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# Experimental study of evaluation of mechanical parameters of heterogeneous porous structure

**O Gerasimov, E Koroleva and O Sachenkov**[a]

Kazan Federal University, 18, Kremlyovskaya St., Kazan, 420008, Russia

E-mail: [a] 4works@bk.ru

**Abstract**. The paper deals with the problem of determining the mechanical macroparameters of the porous material in case of knowing the information about it's structure. Fabric tensor and porosity was used to describe structure of the material. Experimental study presented. In research two-component liquid polyurethane plastics of cold curing Lasilcast (Lc-12) was used. Then samples was scanned on computer tomography. Resulting data was analyzed. Regular subvolume was cut out after analyses. Then mechanical tests was performed. As a result we get information about fabric tensor, porosity, Young's modulus and Poisson ratio of the sample. In the abstract presented results for some samples. Taking into account the law of porosity variation, we considered the problem of evaluating the mechanical macro parameters depending on the nature of the porous structure. To evaluate the macroparameters, we built the dependence of the Young's modules and Poisson ratio of the material on the rotation angle α and the pore ellipticity parameter λ. The sensitivity of the deformations to the elastic constants was also estimated.

## 1. Introduction

When solving the problems of determining the stress-strain state (SSS) of porous structures, it is necessary to take into account structural peculiarities of the material [1-5]. Important problem is evaluation of mechanical parameters using structural data. Nowadays, in biomechanics is popular to use fabric tensor [6-9]. It is assumed that the fabric tensor is a quadratic form that describes the shape of a pore. Some physical relations which connect the stress-strain tensor through the elastic constants, the fabric tensor, and the solid volume fraction in the material is known [10]. In this paper experimental study is presented. The goal of investigation is to show dependence between structure and integral mechanical parameters (Young's modulus and Poisson's ratio).

## 2. Materials and Methods

In abstract we consider some experiments to show relations between structure and mechanical parameters. It was shown by mathematical models that this relation exist [11-13]. Parametric model which connects mechanical parameters and structural parameters in terms of fabric tensor was built (we use two parameters: λ – ellipticity and α – direction). In presented paper we performed experimental study. We produced parallelepiped model (length was greater than over two dimensions) using casting of plastics. Using the same plastic we produced porous models (using active chemical reaction). After that we scan every sample on computer tomography (CT) and examine received data (see fig. 1). To find regular volume, the received data was meshed to smaller cubes and in every cube porosity and fabric tensor was calculated. Then we analysed distribution of structural parameters and cut out regular sub volume.

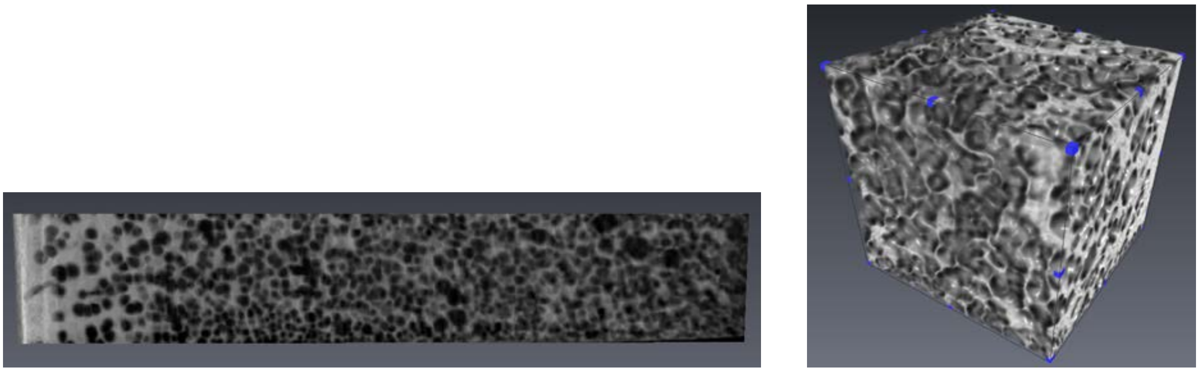

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**Figure 1.** CT scan of sample (a) and sub volume of sample (b).

Extracted sub volume after trimming was tested on test set (see fig. 2). Sample (1 on fig. 2) was setup in support (4 on fig. 2) on cross-arm (5 and 6 on fig. 2). We fixed strain gauge on sample (2 on fig. 2) in transverse direction. To measure longitudinal strain we used test's sensor (3 on fig. 2). During testing motile cross-arm (5 on fig. 2) moved up. During compression of sample we measured longitudinal and transverse strain and applied force.

