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EFFECT OF THE LOADING RATE, ANGLE OF ORIENTATION OF FIBERS, AND TEMPERATURE ON THE STRENGTH PROPERTIES OF BIRCH

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The present paper reports results of analysis of the strength and strain properties of birch wood at different loading rates, sample temperatures, and angles of orientation of fibers relative to the direction of loading. Dynamic tests ($v = 10$ m/sec) *with axial compression of the samples were conducted by the Kol'skii method on a setup with a Hopkinson compound rod. Noticeable dynamic strengthening of samples with angles of orientation of fibers* $\alpha = 0$ *and* 5° *was observed. At test temperatures* +65, +20, *and* −30°C, *the dynamic strength is higher than the quasistatic strength by approximately* 23, 31, *and* 42% *respectively.*

In engineering practice dealing with pulsed loads, dampers of shock loads have been widely used. They are most frequently used in transportation of freight of various types to decrease the effect of transportation loads, including loads leading to a failure. In most cases, the dampers are materials whose compression by tens of percent proceeds at a practically constant stress ($\sigma = \text{const}$). Such materials are, for example, low-density foam plastics and tubular (in axial compression) and perforated crushers made of metals [1–4]. By choosing a damper material, it is possible to vary the level of transmitted pressure from units (low-density foam plastic) to hundreds and thousands of megapascals (tubular and perforated crushers made of metals).

The deformation of wood under transverse compression is similar in character to the deformation of foam polystyrene [5, 6]. The availability of wood and the great variety of wood species with considerably different mechanical properties make wood an attractive material for use as a damper of shock loads.

Cylindrical test samples (diameter and height 25 mm) having different orientation of their axes relative to the fibers were manufactured from the central board of a birch (Volgo–Vyatskii region). In order that the moisture content of the wood be constant (6–7%), the dried samples were hermetically packaged in a thin (0.02 mm) polyethylene film, in which they were then tested. The initial density of the samples ρ_s varied from 540 to 710 kg/m^3.

Dynamic tests of samples ($v = 10$ m/sec) under uniaxial compression were conducted by the Kol'skii method on a setup with a Hopkinson compound rod [7]. A diagram of the measuring test complex is shown in Fig. 1. A loading pulse of a nearly rectangular shape with an amplitude of $0.2 \cdot 10^6$ N and duration of 200 μsec was generated by an explosive loading device, which contains charge 4 of a liquid explosive (LE) with a mass of 0.75 g, a damping system (steel impactor 5 and perforated crusher 6), and massive supporting disk 2. Explosion was localized in protective reinforced chamber 1. Initiation of the LE charge was performed by spark discharger 3 to which a high-voltage pulse from explosive setup 13 was supplied [8].

In tests at lower (−30°C) and elevated (+65°C) temperatures, samples 11 were previously held at the required temperature in thermostat 10. The time of holding the samples in the thermostat was not less than 1 h to equalize the temperature over the volume. The signal from strain gauges 9 was recorded by strain station

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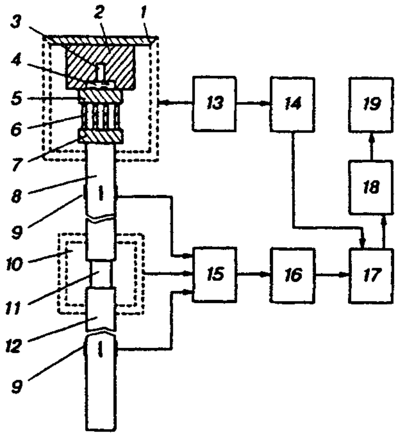

Fig. 1. Diagram of the measuring test complex: 1) protective reinforced chamber; 2) massive support; 3) spark discharger; 4) liquid explosive charge; 5) steel impactor; 6) aluminum perfocrusher; 7) disk adapter; 8) loading rod; 9) strain gauges; 10) thermostat; 11) test sample; 12) bearing rod; 13) high-voltage plant; 14) synchronizer; 15) strain station; 16) amplifier; 17) digital recorder; 18) personal computer; 19) printer.

