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RHEOLOGICAL CHARACTERISTICS OF MODIFIED WOOD

The object of the study is birch wood, impregnated with polyester resin PN-1 and phenolic alcohols. Resin PN-1 is a filler, which do not penetrate the cell walls of wood, and phenolic alcohols, on the contrary, represent a class of fillers, which penetrate the cell walls. The degree of impregnation of wood is estimated by coefficient k. When impregnated with resin PN-1, it is equal to 0.8, when impregnated with phenolic alcohols – 0.2. To study the behavior of modified wood in long-term loading the real body is represented as a set of two environments: perfectly elastic, deformable according to Hooke's law, and viscous, which obeys Newton's law. As with natural wood in the description of creep modified birch wood we use rheological equation of Maxwell − Thomson, otherwise, the law of deformation "typical body". The study of natural birch wood on base of what the modified wood is obtained is accomplished for the subsequent comparison of the rheological characteristics of these two materials. According to the experimental creep curves are defined instant and long elastic moduli, the relaxation time. Using these rheological characteristics, the coefficients of viscosity and modified natural birch wood are calculated. Rheological characteristics of modified wood appeared higher than those of natural wood.

Key words: wood, impregnation, modification, creep, compression strength, elastic modulus, relaxation time, the coefficient of viscosity.

Introduction. In the study of viscoelastic properties of modified wood the aim was to get the creep curves showing its behavior under long-term compressive load in the main directions, to describe these curves, to calculate the rheological characteristics. Furthermore, it was necessary to assess the impact of the modification on the rheological properties of wood as with the resin PN-1 which does not penetrate the cell walls of the wood, and with phenols, which are a class of fillers, penetrating the cell walls. The amount of filler in wood was evaluated by impregnation coefficient *k* [1]. For wood, impregnated with resin PN-1, *k* = 0,8, when impregnated with phenol *k* = 0.2. For comparison, in addition to a modified was studied natural birch wood too.

Main part. Tests on compressive load duration were performed on samples of sizes 20×20×60 mm. The long side of the sample corresponded to the direction of the compressive load (along the fibers, radial and tangential). Prepared samples were endured in the laboratory conditions (air temperature (20 ± 2)°C, relative humidity (75 ± 5)%) to get the equilibrium moisture of 5–8%. Under these conditions experiments were conducted. Three groups of samples, the hallmark of which is the level of stress were exposed to long-term loading compression tests. For samples loaded along the fibers it was created stress of 15, 30 and 45% of the tensile strength along the fibers obtained in short-term tests. During the compression across the fibers – 10, 16 and 22% of the respective tensile strengths. The duration of the tests ranged from 9 to 98 days depending on the stress in the sample and the direction of deformation. The experience was stopped, as a rule, when the picture of the dying down of deformation of the sample was well developed. In all cases the growth of the deformation in time is observed but it is manifested differently for each deformable sample depending on the material, the direction of deformation, the load values. The research results of creep of various composite materials show that in some cases there is the use of the linear theory of viscoelasticity, in other cases – nonlinear. Depending on this fact the approach to the determination of rheological characteristics will be different. Isochronous creep curves [2] rebuilt from the curves of direct creep give the idea of a linear or nonlinear relationship between the stresses and deformations. For the used materials the linear dependence of deformations on the stress occurs in natural and modified with resin *PN-1* wood at compression along the fibers, while in the modified with phenols wood – along and across the fibers. It should be noted that for the natural wood at compression across the fibers the character of the nonlinear relationship deformation – stress is weakly developed. The same remark can be made for wood, modified with resin PN-1 with the stress up to 16% of σ_b. When σ = 16–22% of σ_b nonlinear dependency occurs. Therefore, this area of the stress state of wood modified with resin PN-1, will not be considered. Thus, we consider the behavior of natural and modified birch wood as the behavior of linear viscoelastic material.

If we accept [3] in the integral equation of Boltzmann – Volterra

$$\varepsilon(t) = \frac{\sigma(t)}{\mathrm{E}} + \int_{-\infty}^{t} K(t-\theta)\sigma(\theta)\,d\theta,$$

which is used in such cases, the influence function

$$K(t-\theta)=\frac{E-H}{nE^2}\exp\left(-\frac{Ht}{nE}\right),$$

the creep equation has the form at σ = const, θ = 0:

$$\varepsilon(t)=\frac{\sigma}{H}+\sigma\left(\frac{1}{E}-\frac{1}{H}\right)\exp\left(-\frac{Ht}{nE}\right), \qquad (1)$$

where E, H, n – instantaneous modulus of elasticity, long modulus of elasticity, relaxation time.

