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The performance of composites from vegetable raw materials with changes in temperature and humidity

Показатели композитов из растительного сырья при изменениях температуры и влажности

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Abstract. The composite board materials with woodchip fillers and nonprocessable flax and cotton processing waste based on the thermosetting binder matrix can be used as construction material for thermal insulation purposes. Research methods of temperature and humidity change influence on adhesive-bonded board materials' qualities are reviewed. The results of strength and loss of mass behaviour of board materials after the cyclic tests of soaking/freezing/thawing/drying are discribed. Board of unrecoverable waste spinning flax and cotton have the remaining strength is more than 60 % after ten cycles. The experimental data confirm the existence of long-term resistance of the composites to variable temperature and humidity effects.

Аннотация. Композиционные плитные материалы с наполнителями из древесной стружки и невозвратных отходов переработки льна и хлопка на основе матрицы из термореактивного связующего могут использоваться в качестве строительного материала теплоизоляционного назначения. Рассмотрено влияние температуры и влажности окружающей среды на показатели композиционных плитных материалов. Приведены результаты динамики прочности и потери массы плитных материалов после циклических испытаний «замачивание – замораживание – оттаивание – сушка». Волокнистые плиты из невозвратных отходов прядения льна и хлопка имеют остаточную прочность более 60 % после десяти циклов испытаний. Экспериментальные данные подтверждают наличие длительной стойкости композитов к переменным температурно-влажностным воздействиям.

Introduction

When using board products for construction purposes, the stability of their quality characteristics is of importance that determines their long-term performance. One of the major signs of material aging is strength reduction. The environment with variable temperatures and humidity has an attenuation effect on the strength of the construction materials.

Stresses arise in the adhesive material and the filler due to changes in temperature and humidity in the composite products with vegetable fillers based on the matrix from thermosetting binders. A parallel flow of further structuring processes is quite possible thus resulting in an increase in the stiffness of glued joints and stress concentrations as well as polymer's hydrolytic degradation.

Humidity stresses that develop in the adhesive layer of the glue joint will affect the polymer and the glued material in a different way. The stresses that pass from the glue contact area will emerge on the border of the rigid cross-linked polymer and vegetable filler with a higher relaxation action. The magnitude of the stresses also will be influenced by the vegetable filler's structure (the wooden one or

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from annual plant's waste) i.e. fractional size, porosity, availability of mineral, extraneous or fat and wax substances.

Under the operating conditions, the construction materials including three-layered structures (building boards, etc) [1] are affected by variable factors such as heating, humidification, freezing, etc. According to B.S. Batalin, changes in the operational properties of thermal insulation materials "may occur due to ongoing photo-oxidative and thermo-oxidative processes, which result in changes in the molecular mass and molecular-mass distribution. Apart from that, the reason for the changes in the operational properties may become structural changes that occur over time under the influence of a relatively low temperature. The successful use of any polymeric material under different conditions depends on its ability to preserve its performance characteristics, i.e. on its long service life [2]. Therefore, in order to predict the aging of materials during operation, they use field tests or accelerated cyclic exposure methods.

The field test methods are more informative and precise as for the practical application [3–10]. There exist grapho-analytical methods for comparing field tests in the atmosphere with control laboratory samples of the materials that greatly reduce labour intensiveness and time of study [11–13]. According to the data provided by A.S. Freydin, the use of grapho-analitical methods in predicting the use of these materials in construction for a period of thirty years (10^9 c) will require conducting field tests for 5 10^7 c (i.e. 1.5 years.) However, the calculation analogue methods [14] used for the predicting are theoretically substantiated for the materials in rubberlike state, and to a lesser degree, are applicable to the board materials on thermosetting matrix. It is difficult to use the methods of random/degradation functions to predict the strength of composites from vegetable raw materials based on thermosetting binders that adequately describe the systems from wood chips and mineral binders (such as cement bonded particle boards.) [1, 15–17].

It should be noted that the complexity and duration of full-scale testing reduces the efficiency of decision-making on the choice of technological impact on the material. The strength reduction of materials during operation will be a consequence of residual technological, temperature or humidity stresses as well as of a more intensive influence of alternating loads.

It has been proven that the composite components react differently to variations in temperature and humidity. The lignocellulosic filler will remain rather stable in these conditions for a long time. According to the data provided by E. Pokrovskaya, "the infrared spectra of the wood samples display no chemical changes in the xyloid substance in the course of time. There is only a quantity change of the components; the lignin-carbohydrate complex in the conditions of variable humidity … displays stability in the course of time" [18].

Thus, J. Zhu notes that the sensitivity of lignocellulosic materials to humidity poses a problem as before, whereas the properties of composite materials made of flax fibers are more dependent on the type of binder (thermoplastic, thermosetting materials or biomaterials) [19].

The use of flax and cotton fibers as fillers ensures high strength characteristics of composite materials, where the strength of the composite is inversely proportional to the share of lignocellulosic filler [20, 21].

The strength of composite with vegetable filler is determined by the strength of the thermosetting binder matrix.

According to the data provided by V.M.Khrulev, the reduction in glued joint strength is directly proportional to the speed of swelling [22].

If the material is exposed to alternating impacts, the relaxation efficiency of the glued joint is weakened, at the same time the adhesive bonds will be the weakest [23, 11].

