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SIMULATION OF NONISOTHERMAL MOISTURE TRANSFER AND STRESSES IN WOOD IN DRYING

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We obtain a numerical solution for a two-dimensional problem of nonisothermal moisture transfer in the anisotropic structure of wood (lumber) in convective drying. On the basis of elasticity theory we determine internal thermal and moisture stresses.

Introduction. The drying of wood is one of the most important production processes in the technology of wood processing. The complexity of the drying of lumber is attributable to the variety of physicomechanical properties of different species, anisotropy of wood structure, interrelation between the phenomena of heat and moisture transfer, strains and stresses occurring in drying, and large differences in the dimensions of assortments. The quality of articles made of wood, capacity of drying equipment, and energy consumption depend largely on the conditions of lumber drying. Rational conditions for drying lumber can be established from an analysis of the internal processes of heat and moisture transfer and the stress-strain state, which is determined by the dynamics of the moisture and temperature fields.

Heating and drying of lumber leads to the development of multidimensional heat and moisture transfer in the anisotropic structure of wood. Usually, the length of the lumber considerably exceeds the other dimensions, i.e., the width (L_1) and thickness (L_2), and therefore, more often than not, it is worthwhile to confine considerations to a two-dimensional model.

Several methods are available for taking into account the multidimensional nature and anisotropy of wood in practical calculations of the process of heating and drying of materials: based on the analytical solution to a multidimensional problem of moisture diffusion; construction of special dimensionless diagrams; introduction of corrections for the multidimensional nature (an equivalent dimension of the body or a diameter quotient). A review of these investigations is set out rather comprehensively in [1, 2].

Below we solve a two-dimensional problem of nonisothermal moisture transfer in the anisotropic structure of wood and determine internal stresses in wood in drying and limiting strengths.

Mathematical Model. We will consider the cross section of a specimen, with the coordinate origin fixed at its center. Then the point with the coordinates (l_1, l_2), where $l_1 = L_1/2$, $l_2 = L_2/2$, will correspond to the specimen edge (Fig. 1).

In drying of the capillary-porous structure of wood the convective component is small compared to the conductive component [3]. As is known, the system of differential equations of nonisothermal moisture transfer in the case of a small total-pressure gradient has the following form for the two-dimensional problem:

$$c\rho \frac{\partial t}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda_1 \frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_2 \frac{\partial t}{\partial y}\right) + \varepsilon \rho_0 r \frac{\partial u}{\partial \tau}, \qquad (1)$$

$$\frac{\partial u}{\partial \tau} = \frac{\partial}{\partial x}\left(a_1' \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(a_2' \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial x}\left(a_1' \delta \frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(a_2' \delta \frac{\partial t}{\partial y}\right) \qquad (2)$$

with the initial conditions

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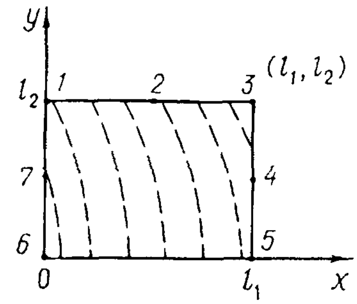


Fig. 1. Diagram of the specimen: 1-7) test points of the specimen.

$$t\,(x, y, 0) = t_0\,(x, y)\,, \quad u\,(x, y, 0) = u_0\,(x, y) \tag{3}$$

and the boundary conditions

$$\lambda_1 \left.\frac{\partial t}{\partial x}\right|_{x=l_1} + \rho_0\,(1-\varepsilon)\, r\beta_1\,(u|_{x=l_1} - u_{\text{eq}1}) = \alpha_1\,(t_{\text{med}1} - t|_{x=l_1})\,, \tag{4}$$

$$\lambda_2 \left.\frac{\partial t}{\partial y}\right|_{y=l_2} + \rho_0\,(1-\varepsilon)\, r\beta_2\,(u|_{y=l_2} - u_{\text{eq}2}) = \alpha_2\,(t_{\text{med}2} - t|_{y=l_2})\,, \tag{5}$$

