Parametric analysis of cancellous bone damage

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Abstract

Evaluation of bone damage properties is a challenging task in biomechanical research. Cancellous bone is of a particular interest in this subject. Due to its porous microstructure, the analysis of its damage properties has inevitably a multiscale character. It requires (i) establishing a reliable damage criterion of trabecular bone tissue and (ii) formulation of a macroscopic damage criterion, with a corresponding damage surface, in the macro scale where the porous cancellous tissue is treated as material continuum.

The main difficulty regarding the first issue is lack of experimental data. This is due to the fact that individual trabeculae are objects of a too small size for conducting reliable experiments examining their material strength. However, a number of publications exist in which this problem is solved in a combined experimental-numerical manner. Putting it short, damage experiments are performed in the macro scale on actual cancellous bone specimens whose microstructure geometry is first digitalized using micro-CT techniques. Then, FE analysis is performed on the digitalized model to reproduce the experimental conditions and different local damage criteria are examined in order to find the one that fits best the experimental results. This approach has been successfully utilized to evaluate bovine [1] and human [2] trabecular tissue damage properties.

Generalization of experimental results to cancellous bone with various geometric microstructure is in fact a fully computational task. Given the mechanical properties at the micro level and macroscopic geometry of the microstructure, determination of damage limits for various macroscopic stress/strain states is just a standard computational procedure and was the subject of many publications, see e.g. [3]. Yet, this approach is applicable for a particular microstructure geometry and does not lend itself to be generalized, i.e. extrapolated to other geometries. Formulation of a general damage criterion able to describe damage conditions for wide spectrum of cancellous bone types is a problem that has not been resolved so far.

This contribution is an attempt to formulate such a generalized criterion. The family of somewhat idealized, macroscopically orthotropic cancellous bone geometries parameterized by a few geometric variables was once proposed in [4] and utilized to determine macroscopic elastic properties as functions of the microstructural parameters. It is postulated that any actual geometric cancellous architecture can be approximated by the idealized geometry at a right selection of best-fitting parameter values. The same model family has now served to perform damage analysis and establish damage limit values for a variety of macroscopic strain states. The results form a large database that will be made publicly accessible and can be easily interpolated to determine damage limit for any stress/strain state and for any particular set of microstructure parameters. This is equivalent to providing a straightforward numerical recipe to evaluate the approximate parameterized damage surfaces for any type of cancellous bone of known micro-level geometry.

Application of the results may have substantial significance for biomechanical analysis of bone. It should be noted, however, that their area of impact may be even wider. The family of microstructures may be a good basis to design e.g. biomimetic bone-like materials that gain increasing interest in structural engineering, see [5] for an example of their analysis in this context. The results may improve their analysis and design by adding some systematic knowledge about their strength properties.

Scientific field: biomechanics

Keywords: cancellous bone, damage properties, parametric studies

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