This equation corresponds to the solution of a differential equation of Maxwell – Thomson:

$$nE\dot{\varepsilon}+H\varepsilon=\sigma+n\dot{\sigma},$$

describing the behavior of the rheological model of a "typical body" (Fig. 1) for σ = const.

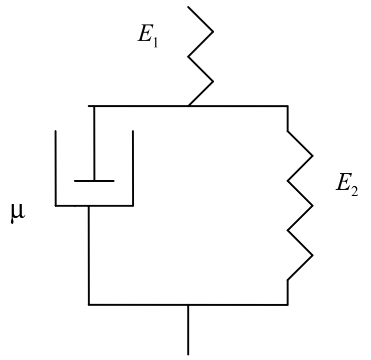

Fig. 1. The rheological model of a "typical body"

In the rheological model of a "typical body" a real body is represented as the set of two environments: perfectly elastic, deforming according to Hooke's law ($\sigma = E\varepsilon$), and viscous, obeying Newton's law ($\sigma=\mu\dot{\varepsilon}$). The justification of the use of the rheological model of a "typical body" to describe the deformation of wood at long-term loading is given in the work [4]. The rheological characteristics of the E, H, n in the equation (1) are located at creep curves of natural and modified wood by the method described in the work [5]:

$$E=\frac{\sigma}{\varepsilon(0)}=\frac{\sigma}{\varepsilon_y};$$

$$H=\frac{\sigma}{\varepsilon(\infty)}=\frac{\sigma}{\varepsilon_y+\varepsilon_n}=\frac{\sigma}{\varepsilon_{\text{tot}}}.$$

If the experiment is terminated before the full-damping of the creep process, the determination of ε(∞) is connected with possible rough mistakes. In this case it is better to use the formula

$$H=\sigma\frac{2\varepsilon_1-(\varepsilon_0+\varepsilon_2)}{\varepsilon_1^2-\varepsilon_0\varepsilon_2};\; t_2=2t_1,$$

where ε_0 – deformation at the moment t = 0; ε_1 and ε_2 – deformation at some points of time, which are in a particular conformity.

The sample was left under a constant load during the time $\tau=nE/H$, will have the deformation, defined in the following equation of creep (1):

$$\varepsilon(\tau)=\frac{\sigma}{H}+\sigma\left(\frac{1}{E}-\frac{1}{H}\right)e^{-1}=\varepsilon_y+0{,}632\varepsilon_n.$$

According to the experimental creep curves time τ, which corresponds to the deformation of ε (τ), is determined and the time of relaxation (Tables 1–3) is calculated:

$$n=\frac{H\tau}{E}.$$

Table 1

The rheological characteristics of natural birch wood

σ_a, MPa	σ_r, MPa	σ_t, MPa	$E\cdot10^{-2}$, MPa	$H\cdot10^{-2}$, MPa	n, h
11.17	–	–	193	149	131
22.34	–	–	188	154	118
33.51	–	–	186	146	75
–	1.11	–	10.58	5.98	41
–	1.77	–	10.29	5.19	32
–	2.44	–	10.09	4.31	31
–	–	0.69	5.92	3.82	40
–	–	1.10	5.94	3.14	32
–	–	1.51	5.90	3.04	28

Table 2

The rheological characteristics of the birch wood, modified with resin PN-1

σ_a, MPa	σ_r, MPa	σ_t, MPa	$E\cdot10^{-2}$, MPa	$H\cdot10^{-2}$, MPa	n, h
22.54	–	–	214.6	198.0	138
45.08	–	–	212.7	160.7	121
67.62	–	–	225.4	153.7	75
–	9.80	–	31.65	6.96	159
–	15.68	–	28.81	7.15	149
–	–	9.80	29.11	5.78	87
–	–	15.68	21.85	5.59	49

Calculated rheological characteristics allow to determine the viscosity coefficient μ of natural and modified wood (Tables 4–6), as basing on the adopted rheological model it is possible to obtain the following:

$$H = \frac{E_1 E_2}{E_1 + E_2},\ E_1 = E,\ n = \frac{\mu}{E_1 + E_2}.$$

Then $E_2 = \dfrac{E_1 H}{E_1 - H}$, $\mu = n(E_1 + E_2)$.

