
HIERARCHICAL ELASTOPLASTICITY OF CORTICAL BONE: OBSERVATIONS, MATHEMATICAL MODELING, VALIDATION

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Abstract

While the mechanical failure of bone is classically associated with the formation of microcracks, with sizes ranging from 50 to 300 microns, a variety of experiments and computations, including solid-state nuclear magnetic resonance tests, molecular dynamics simulations, and mechanical tests on cuboidally or cylindrically shaped micropillars of bone extracellular matrix, have evidenced that the nanoscale source for material degradation and bone strength appears to be of plastic and ductile nature, coming from mutual dissipative sliding of hydrated hydroxyapatite mineral crystals within the extracellular bone matrix. We here quantify the macroscopic strength effects of this nanoscale source, through a six-step hierarchical elastoplastic micromechanics model: A non-associated Mohr-Coulomb plasticity model is adopted for the description of plastic events arising right at the nanolevel of the hydrated mineral crystals found within the ultrastructure of bone. The latter is first integrated in a fashion inspired by the so-called return-mapping algorithm which was popularized in nonlinear Finite Element analysis, and then combined with a hierarchical concentration-influence tensor concept, yielding elasticity and strength values throughout the entire hierarchical organization of bone. Finally, the six-step homogenization scheme is carefully validated against a broad selection of biochemical and biomechanical experiments.

References:

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