UDK 539.3

INVESTIGATION OF CHARACTERISTICS OF COMPOSITE POROUS MEDIUM

V.G.Piskunov, Ph.D.
I.M.Didychenko, Ph.D.

Porous (composite) materials are increasingly used in different fields of modern technology [1-3]. Porous materials have relatively high rigidity and strength, and, at the same time, they are light. In addition, due to the presence of internal pores these materials can be used in the construction of sewage treatment plants, the creation of machines and mechanisms through which gases or liquids flow.

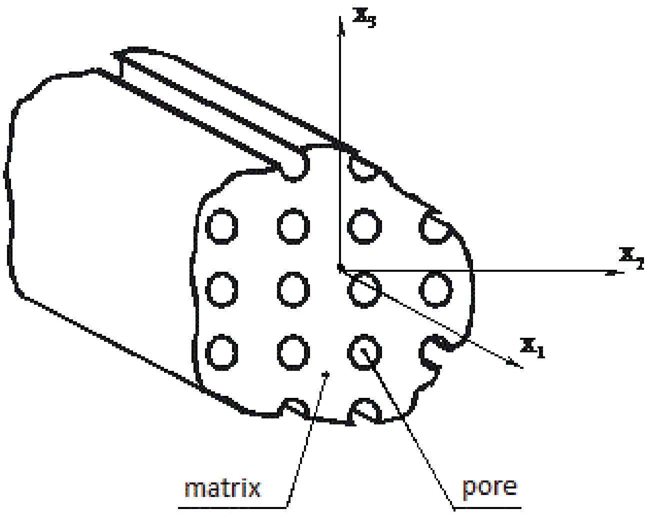


Fig.1 – The cross section of the porous medium

Often there is not necessary to use complex solutions of elasticity theory for calculating real structural elements. Sufficient precision results can be achieved on the basis of hypotheses, which are usually taken in strength of materials. For example, in determining the integral characteristics such as load, moment and displacement is no need to take into account the microstructure of composite materials and composite can be considered homogeneous but anisotropic.

Let us consider a solid matrix with hollow pores (Fig.1) and find the value of elastic constants provided pores filling liquid or gas.

To take into account the porosity of the material, we introduce the factor $\eta = V_C / V$, which will be called the continuity coefficient. Here V_C and V are the volume of solid phase (matrix) and full layer volume, including pores.

We assume the rigidity of pores equal zero. We write shear modules for longitudinal shear

$$G_{12} = G_{13} = G \frac{\eta}{2-\eta} \tag{1}$$

and for transverse shear

$$G_{23} = \frac{G\eta}{1+(3-4\nu)\cdot(1-\eta)}. \tag{2}$$

Here $G = \dfrac{E}{2(1+\nu)}$, and ν are shear modulus and Poisson's coefficient of the matrix material; E - elastic modulus of the matrix material.

Based on these assumptions elastic modulus in the longitudinal and transverse directions can be represented as follows:

$$E_1 = \eta E \tag{3}$$

$$\frac{1}{E_2} = \frac{1}{E_3} = \frac{1}{\eta}\left[\frac{\nu}{E} + \frac{(1-\nu)\cdot(3-2\eta)}{2G}\right], \tag{4}$$

and Poisson's coefficients as

$$\nu_{21} = \nu_{31} = \nu$$

$$\frac{\nu_{23}}{E_2} = \frac{1}{\eta E}\left\{-\nu^2 + (1+\nu)[1-\nu-\eta(1-2\nu)]\right\} \tag{5}$$

Assume that for a porous material are known relations of anisotropic medium between stress and deformations and also consider that between mechanical characteristics there are a relationships $E_1\nu_{12} = E_2\nu_{21}$, $E_2\nu_{23} = E_3\nu_{32}$, $E_3\nu_{31} = E_1\nu_{13}$. Then we obtain the following formulas for stresses:

$$\sigma_{11} = E^*\left[\varepsilon_{11} - \frac{\nu}{B_1 + B_2}(\varepsilon_{22} + \varepsilon_{33})\right],$$

$$\sigma_{22} = \frac{E^*}{B_1 - B_2}\left\{-\varepsilon_{11}\nu + \frac{1}{B_1 + B_2}\left[\varepsilon_{12}B_1 + \varepsilon_{33}B_2 - \nu^2(\varepsilon_{22} + \varepsilon_{33})\right]\right\},$$

$$\sigma_{33} = \frac{E^*}{B_1 - B_2}\left\{\varepsilon_{11}\nu + \frac{1}{B_1 + B_2}\left[\varepsilon_{22}B_2 + \varepsilon_{33}B_1 + \nu^2(\varepsilon_{33} - \varepsilon_{22})\right]\right\},$$

$$\sigma_{12} = \frac{E^*}{2(1+\nu)\cdot(2-\eta)}\varepsilon_{12},$$

$$\sigma_{13} = \frac{E^*}{2(1+\nu)\cdot(2-\eta)}\varepsilon_{13},$$

$$\sigma_{23} = \frac{E^* B_3}{2(1+\nu)}\varepsilon_{23}. \tag{6}$$

Here

$$B_1 = (1-\nu^2)\cdot(3-2\eta) + \nu^2,$$
$$B_2 = (1+\nu)[(1-\nu) - \eta(1-2\nu)],$$
$$B_3 = 4(1-\nu) - \eta(3-4\nu),$$
$$E^* = E\eta. \tag{7}$$

