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Stressed state and stability of porous bodies form in the drying process

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On the basis of the solution of a weight transfer problem in the drying process for models of cylindrical capillaries, namely, models of equivalent radius and stochastic model and cylindrical capillaries of various radiuses on uniform distribution of pores by their radiuses taking into account Young's module and Poisson's coefficient changes with change of a relative saturation by moisture accepted in the form of continuous splines by which experimental study for cement stone materials are approximated, results of calculations of stress-deformed condition in the different planes by the thickness with change of border of phase transition in symmetric drying are given. The problem about on divergent stability of a form of an ortotropny porous plate with instant bilateral heating and uneven distribution of moisture content by the thickness in drying process, in particular, distribution of critical efforts and critical time in natural drying is considered.

Keywords: natural drying, stressed state, stability of form, relative moisture saturation of the pore.

Introduction. Processes of mass and heat transfer in porous media are influenced significantly by structure of vapor space, which is difficult system of the interconnected separate emptiness (pores) [1, 2]. For its description in literature stochastic models of cylindrical capillaries, serial models, trellised, models of pores of variable radius which branch, etc. often use. In capillary models space of the pores is considered in the form of system of channels with certain geometrical properties. In model of identical parallel capillaries the equivalent radius which is accepted equal to radius of a cylindrical capillary in which fluid rises on height of the measured capillary lifting of moistening fluid in the porous medium is the main parameter. Systems of parallel capillaries of various radiuses are generalization of this model. Within the limits of this model it is accepted, that all capillaries are connected one with another by the developed system of micropores.

In the model of cylindrical capillaries of various radiuses the widest pores which go to external surfaces are liberated at first from fluid. The narrow pores going to external surfaces, are nourished with by fluid at the expense of capillary accumulate. In a layer the diphasic area is formed where capillary accumulate of fluid and convective-diffusion vapour transfer are dominating mechanisms of transfer. Over time the spatial front changes its width and moves inside the porous material, or other surface (at asymmetrical drying). With the further evaporation process of a capillary condensate the porous body is saturated with gas.

In works [3, 4] it is established that at indicative and normal distributions width of the two-phase zone is small and the two-phase zone practically degenerates in a surface. Its parameters significantly depend on coefficients of permeability and a relative saturation of a body.

Most significantly it is manifested at the uniform distribution, since width of the diphasic area and its changes for such distribution are the greatest. The more permeability of fluid is, the wider the diphasic zone is. At small width of the diphasic area the influence of a dispersion of the pores sizes at the radiuses can be neglected.

The purpose of this work was: on the basis of the constructed mathematical models to establish dependences between processes of a heatmass transfer and the intense deformed condition caused by them and stability of a form of studied objects.

1. Stress-deformed state of the porous layer at symmetric and asymmetrical drying with the account and without account of dispersion of the pores sizes at the radii

Deformable bodies can undergo structural changes in the mass transfer processes. Swelling at saturation with fluid and shrinkage at drying concerns reorganization processes of structure [5]. Shrinkage process represents the change of volume which is occupied by the ordered structure owing to change of mass content of moisture. In the porous bodies with the various pores sizes shrinkage begins at the expense of narrowing of the rough pores at first. After formation of capillary meniscuses in thinner channels their deformation occurs changing the rate of shrinkage. At wide distribution of the pores on the sizes nonlinear shrinkage with gradually variable coefficient of shrinkage β can be developed.

Components of the stress tensor $\hat{\sigma}$ are satisfied by the equations of balance and the compatibility equation, similar Beltrami-Mitchela equation in thermoelasticity. In one-dimensional case for an isotropic material of the layer the problem is reduced to the equation solution

$$\frac{\partial^2}{\partial z^2}\left(\sigma_n(z)+\frac{E}{1-\nu}Q\right)=0. \tag{1}$$

Here Q is distortion, connected with change of moisture content, $\sigma_n=\sigma_{xx}(z)=\sigma_{yy}(z)$ is normal to a stress contour.

Under the conditions of forces absence on lateral surfaces of the layer having the thickness L_0 it follows, that resultant effort an resultant body moment are equal to zero.

Considering distinction of the effective Young's module and Poisson's coefficient in the drained and moist body, we consider these effective characteristics and distortion as the continuous generalized functions of characteristic function of interval. In the case of two boundaries of the section we have

$$E=\sum_{j=0}^{2}E^j\theta^j\left(z_j,z_{j+1}\right);\quad \nu=\sum_{j=0}^{2}\nu^j\theta^j\left(z_j,z_{j+1}\right);\quad Q=\sum_{j=0}^{2}Q^j\theta^j\left(z_j,z_{j+1}\right), \tag{2}$$

where $\theta^j\left(z_j, z_{j+1}\right)=\sigma_0\left(z-z_j\right)-\sigma_0\left(z-z_{j+1}\right)$. We accept shrinkage β_L and β_{Lv} in damp and diphasic areas as constant. On the basis of experimental data shrinkage β_v in the drained area is approximated by continuous linear splines concerning saturation $\overline{z}_m$:

$$\beta_v\left(\overline{z}_m\right)=\sum_{i=1}^{n}\beta_{vi}\left(\overline{z}_m\right)\Theta_i\left(\overline{z}_m\right). \tag{3}$$

Here $\beta_{vi}=\tilde{\alpha}_i\overline{z}_m+\tilde{\beta}_i$ is linear function of the relative saturation which in model of cylindrical capillaries coincides with dimensionless limit of the section of phases; $\overline{z}_m$ is dynamic coordinate of phase transition; $\Theta_i\left(\overline{z}_m\right)=\sigma_0\left(\overline{z}_m-\overline{z}_{m,i-1}\right)-\sigma_0\left(\overline{z}_m-\overline{z}_{m,i}\right)$ is characteristic function of the interval; $\tilde{\alpha}_i=\left(\beta_{vi1}-\beta_{vi0}\right)/\left(\alpha_{m2}-\alpha_{m1}\right)$; $\tilde{\beta}_i=\beta_{vi0}-\tilde{\alpha}_i\alpha_{m1}$; $\alpha_{m1}=0,4$; $\alpha_{m2}=0,4$; $\beta_{v10}=-5,556\cdot10^{-3}$; $\beta_{v11}=-5,556\cdot10^{-4}$; $\beta_{vi1},\beta_{vi0},\alpha_{v2},\alpha_{v1}$ are approximation coefficients, which are established experimentally [5].