$$\left.\frac{\partial t}{\partial x}\right|_{x=0} = 0\,, \quad \left.\frac{\partial t}{\partial y}\right|_{y=0} = 0\,, \tag{6}$$

$$\left.\left(a_1' \frac{\partial u}{\partial x} + a_1'\delta \frac{\partial t}{\partial x}\right)\right|_{x=l_1} = \beta_1\,(u_{\text{eq}1} - u|_{x=l_1})\,, \tag{7}$$

$$\left.\left(a_2' \frac{\partial u}{\partial y} + a_2'\delta \frac{\partial t}{\partial y}\right)\right|_{y=l_2} = \beta_2\,(u_{\text{eq}2} - u|_{y=l_2})\,, \tag{8}$$

$$\left.\left(a_1' \frac{\partial u}{\partial x} + a_1'\delta \frac{\partial t}{\partial x}\right)\right|_{x=0} = 0\,, \tag{9}$$

$$\left.\left(a_2' \frac{\partial u}{\partial y} + a_2'\delta \frac{\partial t}{\partial y}\right)\right|_{y=0} = 0\,. \tag{10}$$

We denote: $R_c = c/c_0$; $R_\rho = \rho/\rho_0$; $R_{\lambda 1} = \lambda_1/\lambda_{10}$, $R_{\lambda 2} = \lambda_2/\lambda_{20}$, $R_\lambda = \lambda_{20}/\lambda_{10}$, $R_L = l_1/l_2$, $R_{a1}' = a_1'/a_{10}'$, $R_{a2}' = a_2'/a_{20}'$, $R_\delta = \delta/\delta_0$, $R_a' = a_{20}'/a_{10}'$, $T = (t - t_0)/t_0$, $U = (u_0 - u)/u_0$.

Then the system of equations (1)-(10) will be written in dimensionless form as

$$R_c R_\rho \frac{\partial T}{\partial \text{Fo}} = \frac{\partial}{\partial X}\left(R_{\lambda 1}\frac{\partial T}{\partial X}\right) + R_\lambda R_L^2 \frac{\partial}{\partial Y}\left(R_{\lambda 2}\frac{\partial T}{\partial Y}\right) - \varepsilon \text{Ko}\frac{\partial U}{\partial \text{Fo}}\,, \tag{11}$$

$$\begin{aligned}\frac{\partial U}{\partial \text{Fo}} &= \text{Lu}\frac{\partial}{\partial X}\left(R_{a1}'\frac{\partial U}{\partial X}\right) + \text{Lu} R_L^2 R_a' \frac{\partial}{\partial Y}\left(R_{a2}'\frac{\partial U}{\partial Y}\right) - \\ &- \text{Lu Pn}\frac{\partial}{\partial X}\left(R_{a1}' R_\delta \frac{\partial T}{\partial X}\right) - R_L^2 R_a' \,\text{Lu Pn}\frac{\partial}{\partial Y}\left(R_{a2}' R_\delta \frac{\partial T}{\partial Y}\right).\end{aligned} \tag{12}$$

The dimensionless boundary conditions are

$$R_{\lambda 1}\frac{\partial T}{\partial X}\bigg|_{X=1} + \text{Ko Lu Ki}_{m1}(\text{Fo})(1-\varepsilon) = \text{Ki}_{t1}(\text{Fo}), \tag{13}$$

$$R_{\lambda 2}\frac{\partial T}{\partial Y}\bigg|_{Y=1} + \text{Ko Lu Ki}_{m2}(\text{Fo})(1-\varepsilon) = \text{Ki}_{t2}(\text{Fo}), \tag{14}$$

$$\left(-R'_{a1}\frac{\partial U}{\partial X} + R'_{a1}R_\delta \,\text{Pn}\frac{\partial T}{\partial X}\right)\bigg|_{X=1} + \text{Ki}_{m1}(\text{Fo}) = 0, \tag{15}$$

$$\left(-R'_{a2}\frac{\partial U}{\partial Y} + R'_{a2}R_\delta \,\text{Pn}\frac{\partial T}{\partial Y}\right)\bigg|_{Y=1} + \text{Ki}_{m2}(\text{Fo}) = 0, \tag{16}$$

