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MATHEMATICAL MODELING OF THE PROCESS OF COMPACTION OF WOOD

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Within the framework of the mechanics of heterophase systems a mathematical model for the process of pressing of wood has been offered; this model takes account of the influence of its complex rheological properties and surface phenomena in thin interlayers of water on the change in a porous structure. With numerical methods, a study has been made of the influence of the sample's humidity and temperature fields on the strength and quality of the material obtained.

Introduction. An important problem in creating modified wood is technological regulation of the conditions of its formation. The methods developed to improve the physical and mechanical properties of natural wood of less valuable types are based on the use of such technological operations as heating, pressing, drying, cooling, and impregnation with various compositions. Wood is a natural composite with a complex irregular structure. It belongs to unstable biopolymer systems whose rheological characteristics are substantially determined by temperature and humidity conditions, which complicates investigation of the behavior of wood when it is modified.

In this work, we study the stressed-strained state of wood during the pressing at different temperatures. The purpose of the investigation is an analysis of the influence of the temperature of wood samples with different distributions of humidity and porosity on the degree of pressing, the uniformity of compaction, and the strength of the billets.

Mathematical Model. Mathematical modeling of the process of straining of wood has been conducted within the framework of the mechanics of heterogeneous media [1]. Wood is considered as a three-phase system containing a solid phase (wood substance), a liquid, and a vapor-gas mixture. The method of averaging over individual phases makes it possible to take account of the influence of surface forces in thin capillaries of wood cells' walls on the change in the structural parameters of a porous system.

The total stress tensor in the wood material σ^{kl} is represented as the sum of the averaged stresses in the phases

$$\sigma^{kl} = \alpha_1 \langle \sigma_1'^{kl} \rangle_1 + \alpha_2 \langle \sigma_2'^{kl} \rangle_2 + \alpha_3 \langle \sigma_3'^{kl} \rangle_3 \,, \quad \langle \sigma_i'^{kl} \rangle_i = \frac{1}{dV} \int\limits_{dV_i} \sigma_i'^{kl} \, d'V \,. \tag{1}$$

It is assumed that the stress tensors in the liquid and gaseous phases are spherical:

$$\langle \sigma_1'^{kl} \rangle_1 = - p_1 \delta^{kl} \,, \quad \langle \sigma_2'^{kl} \rangle_2 = - p_2 \delta^{kl} \,.$$

To describe the rheological behavior of wood, a rheological equation [2] is used as a generalization of a rheological model of a medium with dual porosity [3]. Its peculiarity is that, along with the parameters of the viscoelastic behavior of the structural skeleton of wood and the material of the cell walls, it obviously contains the characteristics of the wood structure, such as the volume content of large pores, capillaries, water, and a wood substance:

$$\varepsilon^{ij} = \Pi_{\rm s}^{ijkl}(0) \left[\Xi_{\rm s}^{kl} + \int\limits_0^t K_{\rm s}^{ijkl}(t - t') \, \Xi_{\rm s}^{ij} \, dt' \right] + \Pi_{\rm f}^{ijkl}(0) \left[\Xi_{\rm f}^{kl} + \int\limits_0^t K_{\rm f}^{ijkl}(t - t') \, \Xi_{\rm f}^{ij} \, dt' \right] + \Lambda_{\rm s}^{ij} \Theta_3 \,, \tag{2}$$

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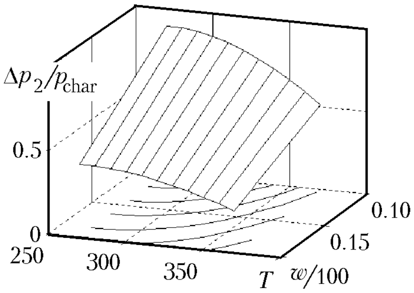

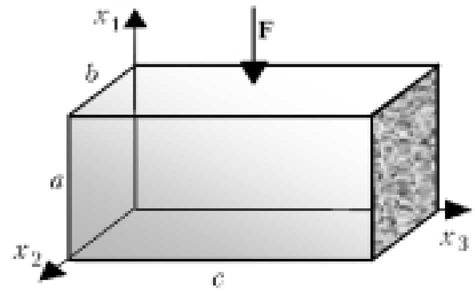

Fig. 1. Component of disjoining pressure Δp_2 vs. humidity w and temperature T for $I_\sigma = -20$ MPa. Δp_2, MPa; w, %; T, K.