Results of calculations at the accepted approximations are given in the table 1. The analysis shows that at reduction of relative humidity at coincidence of the plane of stresses measurement with the plane of phase gas transition is the diphasic area jumps of stresses and deformations ε_{zz} take place. Taking into account the diphasic area stresses are larger than at model of the equivalent pore. At asymmetrical drying the moments from distortions which are absent in symmetric drying play the main role. The calculations for the material of a cement stone have shown that the influence of stress on moisture content is small. Porosity of the material slowly grows only when the relative saturation comes to zero. The account of change of porosity on the intense-deformed state of the cement stone leads to the change of the intense-deformed state that does not exceed 2 %. The account of dispersion of the pores sizes is important at asymmetrical drying as the maximum stresses in this case are more.

Table 1

Dependence of stresses in model of equivalent pore and in model of capillaries of various radii in planes $\overline{z}=0,1$; $\overline{z}=0,9$ at change $\overline{z}_m$

$\sigma_{xx}\left(300;0,5;\overline{z}_m;0,1\right)$	$\sigma^*_{xx}\left(300;0,5;\overline{z}_m;0,1\right)$	$\sigma_{xx}\left(300;0,5;\overline{z}_m;0,9\right)$	$\sigma^*_{xx}\left(300;0,5;\overline{z}_m;0,9\right)$
$2,855\cdot10^{-4}$	$-665,004$		$2,855\cdot10^{-4}$
$2,855\cdot10^{2}$	$1,221\cdot10^{3}$	0	$-2,57\cdot10^{3}$
$1,141\cdot10^{3}$	$1,185\cdot10^{3}$	$-4,998\cdot10^{3}$	$-4,657\cdot10^{3}$
$2,566\cdot10^{3}$	$3,110\cdot10^{3}$	$-6,187\cdot10^{3}$	$-5,594\cdot10^{3}$
$4,562\cdot10^{3}$	$4,952\cdot10^{3}$	$-6,902\cdot10^{3}$	$-6,851\cdot10^{3}$
$7,127\cdot10^{3}$	$7,376\cdot10^{3}$	$-7,127\cdot10^{3}$	$-7,138\cdot10^{3}$
$1,026\cdot10^{4}$	$1,039\cdot10^{4}$	$-6,831\cdot10^{3}$	$-6,856\cdot10^{3}$
$3,636\cdot10^{4}$	$3,641\cdot10^{4}$	$-1,561\cdot10^{4}$	$-1,563\cdot10^{4}$
$6,956\cdot10^{4}$	$6,957\cdot10^{4}$	$-1,796\cdot10^{4}$	$-1,747\cdot10^{4}$
$1,098\cdot10^{5}$	$1,098\cdot10^{5}$	$-1,230\cdot10^{4}$	$-1,230\cdot10^{4}$
$-140,413$	$-139,723$	$-141,658$	$-142,348$

The given approach allows to find out change influence of moisture content in the process of deepening the boundary of phase transition and the reasons of stability loss of the form of thin-walled elastic porous elements that is important for preservation of quality and efficiency of this or that way of drying.

2. Stability of flat elements form in the drying process

Research of the form stability of flat elements in the drying process is important from the point of view of efficiency and quality of the drying process. According to the law of conservation of energy the quantity of heat which is accumulated in elementary volume, causes the corresponding increase of temperature and in its turn stimulates transfer of moisture and phase transitions in the porous body.

We accept model of cylindrical capillaries of the porous material. We consider a hypothesis about deepening phase transition boundary at body drying is fair. We will write down Generalized Hooke's law for orthotropic body in the case of flat stress state in a kind

$$e_{xx}=\frac{1}{E_1}\sigma_{xx}-\frac{\nu_{21}}{E_2}\sigma_{yy}+\alpha_1\left(T-T_0\right)+\beta_1\left(W-W_0\right),$$
$$e_{yy}=\frac{1}{E_2}\sigma_{yy}-\frac{\nu_{12}}{E_1}\sigma_{xx}+\alpha_2\left(T-T_0\right)+\beta_2\left(W-W_0\right),\quad e_{xy}=\frac{1}{G}\sigma_{xy},\tag{4}$$

where e_{xx}, e_{yy}, e_{xy} are components of total deformation; σ_{xx}, σ_{yy}, σ_{xy} are components of the elastic intense state; $E_1\left(W,T\right),E_2\left(W,T\right)$ are elasticity modules in a direction of axes Ox, Oy; W, W_0 are moisture content and T, T_0 are temperature during the actual and initial moments; ν_{12} is coefficient of cross-section compression in the direction Oy at a stretching in the direction Ox; ν_{21} is coefficient of cross-section compression in the direction Ox at the stretching in the direction Oy; $\alpha_1\left(T,W\right),\alpha_2\left(T,W\right)$ are coefficients of linear temperature expansion in the direction of axes Ox, Oy; $\beta_1\left(T,W\right),\beta_2\left(T,W\right)$ are coefficients of shrinkage in the direction of axes ox,oy respectively; $G\left(W,T\right)$ is the shear module.

Between characteristics E_1, E_2, ν_{12}, ν_{21} the dependence $E_1\nu_{21}=E_2\nu_{12}$ takes place. Deformations of a layer which is at a distance z from a median surface, we will define by formulas: $e_{xx}=\varepsilon_x+z\kappa_x, e_{yy}=\varepsilon_y+z\kappa_y, e_{xy}=\varepsilon_{xy}+2z\kappa_{xy}, e_{xx}=\varepsilon_x+z\kappa_x, e_{yy}=\varepsilon_y+z\kappa_y, e_{xy}=\varepsilon_{xy}+2z\kappa_{xy}$,

$\varepsilon_x=\frac{\partial u}{\partial x}+\frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2$, $\varepsilon_y=\frac{\partial \upsilon}{\partial y}+\frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2$, $\varepsilon_{xy}=\frac{\partial u}{\partial y}+\frac{\partial \upsilon}{\partial x}+\frac{\partial w}{\partial x}\frac{\partial w}{\partial y}$ is deformation of the middle surface; $\kappa_x=-\frac{\partial^2 w}{\partial x^2}, \kappa_y=-\frac{\partial^2 w}{\partial y^2}, \kappa_{xy}=-\frac{\partial^2 w}{\partial x\partial y}$ are curvatures; u, v, w are moving in the plane of the plate and deflection respectively. Deformations of elongations and landslips of the median surface will be defined in geometrically nonlinear statement [6, 7].