Table 3

The rheological characteristics of wood, modified with phenols

σ_a, MPa	σ_r, MPa	σ_t, MPa	$E \cdot 10^{-2}$, MPa	$H \cdot 10^{-2}$, MPa	n, h
21.56	–	–	198.74	173.85	314
43.12	–	–	204.13	189.14	215
64.68	–	–	206.00	175.71	85
–	3.23	–	16.56	10.39	74
–	6.57	–	16.17	10.49	64
–	9.80	–	15.39	11.16	62
–	–	1.96	11.17	5.88	25
–	–	3.92	10.49	6.08	24
–	–	5.88	11.27	6.76	15

Table 4

The viscosity coefficients of natural birch wood

σ_a, MPa	σ_r, MPa	σ_t, MPa	$\mu \cdot 10^{-10}$, MPa · s
11.17	–	–	3.992
22.34	–	–	4.428
33.51	–	–	2.472
–	1.11	–	0.036
–	1.77	–	0.024
–	2.44	–	0.019
–	–	0.69	0.024
–	–	1.10	0.015
–	–	1.51	0.012

Table 5

The viscosity coefficient of birch wood, modified with resin PN-1

σ_a, MPa	σ_r, MPa	σ_t, MPa	$\mu \cdot 10^{-10}$, MPa · s
22.54	–	–	13.8
45.08	–	–	3.78
67.62	–	–	1.91
–	9.8	–	0.23
–	15.68	–	0.21
–	–	9.8	0.11
–	–	15.68	0.05

Table 6

The viscosity coefficient of birch wood, modified with phenols

σ_a, MPa	σ_r, MPa	σ_t, MPa	$\mu \cdot 10^{-10}$, MPa · s
21.56	–	–	17.9
43.12	–	–	21.5
64.68	–	–	4.31
–	3.23	–	0.12
–	6.57	–	0.11
–	9.80	–	0.14
–	–	1.96	0.021
–	–	3.92	0.022
–	–	5.88	0.015

Conclusion. As it should be expected, instant and long modulus of elasticity and the relaxation time (Tables 1–3) depend on the type of the tested material, the direction of action and compressing load. The difference in the values of long-time and instant modulus of elasticity at different levels of stress for one direction of compression should be considered as a statistical spread of the results of experiments taking into account that such nonhomogeneous material as wood was subjected to a test. As for the relaxation time, this value varies depending on the load level in one direction more significantly than the modulus of elasticity. The general trend towards a decrease in the relaxation time with the increase of load is noticed.

For all tested materials long modulus of elasticity is less than instant modulus of elasticity, the largest values of E and H are along the fibers and the smallest – in the tangential direction. It corresponds to the representation about the behavior of wood under load and confirms the anisotropy of mechanical properties of natural and modified wood under long-term loading.

Comparing E and H, we see that the smallest differences occur along the fibers. This can be explained by the structure of wood and the difference of rheological properties of wood and polymers. Resin PN-1, fill only the cavities of cells having instantaneous modulus of elasticity in one order, and long modulus of elasticity in two orders less [6] than that of natural birch wood in the direction along the fibers and can not have a significant influence on the behavior of wood under long-term loading along the fibers. In this direction, rheological properties are mainly defined by wood fibers. In the direction perpendicular to the fibers this wood because of the previously mentioned reason shows a higher property to increase the creep deformation. As a result, H in radial and tangential directions was almost five times less than E, although the absolute H values of modified wood were still more than those of natural wood. As for wood modification with phenols, they penetrate into the wood cell walls and thus increase their stiffness. As a result creep of such wood decreases a little.

The viscosity coefficients calculated for investigated material (Tables 4–6) also depend on the direction of the compressive effort. In natural birch wood the viscosity coefficient μ along the fibers was two orders higher than that across the fibers. In the wood, modified with resin PN-1, the coefficient of viscosity along the fibers in average 10 times higher than μ in the direction across the fibers, and it is twice bigger in the radial direction, compared with tangential.

In the birch wood, modified with phenols, viscosity coefficient μ along the fibers has the order of 10^{11} MPa · s, in the radial direction – 10^{9} MPa · s, in the tangential direction – 10^{8} MPa · s.

The data may be used to predict the behavior of wood under the action of long-term loading.

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