Fig. 2. Scheme of pressing.

$$\Xi_s^{kl} = \frac{\sigma^{kl} + \alpha_2 p_2 \delta^{kl} + \alpha_1 p_1 \delta^{kl}}{\alpha_3} \; ; \quad \Xi_f^{kl} = \frac{\sigma^{kl}}{1 - m_p} + \beta_2 p_2 \delta^{kl} + \beta_1 p_1 \delta^{kl} \; ;$$

$$\beta_1 = \frac{m_p \alpha_{p1}}{1 - m_p} + \alpha_{\hat{e}1} \; ; \quad \beta_2 = \frac{m_p \alpha_{p2}}{1 - m_p} + \alpha_{c2} \; ; \quad \alpha_{p1} + \alpha_{p2} = 1 \; ; \quad \alpha_{c1} + \alpha_{c2} = 1 \; .$$

Here m_p is the porosity determined by the ratio of the volume of macropores to the volume of the material and α_{ci} and α_{pi} (i = 1, 2) are the volume contents of the ith phase in the volume of capillaries and pores, respectively.

The physical properties of water contained in wood are complex, since water here is not only in a free state but also in a bound state characterized by a changed molecular structure near solid surfaces [4]. Bound water can be found in wetting films and in thin interlayers. The pressure p_2 averaged over the volume of the liquid phase depends on the values of the volume content and the pressure for free and bound water in wetting films and thin pores. Bound water in thin interlayers creates a disjoining pressure, which makes the main contribution to the value of p_2. For thin interlayers it can be represented as the sum $P + \Delta p_2(\alpha_2, I_\sigma, T)$. Here P is determined either using isotherms or using theoretical approaches, for example, [5]; Δp_2 depends on the intensity of loading of the porous material [6].

The parameters of the rheological model and the components of the disjoining pressure as applied to pine wood were obtained by treatment of the creep curves in compression in the principal directions of anisotropy at different temperatures [7, 8] and by processing of the experimental data on swelling and shrinkage [9]. Figure 1 illustrates the obtained dependence of Δp_2 on temperature and humidity. The creep kernels were represented in the form of exponents:

$$K_n^{ijkl}(t) = d_n^{ijkl} \exp\left(-t/\lambda_n^{ijkl}\right) , \quad n = \text{s, f} .$$

The compaction of wood takes place in a special mold with rigid walls [10]. In the case of pressing across the fibers, the mold has open end surfaces. The degree of pressing across the fibers can reach 50%; the strains along the fibers are negligibly small.

Let us choose a coordinate system as shown in Fig. 2. We assume that the size of the long side of the sample many times exceeds its transverse dimensions, and the distribution of load in the zone of contact between the press and the sample along the x_3 axis is practically uniform. This makes it possible to consider that we have implemented a state of plane strain or unilateral compression for samples with inhomogeneous or homogeneous structural characteristics respectively. It is heated wood that is usually subject to straining. The temperature field in the volume of the billet is nonuniform in the general case. The temperature of the medium's particles is considered to be constant, which is correct, since the characteristic time of heat transfer in the solid and liquid phases of wood is substantially longer than the time of the process of pressing.

The process of straining can be considered as quasiequilibrium, so the equilibrium equations [1]

$$\frac{\partial\left(\alpha_3 \langle \sigma_3^{\prime 11} \rangle_3\right)}{\partial x_1} + \frac{\partial\left(\alpha_3 \langle \sigma_3^{\prime 12} \rangle_3\right)}{\partial x_2} + p_3 \frac{\partial \alpha_3}{\partial x_1} + R_{13}^1 + R_{23}^1 = 0 \,,$$

$$\frac{\partial\left(\alpha_3 \langle \sigma_3^{\prime 12} \rangle_3\right)}{\partial x_1} + \frac{\partial\left(\alpha_3 \langle \sigma_3^{\prime 22} \rangle_3\right)}{\partial x_2} + p_3 \frac{\partial \alpha_3}{\partial x_2} + R_{13}^2 + R_{23}^2 = 0 \,, \quad p_3 = -\frac{1}{3} \langle \sigma_3^{\prime ij} \rangle_3 \tag{3}$$

are correct.

Setting the strains to be small and taking the density of the wood substance to be constant, we can obtain the relation

$$\varepsilon_3^{kk} - \varepsilon_{30}^{kk} = -\frac{\alpha_3 - \alpha_{30}}{\alpha_{30}} \,, \quad \varepsilon_3^{ij} = \frac{1}{2}\left(\frac{\partial \langle h_3^{\prime j} \rangle_3}{\partial x^i} + \frac{\partial \langle h_3^{\prime i} \rangle_3}{\partial x^j}\right), \tag{4}$$

$$\langle h_3^{\prime i} \rangle_3 = \langle h_3^{\prime i} (x_1^{\prime}, x_2^{\prime}) \rangle_3 \,, \quad \langle h_3^{\prime 3} \rangle_3 = 0 \,, \quad i, j = 1, 2$$

from the equation of conservation of the solid-phase mass.