## 3. Results and Discussion

In research two-component liquid polyurethane plastics of cold curing Lasilcast (Lc-12) was used. Declared properties: mixture viscosity 105 mPa, Shore hardness – 75, density 1.05 gm/sm$^3$, Young's modules 500 MPa (for compression). We produced solid and porous samples. For CT scan we used Vatech PaX-I 3D. Raw CT data was analyzed to find regular volumes. In this paper we presents results for sub volumes with porosity 45% and 50%. For the samples eigenvalues of fabric tensor was calculated either. The main of eigenvectors was directed in longitudinal direction. Quotient of two last eigenvalues was 0.54 and 0.62 respectively. Then the samples was extracted and tested (by the method described above). After treatment the data diagrams of changing Young's (E) modules and Poisson's ratio ($\nu$) during the deforming was built (see fig. 3). So, for solid sample Young's modules was 518 MPa, Poisson's ration – 0.24. For sample with porosity 45% and ellipticity 0.54 was received: Young's modules – 267 MPa, Poisson's ration – 0.2. For sample with porosity 50% and ellipticity 0.62 was received: Young's modules – 163 MPa, Poisson's ration – 0.14.

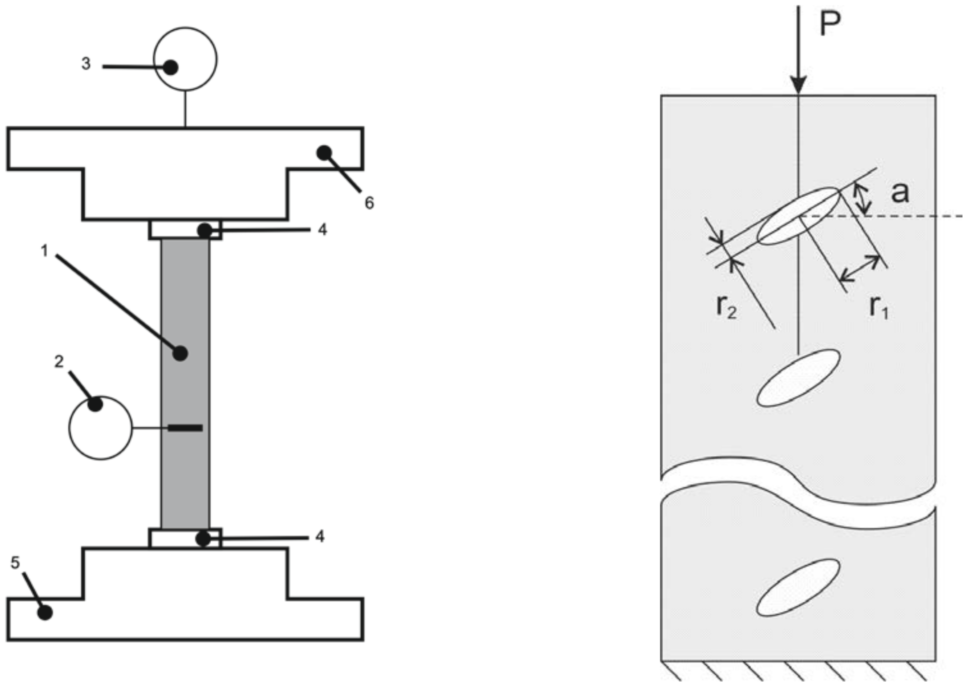


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**Figure 2.** Scheme of test set (a) and computational scheme (b).

In previous paper [10] a block diagram loaded by the compressive force P was considered. It was assumed that the sample uniformly filled with pores having the porosity $\nu_0$. The pores have an elliptical shape with the fixed semi-radii and form an angle $\pi/2$-$\alpha$ with the line of action of the applied force.

For description of the porous structure, we will use the formalism associated with the fabric tensor. Then we will supplement the system by introducing physical relations in the form [10, 14-16]:

$$\tilde{\sigma} = (g_1 + g_2 e) tr\tilde{\varepsilon} \times E + (g_3 + g_4 e)\tilde{\varepsilon} + g_5(\tilde{\varepsilon}\tilde{K} + \tilde{K}\tilde{\varepsilon}) + \\ + g_6\left(tr(\tilde{K}\tilde{\varepsilon}) \times E + tr\tilde{\varepsilon} \times \tilde{K}\right), \bar{x} \in \bar{S}, t \geq 0, \tag{1}$$

here e is the variation of the solid bone volume fraction, $\tilde{K}$ is the fabric tensor deviator, $g_i$ are the elastic constants.