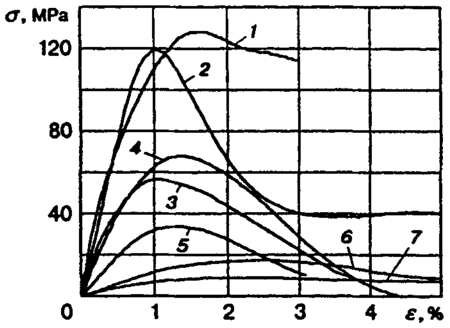

Fig. 2

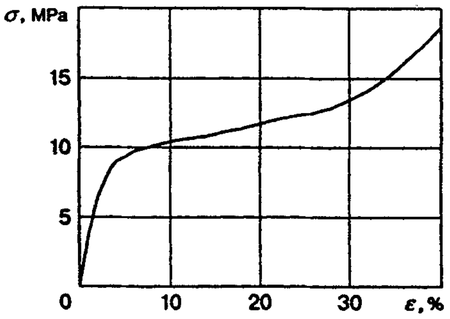

Fig. 3

Fig. 2. Dynamic σ–ε curves of birch wood under uniaxial compression ($T = -30°$C): $\alpha = 0, 5, 10, 15, 30, 45$, and 90° (curves 1–7, respectively).

Fig. 3. Strain characteristics of birch wood under transverse compression ($\alpha = 90°$).

15 on digital recorder 17 made in the CAMAC system and controlled by personal computer 18. Information from the strain gauges was put onto a diskette for further processing.

In the experiments, we measured the strain of the first (loading) rod 8 $\varepsilon_1(t)$ under the action of the loading compression pulse and the strain of the second rod 12 $\varepsilon_2(t)$ under the action of the transmitted compression pulse. From the experimental dependences $\varepsilon_1(t)$ and $\varepsilon_2(t)$, we determined the stress in the sample versus time $\sigma_s(t) = \varepsilon_2(t) \cdot EF_r/F_s$, where F_r and F_s are the cross-sectional areas of the rod and sample, respectively, and the strain of the sample versus time $\varepsilon_s(t) = (2a/l) \int\limits_0^t [\varepsilon_1(t) - \varepsilon_2(t)]\, dt$, where a is the speed of propagation of elastic waves in the rod and l is the initial length of the sample. The rate of loading of the sample v was determined from the formula $v = \sigma_m/\rho a$, where ρ is the density of the rod material, $\sigma_m = \varepsilon_{1m}E$ is the maximum stress in the compression wave in the first rod (ε_{1m} is the maximum elastic strain and E is the elastic modulus of the rod material).

TABLE 1

α, deg	ρ_s, kg/m^3	σ_s, MPa	ε_s, %
	$T = -30$°C		
0	620 ± 10	88 ± 5	2.7
5	605 ± 35	85 ± 10	1.4
10	600 ± 20	65 ± 13	1.7
15	620 ± 50	71 ± 6	1.6
30	620 ± 15	38 ± 4	3.3
45	605 ± 15	24 ± 3	2.8
90	580 ± 15	12 ± 2	32
	$T = +20$°C		
0	635 ± 15	81 ± 3	2.1
5	595 ± 55	81 ± 10	1.6
10	610 ± 30	65 ± 8	2.8
15	625 ± 85	66 ± 8	3.4
30	620 ± 25	35 ± 5	4.2
45	610 ± 45	23 ± 4	4.6
90	595 ± 45	11 ± 1	41
	$T = +65$°C		
0	635 ± 15	86 ± 3	2.4
5	600 ± 30	78 ± 7	1.9
10	595 ± 15	58 ± 11	2.9
15	640 ± 60	74 ± 5	2.0
30	620 ± 15	35 ± 6	3.6
45	590 ± 15	16 ± 2	2.7
90	600 ± 30	10 ± 1	36

TABLE 2

α, deg	ρ_s, kg/m^3	σ_s, MPa	ε_s, %
	$T = -30$°C		
0	615 ± 5	128 ± 5	1.5 ± 0.3
5	598 ± 42	119 ± 26	1.1 ± 0.2
10	605 ± 5	57 ± 1	1.05 ± 0.50
15	618 ± 42	65 ± 7	1.50 ± 0.25
30	640 ± 10	34	1.5
45	640	17	2.6
90	590 ± 10	8	14 ± 2
	$T = +20$°C		
0	620 ± 10	105 ± 8	1.25 ± 0.05
5	610 ± 20	108 ± 1	1.4
10	610 ± 20	77 ± 31	1.05 ± 0.05
15	620 ± 40	81 ± 5	1.4
30	625 ± 15	35 ± 2	1.7
45	620	19 ± 1	2.0 ± 0.4
90	590	12	12
	$T = +65$°C		
0	620	104	1.6
5	580	94	1.8
10	600 ± 20	61 ± 17	1.55 ± 0.50
15	540	68	1.2
30	610	32	1.5
45	590	18	1.7
90	580	10	17

