PARAMETER IDENTIFICATION OF A NONLOCAL HARDENING-SOFTENING ELASTOPLASTIC CONSTITUTIVE LAW FOR TRABECULAR BONE

[1]Mathieu Charlebois, [2]Philippe K. Zysset and [1]Milan Jirásek

[1]Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague; email: mathieu.charlebois@fsv.cvut.cz

[2]Institute of Lightweight Design and Structural Biomechanics, Vienna University of Technology

INTRODUCTION

Investigations of bone stiffness and strength based on continuum finite element (FE) models have big advantages in terms of computational cost when compared to micro FE models. A nonlocal elastoplastic constitutive law with damage that leads to softening has recently been developed for the compressive behavior of trabecular bone [1]. Mechanical tests on human trabecular bone biopsies originating from several anatomical sites have been performed using a large-strain protocol in compression [2]. The aim of this work is to identify the parameters of the nonlocal constitutive law using the experimental data, and to present a three-dimensional application example.

METHODS

At first, homogeneity of the samples was assumed in order to use previous analytical models accounting for morphology, which is characterized by the bone volume fraction (ρ) and by fabric tensor (**M**). Such models, combined with certain additional simplifying assumptions, e.g. independence of the strain at peak stress and at the local stress minimum on ρ, permitted to perform a single regression using the weighted least-square method. Therefore, parameters for modulus, strength, and minimum stress were evaluated simultaneously. To complete the identification of the homogeneous parameters, the hardening and softening parameters of the constitutive law were adjusted to match the mean experimental values of stress and strain at peak and at the local minimum point.

In the second step, continuum FE models of five biopsies with resolution of 1.3 mm were created in order to account for the heterogeneity of material properties, which has an impact on the strain localisation pattern. The nonlocal parameter values were estimated according to their physical meaning and, subsequently, the hardening and softening parameters were readjusted. Finally, the constitutive law with the identified parameters was exploited by continuum finite element models of two vertebral bodies taken from [3].

RESULTS AND DISCUSSION

Regressions using the analytical model show good correlations between morphology and elastic modulus, ultimate stress, and minimum stress (R^2>0.8). The influence of volume fraction and the axial fabric component, m_a, on the stress-strain curves is well captured by the simulations (Figure 1).

The heterogeneous model, composed of elements with a wide range of bone volume fractions, predicted strain localisation in each simulation, and the nonlocal formulation prevented spurious sensitivity of the results to the element size.

Softening of the constitutive law in continuum models of vertebral bodies has a clear impact on the regions where inelastic processes occur. During hardening, these processes accumulate in several layers, while beyond the peak stress they concentrate into a single layer (Figure 2).

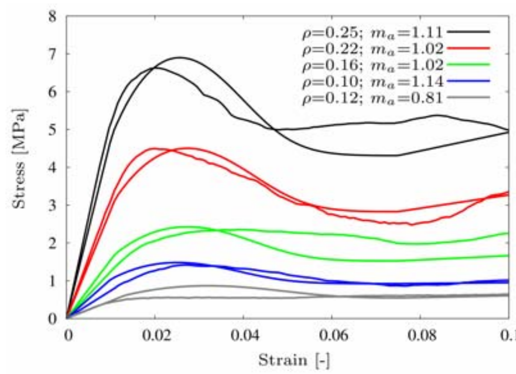

Figure 1: Stress-strain curve comparing experimental data with results obtained with the homogeneous model.

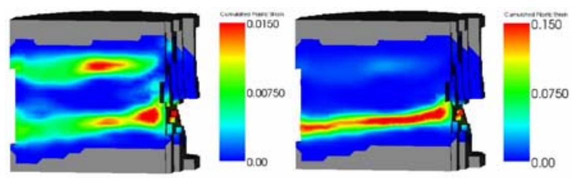

Figure 2: Lateral cut of continuum FE model of a vertebral body depicting the cumulated plastic strain before the peak (left) and after the peak (right).

CONCLUSIONS

To our knowledge, this study describes for the first time finite element analysis of whole bones using a constitutive law with properly regularized softening. Further refinement of continuum FE models together with quantification of the mechanical behaviour of complete bone structures (e.g. vertebral bodies and distal radii) at moderate strains are natural future developments.

ACKNOWLEDGEMENTS

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