The law of porosity variation was used in the following form:

$$\nu = \frac{\nu_0 + \sigma_i \left( \frac{1}{3K_{sp}} - \frac{1}{3K_s} \right)}{1 + \frac{\sigma_i}{3K_{sp}}}, \tag{2}$$

where $K_{sp}$ is the bulk modulus of elasticity of the skeleton with pores, $K_s$ is the bulk modulus of elasticity of the skeleton, $\nu$ and $\nu_0$ are the actual and initial porosities respectively, and $\sigma_i$ is the compressive stress.

To describe structure was uses two parameters: $\lambda$ – ellipticity and $\alpha$ – direction. In this case fabric tensor can be presented in the following form:

$$\tilde{H} = Q(\alpha) \cdot \begin{pmatrix} \lambda \cdot h & 0 \\ 0 & h \end{pmatrix} \cdot Q^T(\alpha), \tag{3}$$

where $Q(\alpha)$ – rotational matrix.

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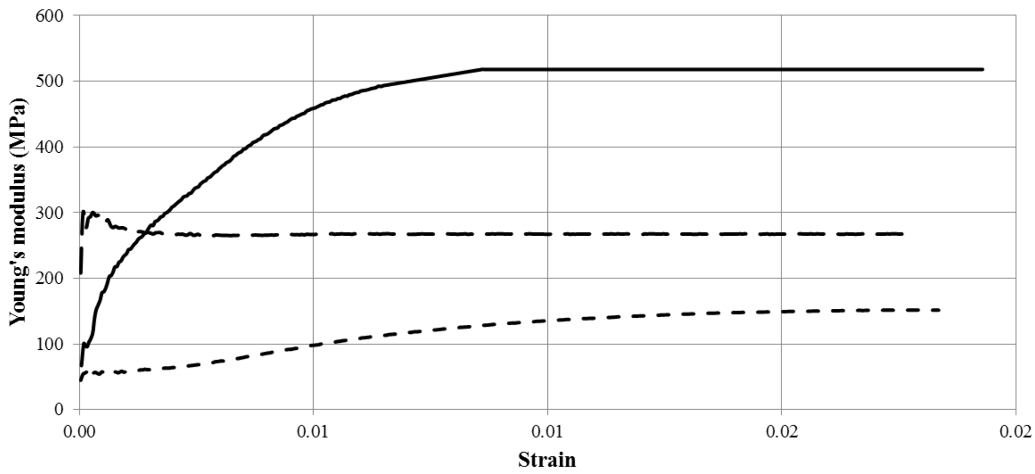


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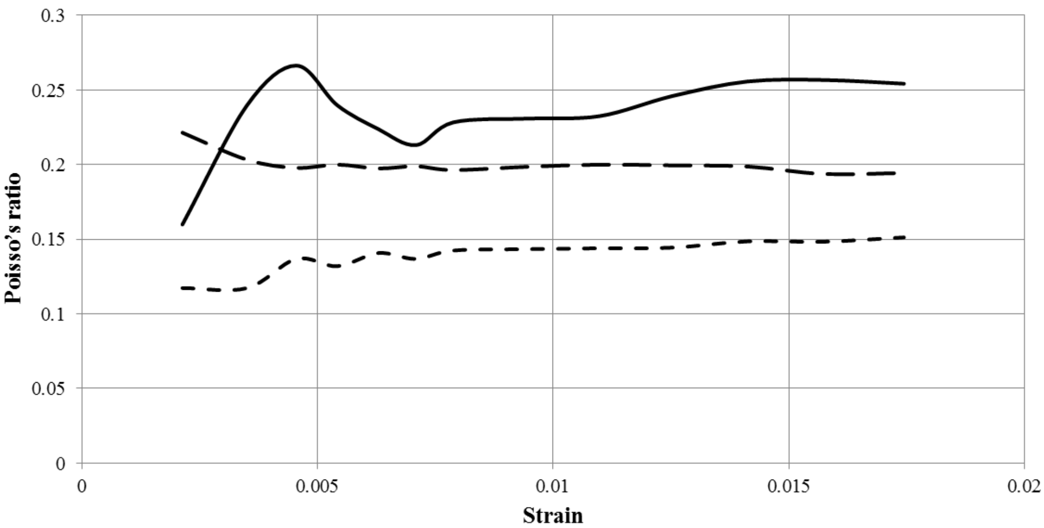