The low temperature can particularly affect the relaxation capacity of glued joints. If a temperature is -8 °C or still lower, the ice is formed in the pores of the vegetable raw material-based composites including the wood. The material rigidity will sharply increase, and in the joints of two dissimilar materials (polymer and vegetable filler) that have a different thermal expansion coefficient, thermal stresses will occur. At a low temperature, densely cross-linked polymers behave as brittle bodies; they can even be destroyed by a relatively small deformation [20]. Because of a short soaking – freezing – thawing – drying period, the stresses do not have time to relax, a devastating impact on the material increases as compared to the natural conditions. In consideration of the foregoing, the accelerated cyclic tests will be more preferable.

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V.M. Khrulev [25–27] made a considerable contribution into the concept of the structure formation of wooden composite materials used for construction purposes. He proposed a cyclic test mode to assess the weather resistance of laminated wood and board materials where the samples should be kept in water for five hours and then are subject to drying at 70 °C within twenty-four hours. For the progress of his own and his colleagues' research, they developed Russian State Standard GOST 17580 "Wooden laminated structures. Method to determinate stability of glued joints against cyclic temperature-and humidity influences" (the wording of 1972). This method is applicable to the assessment of structural construction adhesives [14]. In [28] comprises testing of materials in boiling water. Later, the exposure to temperature changes and environmental humidity factors were modeled in the form of cyclic tests in standard procedures [29–32].

Scientists performed research on the influence of factors on physical-mechanical properties of materials using self-developed [33, 35, 36, 38–43] and the standard [34, 37] procedures. According to H.D. Dibaba, the cyclic test helps to evaluate the deformation, fatigue and creep properties of a material in polymers and polymer-composites [39].

It should be noted that thermal insulating materials serving as engineering structure elements are also exposed to temperature and humidity changes. However, they must retain their performance characteristics with temperature and humidity changes due to weather conditions in relation to the conditions of use.

For insulation panels, unlike the structural water resistant ones, the strength and swelling in thickness after the cyclic tests is not specified. In practice, any change in temperature corresponds to a humidity change of the environment air. But for all that, as a result of ongoing sorption-desorption processes of water vapour, the low density material having some open pores periodically absorbs and produces moisture. This phenomenon significantly affects the vapour permeability of heat insulation materials [44]. These processes entail the development of temperature/humidity stresses. If the stresses do not have time to decompress, and their intensity is higher than the adhesion bond strength, it will result in reduction of the composite strength and in deterioration of shape stability and thermal properties.

Accordingly, in the course of work, the decision has been made to use a standard cyclic test method of the material [29]. The results of cyclic tests will permit to assess the resistance of the material to temperature and humidity changes while in the course of service.

Experimental Part

In the laboratory of forest harvesting/woodworking department of the Kostroma State University (Kostroma, Russia), some chipboards and composite fibre board based on fillers from nonprocessable waste of cotton and flax fibre production based on the matrix from synthetic and non-organic binders have been tested for their resistance to temperature and humidity effects [45]. As a binder alternative for the boards were chosen: liquid glass $Na_2O(SiO_2)_n$, (module n = 1.6…3.75), phenol-formaldehyde resin and aluminium-chromium-phosphate binder $CrAl_3(H_2PO_4)_n$, (n = 8.8…9.6). The heat insulation composite material had a medium density of 375 kg/m^3, the consumption of binders was 40 % from the mass of filler. The material samples were dried at 80°C to reach 8±1 % humidity.

The cyclic temperature and humidity tests were made under [29]. One cycle of sample temperature/humidity exposure included the following procedures: the immersion of samples into water at 20 °C for twenty hours, freezing of wet samples at -20 °C for six hours, thawing at 20 °C for sixteen hours and heating at 60 °C for six hours.

The results of physical and mechanical performance determination of the materials after each of the ten test cycles are shown in Tables 1–5. Table 6 presents the dependences of residual strength of composite board materials (У) on the number of tests (x). As a rule, the reduction of strength is expressed with a function of varying complexity beginning from a simple exponential [11]. In research, we construct dependences ranging from the exponential to the fourth degree polynomials. Values of approximation validation are shown for each model.

Table 1. Behaviour of chipboard* in cyclic tests

Cycles	Loss of mass, Δm, %	Bending strength, σ_i, MPa	Swelling in thickness, P_s, %	Residual mass, %	Residual strength, %
Prior to tests (control)	- / -	25.5/22.97	9.4/24.5	-	-
1	5.38/2.95	21.09/11.39	10.7/24.8	94.62/97.05	82.5/49.6
2	16.82/10.63	18.27/6.50	12.2/25.7	83.18/89.37	71.5/28.3
3	26.3/ broke	16.02/ broke	12.9/ broke	73.7/-	62.9/0
4	28.07/ -	13.20/ -	14.2/ -	71.93/-	51.6/0
5	36.71/ -	10.47/ -	15.31/ -	63.29/-	41.0/0
6	41.82/ -	7.95/ -	17.91/ -	58.18/-	31.3/0
7	45.98/ -	6.00/ -	19.81/ -	54.02/-	23.5/0
8	46.25/-	4.72/-	22.16/-	53.75/-	18.5/0
9	46.87/-	4.28/-	25.38/-	53.13/-	16.8/0
10	47.14/-	3.51/-	28.56/-	52.86/-	13.7/0

***** Above the line are the values for chipboard with phenol-formaldehyde binder; under the line – with urea-formaldehyde binder (carbamide-formaldehyde resin)

Table 2. Behaviour of fibre boards** with phenol-formaldehyde resin in cyclic tests