For convenience of further computations present (6) in a different way - through deformations:

$$\varepsilon_{11} = \frac{1}{E^*}\left[\sigma_{11} - \nu(\sigma_{22} + \sigma_{33})\right],$$

$$\varepsilon_{22}=\frac{1}{E^*}\left[-\nu\sigma_{11}+B_1\sigma_{22}-B_2\sigma_{33}\right],$$

$$\varepsilon_{33}=\frac{1}{E^*}\left[-\nu\sigma_{11}-B_2\sigma_{22}+B_1\sigma_{33}\right],$$

$$\varepsilon_{23}=\frac{2(1+\nu)B_3}{E^*}\sigma_{23},$$

$$\varepsilon_{13}=\frac{2(1+\nu)\cdot(2-\eta)}{E^*}\sigma_{13},$$

$$\varepsilon_{12}=\frac{2(1+\nu)\cdot(2-\eta)}{E^*}\sigma_{12}. \quad (8)$$

We emphasize that in the case of a continuous medium $(\eta=1)$ we obtain the known expressions of three-dimensional elasticity theory of isotropic body from (6) and (8).

Let us consider the effect of the coefficient η on the physic-mechanical properties of the porous material. We represent the parameters that we are studying, in a dimensionless form:

$$\frac{E_2}{E}=\frac{\eta}{\nu^2+(1-\nu^2)\cdot(3-2\eta)},$$

$$\frac{G_{12}}{G}=\frac{G_{13}}{G}=\frac{\eta}{2-\eta},$$

$$\frac{G_{23}}{G}=\frac{\eta}{1+(1-\eta)\cdot(3-4\eta)},$$

$$\nu_{23}=\frac{(1+\nu)\cdot[1+2\eta+(3-4\nu)\cdot(1-2\eta)]-4\nu^2}{4\left[\nu^2+(1-\nu^2)\cdot(3-2\eta)\right]}. \quad (9)$$

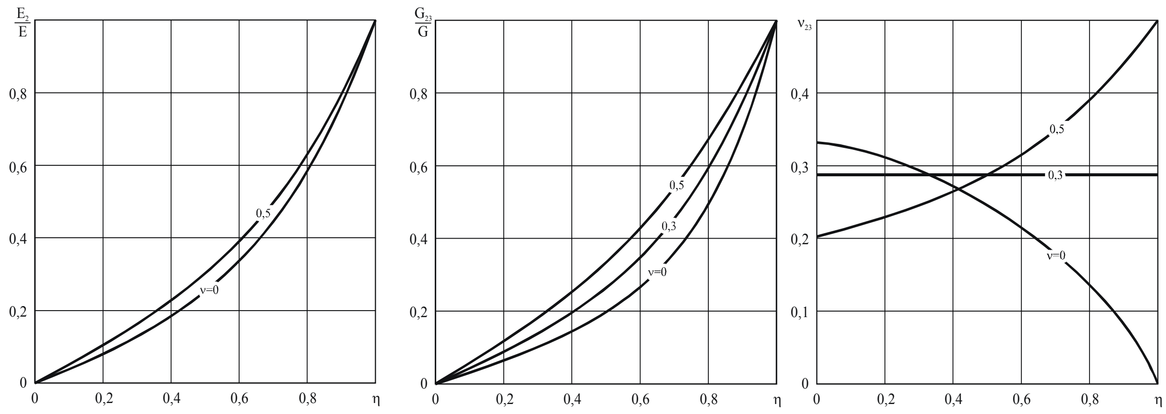
It is seen (Fig. 2) that the transverse modulus of elasticity E_2 is only slightly dependent on the Poisson's coefficient. Within the possible values of continuity coefficient $0\le\eta\le1$ ratio E_2/E varying nonlinearly increases significantly slower than η.

For real values $0.2\le\eta\le1$ $E_2/E_1>0.1$, so we can conclude that when create the solves equations for a layered porous medium we can use the approximation of technical theory and the Kirchhoff hypotheses.

The transverse shear modulus G_{23} more strongly depends on the Poisson's coefficient of the matrix (Fig.2b). Its value at $\nu=0.5$ corresponds to the value of longitudinal shear modulus G_{12} and G_{13}, which depend only on the coefficient η. It follows that for values ν, close to 0.5, longitudinal and transverse shear modulus are almost identical. This, to some extent, can lead to a simplification of the solutions.

Poisson's and continuity coefficients also significantly change the value ν_{23} (Fig.2c). Moreover, the influence increases for the extreme values ν, and for the average $\nu=0.3-\nu_{23}$ almost does not depend on η.