In the theory of plates instead of stresses it is favourable to consider statically equivalent forces and the moments. The equations (4) are statically equivalent to elastic efforts N_{11}, N_{22}, N_{12} and to the moments M_{11}, M_{22}, M_{12} which are connected with deformations by the system of the equations:

$$N_{11} = B_{11}\varepsilon_x + B_{12}\varepsilon_y + A_{11}\kappa_x + A_{12}\kappa_y - N_{1TW},$$

$$N_{22} = B_{12}\varepsilon_x + B_{22}\varepsilon_y + A_{12}\kappa_x + A_{22}\kappa_y - N_{2TW}, \quad N_{12} = B_{33}\varepsilon_{xy} + 2A_{33}\kappa_{xy}, \tag{5}$$

$$M_{11} = D_{11}\kappa_x + D_{12}\kappa_y + A_{11}\varepsilon_x + A_{12}\varepsilon_y - M_{1TW},$$

$$M_{22} = D_{12}\kappa_x + D_{22}\kappa_y + A_{12}\varepsilon_x + A_{22}\varepsilon_y - M_{2TW}, \quad M_{12} = 2D_{33}\kappa_{xy} + A_{33}\varepsilon_{xy}, \tag{6}$$

where

$$B_{ii} = \frac{1}{1-\nu_{12}\nu_{21}}\int_{-L_0}^{L_0} E_i(T,W)\,dz, \quad A_{ii} = \frac{1}{1-\nu_{12}\nu_{21}}\int_{-L_0}^{L_0} E_i(T,W)\,z\,dz,$$

$$D_{ii} = \frac{1}{1-\nu_{12}\nu_{21}}\int_{-L_0}^{L_0} E_i(T,W)\,z^2 dz \quad (i = 1, 2),$$

$$A_{33} = \int_{-L_0}^{L_0} G(T,W)\,z\,dz, \quad D_{33} = \int_{-L_0}^{L_0} G(T,W)\,z^2 dz,$$

$$D_{12} = \frac{\nu_{21}}{1-\nu_{12}\nu_{21}}\int_{-L_0}^{L_0} E_1(T,W)\,z^2 dz,$$

$$N_{iTW} = \tilde{\nu}\int_{-L_0}^{L_0} E_i(T,W)\left\{\alpha_i^*(T-T_0) + \beta_i^*(W-W_0)\right\}dz,$$

$$M_{iTW} = \tilde{\nu}\int_{-L_0}^{L_0} E_i(T,W)\left\{\alpha_i^*(T-T_0) + \beta_i^*(W-W_0)\right\}z\,dz \quad (i = 1, 2),$$

$$\tilde{\nu} = (1-\nu_{12}\nu_{21})^{-1}, \quad \alpha_1^* = \alpha_1 + \nu_{21}\alpha_2, \quad \beta_1^* = \beta_1 + \nu_{21}\beta_2,$$

$$\alpha_2^* = \alpha_2 + \nu_{12}\alpha_1, \quad \beta_2^* = \beta_2 + \nu_{12}\beta_1. \tag{7}$$

The equation of deformations compatibility taking into account expressions of deformations through the efforts takes the form

$$\frac{\partial^2}{\partial x^2}\left[B_{11}\tilde{B}\left(N_{22}+N_{2TW}\right)\right] - \frac{\partial^2}{\partial x^2}\left[B_{12}\tilde{B}\left(N_{11}+N_{1TW}\right)\right] +$$

$$+\frac{\partial^2}{\partial y^2}\left[B_{22}\tilde{B}\left(N_{11}+N_{1TW}\right)\right] - \frac{\partial^2}{\partial y^2}\left[B_{12}\tilde{B}\left(N_{22}+N_{2TW}\right)\right] -$$

$$-\frac{\partial^2}{\partial x\partial y}\left[\frac{N_{12}}{B_{33}}\right] = 2\frac{\partial^2}{\partial x\partial y}\left(\frac{A_{33}}{B_{33}}\frac{\partial^2 w}{\partial x\partial y}\right) + \left(\frac{\partial^2 w}{\partial x\partial y}\right)^2 - \frac{\partial^2 w}{\partial x^2}\frac{\partial^2 w}{\partial y^2}, \tag{8}$$

and the balance equation at bend is the such:

$$\frac{\partial N_{11}}{\partial x}+\frac{\partial N_{12}}{\partial y}=0,\quad \frac{\partial N_{12}}{\partial x}+\frac{\partial N_{22}}{\partial y}=0,\quad \frac{\partial M_{11}}{\partial x}+\frac{\partial M_{12}}{\partial y}=Q_1,\quad \frac{\partial M_{12}}{\partial x}+\frac{\partial M_{22}}{\partial y}=Q_2,$$

$$\frac{\partial Q_1}{\partial x}+\frac{\partial Q_2}{\partial y}=-N_{11}\frac{\partial^2 w}{\partial x^2}-2N_{12}\frac{\partial^2 w}{\partial x\partial y}-N_{22}\frac{\partial^2 w}{\partial y^2}. \tag{9}$$

Here Q_1, Q_2 are cutting forces which through deflection w are expressed as follows:

$$Q_1=-\frac{\partial}{\partial x}\left[D_{11}\frac{\partial^2 w}{\partial x^2}+D_3\frac{\partial^2 w}{\partial y^2}\right]-\tilde{\nu}E_1\left(2L_0\right)^2\frac{\partial}{\partial x}M_{1TW},$$

$$Q_2=-\frac{\partial}{\partial y}\left[D_{22}\frac{\partial^2 w}{\partial y^2}+D_3\frac{\partial^2 w}{\partial x^2}\right]-\tilde{\nu}E_2\left(2L_0\right)^2\frac{\partial}{\partial y}M_{2TW},$$

$$\tilde{B}=\left(B_{11}B_{22}-B_{12}^2\right)^{-1},\quad D_{11}\nu_{21}=D_{22}\nu_{12},\quad D_3=\left(2D_{33}+\nu_{21}D_{11}\right).$$

We introduce the function of stresses Φ: $N_{11}=2L_0\frac{\partial^2\Phi}{\partial y^2}$, $N_{22}=2L_0\frac{\partial^2\Phi}{\partial x^2}$, $N_{12}=-2L_0\frac{\partial^2\Phi}{\partial x\partial y}$.