Cycles	Loss of mass, Δm, %	Bending strength, σ_i, MPa	Swelling in thickness, P_s, %	Residual mass, %	Residual strength, %
Prior to tests (control)	- / -	0.49/0.55	3.36/8.2	-	-
1	7.42/8.61	0.46/0.53	1.82/4.32	92.58/91.39	0.94/0.96
2	22.11/26.21	0.46/0.53	1.96/4.88	77.89/73.79	0.94/0.96
3	36.82/41.63	0.44/0.52	2.07/5.27	63.18/58.37	0.89/0.94
4	38.64/44.52	0.43/0.51	2.23/5.58	61.36/55.48	0.87/0.93
5	51.01/59.45	0.41/0.49	2.31/5.93	48.99/40.55	0.83/0.89
6	58.48/66.04	0.41/0.47	2.38/6.84	41.52/33.96	0.83/0.85
7	64.37/72.44	0.40/0.47	2.91/7.32	35.63/27.56	0.81/0.85
8	64.75/73.08	0.38/0.41	3.22/8.30	35.25/26.92	0.77/0.74
9	65.42/73.47	0.31/0.32	3.48/8.76	34.58/26.53	0.63/0.58
10	65.61/74.59	0.15/0.26	3.62/9.29	34.39/25.41	0.31/0.47

****** Above the line for boards from cotton; under the line for boards from flax.

Table 3. Behaviour of fibre boards with carbamide-formaldehyde resin in cyclic tests***

Cycles	Loss of mass, Δm, %	Bending strength, σ_i, MPa	Swelling in thickness, P_s, %	Residual mass, %	Residual strength, %
Prior to tests (control)	- / -	0.38/0.49	3.26/6.9	-	-
1	7.56/8.79	0.37/0.47	1.91/3.7	92.44/91.21	0.97/0.96
2	18.9/21.97	0.37/0.47	2.44/4.25	81.1/78.03	0.97/0.96
3	35.91/41.74	0.35/0.47	2.71/4.63	64.1/58.26	0.92/0.96
4	42.54/49.63	0.32/0.46	2.94/4.89	57.46/50.37	0.84/0.94
5	51.26/58.34	0.27/0.43	3.08/5.16	48.74/41.66	0.71/0.88
6	58.12/65.75	0.22/0.43	3.22/5.54	41.88/34.25	0.58/0.88
7	63.41/71.68	0.22/0.42	3.39/5.91	36.59/28.32	0.58/0.85
8	68.29/76.13	0.20/0.41	3.44/6.68	31.71/23.87	0.52/0.83
9	71.63/78.41	0.18/0.35	3.51/7.03	28.37/21.59	0.47/0.71
10	73.55/80.80	0.11/0.30	3.58/7.61	26.45/19.2	0.29/0.61

******* Above the line for boards from cotton; under the line for boards from flax.

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Table 4 Behaviour of fibre boards with liquid glass in cyclic tests***

Cycles	Loss of mass, Δm, %	Bending strength, σ_i, MPa	Swelling in thickness, P_s, %	Residual mass, %	Residual strength, %
Prior to tests (control)	- / -	0.71/0.88	5.68/9.16	-	-
1	7.71/9.12	0.70/0.87	2.98/4.52	92.29/90.88	0.98/0.99
2	16.23/20.54	0.67/0.85	3.41/5.06	83.77/79.46	0.94/0.96
3	31.62/39.67	0.62/0.81	3.92/5.71	68.38/60.33	0.87/0.92
4	40.24/43.75	0.60/0.77	4.15/6.34	59.76/56.25	0.84/0.87
5	49.13/51.62	0.57/0.76	4.73/7.02	50.87/48.38	0.80/0.86
6	53.97/56.73	0.55/0.73	5.01/7.69	46.03/43.27	0.77/0.83
7	59.64/62.12	0.51/0.72	5.38/8.21	40.36/37.88	0.72/0.82
8	64.82/65.53	0.49/0.69	5.84/9.05	35.18/34.47	0.69/0.78
9	68.32/69.41	0.44/0.48	6.04/10.11	31.68/30.59	0.62/0.54
10	70.69/70.75	0.38/0.41	6.35/10.78	29.31/29.25	0.53/0.46

******* Above the line for boards from cotton; under the line for boards from flax.

Table 5. Behaviour of fibre boards with aluminium-chromium-phosphate in cyclic tests***

Cycles	Loss of mass, Δm, %	Bending strength, σ_i, MPa	Swelling in thickness, P_s, %	Residual mass, %	Residual strength, %
Prior to tests (control)	- / -	0.69/0.81	3.07/3.72	-	-
1	6.12/ 7.45	0.68/0.79	1.82/1.96	93.88/92.55	0.98/0.97
2	14.28/15.61	0.66/0.78	2.01/2.15	85.72/84.39	0.95/0.96
3	30.42/34.72	0.65/0.76	2.83/2.94	69.58/65.28	0.94/0.94
4	38.16/41.26	0.64/0.75	3.06/3.27	61.84/58.74	0.93/0.92
5	45.17/49.24	0.64/0.73	3.53/3.86	54.83/50.76	0.93/0.90
6	51.83/53.62	0.58/0.69	3.94/4.18	48.17/46.38	0.84/0.85
7	58.27/60.78	0.49/0.61	4.14/4.69	41.73/39.22	0.71/0.75
8	66.71/69.28	0.41/0.52	4.85/5.12	33.29/30.72	0.59/0.64
9	70.29/73.68	0.33/0.46	5.12/6.59	29.71/26.32	0.48/0.57
10	74.22/76.48	0.28/0.39	5.47/7.62	25.78/23.52	0.40/0.48

