Russian Journal of Biomechanics, Vol. 4, № 3: 93-97, 2000

ANALYSIS OF COMPLIENCE OF BIOMEDICAL SHEETING BASED ON POROUS MATERIALS. PART 1

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Abstract: The paper is devoted to analyzing deformation behavior of protecting coatings used in prosthetics, sport equipment, etc. Deformation characteristics of the coatings made from porous materials with various internal structure have been compared and the effect of the structure type on coating toughness has been estimated. In the process of studying stress-strain state of the porous material a macroscopic homogeneous isotropic structure has been considered showing efficient mechanical characteristics. These characteristics were determined by a method of allocation of structural unit in a rod design simulating internal structure of a porous material. In the given work the two-dimensional model of materials was considered. As a result of accounts it was established that for porous materials with small content of solid phase the material structure influenced significantly on rigidity of a covering. The greatest rigidity had the layer with sells of square form and the least one – with cells of concave form.

Key words: porous materials, effective characteristics, structural models, layer pliability

Minimization of traumatism has great meaning for sportsmen. One reason of traumatism is the occurrence of significant shock loading as a result of jumps, falls, etc. Carpets, mats, elastic coatings are the means of protection from shock loading. The products used for prosthetics of human locomotor system and damping coverings used in transport carry out similar protective functions. Similar purposes are also pursued by the developers of household and, in particular, medical (taking into account low mobility of the patient) furniture.

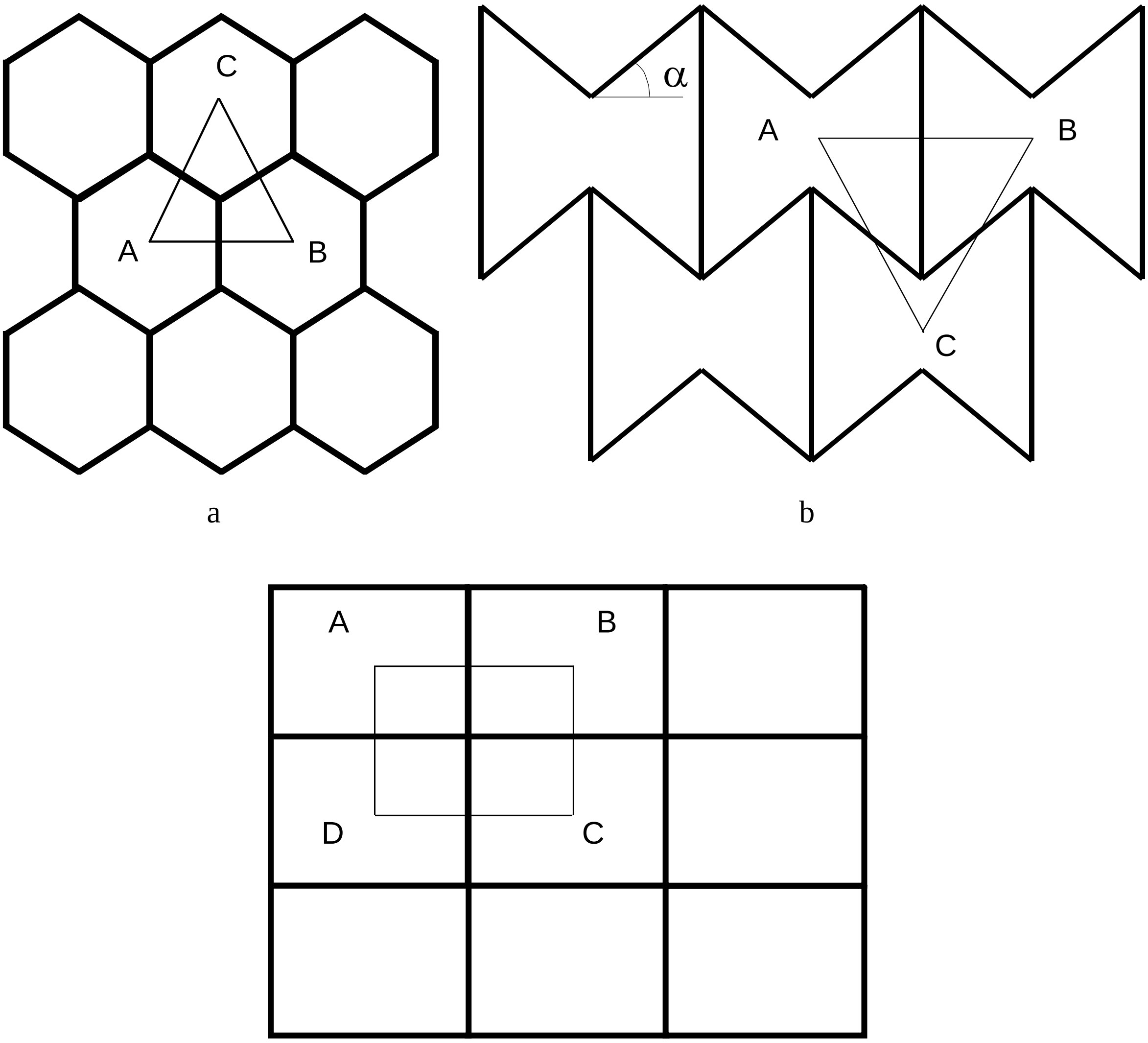
To manufacture the specified products the various porous materials are widely applied. The pliability (antonym – rigidity) of such materials is determined by the cells structure, volumetric content and elastic properties of a solid phase. These parameters may be optimized by modelling the interaction of human body and its sites with elastic materials by methods of contact mechanics [1]. In this connection the certain prospects open due to occurrence of materials with the special elastic properties, in particular, supercompressible auxetic foams [2].

