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Deformations during drying of wooden corner elements of I-beams

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Abstract. At present, environmental degradation is occurring, which affects forests. Increasingly, in the trunks of conifers there is core (sound) rot. Round timber with sound rot is left in the forest, which does not contribute to improving the environmental situation. A new technological process is proposed for producing lumber from round timber with sound rot for the manufacture of structural elements for construction. In the process of cutting, the rot is removed, and the elements of the angular cross section are obtained. In the future, they are used for the manufacture of I-beams. A method of drying elements of an angular cross section in convection chambers of periodic action is considered. Samples were made in which the change in the angles of the inner quarter was measured. Samples were dried to a moisture content of 6 ± 2%. During drying, the samples were fixed in pairs using clamps (clamps). It is established that the deviation of the angles of the side of the quarter of the bar of the angular cross section increases with increasing size of the quarter. The transverse warping of the pressed samples is much less than that of the samples without pressure. The optimal size of the core (core) rot should be 30-35% of the diameter of the round assortment at the top. Such rot sizes at the corresponding quarter sizes do not lead to significant allowances for machining and loss of volumes of high-quality structural wood.

1. Introduction

Currently, construction lumber is widely used in construction. This lumber is used in the manufacture of elements of load-bearing building structures for industrial, agricultural construction and low-rise housing construction. For the manufacture of structural elements, softwood, usually pine or spruce, is used.

Recently, however, environmental degradation has been occurring, which affects, among other things, forest areas. Increasingly, in the trunks of conifers there is core (central) rot [1]. The presence of sound rot in lumber for the manufacture of elements of load-bearing building structures is not allowed, therefore, the technological process of cutting tree trunks with rot into sawing logs involves the removal of sections of the trunk with rot. Sound rot primarily affects the part of the trunk located near the root system, and this section of the trunk has the largest diameter. In this part of the tree trunk, in addition to the presence of rot, there is a significant amount of sapwood with high strength characteristics.

Typically, the removal of rot occurs at the stage of harvesting round timber. At the same time, a healthy sapwood is removed together with the wood affected by rot. As a result, a large amount of quality wood remains in the forest. This leads not only to loss of harvested wood. In addition, wood left in the forest leads to the formation of sound rot in growing trees. The rot remaining in the sawn timber assortment supplied to the sawmills is removed in the process of cutting and obtaining sawn timber. The use of existing cutting schemes for sawing assortments with sound rot results in large losses of wood [2]. Recently, technological processes have been developed for the efficient cutting of assortments with the presence of rot. This is a method which consists in the following. Preliminary longitudinal sawing of short round timber is carried out. Perform one or more longitudinal cuts. From the parts of timber obtained after sawing, the core layer is removed, according to the dimensions of the voids formed in these parts, connecting blanks are made of wood. After drying, long timber is formed from the obtained parts of timber and connecting blanks, while the ends of the contact of

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parts of the wood are displaced one relative to the other along the length of the formed timber [3]. In addition, there is a technological process to produce glued beams from elements of angular cross-section [4]. However, the proposed methods do not provide for lumber for construction purposes for construction.

We have a fundamentally new way of obtaining elements of building structures from round timber with sound rot. Production is carried out according to the following scheme. Cutting is done according to the timber scheme. On the first pass, a two-edged beam with core rot and lateral unedged thin lumber are obtained. On the second pass, two bars with core rot, as well as side unedged lumber, are obtained. Then, rot is removed by milling. After milling, the bars have a corner profile. The casts of the angle profile are subjected to chamber drying with mild regimes and their moisture content is adjusted to 14±2%. The bars are sorted so that the quality of the wood corresponds to grade 2 according to GOST 8486, which roughly corresponds to C24 strength class according to European standard EN 338-2011 “Structural wood. Strength classes”. The bars are glued in such a way as to obtain an I-beam. The priority for this method is fixed by the patent for the invention of the Russian Federation [5].

I-beams made of wood are currently widely used in the construction of buildings and structures. Modern construction experience shows the feasibility of using I-beams for flights from 2 to 6 m [6]. High installation speed and ease of assembly increase the manufacturability of the construction of buildings and structures [7-14]. After processing with special compounds, the wood of the beams has the necessary fire resistance, anti-decay and insect damage. There is a great need for such beams in seismically dangerous areas of construction.

Sawing round timber with sound rot and manufacturing lumber for load-bearing building structures reduces the amount of wood with rot left in the forest. This helps to improve the environmental situation. Therefore, structural lumber obtained from such timber will be hereinafter referred to as ecological structural lumber.