$$\frac{\partial T}{\partial X}\bigg|_{X=0} = 0, \quad \frac{\partial T}{\partial Y}\bigg|_{Y=0} = 0, \tag{17}$$

$$\left(-R'_{a1}\frac{\partial U}{\partial X} + R'_{a1}R_\delta \,\text{Pn}\frac{\partial T}{\partial X}\right)\bigg|_{X=0} = 0, \tag{18}$$

$$\left(-R'_{a2}\frac{\partial U}{\partial Y} + R'_{a2}R_\delta \,\text{Pn}\frac{\partial T}{\partial Y}\right)\bigg|_{Y=0} = 0, \tag{19}$$

$$T(X, Y, 0) = 0, \quad U(X, Y, 0) = 0.$$

In solving the system of equations (1)-(10), we took into account the dependence of the thermophysical characteristics on temperature and moisture content. We used the approximating dependences suggested in [1]. We will give some of them.

The thermal conductivity coefficient is

$$\lambda = \lambda_0 k_{x\lambda}\, k_{\rho\lambda}, \tag{20}$$

$$\lambda_0 = 0.00222u\,(t-273) + 10^{0.295\log 100u - 1.022}, \quad 0.05 \le u \le 1,$$

at $\rho_0 = 500$;

$$k_{\rho\lambda} = \frac{1}{1.864 - 0.00175\rho_b},$$

where $k_{\rho\lambda}$ and $k_{x\lambda}$ are the corrections for the wood density and the heat-flux direction, respectively.

The moisture conductivity coefficient is

$$a' = a'_0 k_{xa}\, k_{\rho a}, \tag{21}$$

$$a_0 = 10^{9.36\log t - 32.6}, \quad k_{\rho a} = 1.9 - 0.00205\rho_b \text{ when } \rho_b \le 500; \quad k_{\rho a} = 0.98 \text{ when } \rho_b > 500.$$

It was assumed that $a'_{rad}/a'_{tan} = 1.25$.

The internal stresses in the wood were calculated on the basis of elasticity theory. We consider an orthogonally anisotropic (shortened to "orthotropic") plate of wood that has different elastic, moisture, and temperature properties in two mutually perpendicular directions. The planes of orthotropy coincide with the planes of the adopted coordinate system (x, y). In a plane stressed state the equation of moisture elasticity can be written in the form [4]

$$\frac{\partial^4 F}{\partial x^4} + 2A_1 \frac{\partial^4 F}{\partial x^2 \partial y^2} + A_2 \frac{\partial^4 F}{\partial y^4} = A_3 \left(\frac{\partial^2 \hat{U}}{\partial x^2} + n \frac{\partial^2 \hat{U}}{\partial y^2} \right), \tag{22}$$

where $A_1 = E_y(1/2G - \nu/E_y)$; $A_2 = E_y/E_x$; $A_3 = E_y\gamma_y$; $n = \gamma_x/\gamma_y$; γ_x, γ_y and E_x, E_y are the drying-up coefficients and elasticity moduli in the direction of the x and y axes, respectively; $\hat{U} = u^* - u$ is the drop in hygroscopic moisture content over the specimen cross section; for $u > u^*$ it was assumed that $\hat{U} = 0$, which corresponds to the absence of drying-up in the moist zone. It is known that the drying-up of wood begins when the moisture content decreases beyond the saturation limit of the cellular walls (the maximum hygroscopic moisture content), which is equal, on the average, to $u_{\text{sat.lim}} = 30\%$. Owing to the fact that noticeable changes in the strength, stiffness, and drying-up of wood begin at a moisture content of 25%, this moisture content was taken as the calculated limit $u^* = 0.25$ [5].