******* Above the line for boards from cotton; under the line for boards from flax.

Table 6. Dependence of residual strength of composite board materials from the number of test cycles

Composite material	Dependence of boards' residual strength У, % from number of cycles x	Approximation accuracy R^2
Chipboard with phenolformaldehyde resin	$У = 111.28e^{-0.212x}$	0.9899
Fibre board from cotton with phenolformaldehyde resin	$У = 1.1873e^{-0.083x}$	0.5757
	$У = - 0.0102x^2 + 0.0603x + 0.8443$	0.8741
	$У = - 0.0031x^3 + 0.0412x^2 – 0.1771x + 0.902$	0.9679
Fibre board from flax with phenolformaldehyde resin	$У = 1.1693e^{-0.069x}$	0.7573
	$У = - 0.0088x^2 + 0.0461x + 0.8443$	0.9739
	$У = - 0.001x^3 + 0.0082x^2 – 0.0323x + 0.9903$	0.9866
Fibre board from cotton with urea formaldehyde binder	$У = 1.2591e^{-0.122x}$	0.9098
	$У = - 0.0016x^2 – 0.0584x + 1.0677$	0.9661
	$У = - 0.0004x^3 – 0.0082x^2 – 0.028x + 1.0333$	0.9671
Fibre board from flax with urea formaldehyde binder	$У = 1.081e^{-0.044x}$	0.7904
	$У = - 0.0055x^2 + 0.0247x + 0.932$	0.961
	$У = - 0.0007x^3 + 0.0069x^2 – 0.0323x + 0.9963$	0.9751

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Composite material	Dependence of boards' residual strength У, % from number of cycles x	Approximation accuracy R^2
Fibre board from cotton with liquid glass	$У = 1.0699e^{-0.061x}$	0.9542
	$У = - 0.0459x + 1.0287$	0.9812
	$У = - 0.0013x^2 – 0.0318x + 1.0003$	0.9862
	$У = - 0.0008x^3 + 0.0117x^2 – 0.0915x + 1.0677$	0.9969
Fibre board from flax with liquid glass	$У = 1.166e^{-0.073x}$	0.7624
	$У = - 0.0521x + 1.0893$	0.83
	$У = - 0.0069x^2 + 0.0242x + 0.9368$	0.9241
	$У = - 0.0019x^3 + 0.0237x^2 – 0.1173x + 1.0963$	0.9638
Fibre board from cotton with aluminium-chromium-phosphate	$У = 1.2697e^{-0.097x}$	0.8359
	$У = - 0.0667x + 1.142$	0.8783
	$У = - 0.0091x^2 + 0.0329x + 0.9428$	0.9817
	$У = 0.0005x^3 – 0.0166x^2 + 0.0679x + 0.9033$	0.9833
	$У = - 0.0006x^4 – 0.0128x^3 + 0.0807x^2 – 0.1981x + 1.1108$	0.9977
Fibre board from flax with aluminium-chromium-phosphate	$У = 1.182e^{-0.076x}$	0.8627
	$У = - 0.0558x + 1.1047$	0.902
	$У = - 0.0069x^2 + 0.0205x + 0.9522$	0.9912
	$У = 0.0002x^3 – 0.109x^2 + 0.039x + 0.9313$	0.9918

In Figures 1, 2 the dependence of residual strength at a static bending, % (the results with the calculate confidence interval) for plates from the waste of linen and cotton after cycles of temperature and humidity exposure, in Figure 3 – dependence of this indicator for chipboard, tiles made of waste linen and cotton with phenol-formaldehyde binder.

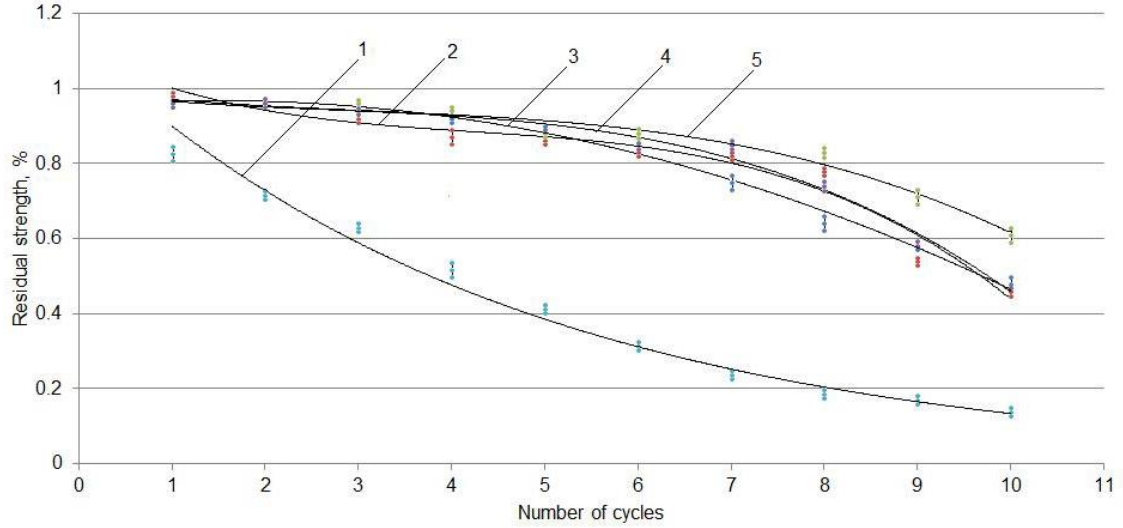

Figure 1. Limit of residual strength for boards from flax waste at static bending, % after cycles to temperature and humidity exposure: 1 – chipboard with phenol-formaldehyde resin; 2 – fibre board from flax with liquid glass; 3 – fibre board from flax with aluminium-chromium-phosphate; 4 – fibre board from flax with phenol-formaldehyde resin; 5 – fibre board from flax with urea-formaldehyde binder (carbamide-formaldehyde resin*).*