The greatest difficulty in applying this method is the drying of the corner elements to operational humidity. Drying is accompanied by lateral warping, which increases the loss of wood during further processing. The warping of lumber in the transverse direction has been an object of research for a long time. As early as 1878, P.A. Afanasyev [15] in his work describes the possible types of contortion, the reasons for its appearance and factors affecting the decrease in its size. He proposed a formula for calculating the maximum deflection boom for lateral warping of lumber:

$$f_{\max} = \frac{\pi}{2}\left(W_{п.н} - W_{к}\right)\left(K_t - K_r\right)\frac{B}{2}, mm \tag{1}$$

where W_s is saturation limit of wood cell walls, %; W_f is final wood moisture, %; K_t , K_r are tangential and radial shrinkage coefficients; B is lumber width, mm.

The maximum deflection arrow will be at the board, on the lower face of which there is a core. That is, the deflection will be the greater, the closer the sawn boards are located closer to the core of the round assortment. From equation (1) it follows that all boards, except for radial ones, after drying will have a grooved shape.

In 1971, G.G. Petrukhin obtained an approximate solution to the problem of structural warping of the cross section of lumber [16]. The solution was obtained on the basis of the provisions of the theory of deformations and the theory of elasticity. The author believes that the solutions to this problem obtained earlier by P.A. Afanasyev, K.I. Kolenchuk, V.A. Shevchenko, M.N. Feller and the solutions contain several incorrect assumptions and give various numerical results. He obtained equations for determining the cross-sectional shape of warped boards:

$$u = -\Delta W\left[K_r x - \left(K_r - K_t\right) y \cdot arctg\left(\frac{x}{y}\right)\right], mm \tag{2}$$

$$\upsilon = -\Delta W\left[K_r y - \left(K_r - K_t\right) x \cdot arctg\left(\frac{x}{y}\right)\right], mm \tag{3}$$

where u, v are components of the movement of the points of the cross section of the assortment after drying, mm; x, y are coordinates of points before drying, mm; K_r , K_t are radial and tangential shrinkage coefficients; $\Delta W = W_{s.} - W_f$ is moisture difference between the saturation limit of the cell walls of wood and the final humidity (hygroscopic humidity), %.

Formulas (2) and (3) are obtained in a rectangular coordinate system x, y with the beginning in the center of the cross section of a round assortment.

It is known that the main cause of warpage of lumber is the anisotropy of shrinkage due to the anisotropy of the elastic characteristics of wood. Anisotropies of the elasticity characteristics of wood are considered in detail in the works of E.K. Ashkenazi [17] and N.L. Leontyev [18] and others. In particular, E.K. Ashkenazi considers wood as an orthotropic material (Fig. 1).

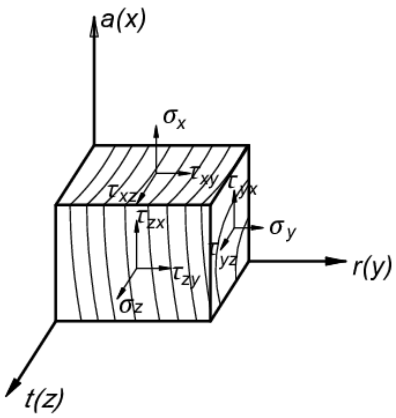

Figure 1. The stress state of the triaxial equal compression hydrostatic pressure.

The magnitude of the deformation depends not only on the magnitude of the acting stresses, but also on the direction of their action in the material. The author presents Hooke's law at first in the case of a triaxial stress state, i.e., stress and strain components are assigned to some Cartesian coordinate axes x, y, z and the elastic properties are determined by the characteristics of the elastic modulus E, transverse strain coefficient μ and shear modulus G. Then, if Cartesian coordinates with the directions of the axes of symmetry. Then the quantities E, μ, G have their own meaning for each direction in the material, which is expressed in the formula 4:

$$\begin{aligned} \varepsilon_x &= \frac{\sigma_x}{E_x} - \frac{\mu\sigma_y}{E_y} - \frac{\mu\sigma_z}{E_z} \\ \varepsilon_y &= -\frac{\mu\sigma_x}{E_x} + \frac{\sigma_y}{E_y} - \frac{\mu\sigma_z}{E_z} \\ \varepsilon_z &= -\frac{\mu\sigma_x}{E_x} - \frac{\mu\sigma_y}{E_y} + \frac{\sigma_z}{E_z} \\ \gamma_{xy} &= \frac{\tau_{xy}}{G}; \gamma_{yz} = \frac{\tau_{yz}}{G}; \gamma_{xy} = \frac{\tau_{zx}}{G} \end{aligned} \quad (4)$$

where τ is shear stress applicable on the sites, MPa; γ is angular deformations.