The purpose of this paper is to compare various structures of porous materials for development of recommendations on their use in the biomechanical applications.

To predict the deformational behavior of porous materials the concept of effective modulus of elasticity is introduced. In this case non-uniform porous media is considered to be macroscopically homogeneous with mechanical characteristics depending on properties of a solid material, its volumetric content and internal structure.

The existing methods of determination of the effective characteristics are based on phenomenological models [3]; models of composites [4]; structural ones (mesomechanical approach).

The structural methods are most productive from the point of view of deformational effects imitation and account of features of internal structure. The analysis of microstructure of porous materials and agreement between theoretical and experimental data [5, 6] allow to



a b

c

Fig. 1. Two-dimensional models of porous materials
a) hexagonal cells; b) concave cells; c) square cells.

describe the deformation of such materials with the help of rods (for open-cell foams) or closed shells (for closed-cell foams).

The two-dimensional model most frequently used for the analysis of low-density porous materials, is shown in Fig. 1a. It consists of regular hexagonal cells and corresponds to an isotropic porous material. The method of allocation of structural unit developed, in particular, in works [7, 8] is used. Selected structural unit *ABC* is shown in Fig. 1a. It is possible to determine the effective elastic characteristics of a simulated material: *E* (Young's modulus) and ν (Poisson's ratio) by analyzing the stress-strain condition of allocated structural unit. The use of a method of structural unit gives the following relations

$$E = \frac{2}{\sqrt{3}(N+3M)}, \quad \nu = \frac{(N-M)}{(N+3M)},$$

where *N*, *M* are transversal and longitudinal pliabilities of rods, respectively [8]. The magnitudes *N* and *M* depend on properties of solid phase E_f and ν_f, volumetric content of solid fraction V_f which is equal to ratio between volume of a solid material and total volume of foam, and form of cells. For hexagonal cells in case of small value of V_f

$$N = \frac{4}{3\sqrt{3}E_f V_f} + \frac{\sqrt{3}(1+\nu_f)}{E_f V_f}, \quad M = \frac{1}{\sqrt{3}E_f V_f}.$$

The proposed method allows to find the macroscopic characteristics of porous materials with more complex structure. Let us consider the model of a material with concave form of cells (Fig. 1b). For example, such a structure has auxetic materials with negative Poisson's ratio [9]. The offered model has the strict order of orientation of cells that is absent in real porous materials. Therefore it is necessary to average the obtained results [7]. After that we receive, as well as for structural unit shown in Fig. 1a, equations for calculation of E and ν of macroscopically homogeneous isotropic material.