Due to the change in the volume of the billet, the change in the volume content of the liquid phase is taken account of using a relation similar to (4). If the sample has a humidity lower than the hygroscopic saturation point of the cell walls, the water in it is found either in thin interlayers or in wetting films. The transfer of moisture in this case is only possible in wetting films from a region with a higher saturation to a less saturated region. We can determine the pressure gradient in wetting films, following [11]. Evaluations show that the contribution of capillary return flows of moisture to the change in the liquid-phase concentration field in the process of pressing of the capillary-porous system studied is insignificant, since the time of pressing is much shorter than the characteristic time of transfer of water in the cross section of the bar. In the case of compaction of wood of high humidity in the direction across fibers there may occur displacement of free water predominantly along the fibers through end surfaces. In calculations, account is taken of the reduction of the mass of water in a wet wood sample with neglect of the resistance to displacement.

The forces of friction between the composite being formed and the walls of the mold and also the die are disregarded. The condition of contact interaction of the upper bound of the sample with the lower surface of a rigid die represents an equality of the normal components of the displacement vector over the entire contact surface: $\langle h_3^1(a + Y(t),\ x_2^{\prime}) \rangle_3 = Y(t),\ Y < 0$. The other boundary conditions of the problem have the form

$$\langle h_3^{\prime 1} (0, x_2^{\prime}) \rangle_3 = 0 \,, \quad \langle h_3^{\prime 2} (x_1^{\prime}, 0) \rangle_3 = 0 \,, \quad \langle h_3^{\prime 2} (x_1^{\prime}, b) \rangle_3 = 0 \,,$$

$$\langle \sigma_3^{\prime 12} (0, x_2^{\prime}) \rangle_3 = 0 \,, \quad \langle \sigma_3^{\prime 12} (a + Y, x_2^{\prime}) \rangle_3 = \langle \sigma_3^{\prime 12} (x_1^{\prime}, 0) \rangle_3 = \langle \sigma_3^{\prime 12} (x_1^{\prime}, b) \rangle_3 = 0 \,. \tag{5}$$

Normal stresses in the contact zone satisfy the condition

$$\int_0^b \int_0^c \sigma^{11} dx_1 dx_3 = F \,. \tag{6}$$

Numerical Investigation. The boundary-value problem posed (1)–(6) is nonlinear even for materials with a uniform distribution of humidity and porosity, since we do not know in advance the position of the lower bound of the die at each instant of time and the level of stresses depends on the volume content of the phases. To carry out a computational experiment aimed at studying a stressed-strained state in a wood sample with a varying porous structure, finite-difference equations have been constructed and an iteration algorithm has been developed for their implementation.

It is evaluation of its strength that is an important element of the analysis of the process of straining of a wood billet. The polynomial criterion of the 4th degree suggested by E. K. Ashkenazi [12] was selected as a strength criterion. It showed itself to advantage for highly anisotropic materials, which include, in particular, softwood. The criterion does not provide inversion of tensile and compressive strength, but the use of a piecewise limiting strength surface makes it possible to take account of this feature of the material. For the three-axial stressed state with selection of the coordinate axes in the direction of the principal axes of anisotropy the strength condition has the form [12]

$$\frac{\sigma_{aa}^2 + c_1\sigma_{rr}^2 + b_1\sigma_{tt}^2 + d_1\tau_{ar}^2 + p_1\tau_{rt}^2 + g_1\tau_{ta}^2 + s_1\sigma_a\sigma_r + t_1\sigma_r\sigma_t + f_1\sigma_t\sigma_a}{(\sigma_{aa}^2 + \sigma_{rr}^2 + \sigma_{tt}^2 + \tau_{ar}^2 + \tau_{rt}^2 + \tau_{ta}^2 + \sigma_a\sigma_r + \sigma_r\sigma_t + \sigma_t\sigma_a)^{1/2}} \le \sigma_{\mathrm{t}a} ,$$

$$c_1 = \sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}r} ; \quad b_1 = \sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}t} ; \quad d_1 = \sigma_{\mathrm{t}a}/\tau_{\mathrm{t}ar} ; \quad p_1 = \sigma_{\mathrm{t}a}/\tau_{\mathrm{t}rt} ; \quad g_1 = \sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}ta} ;$$

$$s_1 = 4\sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}ar}^{(45)} - c_1 - d_1 - 1 ; \quad t_1 = 4\sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}rt}^{(45)} - c_1 - b_1 - p_1 ; \quad f_1 = 4\sigma_{\mathrm{t}a}/\sigma_{\mathrm{t}at}^{(45)} - b_1 - g_1 - 1 .$$