b


**Figure 3.** Results of experiments: the Young's modules (a) and Poisson's ratio(b) for different samples.

For evaluating the macroparameters, we built a dependence of the Young's modules and Poisson's ratio of the material on the λ-α axes (see Fig. 4). It was noted that in the case of circular pores, the obtained dependence does not depend on the parameters n, $\nu_0$, $K_s$ (but obviously depends on the elastic constants $g_i$). We used data of solid sample to calculate constants $g_i$. Using them diagrams for the Young's modules and Poisson's ratio in the λ-α axes was built (see fig. 4). Previously it was shown that sensitivity to the elastic constants showed their underestimation to the value of up to 20% results in the deformation increase by up to 30%. With an increase of the elastic constants by 20%, the deformations decrease by 20%.

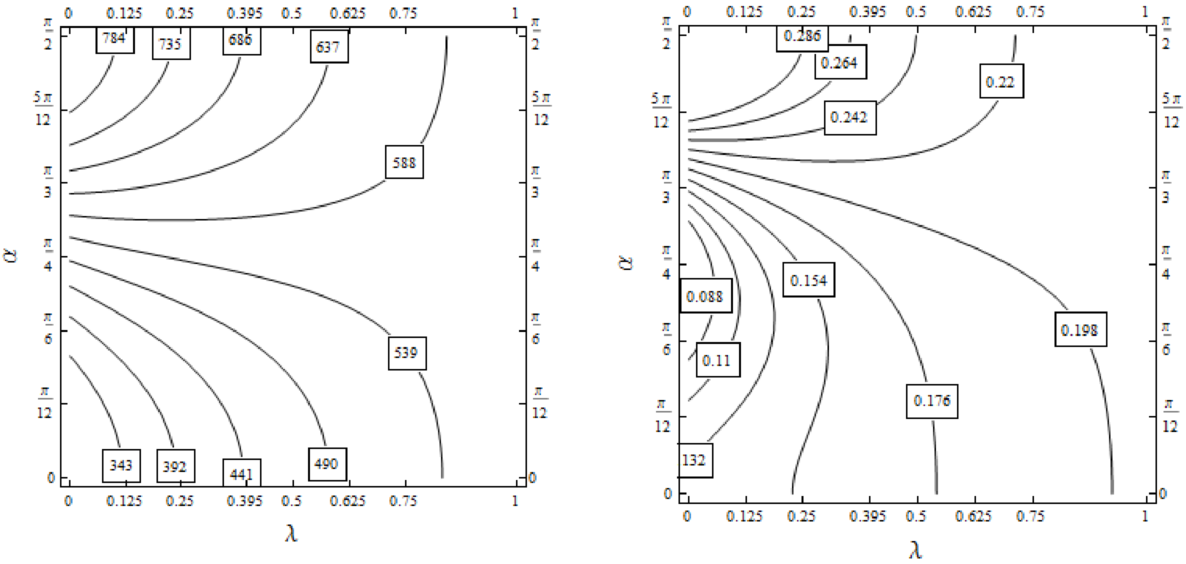


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**Figure 4.** Diagrams of computed Young's modules (a) and Poisson's ratio (b).

## 4. Conclusion

This study examines the problem of finding dependence between structure and mechanical parameters. Experimental study was presented. Fabric tensor and porosity was used to describe structure of the material. We consider samples which was made of plastic. After producing of samples we scan them on CT and then examine the structure. The first step was to find in the sample regular subvolume and then cut it out. On the second step we produced mechanical text of the sample. As a result we get information about fabric tensor, porosity, Young's modulus and Poisson ratio of the sample. In the abstract presented results for some samples. For the stated law of porosity variation, we considered the problem of evaluating the stress-strain state and get diagrams of the Young's modules and Poisson's. To evaluate the macroparameters, we built the dependence of the Poisson ratio of the material on the rotation angle $\alpha$ and the pore ellipticity parameter $\lambda$. The sensitivity of the deformations to the elastic constants was found to be 20–30%

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