The boundary conditions are

$$\frac{\partial^2 F}{\partial x^2} = 0 \quad \text{at} \quad y = \pm l_2, \quad \frac{\partial^2 F}{\partial y^2} = 0 \quad \text{at} \quad x = \pm l_1, \quad \frac{\partial^2 F}{\partial x \partial y} = 0 \quad \text{at} \quad x = \pm l_1, \quad y = \pm l_2, \tag{23}$$

$F(x, y, \tau)$ is the stress function,

$$\sigma_x = \frac{\partial^2 F}{\partial y^2}, \quad \sigma_y = \frac{\partial^2 F}{\partial x^2}, \quad \tau_{xy} = -\frac{\partial^2 F}{\partial x \partial y}. \tag{24}$$

Similarly to [6] we will seek the solution to Eq. (22) in the form

$$F(x, y, \tau) = A_3 Z(x, y) S(\tau). \tag{25}$$

Substituting Eq. (25) into Eq. (22), we obtain

$$\frac{\partial^4 Z}{\partial x^4} + 2A_1 \frac{\partial^4 Z}{\partial x^2 \partial y^2} + A_2 \frac{\partial^4 Z}{\partial y^4} = \frac{\partial^2 \breve{U}}{\partial x^2} + n \frac{\partial^2 \breve{U}}{\partial y^2}, \tag{26}$$

where $\breve{U}(x, y) = \hat{U}(x, y, \tau)/S(\tau)$.

The boundary conditions are

$$\frac{\partial^2 Z}{\partial x^2} = 0 \quad \text{at} \quad y = \pm l_2, \quad \frac{\partial^2 Z}{\partial y^2} = 0 \quad \text{at} \quad y = \pm l_1,$$
$$\frac{\partial^2 Z}{\partial x \partial y} = 0 \quad \text{at} \quad x = \pm l_1, \quad y = \pm l_2. \tag{27}$$

We represent the function $Z(x, y)$ in the form of the polynomial

$$Z(x, y) = (x^2 - l_1^2)^2 (y^2 - l_2^2)^2 \sum_{i=0}^{\infty} \sum_{k=0}^{\infty} a_{ik} x^i y^k. \tag{28}$$

It is not difficult to see that the function $Z(x, y)$ satisfies boundary conditions (27).

In order to determine the constants a_{ik}, we use the Galerkin method. Substituting Eq. (28) into Eq. (26) and limiting ourselves to three terms of the series, we obtain

$$Z(x, y) = (x^2 - l_1^2)^2 (y^2 - l_2^2)^2 (a_{00} + a_{10}x + a_{01}y), \tag{29}$$

$$\sigma_x = A_3 S(\tau) \frac{\partial^2 Z(x, y)}{\partial y^2}, \quad \sigma_y = A_3 S(\tau) \frac{\partial^2 Z(x, y)}{\partial x^2}, \quad \tau_{xy} = -A_3 S(\tau) \frac{\partial^2 Z(x, y)}{\partial x \partial y}. \tag{30}$$

Upon substitution of Eq. (29) into Eq. (26), we obtain

$$a_{00} = \frac{1575 \int\limits_{-l_1}^{l_1} \int\limits_{-l_2}^{l_2} \left(\frac{\partial^2 U}{\partial x^2} + n \frac{\partial^2 U}{\partial y^2} \right) z_0 \, dxdy}{32768 \, l_2^5 l_1^9 \left[A_2 + \frac{4A_1}{7} \left(\frac{l_2}{l_1} \right)^2 + \left(\frac{l_2}{l_1} \right)^4 \right]}, \tag{31}$$

$$a_{10} = \frac{2205 \int\limits_{-l_1}^{l_1} \int\limits_{-l_2}^{l_2} \left(\frac{\partial^2 U}{\partial x^2} + n \frac{\partial^2 U}{\partial y^2} \right) z_0 \, x dxdy}{32768 \, l_1^7 l_2^9 \left[1 + \frac{4A_1}{15} \left(\frac{l_1}{l_2} \right)^2 + \frac{7A_2}{55} \left(\frac{l_1}{l_2} \right)^4 \right]}, \tag{32}$$

$$a_{01} = \frac{2205 \int\limits_{-l_1}^{l_1} \int\limits_{-l_2}^{l_2} \left(\frac{\partial^2 U}{\partial x^2} + n \frac{\partial^2 U}{\partial y^2} \right) z_0 \, y dxdy}{32768 \, l_1^9 l_2^7 \left[A_2 + \frac{4A_1}{15} \left(\frac{l_2}{l_1} \right)^2 + \frac{7}{55} \left(\frac{l_2}{l_1} \right)^4 \right]}, \tag{33}$$