Other kind of porous material structure having square configuration of cells with structural unit *ABCD* is given in Fig.1c. The corresponding results as well as for structure shown in Fig. 1b also require averaging

$$E = \frac{M+N}{M(M+3N)}, \quad \nu = \frac{N-M}{M+3N}.$$

So, the effective elastic modules of simulated porous materials E and ν are determined using the characteristics of solid fracture E_f and ν_f, volumetric content of this material V_f and geometry of structure (Fig. 1). For the plane strain case the edges of cells have sides of identical length and thickness, indefinitely extended in a direction, perpendicular to plane of drawing (Fig. 1).

After determination of elastic properties of the material, its behavior can be analyzed under surface load action. Let us consider the simplest case of an infinite layer loading having thickness h freely lying on a rigid base, and evenly distributed under pressure p over length $2c$ (Fig. 2). Pliability index of the layer is $K = u / p$. Here u is vertical shift of the point located in the origin of coordinates.

The layer consists of macroscopic isotropic porous material with the effective elastic characteristics E and ν. The dependence of K on elastic constants E and ν is determined as [10]

$$K = h\frac{(1+\nu)(1-2\nu)}{\pi E}\int_0^\infty \frac{\mathrm{sh}^2\beta}{\mathrm{sh}2\beta + 2\beta}\,\frac{\sin\frac{\beta c}{h}}{\beta^2}\,d\beta.$$

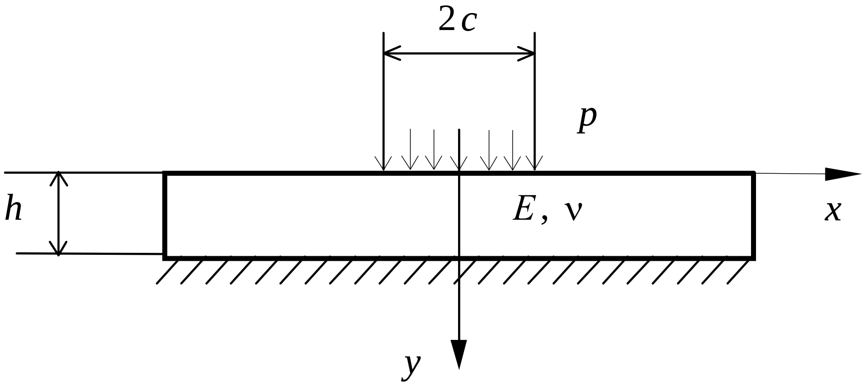


Fig. 2. Layer loading diagram.