It was noted that the formulas indicate experimentally established features of the elastic deformation of anisotropic bodies. This fact will have a negative value in the future. The full set of characteristics of the elastic deformation of an orthotropic material consists of nine independent quantities (elastic constants). These include lateral strain coefficients, shear moduli, and elastic modulus when the coordinate system rotates through an angle of 45° around z axis. The author took the advantage of the rotation of the system at an angle of 45° alternately around each of the axes. This is necessary to obtain equations that calculate the elastic constants.

A significant amount of research on solving the issues of transverse warping was performed by Professor of Saint Petersburg University of Architecture and Civil Engineering V.N. Glukhikh. In [19] V.N. Glukhikh believes that the formulas for calculating the elastic constants are difficult due to the use of a number of experimentally determined quantities. It is known that the elastic deformation of wood is characterized by the reciprocal of the elastic modulus and varies depending on the angle of inclination of the annual layer to the face. The author suggests determining E_{xy}^{45} elastic modulus theoretically and believes that this would greatly simplify the task of studying the deformability of wood across the fibers. The author concludes that "E_{xy}^{45} modulus is equal to the elastic modulus in the tangential direction". Or in other words, at an annual layer inclination angle of 45°, the elastic modulus in the direction of x axis is equal to the elastic modulus in the tangential direction. To study the deformability of lumber, he suggests using the function:

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_r} + \frac{\sin^4\theta}{E_t} + \frac{3-a^2}{E_t}\sin^2\theta \cdot \sin^2\theta \quad (5)$$

where $a^2 = \frac{E_t}{E_r}$; θ is annual ring slope; E_r, E_t are modulus of elasticity of wood in the radial and tangential directions, GPa.

For convenience, expression (4) is written in Cartesian coordinates:

$$\frac{1}{E_x} = \frac{a^2x^4 + \left(3-a^2\right)x^2y^2 + y^4}{E_t\left(x^2+y^2\right)^2} \quad (6)$$

The results of calculations by formula (5) show that for boards with a symmetry axis of the cross section coinciding with *Y* axis (Fig. 2), the least deformability takes place in the middle of the face width. From the middle to the edges of the face, the deformability increases, reaches its maximum value, and then decreases, tending in the limit to the reciprocal of the elastic modulus in the radial direction.

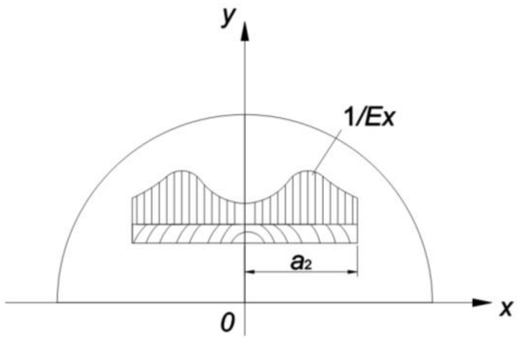

Figure 2. Deformability along the width of the boards of a semi-radial cut:
1/Ex is change in the value of deformability along the width of the board;
a_2 is half the width of the board, mm.

The work also noted that “deformability of the radial boards along the width of the face changes imperceptibly, excluding a narrow local area adjacent to the middle of the width of the board”. For tangential boards, the deformability along the face also changes imperceptibly. According to the seam of semi-radial boards, the deformability varies from the smallest values along the edges to the maximum value in the middle.

This, as well as a slightly higher tensile strength in the radial direction compared with the tangential, ensures the absence of reservoir cracks during drying. The aim of this study is to develop a methodology for compiling individual patterns for cutting round timber into sawn timber, which excludes the negative influence of the anisotropy factor of wood during subsequent drying. The methodology for determining the greatest deformability of the board in cross section allows you to analyze any pattern of cutting logs. In [20] V.N. Glukhikh concludes that warping can be reduced by rationally sawing logs, since the deflection arrow in lateral warping depends on the size of the sawn timber, the anisotropy of drying, and the moisture content of the wood. In another work [12] V.N. Glukhikh gives a theoretical calculation and diagrams for determining the favorable sizes of lumber and their location in the section of sawing logs. Based on the calculations, an analysis is made of the options for cutting logs in which the quality of lumber does not suffer during drying.

Later studies [21, 22] showed that lateral warping is influenced not only by the width, but also the thickness of the lumber. A formula was obtained for calculating the magnitude of the transverse warpage, provided that the moisture distribution over the board section was evenly distributed (final drying period):

$$b_k = \frac{b^2\Delta W\left(\alpha_2-\alpha_1\right)}{4S}, mm \quad (7)$$

where b is board width, mm; S is board thickness, mm; ΔW is difference between the hygroscopicity limit and final moisture content of wood during drying,%; α_1, α_2 are shrinkage coefficients of the inner and outer faces of the board.