$$z_0 = (x^2 - l_1^2)^2 (y^2 - l_2^2)^2;$$

$$\sigma_x' = 4A_3 S(\tau) (x^2 - l_1^2)^2 [a_{00}(3y^2 - l_2^2) + a_{10}x(3y^2 - l_2^2) + a_{01}y(5y^2 - 3l_2^2)], \tag{34}$$

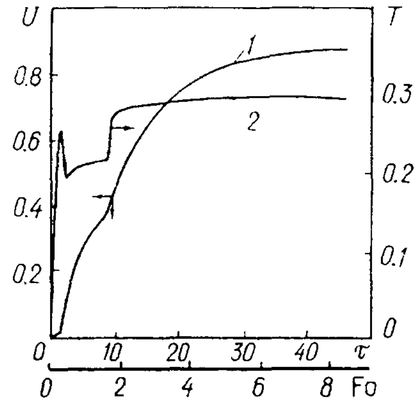
$$\sigma_y' = 4A_3 S(\tau) (y^2 - l_2^2)^2 [a_{00}(3x^2 - l_1^2) + a_{10}x(5x^2 - 3l_1^2) + a_{01}y(3x^2 - l_1^2)], \tag{35}$$

$$\tau_{xy} = -4A_3 S(\tau) (x^2 - l_1^2)(y^2 - l_2^2) [4a_{00}xy + a_{10}y(5x^2 - l_1^2) + a_{01}x(5y^2 - l_2^2)]. \tag{36}$$

Thus, using heat and mass transfer equations (1)-(10) we calculated the moisture-content and temperature fields for each instant of time, and then we determined the curves for the stresses σ_x', σ_y', τ_{xy} from formulas (34)-(36).

The effect of degeneration of elastic deformations into residual ones was considered on the basis of the well-known fact that the elasticity modulus in unloading is 1.5 times larger than the same quantity in loading [5]. In a first approximation, for residual deformations we can write $\varepsilon_{res} = \sigma^{max}/E - \sigma^{max}/(1.5E) = \sigma^{max}/3E$. In view of this, the stresses on the unloading line were calculated approximately from the formulas

$$\sigma_x = \sigma_x' - \sigma_x^{max}/3, \tag{37}$$



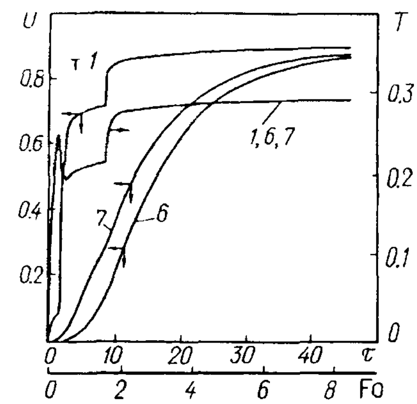


Fig. 2. Dependences of the mean moisture content (curve 1) and temperature (curve 2) of the specimen on time. τ, h.

Fig. 3. Dependences of the moisture content and temperature on time for different points of the specimen (see Fig. 1).

$$\sigma_y = \sigma_y' - \sigma_y^{\max}/3\,, \tag{38}$$

where σ_x' and σ_y' are the stresses calculated from formulas (34) and (35); $\sigma_x^{\max}$ and $\sigma_y^{\max}$ are the maximum local stresses.

Discussion of Results. A numerical solution for the system of equations of heat and moisture transfer (1)-(10) was found by means of an iteration method. Here, two-dimensional equations (1) and (2) were solved by a locally one-dimensional method [7]. The accuracy of the numerical scheme was checked by increasing the number of grid points and time steps. It was noted that a decrease of a step in space and time, compared to those selected, results in a very slight improvement in the quality of the lines and does not lead to substantial quantitative changes. It should be noted that in order to reduce the time of the computations, we carried out calculations of heat and moisture transfer phenomena for both the two-dimensional problem given above and the analogous one-dimensional case.