The maximum load σ_m of 225 ± 5 MPa was the same in every test by accurate weighting-out of the LE. Therefore, the loading rate was also kept constant and was equal to 10 m/sec.

Tests of samples under quasistatic loading ($v = 10^{-4}$ m/sec) were performed on an R-5 installation using thermostats to maintain the required temperature. Results of the quasistatic and dynamic tests are given in Tables 1 and 2, respectively.

Curves of σ–ε obtained in dynamic tests of samples are shown in Fig. 2. The strain curves of the samples at +20 and +65°C are similar. The main difference of the dynamic curves from the quasistatic curves is the smaller (1.5–2 times) value of strain at which failure of the samples begins irrespective of the test temperature.

Under dynamic and quasistatic loading, the transverse compression of the samples ($\alpha = 90°$) proceeds at practically constant stress to considerable strains (30–40%). The σ–ε curve of the samples under transverse compression (Fig. 3) is very similar to the compression curve of low-density foam polystyrene PS-1 ($\rho \sim 300$ kg/m^3) [2].

The effect of the angle of orientation α on the strength of the samples for three temperatures and two loading rates is shown in Fig. 4. As the angle α increases, the strength of the wood decreases rapidly: it is maximal for longitudinal compression ($\alpha = 0$) and minimal for transverse compression ($\alpha = 90°$). The ratio of the limiting values for them is about ten. At the same time, the work expended on the deformation of the samples to failure is almost the same for longitudinal and transverse compression.

The fracture characteristics of the samples depend on the angle of orientation of the fibers: for $\alpha = 0$, 5, 10, and 15°, splitting of the samples takes place, and for $\alpha = 30$ and 45° the samples undergo spallation.

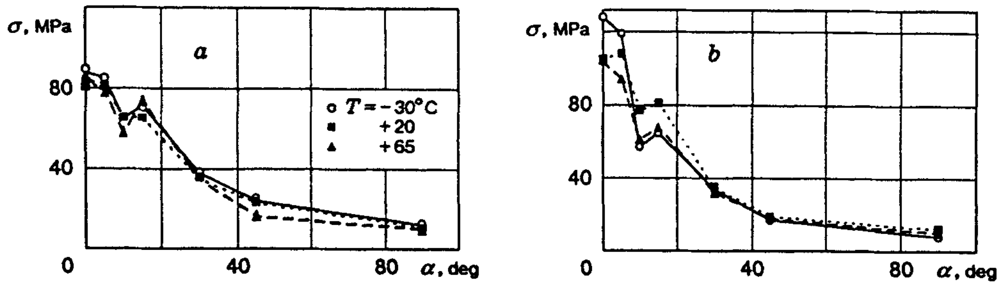

Fig. 4. Strength of birch wood versus the angle of orientation of fibers and temperature: $v = 10^{-4}$ (a) and 10 m/sec (b).

In transverse compression to $\varepsilon \approx 50\%$, only compaction of the samples occurs.

The effect of the test temperature (from −30 to +65°C) on the strain and strength characteristics of the samples ($\alpha = 0, 5, 10, 15, 30, 45$, and $90°$) under quasistatic loading is not observed, unlike in [9, 10], where an increase in temperature is shown to cause a decrease in strength, the effect being more pronounced with increase in the moisture content. In dynamic loading at a temperature of −30°C, the strength of the samples ($\alpha = 0$ and $5°$) exceeds by 10–20% the corresponding values obtained at temperatures of +20 and +65°C.

A marked increase in the strength is observed in dynamic loading compared to static loading for samples with angles of orientation of fibers $\alpha = 0$ and $5°$ [11]. At test temperatures of +65, +20, and −30°C, the dynamic strength is higher than in quasistatic loading by 23, 31, and 42%, respectively.

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