Summarizing the results of the research, the following conclusions can be drawn. The resistance of lumber to warping increases in proportion to the square of their thickness, depends linearly on the difference in the coefficients of drying of the layers and is in a complex dependence on their width. The farther the board is cut from the center of the round assortment, the less its warpage.

Studies [23–25] showed that warpage of lumber during drying can be prevented in whole or in part using special clamps and preset pressure forces. Elastic warping of pressed boards is insignificant compared to warping of dried boards without pressing. In addition, warpage can be reduced by final heat and moisture treatment, as well as the use of high temperatures at the end of drying.

However, it should be noted that in all the above studies, a rectangular cross-section of lumber was considered. There are practically no studies of lateral warping. Therefore, conducting research on the drying of bars of a corner profile is an urgent task.

The objective of this work is to study the possibility of drying wooden corner elements for the manufacture of I-beams of supporting building structures. To achieve the goal, it is necessary to solve the following tasks: determine the amount of transverse warping of corner elements and develop measures to reduce the amount of wood loss during further processing of these elements.

2. Methods

Samples cut from corner elements were selected as the object under study. The breed of wood is pine. Corner elements were made as follows. Initially, four-edged timber with a cross-sectional size of 160×160 mm was cut from round assortments with sound rot with a diameter of at least 190 mm. Then, by longitudinal cutting, four bars were obtained with the presence of rot. Overall dimensions of bars 75×75 mm. By milling, rot was removed from these bars. The length of the samples is 550 mm (Fig.3). The smallest diameter of round timber with sound rot, from which corner elements are obtained, is 200 mm. “Hydromette compact” electric moisture meter was used to measure the wood moisture content of the samples. Range of measurement of humidity is 5–20 %. To change the angles, a quadrant goniometer was used to measure internal and external angles from 0 to 180 °C. G type clamps of 125 mm were used to provide pressure.

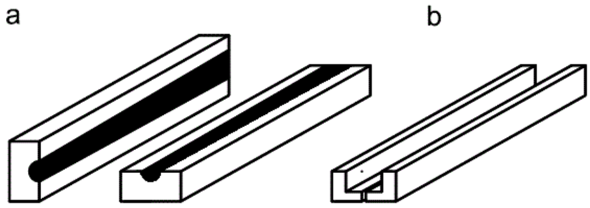

Figure 3. Corner profile elements production flow
a – bars with core rot; b – bars of the corner profile after removal of rot.

All bars are conditionally divided into three groups, each of which has its own quarter size: b_1 = 20 mm; b_2 = 30 mm; b_3 = 37 mm. The dimensions of the quarter corner elements are set depending on the diameter of the rot in round assortments. Determination of the moisture content of the wood samples before drying was carried out using an electric moisture meter. Measurements were taken every 15 cm of the sample length. Drying was carried out using clamps (clamps). Samples were fixed in pairs, or a bar was placed in a quarter (Fig. 4). One group of samples, also with a quarter size b_4 = 37 mm, was dried without the use of a clamp.

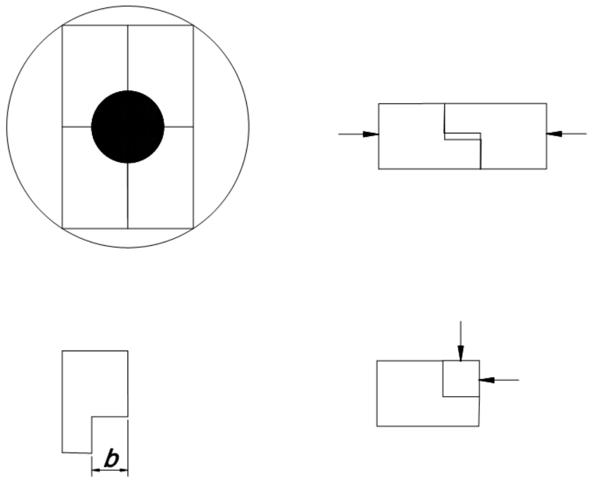

Figure 4. Schemes for fixing the bars during drying:
***b* is the width of the selected quarter along which the corners are folded when pressing.**

Samples were in the upper rows of lumber stacks. Forced drying mode. The temperature of the drying agent is 90 °C. This mode allows you to determine the maximum values of the angle and the size of the allowances.

Based on the conclusions given in the first section, we can assume that in the process of drying the shape of the bar will change as follows (Fig.5).