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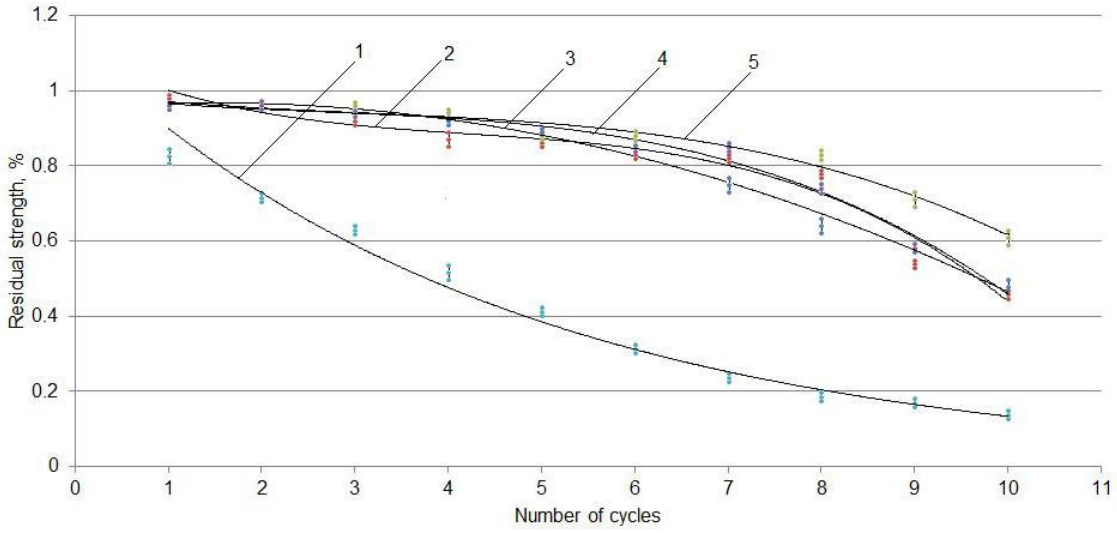


Figure 2. Limit of residual strength for boards from cotton waste at static bending; % after cycles to temperature and humidity exposure: 1 – chipboard with phenol-formaldehyde resin; 2 – fibre board from cotton with phenol-formaldehyde resin; 3 – fibre board from cotton with urea-formaldehyde binder; 4 – fibre board from cotton with liquid glass; 5 – fibre board from cotton with aluminium-chromium-phosphate.

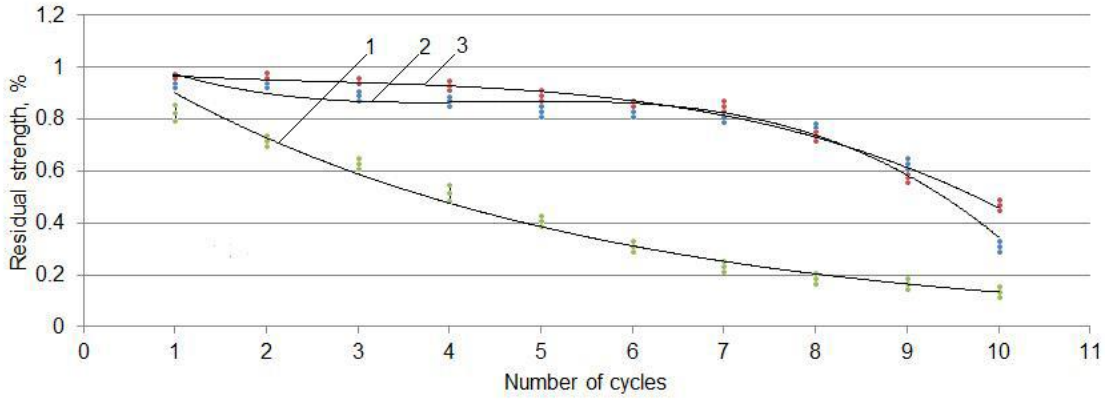


Figure 3. Limit of residual strength for boards at static bending, % after cycles to temperature and humidity exposure: 1 – chipboard with phenol-formaldehyde resin; 2 – fibre board from cotton with phenol-formaldehyde resin; 3 – fibre board from flax with phenol-formaldehyde resin.

Review of Results

Subsequent to the results of experimental tests, it has been determined that the fibre board has a much higher resistance to cyclic temperature and humidity exposure than the chipboard.

