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A multi-scale bone study to estimate the risk of fracture related to osteoporosis

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Objective:

Osteoporosis is a disease marked by decreased density and quality of bone, leading to weakness of the skeleton and increased risk of fracture. Bone fractures caused by the osteoporosis become increasingly important goal for both clinicians and biomedical researchers who try to evaluate and to prevent the risk of fracture. In this study, a finite element model at the nanoscale level “mineralized collagen fibril” is proposed to investigate this problem.

Material and Methods:

The aim of this work is to investigate the effect of mineral density on fracture behaviour of mineralized collagen fibrils (Fig. 1).

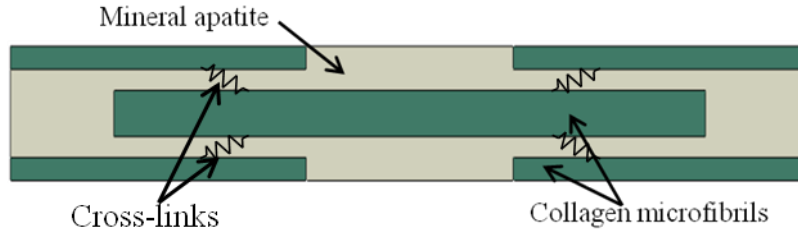


Figure1. Mineralized collagen fibrils model

A two-dimensional finite element model of collagen fibril, which is a composite material containing an inorganic mineral hydroxyapatite reinforced by collagen microfibrils linked together by cross-links, with symmetric and periodic boundary conditions is considered in this study. To model the progressive development of damage of bone through the decrease in its elastic stiffness, a homogenized measure of damage is introduced in quasi-brittle damage law, which in the simplest case is represented by a scalar D , called the damage variable.

$$\sigma_{ij} = (1 - D)C_{ijkl}\varepsilon_{kl} \quad 0 < D < 1 \quad (1)$$

Where: σ_{ij} the Cauchy stress components, ε_{kl} the linear strains and C_{ijkl} the components of elasticity tensor.

Bone mineral density measurements are used to diagnose osteoporosis (a condition marked by decreased bone mass). In this work, the variable reflecting mineral density is given by the formula:

$$E_{mp} = \psi_I E_m \quad (2)$$

$$\psi_I = \frac{\rho_i}{\rho_m} \quad \text{With} \quad 0 \leq \rho_i \leq 1 \quad \text{and} \quad \rho_m = 1 \quad (3)$$

Where E_m Young's modulus of the pure mineral, E_{mp} Young's modulus of the porous mineral and ρ_i the mineral density of the whole structure.

Results:

The result of the proposed finite element simulations coupled to anisotropic damage behavior law is shown below.

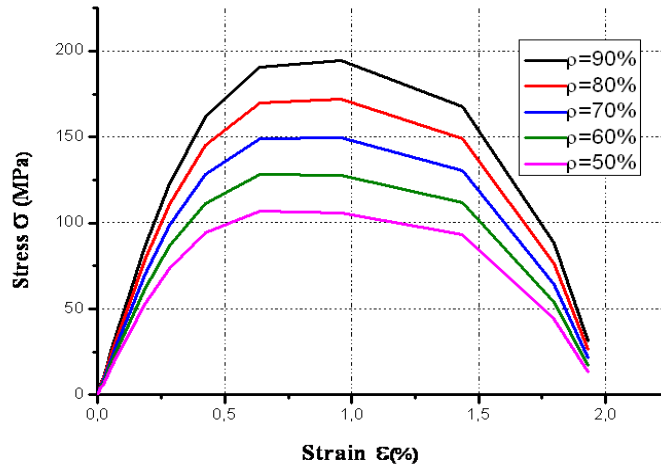


Figure2. Stress-strain curve with varying fibril mineral density

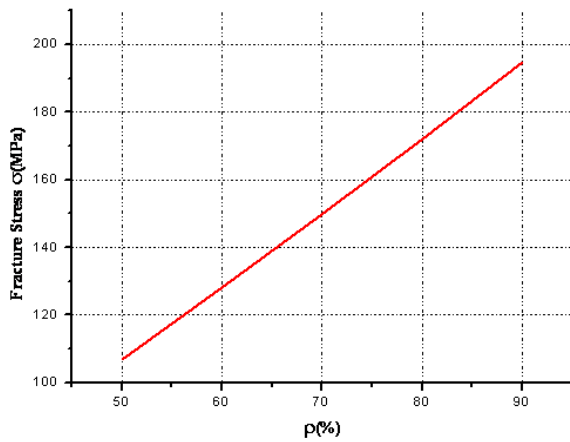


Figure3. Fracture stress of a collagen fibril as a function of fibril mineral density

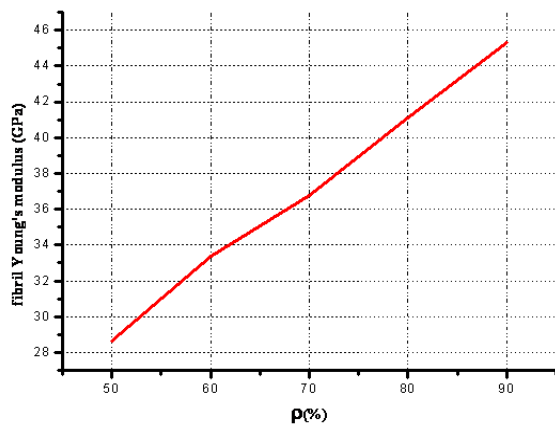


Figure4. Fibril Young's modulus as a function of fibril mineral density

Conclusion:

The proposed model coupling anisotropic behaviour with damage law allows for the simulation of the progressive fracture of the fibril in realistic way. Apparent local failure properties of bone can be predicted from nanoscale level. Such local properties can be assigned to whole bone in order to assess its risk of fracture.

Acknowledgments:

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