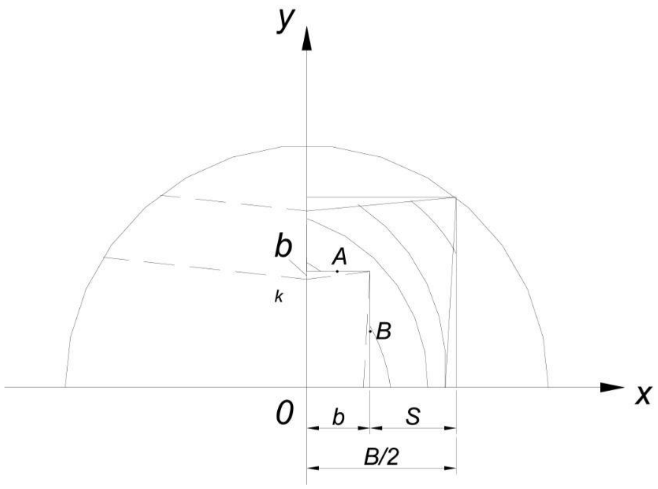

Figure 5. Changing the cross-sectional shape of the corner element during drying:
A is narrow surface of the selected quarter; B is wide surface of the selected quarter;
B/2 is the total width of the corner profile bar, mm;
S is the width of the integral part of the angle bar, mm;
b is width of the selected quarter, mm; b_k is bending value, mm.

The section of the bar is divided into two rectangles, which are a continuation of the boards conditionally sawn from a round assortment. To calculate the magnitude of the transverse warpage, we use the formula (7). Consider the deformation of the cross section of the corner element as semi-radial boards. Therefore, the maximum strain may be at points A and B.

After drying was completed, exposure was carried out in the workshop at an air temperature of 18 °C for 30 minutes. Clamps were not removed. Measurement of wood moisture after drying was carried out similarly to measurements before drying.

Next, measurements were made of the angle of the quarter. Measurements were carried out with a goniometer-quadrant at five points.

During the study, the following tasks.

1. To establish the dependence of the deviation of the angle of the inner quarter of the element from its original position.

2. To determine the allowances for the processing of the corner element at different percentages of rot in round assortments.

3. To identify the difference in the values of the deviations of the angle of the inner quarter during drying with and without pressure.

4. To establish the validity of the assumption that during drying it will look as shown in Fig. 5.

5. The experimental plan is presented in Table. 1.

Table 1. The plan of the experiment.

Experiment number	Drying method	Width b, mm
1		20
2	With pressure	30
3		37
4	Without pressure	37

Based on the results of measurements of the deviations of the angle of the quarter of the sample, a statistical analysis of the deviations of the angle of the sides of the quarter from straightness was performed. According to the statistics obtained, we found the minimum number of measurements for the necessary security of the arithmetic mean of the deviations. Next, we found the regression equation for the change in the deviation of the quarter angle depending on its width. The equation is obtained as a result of a multivariate experiment. The output parameter is the deviation of the quarter angle of the corner element. The output parameter is influenced by the wood species, the location of the element in the round assortment, the direction of the annual rings, the age of the tree, the presence of defects, the shape of the blanks, the conditions and place of growth, the anatomical structure of the wood, the percentage of moisture in the wood, the nature of the treatment, the mode and technology of drying, the condition inter-row gaskets and the location in the stack. Controllable factors: quarter size b_1 = 20 mm; b_2 = 30 mm; b_3 = 37 mm, drying method (with or without pressure). Factors with a constant value: drying mode and temperature of the drying agent, the direction of the annual rings, the shape of the blanks. Disturbing factors that are not controlled: presence of defects, age and anatomical features of wood, percentage of wood moisture. Checked the adequacy of the mathematical model.

3. Results and Discussion

Before drying, the moisture content of the wood samples was changed. The results of changes in wood moisture are given in Table. 2.

Table 2. Moisture values of wood samples before drying.

Sample number	Quarter size, b, mm	Sample condition	Number of humidity measurements, W, %				Average sample humidity, W, %
			1	2	3	4	
1			17.2	17.3	18.4	19.2	18.02
2			16.4	18.3	15.6	17.1	16.85
3		fixed	17.3	18.6	17.8	16.2	17.47
4	20		15.8	16.5	18.7	18.4	17.35
5			18.4	17.3	16.3	17.7	17.42
6			19.3	18.6	18.2	17.3	18.35
7			16.5	17.3	18.7	15.6	17.02
8			16.8	16.3	17.1	16.3	16.62
9			16.7	17.1	17.0	16.8	16.90
10			14.5	14.8	16.3	15.2	15.20
11		fixed	15.2	17.5	16.4	15.8	16.22
12	30		14.8	15.3	17.1	16.6	15.95
13			16.7	17.1	17.0	16.8	16.90
14			14.5	15.7	17.4	15.2	15.70
15			15.2	17.5	17.5	15.8	16.50
16			16.3	15.3	17.1	16.7	16.30
17			19.3	22.5	21.4	20.2	20.85
18			19.1	20.4	21.3	21.6	20.60
19		fixed	19.3	21.3	20.3	19.7	20.15
20	37		18.3	21.8	22.2	19.8	20.52
21			19.3	23.4	21.4	20.7	21.20
22			20.6	20.4	21.3	21.6	20.97
23			18.8	22.5	22.6	20.2	21.02
24			21.3	20.4	23.6	21.6	21.72
25			17.2	22.5	23.2	20.4	20.83
26			17.4	19.6	23.2	21.1	20.35
27		not fixed	18.3	22.3	24.5	19.7	21.20
28	37		19.5	18.5	22.4	22.4	20.70
29			16.8	23.1	23.2	19.7	20.70
30			17.6	19.6	21.9	20.3	19.85
31			18.1	22.8	22.7	20.7	19.85
32			16.5	19.6	22.1	21.2	21.07

