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SHORT-TERM WOOD STRENGTH UNDER STRESS CONCENTRATION CONDITIONS

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A delay in relaxation of maximum stresses in the area of induced high-elasticity strain that manifests itself through the paradox phenomenon in the event of bending [4, 7] should be observed, as we previously believed [3], as a delayed rounding of the peaks and also under stress concentration conditions. The paradox phenomenon [3, 7] is expressed by absence of any increase in the ultimate breaking strength σ_{br} after exceeding a certain rate of load increase during the wood machine test. It is graphically demonstrated by the lg t – σ graph, which shows a deviation of test points *1* downward from the straight line *l* of creep rupture strength (Fig. 1, shown by arrows), which corresponds to slow loading and continuous load (in Fig. 1, t – time before rupture determined based on the duration of test t_1' with constant loading increase rate up to the moment of rupture [7]; σ – breaking stress during test with slowly increasing load (points *2*), or constant stress during long-time test (points *3*); σ, % of σ_{max}).

It is known that transcendence by the edge stress of the limit of induced high elasticity σ_{he} of wood [5] is followed by an intensive development, prior to rupture of the bending element, of nonlinear induced high-elasticity strain, the rate of which increases exponentially with stress. In the outermost compressed grains of the bending element, the rate of edge strain is determined by the elastic core in the remaining portion of the cross-section that restrains the development of induced high-elasticity strain, which causes relaxation of stresses in such grains (development of the incipient rupture fold in the grains causes the bending element to lose strength). During tests with high loading rates, researchers create conditions that delay the development of relaxation, which leads to a reduction in the time prior to development of the fold and subsequent rupture with a reduced value of σ_{br}, i.e., to the paradox phenomenon [4, 7].

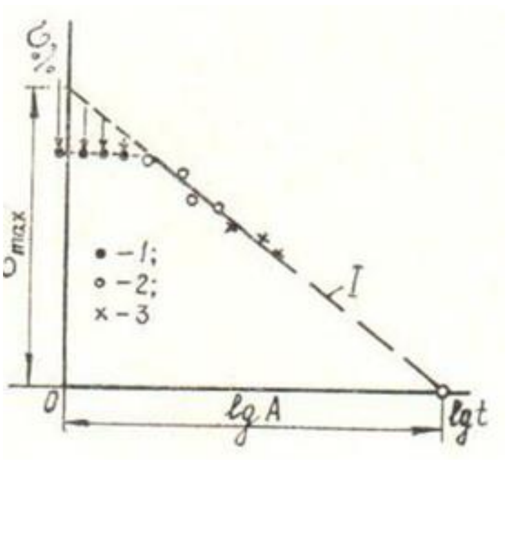

Fig. 1. Diagram showing the paradox of wood bending resistance: test points in the paradox zone (1); for slow loading (2); for long-time loading (3).

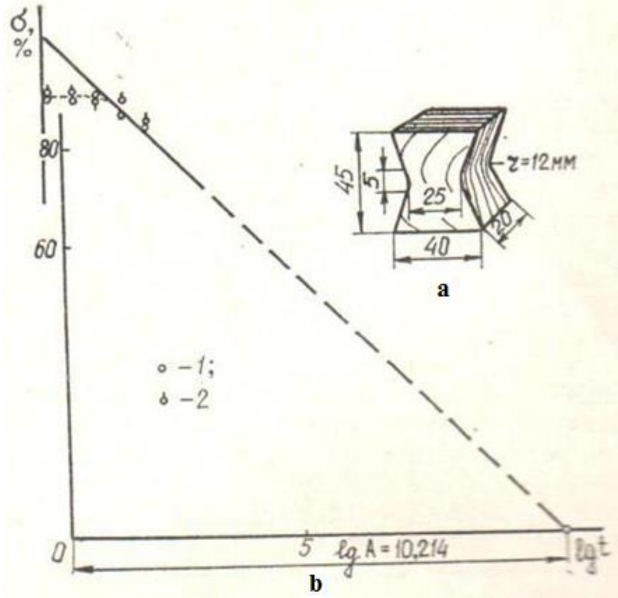

Fig. 2. Results of wood test by tension perpendicular to the wood grain with different loading rates: a – drawing of test specimen (sizes in mm); b – lg t – σ graph with test points for pine (1) and aspen (2).