First two equations of balance (9) are identically satisfied, and the equation of deformations compatibility (8) and the third equation (9) are written down as follows:

$$\frac{\partial^4\Phi}{\partial x^4}+\left(\frac{E_2}{G}-2\nu_{21}\right)\frac{\partial^4\Phi}{\partial x^2\partial y^2}+\frac{E_2}{E_1}\frac{\partial^4\Phi}{\partial y^4}=-E_2\alpha_2\left(\frac{\partial^2 N_T}{\partial x^2}+\frac{\alpha_1}{\alpha_2}\frac{\partial^2 N_T}{\partial y^2}\right)-$$

$$-E_2\beta_2\left(\frac{\partial^2 N_W}{\partial x^2}+\frac{\beta_1}{\beta_2}\frac{\partial^2 N_W}{\partial y^2}\right)-\frac{1}{2}H(w,w), \tag{10}$$

$$D_{11}\frac{\partial^4 w}{\partial x^4}+2D_3\frac{\partial^4 w}{\partial x^2\partial y^2}+D_{22}\frac{\partial^4 w}{\partial y^4}=2L_0H\left(\Phi,w\right)-\frac{D_{11}}{2L_0}\alpha_1^*\frac{\partial^2 M_T}{\partial x^2}-$$

$$-\frac{D_{22}}{2L_0}\alpha_2^*\frac{\partial^2 M_T}{\partial y^2}-\frac{D_{11}}{2L_0}\beta_1^*\frac{\partial^2 M_W}{\partial x^2}-\frac{D_{22}}{2L_0}\beta_2^*\frac{\partial^2 M_W}{\partial y^2}, \tag{11}$$

$$H\left(\Phi,w\right)=\frac{\partial^2\Phi}{\partial x^2}\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2\Phi}{\partial y^2}\frac{\partial^2 w}{\partial x^2}-2\frac{\partial^2\Phi}{\partial x\partial y}\frac{\partial^2 w}{\partial x\partial y}.$$

For the solution of problems under the mixed boundary conditions the balance equation in moving looks like

$$\frac{\partial^4 u}{\partial x^4}+\left(\frac{E_2}{G}-2\nu_{21}\right)\frac{\partial^4 u}{\partial x^2\partial y^2}+\frac{E_2}{E_1}\frac{\partial^4 u}{\partial y^4}=\alpha_1^*\frac{\partial^3 N_T}{\partial x^3}+\beta_1^*\frac{\partial^3 N_W}{\partial x^3}+$$

$$+\frac{\tilde{\nu}E_2}{G}\left\{\alpha_1^*-\alpha_2^*\left[\nu_{12}+\frac{G}{\tilde{\nu}E_1}\right]\right\}\frac{\partial^3 N_T}{\partial x\partial y^2}+\frac{\tilde{\nu}E_2}{G}\left\{\beta_1^*-\beta_2^*\left[\nu_{21}+\frac{G}{\tilde{\nu}E_1}\right]\right\}\frac{\partial^3 N_W}{\partial x\partial y^2};$$

$$\frac{\partial^4 \upsilon}{\partial x^4}+\left(\frac{E_1}{G}-2\nu_{12}\right)\frac{\partial^4 \upsilon}{\partial x^2\partial y^2}+\frac{E_1}{E_2}\frac{\partial^4 \upsilon}{\partial y^4}=\alpha_2^*\frac{\partial^3 N_T}{\partial y^3}+\beta_2^*\frac{\partial^3 N_W}{\partial x^3}+$$

$$+\frac{\tilde{\nu}E_1}{G}\left\{\alpha_2^*-\alpha_1^*\left[\nu_{12}+\frac{G}{\tilde{\nu}E_2}\right]\right\}\frac{\partial^3 N_T}{\partial x^2\partial y}+\frac{\tilde{\nu}E_1}{G}\left\{\beta_2^*-\beta_1^*\left[\nu_{12}+\frac{G}{\tilde{\nu}E_2}\right]\right\}\frac{\partial^3 N_W}{\partial x^2\partial y}, \qquad (12)$$

$$N_T=\frac{1}{2L_0}\int_{-L_0}^{L_0}\left(T-T_0\right)dz, \qquad N_W=\frac{1}{2L_0}\int_{-L_0}^{L_0}\left(W-W_0\right)dz.$$

Last two equations are used at non-uniform distribution of the efforts in the median surface. From the system (10)-(12) it is evident that the influence of moisture distribution and temperature in the drying process is manifested through derivatives of efforts N_T, N_W and the moments M_T, M_W caused by non-uniform distribution of temperature and moisture in the process of deepening of phase transition boundary.

3. Bulging of the orthotropic plates with non-uniform distribution of moisture content and temperature on thickness in the process of drying

From the problem solution of heat and mass transfer we find distribution of temperature and moisture content on thickness of the porous plate in the process of drying. These values are co-ordinate z functions on the thickness and mobile co-ordinate of the phase transition z_m. For simplicity we accept that material characteristics do not depend on temperature and moisture content. The rectangular plate of the sizes a, b is abutted on elastic edges, which temperature and moisture content are constant and different from temperature and moisture content of the plate. Materials of the plate and edges are supposed to be different, and temperature and moisture stresses in such case arise even at uniform heating of all panel. The solution of the equation (10) will be presented in a kind

$$\Phi=\frac{P_1\left(\overline{z}_m\right)y^2}{2}+\frac{P_2\left(\overline{z}_m\right)x^2}{2}.$$

The values $P_1\left(\overline{z}_m\right)$, $P_2\left(\overline{z}_m\right)$, that represent the intensity of compressive effort [8], in the process of drying of the porous medium depend on both co-ordinate of phase transition on thickness, and on the difference of temperatures and moisture between the plate and edges. Their dependence on elasticity of edges we define from conditions of equality of deformations in the planes of joint of the plate and edges. From equations of relative rapprochement of edges of the plate the corresponding deformations of edges we define the values σ_{xp}, σ_{yp} through P_1, P_2. Let F_{xp}, F_{yp} are the areas of cross-section edges. Then

$$\sigma_{xp}=-P_1(z)2L_0b/F_{xp}, \quad \sigma_{yp}=-P_2(z)2L_0a/F_{yp}.$$

From equation of the plate and edges deformations we obtain

$$\frac{P_1-\nu_{12}P_2}{E_1}+Q_{1TW}=-\frac{P_1 2L_0 b}{F_{xp}E_p}+Q_{p1TW}; \quad \frac{P_2-\nu_{21}P_1}{E_2}+Q_{2TW}=-\frac{P_2 2L_0 a}{F_{yp}E_p}+Q_{p2TW}. \qquad (13)$$