Analysis of the moisture content of the wood samples before drying shows that the moisture content of the wood is in the range from 15.2 to 21.7%. This humidity is pre-matured indoors wood.

Next, the samples of the angle profile were dried. The results of measurements of wood moisture after drying are given in table. 3. The moisture parameters of wood correspond to the results of studies in publications [26–33].

Table 3. Moisture values of wood samples after drying.

Sample number	Quarter size, b, mm	Sample condition	Number of humidity measurements, W, %				Average sample humidity, W, %
			1	2	3	4	
1			5.3	5.1	5.8	6.2	5.60
2			8.5	8.3	9.2	8.8	8.70
3		fixed	6.2	5.3	6.2	5.8	5.80
4	20		6.7	4.8	5.5	6.6	5.90
5			8.3	8.3	9.6	7.8	8.20
6			5.3	5.3	6.2	5.8	5.70
7			3.3	5.3	6.7	5.3	5.60
8			4.9	4.9	5.8	6.2	5.80
9			5.2	5.0	5.3	5.3	5.25
10			5.5	5.3	5.8	5.8	5.72
11		fixed	6.1	5.0	5.3	5.3	5.47
12	30		5.5	5.3	6.1	6.1	5.80
13			5.3	5.3	5.8	5.8	5.80
14			5.2	4.9	5.3	5.3	5.20
15			5.0	5.1	6.1	6.1	5.60
16			5.5	5.6	5.6	5.6	5.70
17			5.3	5.3	5.5	6.0	5.50
18			4.8	6.0	6.5	6.3	5.80
19		fixed	5.6	5.3	5.5	5.8	5.50
20	37		6.5	7.2	6.2	6.5	5.60
21			5.6	5.3	5.5	5.8	5.50
22			6.1	7.5	8.2	6.1	6.90
23			5.7	6.0	6.6	5.7	5.90
24			5.6	5.3	5.5	6.0	5.60
25			4.9	5.2	5.1	5.0	5.05
26			5.5	5.7	5.6	5.5	5.60
27		not fixed	6.0	5.5	5.2	5.8	5.60
28	37		5.5	7.5	5.3	6.3	6.10
29			7.2	5.3	5.0	5.3	5.70
30			6.3	6.3	5.6	7.1	6.20
31			5.7	8.3	5.1	6.5	6.20
32			6.1	4.6	5.2	5.2	6.40

The moisture content of the wood samples after drying is in the range of 6±2 %. To determine the boundaries of the values of the deviations of the angle of the sides of the quarter for such a value of the final moisture content of the wood, we performed an estimated calculation of these values by the formula (5).

The final moisture content of the wood samples was taken equal to 6%. Wood density of the samples is 400 kg/m^3. The coefficient of radial shrinkage was calculated by the formula: $K_r = 0.01\rho/W_s = 0.01$ 400/30 = 0.13. Tangential shrinkage coefficient: $K_t = 0.018\rho/W_s = 0.018$ 400/30 = 0.24.

We have obtained value $\alpha_2 - \alpha_1$ at b = 20 mm:

$$\alpha_1 = \frac{2{\cdot}0.11}{150}\left(75{\cdot}arctg\frac{150}{2{\cdot}75} - 20{\cdot}arctg\frac{150}{2{\cdot}20}\right) = 0.048,$$

then bending value will make:

$$b_k = \frac{b^2 \Delta W\left(\alpha_2 - \alpha_1\right)}{4S} = \frac{150^2{\cdot}0.24{\cdot}0.048}{4{\cdot}55} = 1.18, mm.$$

We have obtained value $\alpha_2 - \alpha_1$ at b = 30 mm:

$$\alpha_2 - \alpha_1 = \frac{2 \cdot 0.11}{150}\left(75 \cdot arctg\frac{150}{2 \cdot 75} - 30 \cdot arctg\frac{150}{2 \cdot 30}\right) = 0.034,$$

then bending value will make:

$$b_k = \frac{b^2 \Delta W(\alpha_2 - \alpha_1)}{4S} = \frac{150^2 \cdot 0.24 \cdot 0.034}{4 \cdot 55} = 1.02, mm.$$