It is well known that the values of the ultimate strength decrease with growth in the humidity and temperature but increase with degree of pressing [7, 9]. It is assumed that the character of the influence of these factors of humidity and temperature is the same for the limiting values of stresses in any tests: $\sigma_{\mathrm{t}j} = \sigma_{\mathrm{t}j}(T, w) = \sigma_{\mathrm{t}j}(293, 12)f(T, w)$ ($j = a, r, t$, etc.); $\sigma_{\mathrm{t}j}(293, 12)$ is the value of a corresponding ultimate strength at a temperature of 20°C and a wood humidity of 12%. The function f interpolates experimental data for the ultimate strength along the fibers in the range of values w = 0–30% and T = 273–373 K given in [9]. The change in the value of ultimate strengths as a function of the degree of pressing is taken account of using the relation $\sigma_{\mathrm{t}j} = \sigma_{\mathrm{t}j}(1 - k_{\varepsilon j}Y/a)$, where $k_{\varepsilon j}$ is the coefficient dependent on the type of wood, the plane of pressing, and the type of strain [7].

The calculations were carried out for pine wood for the following values of the rheological parameters: $\Pi_{\mathrm{s}}^{tt}(0) = 0.12\cdot10^{-10}$ Pa^{-1}, $\Pi_{\mathrm{s}}^{rt}(0) = -0.46\cdot10^{-11}$ Pa^{-1}, $\Pi_{\mathrm{s}}^{aa}(0) = 0.57\cdot10^{-12}$ Pa^{-1}, $\Pi_{\mathrm{s}}^{ta}(0) = -0.23\cdot10^{-12}$ Pa^{-1}, $\Pi_{\mathrm{s}}^{ra}(0) = -0.28\cdot10^{-12}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{rr}(0) = 0.49\cdot10^{-8}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{tt}(0) = 0.734\cdot10^{-8}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{rt}(0) = -0.182\cdot10^{-9}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{aa}(0) = 0.95\cdot10^{-10}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{ta}(0) = -0.11\cdot10^{-10}$ Pa^{-1}, $\Pi_{\mathrm{f}}^{ra}(0) = -0.13\cdot10^{-10}$ Pa^{-1}, $S_{\mathrm{s}}^{rt}(0) = 0.29\cdot10^{-10}$ Pa^{-1}, $S_{\mathrm{f}}^{rt}(0) = 10^{-8}$ Pa^{-1}, $d_{\mathrm{f}}^{kl} = 0.02$ sec^{-1}, k and $l = r$, t and a; $\eta_{\mathrm{s}}^{rt} = d_{\mathrm{s}}^{rr}$, $d_{\mathrm{f}}^{rr} = 0.11$ sec^{-1}, $d_{\mathrm{f}}^{tt} = 0.13$ sec^{-1}, $d_{\mathrm{f}}^{aa} = 0.0053$ sec^{-1}, $d_{\mathrm{f}}^{rt} = d_{\mathrm{f}}^{ra} = d_{\mathrm{f}}^{rr}$, $\eta_{\mathrm{f}}^{rt} = d_{\mathrm{f}}^{rr}$, $\lambda_{\mathrm{s}}^{kl} = 1.241\cdot10^{5}$ sec, k and $l = r$, t, and a, and $\vartheta_{\mathrm{s}}^{rt} = \lambda_{\mathrm{s}}^{rr}$, $\lambda_{\mathrm{f}}^{rr} = 41.9$ sec, $\lambda_{\mathrm{f}}^{tt} = 37.5$ sec, $\lambda_{\mathrm{f}}^{aa} = 150.0$ sec, $\lambda_{\mathrm{f}}^{ta} = \lambda_{\mathrm{f}}^{ra} = \lambda_{\mathrm{f}}^{rt} = 52.5$ sec, and $\vartheta_{\mathrm{f}}^{rt} = \lambda_{\mathrm{f}}^{rr}$. Here $S(0)$, η, and ϑ are the instantaneous compliance, the influence-function amplitude, and the relaxation time in shear strains. The data given in [9] ($p_{\mathrm{char}} = 10^2$ MPa, $\rho_2 = 10^3$ kg/m^3, and $\rho_3 = 1.54\cdot10^3$ kg/m^3) are used as the ultimate-strength values for pine wood. It is assumed that the quantity $1 - m_{\mathrm{p}} - \alpha_3$ (volume content of capillaries in the material) is approximately equal to the volume content of moisture under conditions of hygroscopic saturation of wood cell walls at a given temperature. The forces of resistance to filtration transfer are disregarded.