The heat-conduction equation involves the criterion of phase transition ε, which determines the portion of the moisture evaporated inside the body. This parameter takes values from 0 to 1 and depends on the conditions of the process. To estimate the contribution of this parameter, calculations were carried out for different values of ε: ε = 0, 0.15, 0.5, 1.0 using pine wood as an example under the normal drying conditions 3–H (three-stage conditions). It was noted that changes in the criterion ε exert a very slight effect on the values of the temperature and moisture-content parameters. The greatest deviations of the moisture content were observed at the third stage of drying ($u < 25\%$) at the center of the specimen. In subsequent calculations we took the value $\varepsilon = 0.15$ from the results of investigations [8], which was obtained at a temperature of the medium of 60 ... 115°C and a velocity of 1.6 m/sec.

The investigations showed that the heat and moisture conduction exerted an insignificant influence on the duration of drying. At the beginning of the process the heat and moisture conduction somewhat increases the rate of drying, while at the third stage of drying it decreases the intensity of the process, i.e., leads to an increase in the duration of drying under the above-indicated conditions by about 5%. The data obtained agree with results of investigations given in [9]. Thus, the effect of heat and moisture conduction can be neglected in engineering calculations.

Figures 2-5 present results of numerical investigations of heat and moisture transfer and internal stresses in a specimen of pine wood measuring 0.125 × 0.027 m under the normal drying conditions 3–H (see Table 1) [10].

Grids of sizes 59 × 15 and 89 × 19 were used in the numerical implementation.

The wood was heated at the temperature of the medium t_{med} = 94°C and the relative moisture content φ = 0.97 until the difference between the temperature of the medium and that at the center of the board specimen

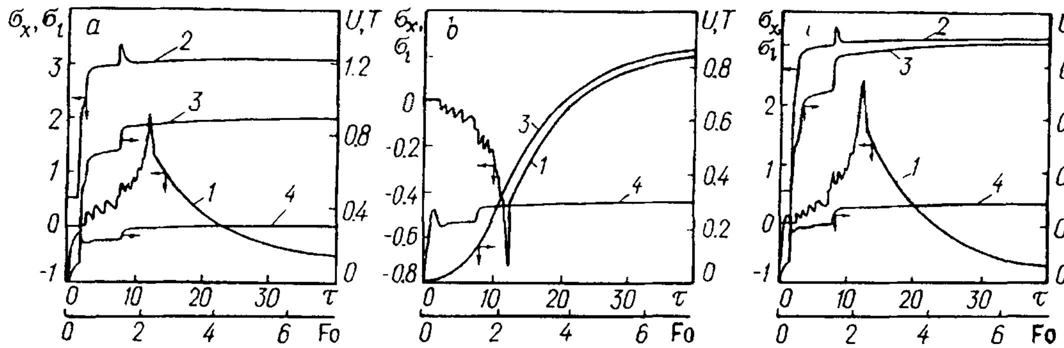


Fig. 4. Dependences of the stresses σ_x (curve 1), strength limit (curve 2), moisture content (curve 3), and temperature (curve 4) on time: a) at point 1, b) at point 6 (curve 2 is not depicted), c) at point 2.

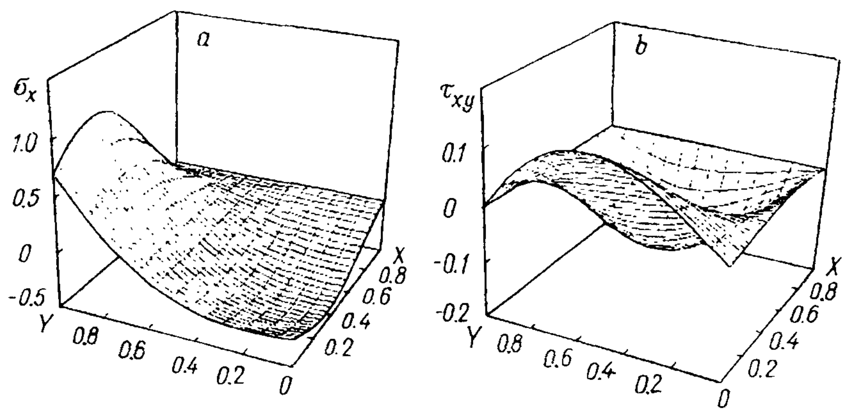


Fig. 5. Spatial change in the normal stresses σ_x (a) and the tangential stresses τ_{xy} (b) at τ = 16.09 h.

