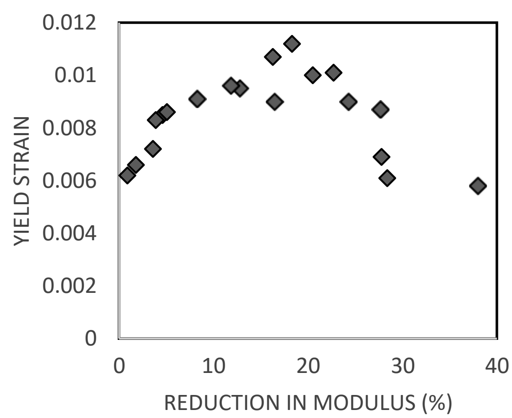

Figure 1: Monotonic compressive yield strain vs fatigue-induced reduction in modulus.

Results: The resulting engineering stress-strain curves obtained in the monotonic tests-to-failure were analyzed using MATLAB (MathWorks, MA, USA). Normalized yield stress, yield strain, cumulative strain, and work to failure were evaluated as a function of the reduction in modulus. Of note, the yield strain was found to increase initially and then abruptly decline, as shown in Figure 1.

Discussion and Conclusions: Referring to Figure 1, the work of Kosmopolous et al. [2] suggests that the initial increase in yield strain with reduction in modulus is due to a crack-redistribution toughening mechanism in which many small microcracks develop, thereby allowing for an increase in elastic strain. The sudden decrease in yield strain at a critical reduction in modulus is believed to be caused by a significant scale of crack growth in a few microdamaged regions. This explanation is supported by Kosmopolous et al. who correlated a decrease in mechanical properties with the development of a few, larger microdamage sites.

References:

[1] Osterhoff et al. (2016). Bone mechanical properties and changes with osteoporosis. Injury Vol 47 (2) p. S11-S20.

[2] Kosmopolous et al. (2008). Modeling the onset and propagation of trabecular bone microdamage during low-cycle fatigue. Journal of Biomechanics Vol 41 (3) p. 515-522.