Here $Q_{piTW}=\frac{1}{2L_0}\int_{-L_0}^{L_0}\left[\alpha_{ip}\left(T_{ip}-T_{0i}\right)+\beta_{ip}\left(W_{ip}-W_{0i}\right)\right]dz$, $Q_{iTW}=\frac{1}{2L_0}\int_{-L_0}^{L_0}\left[\alpha_i\left(T-T_0\right)+\right.$ $\left.+\beta_i\left(W-W_0\right)\right]dz=\alpha_i N_T+\beta_i N_W$ depend on distribution of temperature, relative saturation and coordinate of phase transition which are defined from the problem solution of heat and mass transfer; α_{ip}, β_{ip} are coefficients of temperature and moisture expansions of edges. From the system (13) we find

$$P_1(\bar{z}_m) = K_\nu E_1\left[\left(Q_{p1TW} - Q_{1TW}(\bar{z}_m)\right)K_y + \nu_{21}\left(Q_{p2TW} - Q_{2TW}(\bar{z}_m)\right)\right];$$
$$P_2(\bar{z}_m) = K_\nu E_2\left[\left(Q_{p2TW} - Q_{2TW}(\bar{z}_m)\right)K_x + \nu_{12}\left(Q_{p1TW} - Q_{1TW}(\bar{z}_m)\right)\right], \qquad (14)$$

where $K_\nu = \left(K_x K_y - \nu_{12}\nu_{21}\right)^{-1}$, $K_x = 1 + E_1 b 2L_0/F_{xp}E_p$, $K_y = 1 + E_2 a 2L_0/F_{yp}E_p$, $\bar{z}_m = z_m/L_0$ is dimensionless co-ordinate of phase transition in the process of drying. For definition of deflection $w(x,y)$ we use the equations (11). If we present the deflection $w(x,y)$ in the form of a series $w(x,y) = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} w_{mn}\sin(m\pi x/a)\times$ $\times\sin(n\pi y/b)$ then the solution satisfies the following conditions:

$$w = 0, \quad D_{11}\frac{\partial^2 w}{\partial x^2} + \tilde{\nu}E_1(2L_0)^2 M_{1TW} = 0 \quad \text{for} \quad x = 0,\ x = a;$$
$$w = 0, \quad D_{22}\frac{\partial^2 w}{\partial y^2} + \tilde{\nu}E_2(2L_0)^2 M_{2TW} = 0 \quad \text{for} \quad y = 0,\ y = b.$$

Here M_{iTW} is defined by formulas (7). The moments M_{1TW}, M_{2TW} are presented in the form of schedule in Fourier numbers on sines from arguments $m\pi x/a$, $n\pi y/b$, and we substitute these series in formulas (9), we obtain

$$\frac{w_{mn}}{2L_0} = 4\frac{\tilde{\nu}\left[(-1)^m - 1\right]\left[(-1)^n - 1\right]}{\pi^2(\ )^2 F}\left[M_{1TW}E_1(mb/a)^2 + M_{2TW}E_2 n^2\right],$$

$$F = \frac{\pi^2\sqrt{D_{11}D_{22}}}{2L_0 b^2}\left[\left(\frac{mb}{a}\right)^2\sqrt{\frac{D_{11}}{D_{22}}} + \frac{2D_3}{\sqrt{D_{11}D_{22}}}n^2 + \left(\frac{a}{mb}\right)^2\sqrt{\frac{D_{22}}{D_{11}}}\right] + P_1(\bar{z}_m) + P_2(\bar{z}_m)\frac{n^2a^2}{m^2b^2},$$

where $F = 0$ the characteristic equation for definition of critical parametres of the relative saturation of fluid $z_m^* = 1 - \bar{z}_m$,which has evaporated; $P_1(\bar{z}_m)$, $P_2(\bar{z}_m)$ is defined according to formulas (14).

The values of the critical parameters of the relative saturation of the evaporated fluid of orthotropic plate with elastic edges of rigidity are defined from the characteristic equation $F = 0$ and relations (14).

$$\frac{\pi^2\sqrt{D_{11}D_{22}}}{2L_0 b^2}\left[\left(\frac{mb}{a}\right)^2\sqrt{\frac{D_{11}}{D_{22}}} + \frac{2D_3}{\sqrt{D_{11}D_{22}}}n^2 + \left(\frac{a}{mb}\right)^2\sqrt{\frac{D_{22}}{D_{11}}}\right] +$$
$$K_\nu E_1\left\{\left(Q_{p1TW} - Q_{1TW}(\bar{z}_m^*)\right)K_y + \nu_{21}\left(Q_{p2TW} - Q_{2TW}(\bar{z}_m^*)\right)\right\} +$$
$$+\frac{n^2a^2}{m^2b^2}\left\langle K_\nu E_2\left\{\left[Q_{p2TW} - Q_{2TW}(\bar{z}_m^*)\right]K_x + \nu_{12}\left[Q_{p1TW} - Q_{1TW}(\bar{z}_m^*)\right]\right\}\right\rangle = 0.$$

On the smallest root z_m^* we define the critical efforts $P_1(z_m)$, $P_2(z_m)$ from formulas (14). For each concrete way of drying we have dependence between the relative saturation and time, defined from the problem of mass transfer, meaning time of stability loss of the body form.