We have obtained value $\alpha_2 - \alpha_1$ at b = 37 mm:

$$\alpha_2 - \alpha_1 = \frac{2 \cdot 0.11}{150}\left(75 \cdot arctg\frac{150}{2 \cdot 75} - 37 \cdot arctg\frac{150}{2 \cdot 37}\right) = 0.024,$$

then bending value will make:

$$b_k = \frac{b^2 \Delta W(\alpha_2 - \alpha_1)}{4S} = \frac{150^2 \cdot 0.24 \cdot 0.024}{4 \cdot 55} = 0.87, mm.$$

The calculations show that the magnitude of the transverse warpage will have a value of about one millimeter.

The required number of measurements was determined. In the calculation, the data of the fourth experiment were used, since the largest value of the mean square deviation is observed there. The formula for finding the minimum number of measurements:

$$n_{\min} = \left(\frac{t \cdot S}{\Delta}\right)^2, \quad (8)$$

where S is mean-square deviation; t is Student criterion; Δ is set confidence probability.

With a confidence probability of 0.95, the number of samples will be 7.35. We accept 8 samples for each experiment.

Further, for each sample, the angle of deviation of the sides of the quarter from the right angle was measured after drying. We performed a statistical analysis of the angle deviation for samples of each quarter size and the state of the sample during drying (with fixation and without fixation). In addition, the necessary allowance was calculated to straighten one side of a quarter of the sample after drying. Statistical indicators are given in Table. 4.

Table 4. Statistical indicators of the deviation of the angle of the sides of the quarter of the samples.

Sample number	Quarter size, b, mm	Sample condition	Statistics						
			$\hat{Y}$, degrees	S, degrees	v, %	S_y, degrees	ξ	S_s	K, mm
1	20	fixed	1.25	0.43	34.40	0.15	12.24	0.108	0.6
2	30		2.37	0.48	20.25	0.17	7.20	0.120	1.0
3	37		3.25	0.43	13.23	0.15.	4.70	0.108	1.6
4	37	not fixed	4.87	0.59	12.29	0.21	4.34	0.140	2.5

Designation: $\hat{Y}$ is arithmetic mean of the angle deviation; S is mean square deviation; v is variation coefficient; S_y is arithmetic mean error; ξ is arithmetic mean accuracy indicator; S_s is standard deviation error; K *is* the amount of machining allowance on one side of the quarter.

The required prerequisites for statistical analysis are the normality of the distribution of the output value and the homogeneity of the variances of the experiments. The homogeneity of the dispersions of the experiments was checked with uniform duplication by G is Cochren criterion. For this, the calculated G_{calc} is ratio was calculated by the formula:

$$G_{calc} = \frac{s_{\max}^2}{s_1^2 + s_2^2 + \ldots + s_N^2}, \quad (9)$$

Where $s_1^2, s_2^2, \ldots s_N^2$ are variance of experimental values 1, 2, N; $s_{\max}^2$ is maximum dispersion value.

According to the selected level of significance, the number of degrees of freedom and the number of experiments, we obtain the value G_{tab}. If $G_{calc} < G_{tab}$, then the hypothesis of homogeneity of variances is accepted.

Check the adequacy of the regression model. Checking the adequacy of the mathematical model answers the question of whether the constructed model of the output quantity with sufficient accuracy.

Let N be the number of series of parallel experiments, n is the number of duplicated experiments in every series, p is the number of estimated regression coefficients of the mathematical model. We have determined the sum of the squares characterizing the adequacy of the model S_{ad}. With uniform duplication, we calculate it by the formula:

$$S_{ad} = n\sum_{j=1}^{N}\left(y_i - y_j\right)^2, \tag{10}$$

where $\hat{y}_j$ is average value of experimental results in the j-th series of duplicated experiments; j = 1, 2,… N; $\hat{y}_i$ value of the output value calculated by the regression equation for the i-th main experiment.

After the calculations, we obtained S_{ad} = 0.42. We calculated the value of $\underline{F}$ - Fisher criterion and compared it with the table value. Its value is 1.62. We compare the calculated $\underline{F_{calc}}$ and tabular $\underline{F_{tab}}$ of the value of Fisher criterion. The calculated value should not exceed the table value. $\underline{F_{calc.} < F_{tab}}$ 1.62 <4.32. Thus, we proved that the chosen mathematical model is adequate to the experimentally obtained values.