The pine-wood sample's cross section initially has a square shape, i.e., $a = b$ and $c/a = 5$. The initial distribution of the volume content in the general case is nonuniform across the cross section and is assigned in the form $\alpha_{20} = A_{20} + B_{20} \sin(\pi x_1/a) \sin(\pi x_2/b)$. Since wood has the properties of a colloid body and swells in the saturation of cell walls with water, at a humidity lower than the hygroscopic saturation limit, a nonuniform content of the liquid phase also corresponds to a nonuniform distribution of the solid phase in the material. The distribution of humidity across the sample's cross section is assigned in the range of 12–20% ($A_{20} = 0.054$ and $B_{20} = 0.032$) and 19–10% ($A_{20} = 0.083$ and $B_{20} = -0.04$). The first number in the notation of the range refers to the boundaries, and the second refers to the center of the billet's cross section. Thus, in the first case it is the central zone that is more humid, whereas in the second case it is the boundary zone. In drier regions, the material has a higher concentration of the solid phase. It is assumed that loading is carried out instantaneously with an applied constant force $F = F_0$ (average pressure $F_0/bc = 20$ MPa). The sample's temperature is assigned either as the same at all points of the cross section or similarly to α_{20}.

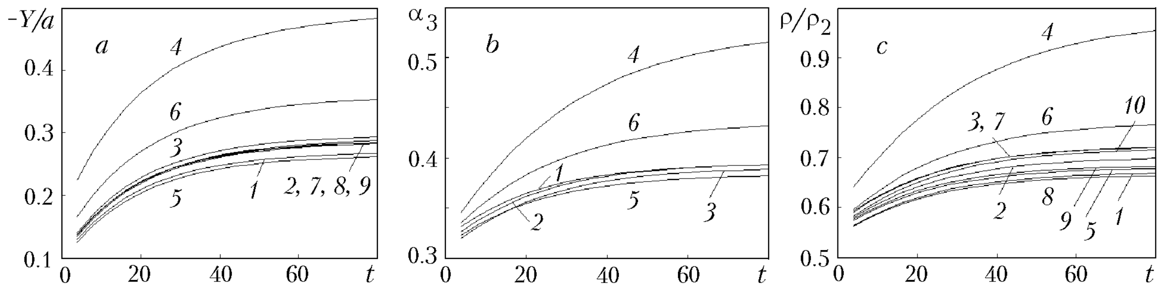

Fig. 3. Time change in the position of the die's lower bound Y (a), the volume content of the solid phase α_3 (b), and the density of the material ρ (at the center of the sample's cross section) (c) in pressing of pine wood across the fibers in the radial direction; 1–3, 7, and 8) samples with temperature T = 60°C; 4 and 6) 100°C; 5) 20°C; the temperature field of samples 9 and 10 varies in the range 65–51°C and 55–68°C respectively. The wood humidity is w = 10% (1); 15% (2, 5, 6, 9, and 10); 20% (3 and 4); the humidity distribution of samples 7 and 8 is assigned in the interval w = 12–20% and 19–10%, respectively. F/bc = 10 MPa. Y, m; ρ, kg/m^3; t, sec.

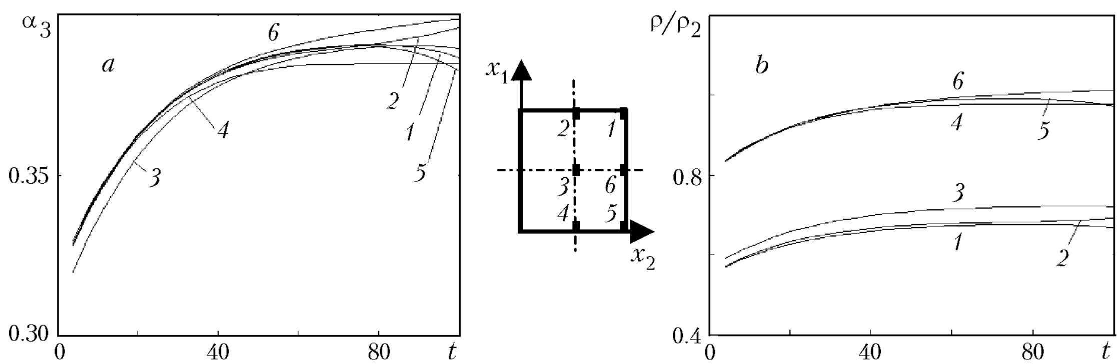

Fig. 4. Time change in the volume content of the solid phase α_3 (a) and the density of the material ρ (b) in pressing of pine wood in the radial direction at the sample's cross-sectional points indicated on the diagram; the humidity distribution is in the range w = 12–20%; the temperature is uniform, T = 60°C. F/bc = 20 MPa. ρ, kg/m^3; t, sec.