To check the assumption in the event of stress concentration, the research team used the results of wood test by tension perpendicular to the wood grain performed with different loading rates (within the range of two orders of magnitude) by L.M. Perelygin [8] with wood specimens that had stress concentration in their smallest cross-section (in the place of rounding with 12 mm radius and 5 mm length [1], see Fig. 2,a).

Results of wood test by tension perpendicular to the wood grain with different loading rates

Wood species (moisture content, %)	Loading rate, MPa x min^{-1}	σ_{br}, %	$\lg_c t$	Statistical parameters for grouping of points, %				
				σ_0	R_{av}	S	m	$\pm a$
Pine	0.2	58.5	1.674					
(10.3)	0.6	90.6	1.178					
				101.38	10	3.23	0.65	1.27
Aspen	0.2	85.0	1.664					
(9.4)	0.6	87.9	1186					
	0	0	10.214					
Pine	2.0	90.6	0.654					
(10.3)	6.0	92.3	0.178					
	20.0	92.3	−0.343	91.83	8	2.54	0.51	1.00
Aspen	2.0	92.7	0.664					
(9.4)	6.0	90.7	0.189					
	20.0	92.1	−0.337					

Note: R_{av} – average sampling range; S – mean square deviation; m – error of S; a – confidence interval of variation for σ_0' and σ_0''; significance of difference between σ_0' and σ_0'' $t_{0.05}$ = 11.56 > 1.96.

The test subjects were specimens of pine and aspen wood, 25 specimens per point (see table above), at normal temperature. To build the graph as shown in Fig. 1, the values of σ_{br} were expressed as a percentage of σ_{max} intercepted on the vertical axis (for the series of tests with a given wood species) by the average straight line plotted on top of the points for slower loading, and on the axis of lg t with horizontal coordinate lg t = lg A. According to the kinetic concept of strength [2], lg A is determined for each solid body using the values of rupture activation energy U_0, kJ/mol, and the period of thermal oscillation of atoms τ_0, sec:

$$\lg A = \frac{U_0}{2.3RT} + \lg \tau_0, \quad (1)$$

where R – thermal motion characteristic (gas constant), kJ / (mol × degree);
T – experiment temperature, K.

The value of lg A for tension perpendicular to the wood grain was calculated by statistical manipulation of the results of gradual load tests in a wide range of duration of tests carried out in Canada [9]. Analysis of this data resulted in lg A = 10.214 for the tension perpendicular to the wood grain [6].

In an endeavour to increase the accuracy of the results, we can combine the test data for both wood species, because the values of σ_{br} are expressed as a percentage of their σ_{max}. Verification of the accuracy of deviation of σ_{br} test values downward from the straight line lg t (σ) (Fig. 1, b) was successful (see table above; the verification was performed using the same technique as that described in [7]).

Consequently, the assumption of influence of wood resistance paradox during tests of wood specimens with stress concentration at different loading rates has been confirmed. The empirical coefficient χ_e of stress concentration [3] depends on the loading rate (since deviations of σ_{br} downward from the straight line lg t (σ) increase as the loading rate grows), meaning that this coefficient, similar to the σ_{br}, is a time-response characteristic of strength. The average value of σ_{br} during standard tests corresponds to the average value of χ_e for such tests.

The paradox phenomenon identified for the nonhomogeneous state of stress (bending) of wood is thus also true for the conditions of stress concentration, specifically in the event of tension perpendicular to the wood grain, which is characterised by a smaller lg A value and a shorter time until rupture. Hence, this is a consistent phenomenon that is more general in nature because it is governed by the properties of nonlinear strain of the wood and is independent of the types of stress and structural directions. This phenomenon, which expressly manifests itself at high loading rates, also indicates that, under the conditions of long-time loading, relaxation of peak stresses develops most fully if it takes place concurrently with accumulation of bond ruptures.

The conclusions made by the authors can be of essential value to studies of wood strength under different scenarios of complex stressed state. When forecasting the long-term strength of wood for such scenarios, the initial data should be represented by the strength values found by tests of wood specimens outside the paradox influence zone (Fig. 1).

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