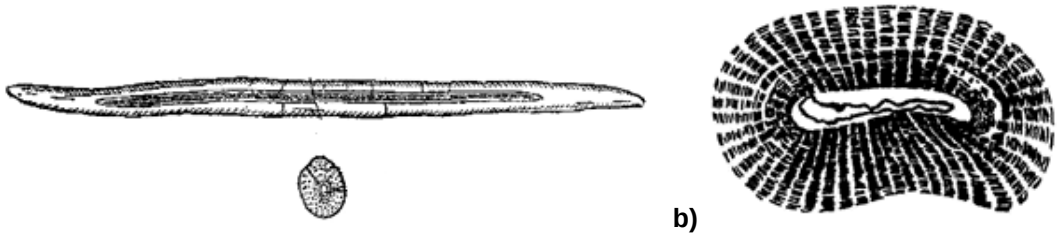
The composites with amino-formaldehyde binder demonstrate the least resistance to temperature and humidity effects assuming that the initial strength at static bending of fibre board can be comparable for all four types of binder. This is comparable with the results of the research A.S. Freidin [11], according to which the composites of solid wood with urea-formaldehyde binder have destructively after six cycles of testing.

A low hydrolytic stability of the amino-formaldehyde binder results in a significant loss of strength of the chipboard immediately after the second test cycle (Table 1); the fibre board from cotton with amino-formaldehyde binder will have a strength under 60 % after the sixth cycle, however, the board with flax binder will have a residual strength above 60 % even after ten test cycles. The conversion of a number of test cycles into real composites' lifetime can be possible after the comparison of strength changes during field and cyclic tests.

The significance of differences is explicitly expressed in the use of one binder and three different fillers (Figure 3). Comparing a composite made by dry method, i.e. chipboard (hot pressing at 180 °C)

with fibre composites made by wet method (drying at 80 °C) when one and the same binder is used (phenol-formaldehyde), it becomes obvious that even incomplete hardening of phenol binder provides the fibre board with a higher dimensional stability (Table 1-3) and a higher residual strength. The reason for these differences lies in the filler's structure. The basic mechanical tissue of wood (libriform and flax fibres) (Figure 4a) have a similar highly elongated spindle shape with closed pointed ends.

However, elementary flax fibre differs from wood chips both in structure and size. The elementary flax fibres have a medium length of 10–24mm; a libriform fibre's length is about 1 mm. Their cross dimension is comparable (11–20 microns.) Apart from the libriform fibre, the wood chips contain water conducting elements, vessels with a diameter about 200 microns whose volume occupies 10…55 % [46]. The wood chips have a higher conducting function than the flax fibre. However, the flax fibre contains twice as much cellulose than wood. The layered fibre wall structure is a consequence of gradual cellulose deposition (with intervals) on the fibre walls



a) b)

Figure 4. Section of fibre: a – longitudinal section of flax fibre; b – cross-section of cotton fibre

A considerably higher orientation of the structural elements relative to the axis in the flax fibre as compared to the cotton fibre, can partially explain a higher strength of flax and its lower capability of elongating due to tension.

The elementary cotton fibres as well as those of flax have a layered structure (Figure 4b) due to a gradual layer-by-layer deposition of cellulose on fibre walls in the form of daily concentric layers. As the fibres ripen, the remainder of the protoplasm in the channel will dry up, and the fibre will get flattened. However, the outer diameter of fibres remains unchanged, and the diameter of channel due to the wall thickening decreases; the strength of the fibres and their elasticity increase, and the sorption properties improve.

It is possible to predict the residual strength of composite boards at static bending by means of regression models (Table 6). All the dependencies have an approximation adequacy of 0.7. An increase in polynomial dependence degree above two results in an increase in the prediction result by 0.06…9.4 % depending on the composite type.

Conclusions

The composites from cotton wastes have a lower cross-breaking strength at static bending than those from flax residue, and a higher loss of strength after the test cycles. This pattern is observed both for liquid phenolic-formaldehyde resin thermosetting binder-based boards, and for the materials based on non-organic binders, e.g. liquid glass and aluminium-chromium-phosphate.

The composites from nonprocessable flax fibre and flax residue display a high stability of the shape after the cyclic tests; a loss of mass over 50 % occurs after 5…6 test cycles. A higher loss of mass here than that of the chipboard can be explained by a removal of the dust fraction (together with water) that do not have chemical or hydrogen bonds in the composite structure where a large number of hydrogen bonds ensures swelling in thickness after ten cycles but not more than 6.4 % for the boards with cotton filler and 10.8 % for the boards with flax residue filler.

The aluminium-chromium-phosphate control samples have a higher strength at static bending as compared to the boards fabricated with phenol-formaldehyde liquid resin and liquid glass. However, after the first test cycles, higher values of residual strength of the composites based on flax and cotton fillers are displayed by the matrices from non-organic binders. A considerable decrease in the residual strength occurs after the fifth cycle for the boards from cotton filler based on amino-formaldehyde binder; for the other composites the strength will be substantially reduced after 8–9 test cycles.

Therefore, it has been proven that the composite board materials made from nonprocessable flax and cotton fibre production residue based on thermosetting and non-organic binders appear to have a

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high resistance capability to cyclic temperature and humidity influences. The acquired experimental data make it possible to recommend such composite materials for use as heat insulation components of building structures.