Figures 3–6 present the results of calculations, illustrating the influence of the rheological and temperature-humidity factors on the parameters of the process of pressing of wood. Due to the viscoelastic properties possessed by the solid phase and the structural skeleton of the material, the maximum degree of compaction is attained within a period of time that is close to the relaxation time λ_f^{rt} (Fig. 3a). The instantaneous elastic strain in the direction of compression amounts to less than 50% of the strain established after completion of the process of creep. The maximum degree of pressing is attained at higher values of the sample's temperature and humidity, which is due to the smaller contribution of disjoining pressure on the total value of the material's resistance to compression. Curves 7–10 in Fig. 3 are calculated for samples having a nonuniform distribution of humidity or temperature. In the central zone the material is more (less) humid or more (less) heated than in the boundary regions. The average-over-the cross section value of the humidity corresponds to 15%, and that of the temperature corresponds to 60°C. As is seen from Fig. 3a, the degree of pressing for billets with selected nonuniform regions of humidity or temperature differs only slightly from this value obtained on condition that there is a uniform distribution of regions (w = 15% and T = 60°C). The calculation of the material-strength surface conducted for these conditions shows that a nonuniform distribution of humidity and temperature leads to the appearance of destruction regions. In the case of uniform temperature and humidity of the material (for example, for w = 20%, T = 60°C and w = 15%, T = 100°C), the destruction occurs due to