4. Thermal and moisture resistance of the plate at fast flowing of heating process

Let's introduce the hypothesis similar to Kirchhoff hypothesis in character of change of temperature field on the thickness, that is, we accept, that the temperature is linear function of co-ordinate on z thickness

$$T = T_0(x, y, \tau) + z\theta(x, y, \tau).$$

Here $T_0(x, y, \tau)$ is the temperature of the median plane $\theta(x, y, \tau)$ is the temperature gradient on the thickness and we consider material characteristics independent of temperature and dynamism of the process. Then at the designations introduced earlier in the right parts of the balance equations (9) inertial members are added, and the solution of this system should satisfy homogeneous initial and corresponding boundary conditions at the plate edges. We consider only forces of inertia which correspond to cross-section moving of elements of the plate that is we consider that longitudinal moving can be found under formulas without inertial forces. We enter function of stresses and we consider presence of initial deflections w_0. Then geometrical relations are nonlinear and the problem is reduced to the solution of the compatibility equation

$$\frac{1}{E_2}\frac{\partial^4\Phi}{\partial x^4} + \left(\frac{1}{G} - \frac{2\nu_{12}}{E_1}\right)\frac{\partial^4\Phi}{\partial x^2\partial y^2} + \frac{1}{E_1}\frac{\partial^4\Phi}{\partial y^4} =$$
$$-\alpha_2\left(\frac{\partial^2 T_0}{\partial x^2} + \frac{\alpha_1}{\alpha_2}\frac{\partial^2 T_0}{\partial y^2}\right) + \frac{1}{2}\left[H(w_0, w_0) - H(w, w)\right] \quad (15)$$

and cross-section displacements

$$D_{11}\frac{\partial^4(w - w_0)}{\partial x^4} + 2D_3\frac{\partial^4(w - w_0)}{\partial x^2\partial y^2} + D_{22}\frac{\partial^4(w - w_0)}{\partial y^4} = N_{11}\frac{\partial^2 w}{\partial x^2} + 2N_{12}\frac{\partial^2 w}{\partial x\partial y} +$$
$$+N_{22}\frac{\partial^2 w}{\partial y^2} - \tilde{\nu}E_1(2L_0)^2\alpha_1^*\frac{\partial^2\theta}{\partial x^2} - \tilde{\nu}E_2(2L_0)^2\alpha_2^*\frac{\partial^2\theta}{\partial y^2} -$$
$$-\tilde{\nu}E_1(2L_0)^2\beta_1^*\frac{\partial^2 M_W}{\partial x^2} - \tilde{\nu}E_2(2L_0)^2\beta_2^*\frac{\partial^2 M_W}{\partial y^2} - \rho 2L_0\frac{\partial^2 w}{\partial\tau^2}, \quad (16)$$

where $\tilde{E}_i = E_i(1 - \nu_{12}\nu_{21})^{-1}$; ρ is the given density of the porous body.

Relations (15), (16) consider temperature of the median surface T_0, temperature drop on the thickness θ and the moments that is the consequence of introduction instead of stresses statistically equivalent to them efforts and the moments.

For an example we assume that the thin moisture plate initially is in the medium at temperature $T = 0$ and at the moment $\tau = 0$ the temperature of medium raises to value $T=\overline{T}$, and coefficient of heat transfer under conditions of convective heat exchange $K_+=K_-=K$. Plate edges are heat isolated. The plate on all contour leans against elastic edges, that are heat isolated and the beginning temperature is not changed. Also we consider that heating is carried out from both parties and the plate is uniformly heated on the thickness. Then θ = 0 and we obtain the following equation: $\frac{dT_0}{d\tau}+\frac{K}{C\rho L_0}T_0=\frac{K}{C\rho L_0}\overline{T}$. The common solution of such equation looks like

$$T_0=\overline{T}\left(1-e^{-\frac{K}{C\rho L_0}\tau}\right). \tag{17}$$

If $K=0$ then plate is the heat isolated; if $K=\infty$ then the surface temperature instantly accepts value $\overline{T}$. The equations (15), (16) take the form

$$\frac{1}{E_2}\frac{\partial^4\Phi}{\partial x^4}+\left(\frac{1}{G}-\frac{2\nu_{12}}{E_1}\right)\frac{\partial^4\Phi}{\partial x^2\partial y^2}+\frac{1}{E_1}\frac{\partial^4\Phi}{\partial y^4}=\frac{1}{2}\left[H\left(w_0,w_0\right)-H(w,w)\right],$$

$$D_{11}\frac{\partial^4\left(w-w_0\right)}{\partial x^4}+2D_3\frac{\partial^4\left(w-w_0\right)}{\partial x^2\partial y^2}+D_{22}\frac{\partial^4\left(w-w_0\right)}{\partial y^4}=-\rho 2L_0\frac{\partial^2 w}{\partial\tau^2}+$$

$$+N_{11}\frac{\partial^2 w}{\partial x^2}+2N_{12}\frac{\partial^2 w}{\partial x\partial y}+N_{22}\frac{\partial^2 w}{\partial y^2}. \tag{18}$$

We will accept full and initial deflections in a kind $w=f\sin\frac{\pi x}{a}\sin\frac{\pi y}{b}$, $w_0=f_0\sin\frac{\pi x}{a}\sin\frac{\pi y}{b}$. Then the first equation of the system (16) takes the form

$$\frac{1}{E_2}\frac{\partial^4\Phi}{\partial x^4}+\left(\frac{1}{G}-\frac{2\nu_{12}}{E_1}\right)\frac{\partial^4\Phi}{\partial x^2\partial y^2}+\frac{1}{E_1}\frac{\partial^4\Phi}{\partial y^4}=\frac{\pi^4}{2a^2b^2}\left(w^2-w_0^2\right)\left(\cos\frac{2\pi x}{a}+\cos\frac{2\pi y}{b}\right),$$

which solution is

$$\Phi=\frac{P_1y^2}{2}+\frac{P_2x^2}{2}+\frac{\delta f^2}{32}\left[E_2\left(\frac{a}{b}\right)^2\cos\frac{2\pi x}{a}+E_1\left(\frac{b}{a}\right)^2\cos\frac{2\pi y}{b}\right], \tag{19}$$

where P_1, P_2 are intensities of compressing efforts $\delta f^2=\left(f^2-f_0^2\right)$. Considering that in the drained and moist areas coefficients of shrinkage and moisture contents are different, from formulas (5)-(7) we find the efforts N_{TW1}, N_{TW2} caused by moisture-thermal deformations which can be written down as follows

$$N_{TW1}=\tilde{E}_1\alpha_1^* 2L_0T_0(\tau)+\tilde{E}_1\left(\beta_1^*/\beta_3\right)\int_{-L_0}^{L_0}\beta_3\left(W(z)-W_0\right)dz,$$

$$N_{TW2}=\tilde{E}_2\alpha_2^* 2L_0T_0(\tau)+\tilde{E}_2\left(\beta_2^*/\overline{\beta}_3\right)\int_{-L_0}^{L_0}\beta_3\left(W(z)-W_0\right)dz .$$