References

1. Zaprudnov V. I. *Trekhsloynyye konstruktsii s drevesno-tsementnymi teploizolyatsionnymi sloyami* [Three-layer constructions with wood-cement heat-insulating layers]. Moscow: MGUL, 2006. 322 s.
2. Batalin B.S., Krasnovskikh M.P. Durability and Heat Resistance of Foam Polystyrene. *Stroitelnyye materialy.* 2014. No. 8. Pp. 64–67. (rus)
3. Turkovskiy S.B., Varfolomeyev Yu.A. Rezultaty naturnykh obsledovaniy derevyannykh konstruktsiy [Results of full-scale inspections of wooden structures]. *Promyshlennoye stroitelstvo.* 1984. No. 6. Pp. 19–20. (rus)
4. Khrulev V.M. Dolgovechnost kleyevykh soyedineniy drevesiny, propitannoy sinteticheskimi oligomerami [Durability of glued wood compounds impregnated with synthetic oligomers]. *Izvestiya vysshikh uchebnykh zavedeniy. Stroitelstvo i arkhitektura.* 1969. No. 2. Pp. 61–68. (rus)
5. Kasatkin V.B., Bondin V.F. Dolgovremennyye ispytaniya armoderevyannykh balok v usloviyakh Kraynego Severa [Long-term tests of armored wooden beams in the conditions of the Far North]. *Izvestiya vysshikh uchebnykh zavedeniy. Stroitelstvo i arkhitektura.* 1972. No. 11. Pp. 12–14. (rus)
6. Turkovskiy S.B. *Opyt primeneniya kleyenykh derevyannykh konstruktsiy v Moskovskoy oblasti* [Experience in the application of glued wooden structures in the Moscow region]. Is. 2. Moscow: Stroyizdat. 1987. 54 p. (rus)
7. Roshchina S.I. Dlitelnaya prochnost i deformativnost treugolnykh arok s kleyenym armirovannym verkhnim poyasom [Long-lasting strength and deformability of triangular arches with glued reinforced upper belt]. *Materialy oblastnoy konferentsii* [Proceedings of regional conference]. Vladimir: VGU, 1999. Pp. 35–37. (rus)
8. Kiseleva O.A., Plotnikova Ye.Ye. Yartsev V.P. Vliyaniye klimaticheskikh vozdeystviy na prochnost stroitelnykh izdeliy iz modifitsirovannoy drevesiny [Influence of climatic influences on strength of building products from modified wood]. *Materialy V Mezhdunarodnoy nauchno-tekhnicheskoy konferentsii "Effektivnyye stroitelnyye konstruktsii: teoriya i praktika"* [Proceedings of the V International Scientific and Technical Conference "Effective Building Constructions: Theory and Practice"]. Penza, 2006. Pp. 147–150. (rus)
9. Turkovskiy S.B., Lomakin A.D., Pogoreltsev A.A. Zavisimost sostoyaniya kleyenykh derevyannykh konstruktsiy ot vlazhnosti okruzhayushchego vozdukha [Dependence of the state of glued wooden structures on the humidity of the ambient air]. *Promyshlennoye i grazhdanskoye stroitelstvo. Trudy instituta.* Moscow: TsNIISK im. V.A. Kucherenko. 2012. No. 3. Pp. 30–32. (rus)
10. Raknes E. Langtidsb best andighet av lim for baerende trekonstruksjoner. *Norsk Skogindustri.* 1975. Vol. 30. No. 6. Pp. 455–469
11. Freydin A.S., Vuba K.T. *Prognozirovaniye svoystv kleyevykh soyedineniy drevesiny* [Forecasting properties of glued wood compounds]. Moscow: Lesnaya promyshlennost, 1980. 223 p. (rus)
12. Ananyev A.I., Lobov O.I., Mozhayev V.P., Vyazovchenko P.A. Fakticheskaya i prognoziruyemaya dolgovechnost penopolistirolnykh plit v naruzhnykh ograzhdayushchikh konstruktsiyakh zdaniy [Actual and predicted durability of expanded polystyrene boards in external enclosing structures of buildings]. *Promyshlennoye i grazhdanskoye stroitelstvo.* 2003. No. 4. Pp. 54–56. (rus)
13. Yasin Yu.D., Yasin V.Yu., Li A.V. Penopolistirol. Resurs i

Литература

1. Запруднов В.И. Трехслойные конструкции с древесно-цементными теплоизоляционными слоями. М.: МГУЛ, 2006. 322 с.
2. Баталин Б.С., Красновских М.П. Долговечность и термическая устойчивость пенополистирола // Строительные материалы. 2014. № 8. С. 64–67.
3. Турковский С.Б., Варфоломеев Ю.А. Результаты натурных обследований деревянных конструкций // Промышленное строительство. 1984. № 6. С. 19–20.
4. Хрулев В.М. Долговечность клеевых соединений древесины, пропитанной синтетическими олигомерами // Известия высших учебных заведений. Строительство и архитектура. 1969. № 2. С. 61–68.
5. Касаткин В.Б., Бондин В.Ф. Долговременные испытания армодеревянных балок в условиях Крайнего Севера // Известия высших учебных заведений. Строительство и архитектура. 1972. № 11. С. 12–14.
6. Турковский С.Б. Опыт применения клееных деревянных конструкций в Московской области. Вып. 2. М: Стройиздат. 1987. 54 с.
7. Рощина С.И. Длительная прочность и деформативность треугольных арок с клееным армированным верхним поясом // Материалы областной конференции. Владимир: ВГУ, 1999. С. 35–37.
8. Киселева О.А., Плотникова Е.Е. Ярцев В.П. Влияние климатических воздействий на прочность строительных изделий из модифицированной древесины // Материалы V Международной научно-технической конференции «Эффективные строительные конструкции: теория и практика». Пенза, 2006. С. 147–150.
9. Турковский С.Б., Ломакин А.Д., Погорельцев А.А. Зависимость состояния клееных деревянных конструкций от влажности окружающего воздуха // Промышленное и гражданское строительство. Труды института. М.: ЦНИИСК им. В.А. Кучеренко. 2012. № 3. С. 30–32.
10. Raknes E. Langtidsb best andighet av lim for baerende trekonstruksjoner // Norsk Skogindustri. 1975. Vol. 30. No. 6. Pp. 455–469
11. Фрейдин А.С., Вуба К.Т. Прогнозирование свойств клеевых соединений древесины. М.: Лесная промышленность, 1980. 223 с.
12. Ананьев А.И., Лобов О.И., Можаев В.П., Вязовченко П.А. Фактическая и прогнозируемая долговечность пенополистирольных плит в наружных ограждающих конструкциях зданий // Промышленное и гражданское строительство. 2003. № 4. С. 54–56
13. Ясин Ю.Д., Ясин В.Ю., Ли А.В. Пенополистирол. Ресурс и старение материала. Долговечность конструкций // Строительные материалы. 2002. № 5. С. 33–35.
14. Фрейдин А.С. Прочность и долговечность клеевых соединений. М.: Химия, 1981. 272 с.
15. Бленд Д.Р. Теория линейной вязкоупругости. М.: Мир, 1965. 199 с.
16. Уткина В.Н., Селяев В.П. Прогнозирование долговечности строительных материалов и конструкций методом деградационных функций // Материалы научно-практической конференции «Долговечность строительных материалов и конструкций». Саранск. 1995. С. 74–75.
17. Селяев В.П., Меркулов И. И., Меркулов А. И. Численное моделирование механического разрушения трехкомпонентного древеснонаполненного композита //