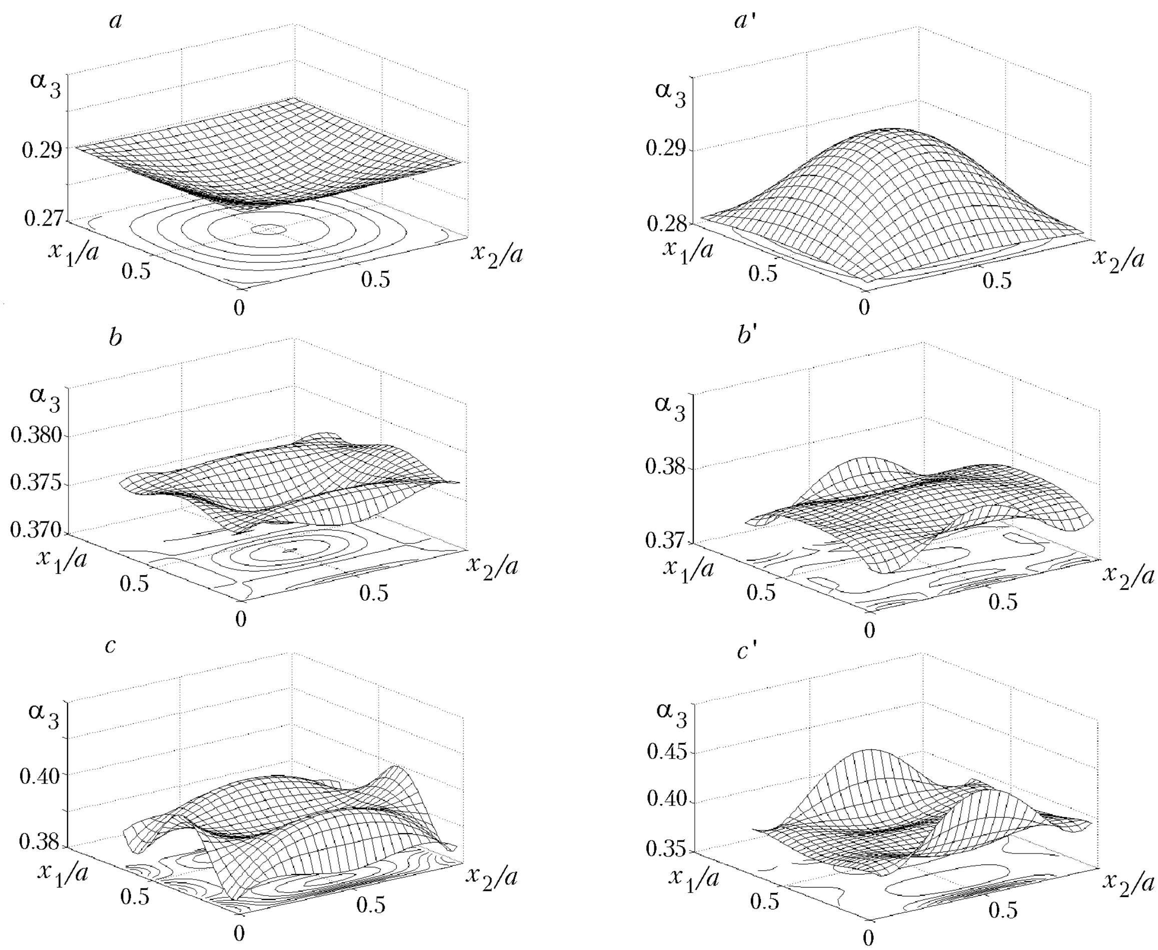

Fig. 5. Distribution of the volume content of the solid phase α_3 in the sample's cross section in radial pressing of pine wood with a uniform temperature distribution (T = 60^{o}C) and a nonuniform humidity field: w = 12–20% (a–c); 19–10% (a′–c′) at t = 0 sec (a and a′); 20 sec (b and b′); 80 sec (c and c′). F/bc = 20 MPa.

the reduction in the strength characteristics of wood, when the humidity and the temperature increase. If the degree of pressing turns out to be sufficiently high, the E. K. Ashkenazi strength criterion, despite the high humidity and temperature (w = 20% and T = 100^{o}C), points out the possibility of obtaining a high-quality sample of compacted wood, which is confirmed by results obtained in practice [7]. The appearance of zones of partial destruction is determined not only by the temperature-humidity step-down correction to the values of strength indicators but also by the complex stressed state of the material. The location of these zones corresponds to regions of maximum concentration of the solid phase, the highest level of volume-compression strain, the maximum tangential stresses, and the total compressive stresses in the direction of the principal axes of wood anisotropy.

In analyzing the results of calculations of the process of pressing of wood, it is necessary to pay attention not only to the density of the material but also to the volume content of the solid phase. Due to the insignificant difference in the values of the density of the solid and liquid phases ($\rho_3/\rho_2 \approx 1.54$), a higher density of pressed material does not always correspond to a higher content of the solid phase (see the mutual position of curves 1 and 2–5 in Fig. 3b and c). In the case of nonuniform humidity or temperature fields as, for example, for w = 12–20% and T = 60^{o}C, at different points of the cross section, there is no complete correspondence between the values of the density and the volume content of the solid state (Fig. 4) either.