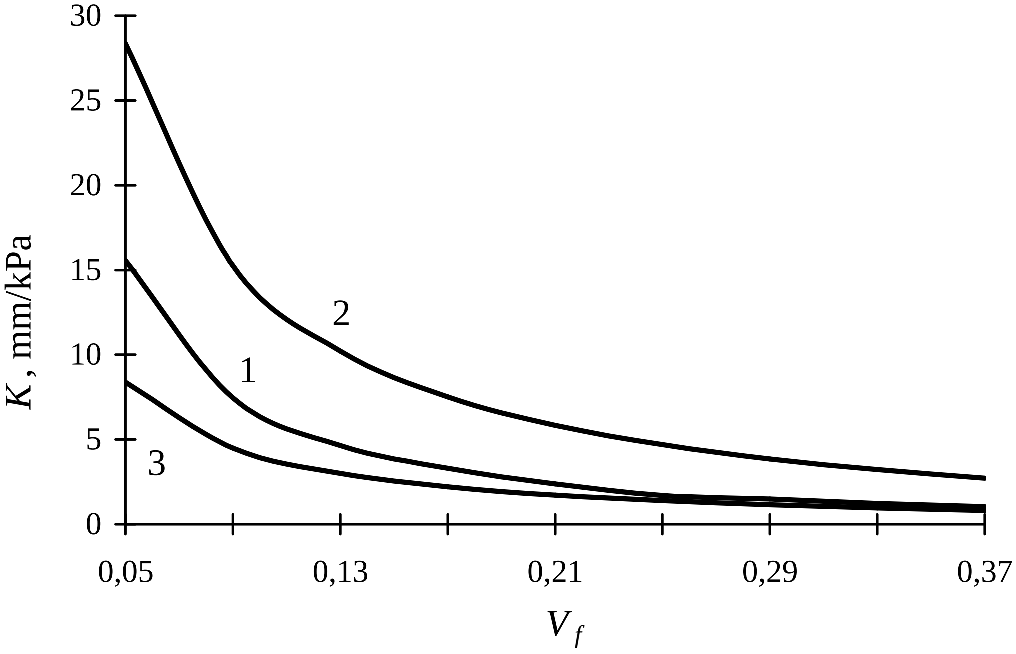


Fig. 3. Dependence of layer pliability on a volumetric share of the contents of a solid phase: 1 – hexagonal cells, 2 – concave cells ($\alpha = 25^0$); 3 – square cells.

Hence, it is possible to establish relation between a pliability K and parameters E_f, ν_f, V_f. In Fig. 3 the dependence of size K on a volumetric share V_f for some types of internal structure is shown (h = 1 cm, 2c = 0.5 cm).

The analysis of Fig. 3 allows to make a conclusion that the character of dependence of a layer pliability on a volumetric content of a solid for the considered types of internal structures is almost identical. Nevertheless, under equal V_f values the least pliability occurs for the layer of porous material having square cells, while the highest pliability – material with concave cells. With increasing V_f these differences smooth.

Conclusions

The analysis of deformation behavior of protective coatings made from porous materials with different inner structure but with similar solid phase content has proved that the highest rigidity is observed in case of square cells. The coating produced from porous material with concave cells displays the least rigidity. The material with regular hexagonal cells occupies intermediate position. These differences are especially pronounced in materials with a small volume portion of the solid phase (V_f < 0.4).

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АНАЛИЗ ПОДАТЛИВОСТИ ЗАЩИТНЫХ ПОКРЫТИЙ БИОМЕДИЦИНСКОГО НАЗНАЧЕНИЯ НА ОСНОВЕ ПОРОМАТЕРИАЛОВ. ЧАСТЬ 1

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Статья посвящена анализу деформационного поведения защитных покрытий, используемых при протезировании, изготовлении спортинвентаря и т.д. Цель работы заключается в сравнении податливости покрытий, изготовленных из пористых материалов с различной конфигурацией внутренней структуры, и оценке влияния вида структуры материала на жесткость покрытия. При анализе напряженно-деформированного состояния пористого материала рассматривалась макроскопически однородная изотропная среда с эффективными механическими характеристиками. Эти характеристики определялись методом выделения структурной единицы в стержневой конструкции, моделирующей внутреннюю структуру пористого материала. Рассматриваются двумерные модели материалов, а при анализе деформирования слоя предполагается выполнение условий плоской деформации.

Установлено, что для пористых материалов с малой объемной долей содержания твердой фазы структура материала оказывают значительное влияние на жесткость покрытия. Наибольшей жесткостью обладает слой из материала с квадратной, а наименьшей – с вогнутой формой ячеек. Библ. 10.

Ключевые слова: пороматериалы, эффективные характеристики, структурные модели, податливость слоя

Received 17 July 2000