reached 3°C; then the first stage of drying began. The calculations were carried out for the following parameters: $t_0 = 291$ K; $u_0 = 0.39$; $r = 2500$ kJ/kg; $\varepsilon = 0.15$; $A_y = 0.28$; $A_x = 0.17$; $\rho_0 = 460$ kg/m^3; $\rho_b = 430$ kg/m^3; $V = 2$ m/sec; $k_{x\lambda} = 1$; $k_{y\lambda} = 1.045$; $k_{xa} = 1$; $k_{ya} = 0.8$; $\delta = 0$; $t_{med} = t_{med\ 1} = t_{med\ 2}$; $u_{eq} = u_{eq\ 1} = u_{eq\ 2}$. The specimen was sawed in quarters. The values of the elasticity modulus and strength limit of the wood were determined from formulas obtained in [1]:

$$E(u, t) = 15tu - 1600u - 5.25t + 575,$$

$$\sigma_l(u, t) = 0.067tu - 17u - 0.035t + 7.1,$$

and the equilibrium moisture content was determined from the formula [1]

$$u_{eq} = 10.6^{\varphi}\,[3.27 - 0.015\,(t_{med} - 273)]/100.$$

The dependences of the mean values of the moisture content and temperature on time and the values at the chosen points of the wood specimen are given in Figs. 2 and 3. From Fig. 3 it is seen that the temperature drop over the specimen cross section is small and the drying process after the heating-up period can be approximately considered as isothermal.

The internal stresses were calculated from formulas (34)-(38). At the beginning of the drying process the tensile stresses in the surface zone increase and then they decrease (Figs. 4 and 5a). It should be noted that the decline in the stresses was observed as soon as the moisture content of the inner zone became lower than the saturation limit of the cellular walls (in this case, the calculated limit of 25%). This fact is in agreement with results of [5]. The appearance of considerable residual deformations at the end of the drying process leads to a change

TABLE 1. Parameters of the Normal Conditions of Drying 3–H and Coefficients of Heat and Moisture Exchange

u	t_{med}, °C	φ	α, W/(m^2·K)	β, m/sec
> 0.35	79	0.77	23	$2\cdot10^{-6}$
0.35–0.25	84	0.62	22.5	$3\cdot10^{-6}$
< 0.25	105	0.27	22	$4.5\cdot10^{-6}$

Note: 1st line, first stage of drying; 2nd line, second stage of drying; 3rd line, third stage of drying.

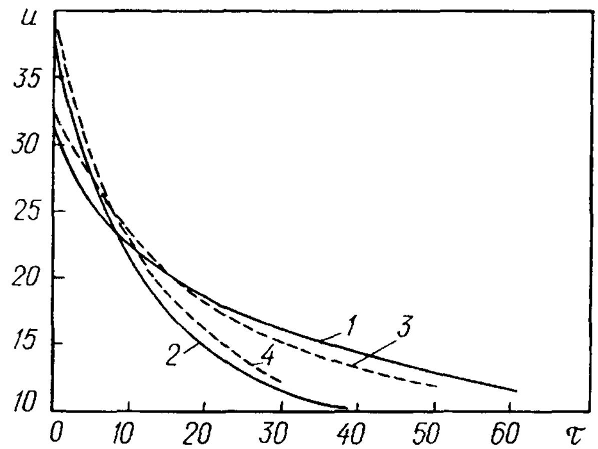


Fig. 6. Comparison between calculated (1, 2) and experimental (3, 4) curves of the drying of lumber: 1, 3) u_0 = 0.32 kg/kg, ρ_b = 400 kg/m^3, specimen of dimensions 0.083 × 0.068; 2, 4) u_0 = 0.39, ρ_b = 430, 0.027 × 0.125. u, %; τ, h.

in the sign of the stresses. In the dried board residual compressive stresses are retained in the surface layers, and tensile stresses in the inner zone.