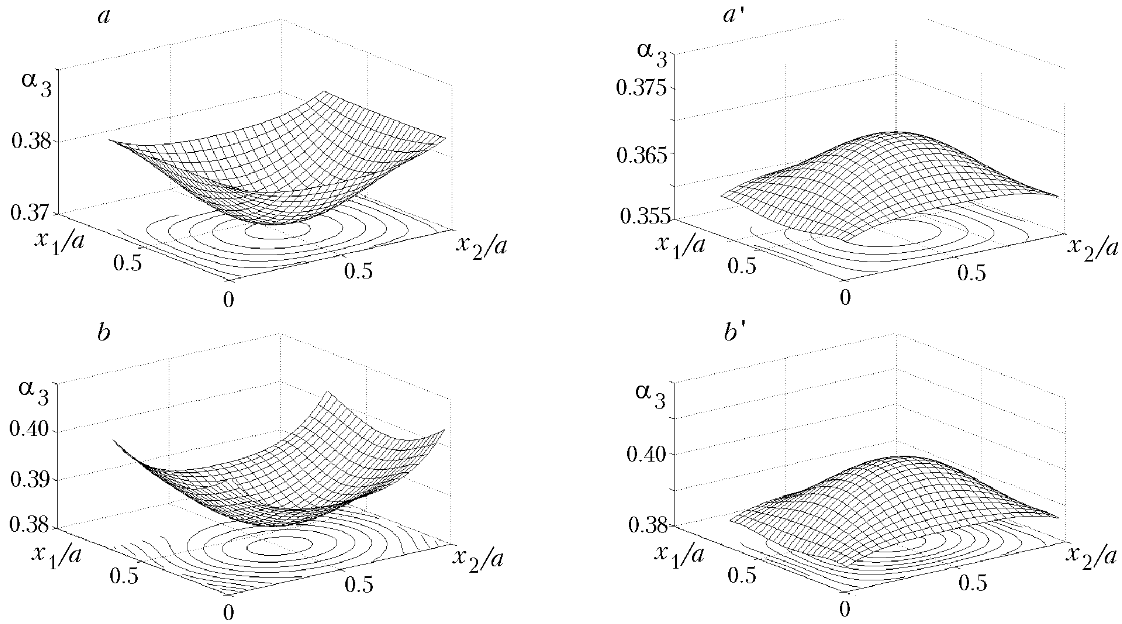

Fig. 6. Distribution of the volume content of the solid phase α_3 in the sample's cross section in radial pressing of pine wood with a uniform humidity distribution, w = 15%, and a nonuniform temperature field: T = 65–51^{o}C (a and b); 55–68^{o}C (a$'$ and b$'$) at t = 30 sec (a and a$'$); 90 sec (b and b$'$). F/bc = 20 MPa.

Redistribution of the solid state in the sample's cross section is due to the features of the rheological behavior of wood at different values of temperature and humidity. The sample that is more humid in the central zone does not have the highest concentration of the solid phase (Fig. 5a–c) at the center. Despite the sufficiently large strain of the wood in this region, the excessively friable initial state of the structural skeleton does not allow the attainment of a greater degree of compaction here. Due to this, the region of maximum pressing is formed in intermediary zones (Fig. 5b and c). As is seen from Fig. 5a$'$–c$'$, the sample is characterized by a higher concentration of the solid phase in these zones after compaction as a result of the more intense straining.

An analysis of the results of the calculations of nonuniformly heated samples (with a uniform initial content of moisture and the solid phase) shows that the qualitative character of distribution of the volume phase in the process of pressing remains constant (Fig. 6). The sample heated inside more than outside turns out, in accordance with the E. K. Ashkenazi criterion, to be stronger than a sample having an opposite temperature distribution.

Calculations show that the negative influence of a nonuniform humidity distribution of wood can be compensated for with a specially selected temperature field.

Conclusions. The formulated mathematical model of the process of pressing of wood takes account of the rheological factor and the effect of disjoining pressure in thin interlayers of water on the change in the material's porous structure in its compaction. Numerical calculations make it possible to predict the degree of pressing and the change in the porous structure over the sample's cross section. Determination of the stress-tensor field makes it possible to use the strength criterion for evaluation of the regime selected for pressing of the prepared samples with an assigned distribution of temperature and humidity.

NOTATION

$\langle ... \rangle_i$, averaging over the volume of the ith phase; a, b, and c, dimensions of a sample, m; $a_{\rm p}$, characteristic dimension of pores, m; A_{20} and B_{20}, constant; d, parameter of the influence function, sec^{-1}; F, resultant compressive force, N; h, displacement, m; I_σ, first invariant of the stress tensor, Pa; $k_{\varepsilon j}$, coefficient; $m_{\rm p}$, volume content of large pores; p, pressure, Pa; P, equivalent disjoining pressure in thin interlayers of water, Pa; Δp_2, nonequilibrium component of disjoining pressure, Pa; R_{13} and R_{23}, forces of resistance to the filtration transfer of the liquid and gaseous phases in a porous material, N; t, times, sec; t', time preceding the observation time t, sec; T, temperature, K; V, volume, m^3; dV, macrovolume element, m^3; w, humidity, %; x_1, x_2, and x_3, Cartesian coordinates, m; Y, displacement of the die, m; α, volume content; δ, unit tensor; ε, strain tensor; K, tensor of the creep-rate functions; λ, parameter of the influence function, sec; Λ, tensor of the temperature expansion coefficients, K^{-1}; $\Pi(0)$, instantaneous-compliance tensor, Pa^{-1}; Θ, difference between the running temperature and a certain initial value of it, K; ρ, density, kg/m^3; σ, stress tensor, Pa; τ, shear components of the stress tensor, Pa. Subscripts: 1, 2, and 3, vapor, water, and a wood substance (solid phase); i and j, phase No.; f, effective (fictitious) values; s, wood substance; p, system of macropores; c, system of capillaries; 0, initial values, char, characteristic value of the parameter; t, hazardous stress (ultimate strength–time resistance); a, r, and t, directions of the principal axes of symmetry of an orthotropic material. Superscripts: i, j, k, and l, tensor components; $'$, parameters average within the microvolume $d'V \ll a_p^3$; 45, ultimate strength in the direction at an angle of 45^o to the anisotropy axes of the material.

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