Based on the data obtained, a point graph, a trend, and a model corresponding to the trend were constructed. A graph of the deviation of the angle of the sides of the quarter element for different sizes of the quarter is shown in Fig. 6. The dependence of the deviation of the angle of the inner quarter, depending on its width, is described by a regression equation of the form:

$$y = 0.043x^2 - 0.1013x + 1.57 \tag{11}$$

$$R^2 = 1$$

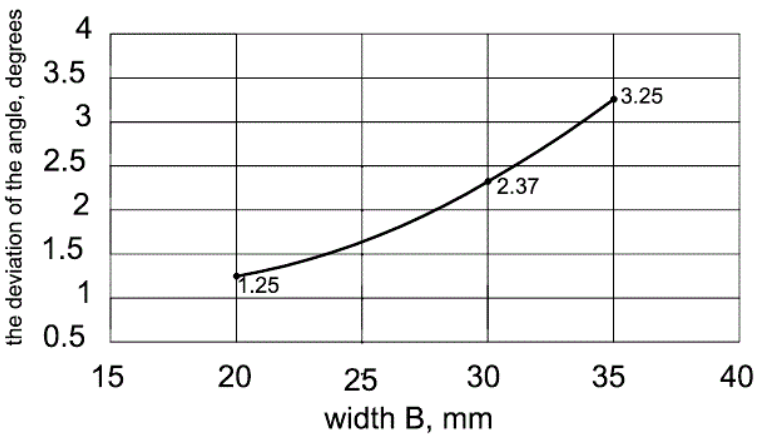

Figure 6. Diagram of the deviation of the angle of the side of the quarter from its width B is quarter width, mm.

The values of the discrepancies in the calculation results of the deviation of the angle of the sides of the quarter of the element from straightness for different sizes of the quarters obtained theoretically and experimentally are given in Table 5.

Table 5. The values of the discrepancy in the results of calculations of the deviation of the angle of the sides of the quarter from straightness.

Central rot content, %	Quarter side size, b, mm	S, mm	B, mm	b_k, mm	K, mm	Difference between K and b_k, %
21	20	55	150	1.18	0.6	96.9
31	30	45	150	1.02	1.0	2.0
38	37	37	150	0.87	1.6	84.0
38	37	37	150	0.87	2.5	187.0

Designation: S is the size of the remainder of the bar after removing the quarter; B is width of the sides of a four-edged bar; b_k is bending value; K is machining allowance.

Analysis of the data given in Table 5 and the research results [34, 35] shows that the formula for calculating the magnitude of the transverse warpage (5) in the case of drying samples of elements of the angular cross section is not applicable. The experimental data indicate completely different trends in the magnitude of the deflection and the deviations of the sides of the corner bar from straightness. The cross-sectional shape of the bar after drying is shown in Fig. 7.

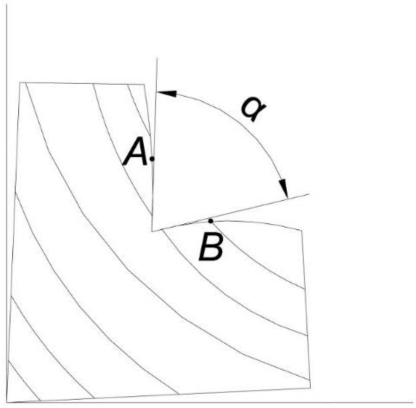

Figure 7. Cross-sectional shape of the bar after drying:
A and B - sides of the selected quarter; α - the angle between the sides of the quarter, deg.

The results of the studies show the absence of theoretical provisions for justifying the relationship between the deviation of the quarter side angle and various factors during drying, therefore, further studies are required for high-quality drying of the bars of the angular cross section.

4. Conclusion

Analyzing the results, we can draw the following conclusions:

1. The cross-sectional shape of the samples has changed as we expected.

2. It is impossible to consider a section of a bar of an angular cross section as two rectangles that are the continuation of the boards, conventionally cut from the round timber.

3. The calculation of the deviations of the angles of the side of the quarter bar of the corner cross-section by analogy with the calculation for calculating the amount of transverse warpage for boards will lead to incorrect results.

4. The amount of warping of the pressed samples is much smaller than that of the samples subjected to drying without pressing.

5. The allowances for the machining of dried non-pressed bars are significantly higher than for dried pressed bars.

6. The magnitude of the deviations of the angles of the side of the quarter of the bar of the angular cross section increases with increasing size of the quarter.

7. The angle of the quarter side after drying the bars with an angular cross-section deviates by 2–3° and is 92–93°.

8. The optimal size of the core (central) rot should be 30–35 % of the diameter of the round assortment at the top. Such rot sizes at the corresponding quarter sizes do not lead to significant machining allowances.

9. It is possible to dry wooden corner elements for the manufacture of beams of load-bearing building structures to operating humidity without significantly changing their shape.

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