Identification of trabecular bone material properties in multiscale model of femur bone

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Abstract

The goal of the paper is to present results of identification of trabecular bone material properties. The identification is performed with use of evolutionary algorithm. The single isotropic trabeculae material properties are obtained on the basis of orthotropic material properties for RVE.

Keywords: multiscale analysis, computational homogenization, identification, evolutionary algorithm

1. Introduction

The multiscale modelling of tissues is emerging and important problem. The tissues have hierarchical structure in most cases. The paper deals with trabecular tissue which is one of the component of the bones. The goal of the paper is identification of material properties of tissue on the base of homogenized material properties. The identification is presented on the example of trabecular tissue in the proximal femur bone. The evolutionary algorithm is used in the identification process. The paper is extension of works presented by the authors in the [3].

2. Multiscale model of femur bone

The proximal femur bone is shown in Figure 1. The cancellous and cortical tissues are two main components of the bone. The cancellous tissue is a porous structure with complicated geometry (Figure 1).

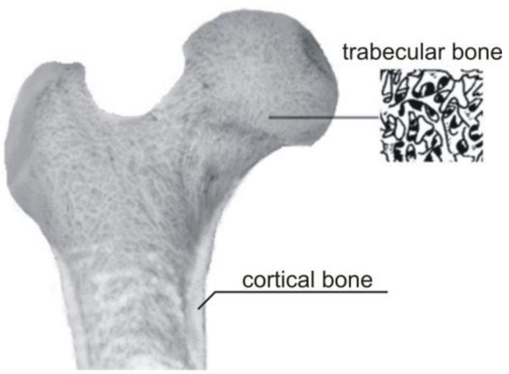

Figure 1: The proximal femur bone geometry and microstructure

The geometry of the cancellous bone changes in different locations of the femur bone. The experimental tests of single trabeculae have showed isotropic material behavior [5], however the material properties of the cancellous tissue are no longer isotropic.

The material properties depend on the tissues structure and change depending on the location in the femur bone. They can be obtained on the basis of the density obtained from CT scans [6]. The multiscale modelling is used in the paper. The heterogeneous material is replaced with a homogenous one. The homogenization is useful when the microstructure is periodic. The influence between scales in the computational homogenization is obtained on the basis of numerical solution of the boundary value problem performed in each scale.

The trabecular bone is modeled as micromodel. The representative volume element (RVE) approach is used.

The material coefficients in the case of linear problems can be obtained once for each microstructure. The six analyses should be performed for each microstructure to obtain the 9 independent material coefficients.

3. Problem formulation

The goal of the identification is to obtain material properties of single trabeculae of trabecular bone. Material parameters of the structures in one scale should be identified on the basis of measurements in another one. In the considered problem the identification of Young modulus E and Poisson ration ν of the single trabeculae is performed on the basis of measured material parameters in the macroscale for representative volume element. The material properties in the macroscale can be obtained by performing identification task on the basis e.g. strains or displacements measured for macromodel. The material properties can be also obtained by using ultrasonic velocity measurement or mechanical test for microspecimens. The problem can be formulated as minimization task:

$$\min_{E,\nu} F \tag{1}$$

$$F = \sum_{i=1}^{n} \left| a_i - \hat{a}_i \right| \tag{2}$$

a_i are computed homogenized RVE material properties, $\hat{a}_i$ are RVE homogenized material properties from the macromodel.

The objective function is multimodal in most cases, the optimization should be performed with use of algorithm resistance to local minima. The wide range of bioinspired algorithms allows to solve the global optimization problems. The minimization problem can be solved using the distributed parallel evolutionary algorithm [1]. The searched materials

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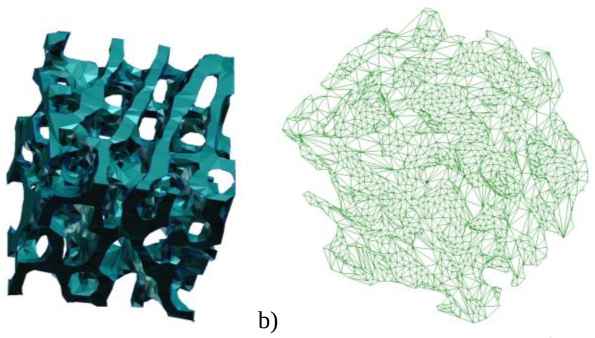
parameters - Young modulus E and Poisson ration ν of the single trabeculae create a chromosome

$$ch = [g_1, g_2] \quad (3)$$

where g_i $(i=1,2)$ are genes:
g_1 - Young modulus E,
g_2 - Poisson ration ν

4. Numerical example

The isotropic material properties for trabeculae can be performed on the basis of known orthotropic material properties for microstructure model. The orthotropic parameters for microscale can be obtained by performing tensile test for trabeculae specimen or on the basis of the ultrasonic velocity measurements. The orthotropic material properties in microscale can be also acquired by performing identification for macro level model.



a) b)
Figure 2: The trabecular RVE model: a) geometry, b)finite element mesh

The identification of material parameters E and ν of the single trabeculae on the micro level has been performed as minimization of the objective function F, given by (1), by the distributed parallel evolutionary algorithm with the parameters presented in Table 1.

Table 1: The evolutionary algorithm parameters

Parameter	Value
Number of subpopulations	2
Total number of chromosomes	30
Number of genes	2
Probability of crossover+Gaussian mutation	90%
Probability of uniform mutation	10%
Ranking selection	-
Number of iterations	35

The microstructure model shown in Figure 2 was used for computations. Numerical results of identification are presented in Table 2.

Table 2: Actual and found material parameters of the trabecular bone in the microscale

Material parameters	Actual	Found	Error %
E [MPa]	3300.0	3305.5	0.16
ν	0.330	0.329	0.30

The history of the objective function F changes during optimization for two populations is presented in Figure 3. The improvements of objective function values in subpopulations after migrations phase can be observed.

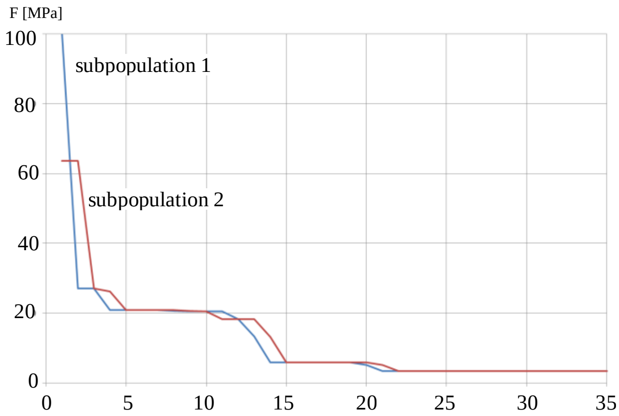


Figure 3: History of the objective function for two subpopulations

5. Conclusions

It is seen very good agreement between actual and found material parameters. The identification problem in the multiscale modelling belongs to a new emerging methodology which is very useful in determining of some material parameters in the microscale having information about some measurements from the macroscale.

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