The integral from the distortion Q, connected with the change of moisture content $Q=\beta_3\left(W-W_0\right)$ taking into account movement of boundary $\overline{z}_m$ of phase transition of fluid in vapour, is presented in a form $\frac{1}{2L_0}\int_{-L_0}^{L_0}Qdz=C\left(\overline{z}_m\right)$ where $C\left(\overline{z}_m\right)$ is defined under formulas

$$C\left(\overline{z}_m\right)=\int_0^{\overline{z}_m}Q_L\left(\overline{z}\right)d\overline{z}+\int_{\overline{z}_m}^{1}Q_v\left(\overline{z}\right)d\overline{z}=Q_L\overline{z}_m+Q_{v1}\left(1-\overline{z}_m\right)+Q_{v2}\frac{2G_1}{a_3}, \qquad (20)$$

$$Q_v\left(\overline{z},\overline{z}_m\right)=\beta_v\left\{C_1^{11}\left[a_1+\left(a_4+a_3\left|\overline{z}\right|\right)^{1/2}\right]+C_2^1\right\},\quad Q_L\left(\overline{z}_m\right)=\beta_L C_2^1\left(1-\overline{z}_m\right),$$

$$Q_{v1}=\beta_v\left(C_1^{11}a_1+C_2^1\right),\quad Q_{v2}=\beta_v\left(C_1^{11}\right),\quad G_1=\frac{\left(a_4+a_3\right)^{3/2}-\left(a_4+a_3\overline{z}_m\right)^{3/2}}{3},$$

$$C_1^1=\rho_n\Pi/\left[\rho_s\left(1-\Pi\right)\right],\quad C_2^1=-\rho_L\Pi/\left[\rho_s\left(1-\Pi\right)\right],\quad C_1^{11}\left(\overline{z}_m(t)\right)=C_1^1\left(1-\overline{z}_m\right),$$

$$a_1=-(1+a)/b,\quad a_2=\left(1-a_1\right)^2,\quad a_3=-2a_1\Gamma_0\lambda,\quad a_4=a_2-a_3\overline{z}_m,$$

$$a=D'M_a\mu_g/\left(K_g\rho_{a1}RT\right),\quad b=\rho_nM_a/\rho_{a1}M_v,\quad \Gamma_0=C_0L_0D_1'/\left(\delta D\right),$$

$$\lambda=-\left(1-\eta_0\right)\left[2a_1-\left(1+\eta_0\right)\right]/\left[a_1-\eta_0+\Gamma_0a_1\left(1-\overline{z}_m\right)\right],C_0=1+\rho_{v1}M_a/\left(M_v\rho_{a1}\right),$$

η_0 is relative density of the vapor on the external surface of the interface, z_m is external border of the two-phase zone, D_1', D' are diffusion coefficients in an interface and pores. R, T are gas constant and absolute temperature, M_a, M_v are molecular masses of air and vapour, ρ_a, ρ_v, ρ_L are density of air, vapour and fluid, K_g, μ_g are penetration of the material concerning gas and viscosity of gas. Thus, moisture-thermal efforts are

$$N_{TW1}=2L_0E_1\tilde{\nu}\left[\alpha_1^*T_0(\tau)+\beta_1^*C\left(\overline{z}_m(\tau)\right)\right],\quad N_{TW2}=2\tilde{\nu}L_0E_2\left[\alpha_2^*T_0(\tau)+\beta_2^*C\left(\overline{z}_m\right)\right],$$

where $\overline{z}_m$ is function of time τ, which is defined from the problem solution of heat and mass transfer. From relations (13), (14) we obtain

$$\frac{\Delta_x}{a}=\frac{P_1-\nu_{12}P_2}{E_1}+\frac{\delta f^2}{2}\frac{\pi^2}{a^2}+\alpha_1N_T+\beta_1N_W,$$

$$\frac{\Delta_y}{b}=\frac{P_2-\nu_{21}P_1}{E_2}+\frac{\delta f^2}{2}\frac{\pi^2}{b^2}+\alpha_2N_T+\beta_2N_W,\quad \delta f^2=\left(f^2-f_0^2\right).$$

Here N_T, N_W are described by expressions (13). With (13), (19) under condition of equality of displacement of the plate edges to deformations of edges, we obtain

$$P_1(\bar{z}_m) = K_\nu E_1\left[\left(Q_{p1} - Q_1(\bar{z}_m)\right)K_y + \nu_{21}\left(Q_{p2} - Q_2(\bar{z}_m)\right) + \frac{\pi^2}{2}\delta f^2\left(\frac{\nu_{21}}{b^2} + \frac{1}{a^2}K_y\right)\right],$$

$$P_2(\bar{z}_m) = K_\nu E_2\left[\left(Q_{p2} - Q_2(\bar{z}_m)\right)K_x + \nu_{12}\left(Q_{p1} - Q_1(\bar{z}_m)\right) + \right.$$

$$\left. + \frac{\pi^2}{2}\delta f^2\left(\frac{\nu_{12}}{a^2} + \frac{1}{b^2}K_x\right)\right], \tag{21}$$

where $Q_{pi} = \left(\alpha_{ip}T_{ip} + \beta_{ip}W_{ip}\right)$ are moisture-thermal deformation of edges in the process of drying;

$$Q_i = Q_{iT} + Q_{iW}, \quad Q_{iT} = \frac{1}{2L_0}\int_{-L_0}^{L_0}\left(\alpha_i T_0(\tau)\right)dz = \alpha_i T_0(\tau),$$

$$Q_{iW} = \frac{1}{2L_0}\left[\int_0^{\bar{z}_m}\beta_{Li}\left(W_L - W_0\right)d\bar{z} + \int_{\bar{z}_m}^{1}\beta_{vi}\left(W_v - W_0\right)d\bar{z}\right]$$

— moisture-thermal deformations of the plate in directions x, y.