According to the given model, in the period of increase of the stresses one could observe a certain relaxation of them. However, it should be noted that when the initial moisture content of the specimen was lower than the calculated limit of 25%, relaxation of stresses was not observed.

The maximum stresses at point 2 are higher than at the center of the surface zone (point 1), and the stresses σ_x at point 1 are considerably higher than the stresses σ_y at point 5.

The spatial change in tangential stresses is presented in Fig. 5b.

In addition, we carried out calculations for a thicker specimen of dimensions 0.125 × 0.05. As the thickness of the board increases, the stresses σ_y on the line 3-5, as well as the tangential stresses, increase.

The mathematical model was checked by comparing calculated and experimental data for pine-wood specimens of dimensions 0.083 × 0.068 and 0.027 × 0.125 for the following drying conditions: t_{med} = 80°C, φ = 0.5, V = 2 m/sec. The computations were performed on a 37 × 31 grid. Figure 6 presents a comparison of calculated data with results of experiments carried out in [1]. An analysis of the figure indicates good agreement between the calculated and experimental data on the kinetics of the drying process for two specimens differing in the initial moisture content.

NOTATION

a_1, a_2 and a_{10}, a_{20}, values of the thermal diffusivity coefficients for moist and dry wood in the direction of the x and y axes, respectively, m^2/sec; a'_1, a'_2 and a'_{10}, a'_{20}, values of the moisture conductivity coefficients for moist wood and at the initial values of temperature t_0 and moisture content u_0, respectively, m^2/sec; a'_{rad}, a'_{tan}, moisture conductivity coefficient in the radial and tangential direction of annual layers, respectively, m^2/sec; c, c_0, heat capacity of moist and dry wood, J/(kg·K); E_x, E_y, elasticity moduli, MPa; G, shear modulus; $j_{t1} = \alpha_1 (T_{med1} - T|_{X=1}) t_0$, heat flux density on the surface, W/m^2; $j_{m1} = -\rho_0 \beta_1 (U|_{X=1} - U_{eq}) u_0$, moisture flux density on the surface, $kg/(m^2 \cdot sec)$; r, specific heat of vaporization, J/kg; t, t_0, current and initial values of the wood temperature, K; t_{med}, temperature of the medium, K; u, u_0, current and initial values of the wood moisture content, kg/kg; u_{eq}, equilibrium moisture content, kg/kg; V, velocity of the medium, m/sec; φ, relative moisture content of the medium; x, y, spatial coordinates, m; X, Y, dimensionless coordinates; α_1, α_2, coefficients of heat transfer on the outer surfaces, $W/(m^2 \cdot K)$; β_1, β_2, coefficients of moisture transfer, m/sec; δ, δ_0, coefficient of heat and moisture conductivity of the moist wood and at the initial values t_0 and u_0, respectively, K^{-1}; ε, phase change criterion; λ_1, λ_2 and λ_{10}, λ_{20}, thermal conductivity coefficients of moist and dry wood, W/(m·K); ν, Poisson coefficient, $\nu = 0.5$; ρ, ρ_b, ρ_0, density of moist wood, base density and density of dry wood, respectively, kg/m^3; σ_x, σ_y, normal stresses, MPa; τ, time, sec; τ_{xy}, tangential stresses, MPa; $Fo = a_{10}\tau / L_1^2$, Fourier number; $Ko = ru_0 / c_0 t_0$, Kossovich number; $Ki_{t1} = j_{t1} L_1 / \lambda_{10} t_0$, Kirpichev heat transfer number; $Ki_{m1} = j_{m1} L_1 / a'_{10} \rho_0 u_0$, Kirpichev mass transfer number; $Lu = a'_{10} / a_{10}$, Luikov number; $Pn = \delta_0 t_0 / u_0$, Posnov number. Subscripts: 1 and 2, values of the parameters in the direction of the x and y axes, respectively.

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