Determination of the mechanical properties distribution of the sample by tomography data

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Abstract. Structural characteristics of the material should be taken into account while the problems of determining the stress-strain state of porous structures are solved. Describing microstructure of porous media is important for inhomogeneous mechanics. Natural experiments are expensive, that’s why nowadays it is popular to use simulation with computer tomography data. These study presents methods to determine mechanical and microstructural properties distribution of the object. Methods were tested on porous samples. Two-phase liquid polyurethane plastics of cold curing Lasilcast was used in research. Produced porous samples was scanned by Vatech PaX-I 3D. Received data were mesh by subvolumes. For every subvolume porosity, fabric tensor and elasticity tensor were calculated. Results were analyzed and compared with natural experiments.

1. Introduction

Structural characteristics of the material should be taken into account while the problems of determining the stress-strain state of porous structures are solved. Describing microstructure of porous media is important for mechanics of inhomogeneous materials [1, 2], soils [3-5], especially for biomechanics [6-8]. Nowadays fabric tensor is well known object of such description [9, 10]. It was shown that eigenvalues of the tensor can be useful for determine orthotropic directions [11]. It was shown that physical activity generates changes in bone tissue. This changes can leads to decreasing of the stress capacity of media – decreasing of the critical stress [12-14]. Correlation between microstructure of bone tissue and macro mechanical parameters was noticed [15]. This study performs techinics to analyze microstructure of object by using computer tomography (CT) data. Natural experiments on human bones are expensive, that’s why it is popular to use plastic porous models (substitutes). But these models should have mechanical properties very similar to real bone tissue, including microstructure properties. In these study methods to determine mechanical and microstructural properties distribution of the plastic object are presents. Calculated parameters can be useful to compare some sample with bone tissue properties.

2. Materials and Methods

Two-phase liquid polyurethane plastics of cold curing Lasilcast (Lc-12) was used in research. This material is using to create bone models for experiments. Declared properties are: mixture viscosity 105 mPa, shore hardness – 75, density 1.05 gm/sm³, Young’s modulus 500 MPa (for compression). Solid
and porous samples were produced. For CT scan Vatech PaX-I 3D was used. The CT data of the object was meshed by regular subvolumes (see figures 1a and 1b).

Every subvolume of the mesh was analyze in terms of fabric tensor. For this purpose mean intercept length (MIL) distribution was built for every element and then MIL was approximated by quadratic form:

\[ L^2(n) = \bar{n} \cdot \bar{M} \cdot \bar{n} \]  

(1)

where \( L \) – is value of the MIL in direction described by vector \( n \).

Then the fabric tensor can be restored by equation:

\[ H(n) = L^{-1/2}(n) \]  

(2)

We used subvolume as representative volume element (RVE), so all subvolumes were meshed by regular hexahedral mesh in order to calculate orthotropic properties. We use binarization threshold to differ the material from pores. To determine mechanical properties of the RVE mechanical properties of the solid medium were applied for elements where material exist and zero stiffness applied for elements where pore was. (see figure 1c)

![Figure 1. CT data: a – whole object, b – subvolume of the meshed object; c – meshed sub volume](image)

Six digital experiments were carried out to quantify the orthotropic properties of the RVE: 3 of them were applying by normal strain and in the remaining experiments were applying by shift strain. In every experiment all components of stress was calculated. Equation for mechanical properties can be written:

\[ \int_A \sigma_{ij} dA = C_{ijkl} \cdot \varepsilon_{ij}^0 \]  

(3)

where \( \varepsilon^0 \) – is known strain which was used in simulations, \( \sigma \) – calculated stress, \( C \) – components of the elasticity tensor.

Equations (3) provide overdetermined system and can be solved by using least squares method. After the elasticity tensor recovered orthotropic axes can be found [16, 17].

3. Results and Discussion

These procedures were made for whole sample. The distribution of the basic microstructure parameters is presented on figure 2, distribution of the porosity is presented on figure 2a and eigenvectors of the fabric tensor are presented on figure 2b. Direction of the orthotropic axes and
eigenvectors of the fabric tensor was closed enough (about 10 degrees of difference). Average mechanical parameters in terms of isotropic material were calculated for the object: Young’s modulus were 210 MPa and Poisson’s ratio were 0.23. This result is close to experimental data [18]. Analyzing results it can be conclude that the object possesses the regular structure. Orthotropic directions is coaxial with geometrical directions (main direction in longitudinal axis and other two directions in transverse plane). Porosity distribution deflected by an angle of 45 degree.

![Microstructure properties distribution](image)

**Figure 2.** Microstructure properties distribution: a – porous distribution, b – distribution of eigenvectors of the fabric tensor (red – 1st eigenvector, yellow – 2nd eigenvector, green – 3d eigenvector).

4. Conclusion
Method for determining the microstructure properties of the porous media by CT data is presented in the article. For well-known samples it was performed. Distribution of the microstructural parameters and information about distribution of orthotropic axes and mechanical properties along these directions were obtained. Average properties of the object were compared with experimental results. Small differences between calculated and experimental results show quality of the method. An error 22% for Young’s modulus and 15% for Poisson’s ratio were got. These method is good for examine microstructure of bone plastic models in order to check their quality.

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