Thus, obviously, the presence of pores must be considered when $\eta<0.9$. For the most complete description of the construction work it should be split into layers that can not take into account the specific form pores. Thus for each layer we must take its own value η.



a b c

Fig.2. - Influence of continuity coefficient on the:
a) transverse elastic modulus and b) transverse shear modulus, c) the value ν_{23}

It must be emphasized that for any other (not only porous) composite material the approach to construction of resolving equations does not change. The difference is only in the coefficients of equation of medium state.

REFERENCES

1. V.V.Vasiliev, Mechanics of composite materials structures [in Russian], Mashinostroenie, Moscow (1988).
2. V.V.Vasiliev, V.D.Protasov, V.V.Bolotin, Composite materials [in Russian], Mashinostroenie, Moscow (1990).
3. N.A.Shul'ga, G.A.Krivov, Yu.M.Fedorenko, Modeling and calculation of structural elements of inhomogeneous materials [in Russian], Technika, Kiev (1996).

РЕФЕРАТ

Піскунов В.Г., Дідиченко І.М. Дослідження характеристик композитного пористого середовища. /Вадим Георгійович Піскунов, Ірина Михайлівна Дідиченко // Вісник НТУ. – К.: НТУ – 2012. – Вип.26.

В статті запропоновано підхід що до побудови розрахункових рівнянь для композитного пористого середовища.

Об'єкт дослідження – композитні пористі матеріали.

Мета роботи – вивчення впливу пористості матеріалу на його фізико-механічні характеристики.

Метод дослідження – аналітичний.

При розрахунках реальних елементів конструкцій нерідко немає необхідності в застосуванні складних рішень теорії пружності. Наприклад, в деяких випадках немає необхідності врахування мікроструктури матеріалів і композит можна розглядати однорідним, але анізотропним.

Для врахування пористості матеріалу введено коефіцієнт суцільності η. Отримано формули рівняння стану для композитного пористого середовища. Враховано можливість поздовжнього і поперечного зсуву. Досліджено вплив коефіцієнта суцільності на фізико-механічні характеристики пористого середовища. Визначено умови, при яких необхідно враховувати наявність пор.

Результати статті можуть бути упроваджені при розрахунках конструкцій з пористих матеріалів, через які проходять гази або рідини.

КЛЮЧОВІ СЛОВА: КОМПОЗИТИ, ПОРИСТІ МАТЕРІАЛИ, ПОВЗДОВЖНІЙ І ПОПЕРЕЧНИЙ ЗСУВ, МОДУЛЬ ПРУЖНОСТІ, КОЕФІЦІЄНТ ПУАССОНА

ABSTRACT

Piskunov V.G., Didychenko I.M. Investigation of characteristics of composite porous medium. /Vadim Piskunov, Iryna Didychenko // Visnuk NTU. – K.: NTU. – 2012. – Vol.26.

The paper proposes approach to construction of resolving equations for composite porous medium.

The object of research - composite porous materials.

The purpose - to study the influence of porosity of the material on its physic-mechanical properties.

Methods of investigation - analytical.

Often there is not necessary to use complex solutions of elasticity theory for calculating real structural elements. For example, sometimes is no need to take into account the microstructure of composite materials and composite can be considered homogeneous but anisotropic.

To take into account the porosity of the material, we introduce the continuity coefficient η. The equation of the state for composite porous medium are obtained. The possibility of longitudinal and transversal shear is taken into account. The influence of the continuity coefficient on the physic-mechanical properties of composite porous medium is investigated. The conditions when it's necessary to take into account the presence of pores are defined.

The results of the article can be used in the calculation of structures with porous material through which gases or liquids flow.

KEYWORDS: COMPOSITE, POROUS MATERIALS, LONGITUDINAL AND TRANSVERSAL SHEAR, ELASTIC MODULUS, POISSON'S COEFFICIENT

РЕФЕРАТ

Пискунов В.Г., Дидыченко И.М. Исследование характеристик композитной пористой среды. / Вадим Георгиевич Пискунов, Ирина Михайловна Дидыченко //Вестник НТУ. – К.: НТУ – 2012. – Вып.26.

В статье предложен подход к построению разрешающих уравнений для композитной пористой среды.

Объект исследования - композитные пористые материалы.

Цель работы - изучение влияния пористости материала на его физико-механические характеристики.

Метод исследования - аналитический.

При расчетах реальных элементов конструкций нередко нет необходимости в применении сложных решений теории упругости. Например, в некоторых случаях нет необходимости учета микроструктуры материалов и композит можно рассматривать однородным, но анизотропным.

Для учета пористости материала введен коэффициент целостности η. Получены формулы уравнения состояния для композитной пористой среды. Учтена возможность продольного и поперечного сдвига. Исследовано влияние коэффициента целостности на физико-механические характеристики пористой среды. Определены условия, при которых необходимо учитывать наличие пор.

Результаты статьи могут быть внедрены при расчетах конструкций из пористых материалов, через которые проходят газы или жидкости.

КЛЮЧЕВЫЕ СЛОВА: КОМПОЗИТЫ, ПОРИСТЫЕ МАТЕРИАЛЫ, ПРОДОЛЬНЫЙ И ПОПЕРЕЧНЫЙ СДВИГ, МОДУЛЬ УПРУГОСТИ, КОЭФФИЦИЕНТ ПУАССОНА