Fall 10-7-2015

In-situ micropillar compression of bone shows remarkable strength and ductility but no damage

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Recommended Citation

[1] J. Schwiedrzik et al., Nature Materials 13, 740-747, 2014.

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IN SITU MICROPILLAR COMPRESSION OF BONE SHOWS REMARKABLE STRENGTH AND DUCTILITY BUT NO DAMAGE

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Bone is a hierarchical composite material featuring a cell-seeded mineralized collagen matrix. It is designed for mechanical support, metabolizing minerals and storing bone marrow. Its strength depends on the amount of mineral measured by clinical densitometry, but also on the micromechanical properties of the bone hierarchical organization. A good understanding has been reached for elastic properties on several length scales, but up to now there is a lack of data with respect to plasticity at the lower length scales. An experimental setup for micromechanical testing allowing a straightforward interpretation of the data due to the uniaxial stress state is micropillar compression. Micron sized pillars were produced by milling of the material using a focused Ga-ion beam and compressed uniaxially to extract mechanical properties such as yield stress and strength.

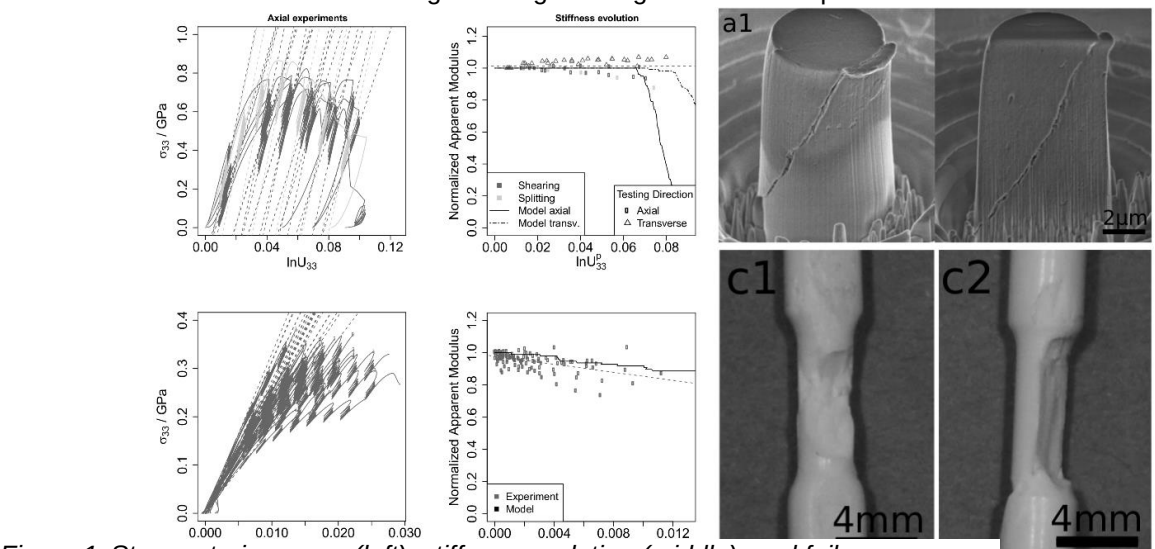

Figure 1: Stress-strain curves (left), stiffness evolution (middle), and failure mechanisms (right) of micropillar (top) and macroscopic (bottom) compression

40 monotonic and 10 cyclic micropillar compression tests observed *in situ* in a scanning electron microscope complemented by micro-indentations and 26 macroscopic cyclic uniaxial compression tests were performed on dry ovine bone to identify its mechanical properties as well as deformation and failure mechanisms [1]. While the elastic properties measured during micropillar compression, microindentation and macroscopic compression tests were consistent, the plastic deformation and failure mechanisms differed between the two length scales. A majority of the micropillars showed a highly ductile behavior with continuous strain hardening until failure by localization in a shear plane, while the macroscopic samples failed in a quasi-brittle fashion. The microscopic compressive strength was 2.4 times higher than at the macroscale (0.75 GPa vs. 0.31 GPa), the maximum plastic strain 6 times higher. Also, cyclic compression tests showed no reduction in elastic modulus of the micropillars as opposed to the macroscopic samples.

These experiments illustrate a transition in bone under compression from ductile behaviour at the microscale to a quasi-brittle response driven by the growth of microcracks along interfaces or in the vicinity of pores associated with modulus reduction at the macroscale. The insights obtained from this study may help to improve our understanding of the fragility of bone due to ageing and disease in the future.

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