The solution of the second equation (18) is constructed by Bubnov-Galerkin method:

$$\int_0^a\int_0^b\left[D_1\frac{\partial^4(w-w_0)}{\partial x^4} + 2D_3\frac{\partial^4(w-w_0)}{\partial x^2\partial y^2} + D_2\frac{\partial^4(w-w_0)}{\partial y^4} + \right.$$

$$\left. + \rho 2L_0\frac{\partial^2 w}{\partial\tau_0^2} - 2L_0 H(\Phi, w)\right]\sin\frac{\pi x}{a}\sin\frac{\pi y}{b}\,dx\,dy = 0\,.$$

If to substitute value w, Φ from (18), (19) in this equation after integration we obtain

$$\frac{\rho a^4}{\pi^2 E_1(2L_0)^2}\frac{\partial^2\xi}{\partial\tau^2} + \frac{\pi^2}{12(1-\nu_{12}\nu_{21})}\left(1 + 2\frac{a^2}{b^2}\frac{D_3}{D_1} + \frac{a^4}{b^4}\frac{D_2}{D_1}\right)(\xi - \xi_0) +$$

$$+ \frac{a^2}{b^2}\left\{\left[-P_1^* + \frac{\pi^2}{16}\left(\xi^2 - \xi_0^2\right)\right] + \frac{E_2}{E_1}\left[-P_2^* + \frac{\pi^2}{16}\left(\xi^2 - \xi_0^2\right)\right]\right\}\xi = 0,$$

where $\xi = f/(2L_0)$, $P_1^* = -P_1 a^2 \big/ \left[E_1(2L_0)^2\right]$, $P_2^* = -P_2 b^2 \big/ \left[E_2(2L_0)^2\right]$. In separate case of an isotropic square continuous plate neglecting moisture content we obtain the equation [8]. Having lowered an inertial member and considering $\xi_0 = 0$ and $\xi \to 0$, we find parameter of critical loading for the plate in the direction x which has no initial deflection, through efforts in the direction y and relations of geometrical and strength parameters

$$P_{1kp}^* = -\frac{E_2}{E_1}P_2^* + \frac{\tilde{\nu} b^2\pi^2}{12a^2}\left(1 + 2\frac{a^2}{b^2}\frac{D_3}{D_{11}} + \frac{a^4}{b^4}\frac{D_{22}}{D_{11}}\right). \tag{22}$$

From the relations (21), (22) provided that on the one hand the expression $P^*_{1kp} + P^*_{2kp}\, E_{22}/E_{11}$ is defined through geometrical and strength parameters, and on the other hand, according to formulas (21), through moisture-thermal parametry, it is possible to define critical relative humidity $\alpha_m = \overline{z}_m$ that corresponds to static loss of stability of the plate. Considering (18), (21) from formula (22) it is possible to define the critical time that corresponds to loss of stability of the plate in the process of drying as function of relative saturation by moisture:

$$\left[\left(Q_{p1} - Q_1\left(\overline{z}_m\right)\right)K_y + \nu_{21}\left(Q_{p2} - Q_2\left(\overline{z}_m\right)\right)\right] +$$
$$+ g\left[\left(Q_{p2} - Q_2\left(\overline{z}_m\right)\right)K_x + \nu_{12}\left(Q_{p1} - Q_1\left(\overline{z}_m\right)\right)\right] = R,$$

where $R = \dfrac{b^2 L_0^2}{a^4}\dfrac{\pi^2 \tilde{\nu} K_\nu^{-1}}{3}\left(1 + 2\dfrac{a^2}{b^2}\dfrac{D_3}{D_{11}} + \dfrac{a^4}{b^4}\dfrac{D_{22}}{D_{11}}\right)$, $g = \dfrac{E_2}{E_1}\dfrac{b^2}{a^2}$.

Opening expressions for $Q_1\left(\overline{z}_m\right), Q_2\left(\overline{z}_m\right)$, and considering (17), we define time, corresponding static loss of stability:

$$\frac{K}{C\rho L_0}\tau = -\ln\left\{1 + \frac{R - \left(Q_{p1} - Q_{W1}\left(\overline{z}_m\right)\right)\left(K_y + g\nu_{12}\right) - \left(Q_{p2} - Q_{W2}\left(\overline{z}_m\right)\right)\left(\nu_{21} + gK_x\right)}{\overline{T}\left[\alpha_1\left(K_y + g\nu_{12}\right) + \alpha_2\left(\nu_{21} + gK_x\right)\right]}\right\}.$$

Here $Q_{Wi}\left(\overline{z}_m\right)$ are the moisture-thermal deformations connected with the change of relative humidity in the process of drying.

Conclusions. From the obtained results it follows, that at small coefficients of heat transfer the plate can not lose stability, at intensive heat transfer the plate can lose stability instantly, and geometrical, strength and kinematic parameters of the porous material and edges influence the time of stability loss. The joint solution of the equation for critical time and communication of relative saturation with time for each concrete way of drying (natural, convective, electroosmotic), allows to define critical humidity and time in which it is reached, taking into account the structure of the body and effective properties of the material which are necessary for timely conducting of hydrotreatment of the body material in the process of drying.

Let's note that the stress state and stability of ortotropny plates taking into account shift stresses were investigated also and stability of the plates form with the big deflection [9] was considered.

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Напружений стан і стійкість форми пористих тіл у процесі сушіння

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На основі розв'язку задачі переносу маси в процесі сушіння для моделей циліндричних капілярів, а саме, моделі еквівалентного радіуса та стохастичної моделі циліндричних капілярів різних радіусів за рівномірного розподілу пор за розмірами з урахуванням залежності модуля Юнга та коефіцієнта Пуассона від відносної насиченості вологою, які прийнято у вигляді непеперервних сплайнів, що апроксимують експериментальні дослідження для матеріалу цементного каменю, наведено результати розрахунків напружено-деформованого стану в різних площинах за товщиною у разі зміни межі фазового переходу за симетричного осушення. Розглянуто задачу про дивергентну стійкість форми ортотропної пористої пластини з миттєвим двостороннім нагрівом і нерівномірним розподілом вологовмісту за товщиною у процесі сушіння, зокрема, розподіл критичних зусиль і критичного часу під час природного осушення.

Напряженное состояние и устойчивость формы пористых тел в процессе сушки

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На основании решения задачи массопереноса в процессе сушки для моделей цилиндрических капилляров, а именно, модели эквивалентного радиуса и стохастической модели цилиндрических капилляров различных радиусов при равномерном распределении пор за размерами с учетом зависимости модуля Юнга и коэффициента Пуассона от относительной насыщенности влагой, которые принято в виде непрерывных сплайнов, аппроксимирующих экспериментальные исследования для материала цементного камня, приведены результаты расчетов напряженно-деформированного состояния слоя в различных плоскостях по толщине при изменении границы фазового перехода при симметричной сушке. Рассмотрена задача о дивергентной устойчивости формы ортотропной пластины при неравномерном распределении влагосодержания и температуры по толщине, в частности, распределении критических усилий и критического времени в процессе естественной сушки.

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