Сусоева И.В., Вахнина Т.Н., Титунин А.А., Асаткина Я.А. Показатели композитов из растительного сырья при изменениях температуры и влажности // Инженерно-строительный журнал. 2017. № 3(71). С. 39–50.

stareniye materiala. Dolgovechnost konstruktsiy [Styrofoam. Resource and aging of the material. Durability of structures]. *Stroitelnyye materialy.* 2002. No. 5. Pp. 33–35. (rus)

14. Freydin A.S. *Prochnost i dolgovechnost kleyevykh soyedineniy* [Strength and durability of adhesive joints]. Moscow: Khimiya, 1981. 272 p. (rus)
15. Blend D.R. *Teoriya lineynoy vyazkouprugosti* [The theory of linear viscoelasticity]. Moscow: Mir, 1965. 199 p. (rus)
16. Utkina V.N., Selyayev V.P. Prognozirovaniye dolgovechnosti stroitelnykh materialov i konstruktsiy metodom degradatsionnykh funktsiy [Forecasting the durability of building materials and structures using the degradation function]. *Materialy nauchno-prakticheskoy konferentsii "Dolgovechnost stroitelnykh materialov i konstruktsiy" [Proceedings of the scientific-practical conference "Durability of building materials and structures"].* Saransk. 1995. Pp. 74–75. (rus)
17. Selyayev V.P., Merkulov I.I., Merkulov A.I. Chislennoye modelirovaniye mekhanicheskogo razrusheniya trekhkomponentnogo drevesnonapolnennogo kompozita [Numerical simulation of mechanical fracture of a three-component wood-filled composite]. *Izvestiya vysshikh uchebnykh zavedeniy. Stroitelstvo.* 1997. No. 9. Pp. 62–67. (rus)
18. Pokrovskaya Ye.N. Vliyaniye stareniya na strukturu i svoystva polimernogo kompozita drevesiny [Effect of aging on the structure and properties of the polymer composite wood]. *Materialy mezhdunarodnoy nauchno-tekhnicheskoy konferentsii "Aktualnyye problemy i perspektivy razvitiya lesopromyshlennogo kompleksa"* [Proceedings of the international scientific and technical conference "Actual problems and prospects for the development of the timber industry complex"]. Kostroma: KGTU, 2012. Pp. 29–31. (rus)
19. Zhu J., Zhu H., Njuguna J., Abhyankar H. Recent development of flax fibres and their reinforced composites based on different polymeric matrices. *Materials.* 2013. No. 6. Pp. 5171–5198
20. Baiardo M., Zini E., Scandola M. Flax fibre–polyester composites. *Composites: Part A.* 2004. Vol. 35. Pp. 703–710.
21. Saxena M., Pappu A., Sharma A., Haque R., Wankhede S. Composite materials from natural resources: recent trends and future potentials. *Advances in Composite Materials – Analysis of Natural and Man-Made Materials.* 2011. Vol. 09. Pp. 121–157.
22. Khrulev V.M., Maltsev M.G., Khasanov R.Sh. *Tsement-nostruzhechnyye plity v stroitelstve* [Cement construction slabs in construction]. Ufa: UGNTU, 2001. 96 p. (rus)
23. Khrulev V.M., Mashkin N.A., Maltsev N.G. Sovremennyye predstavleniya o stukturoobrazovanii drevesnykh kompozitsionnykh materialov [Modern ideas about the formation of wood composite materials]. *Materialy Mezhdunarodnoy konferentsii "Kompozitsionnyye stroitelnyye materialy. Teoriya i praktika"* [Proceedings of the International Conference "Composite Building Materials. Theory and practice"]. Part 2. Penza: Privolzhskiy dom znaniy, 2000. Pp. 138–140. (rus)
24. Van Krevelen D.V. *Svoystva i khimicheskoye stroyeniye polimerov* [Properties and chemical structure of polymers]. Moscow: Khimiya, 1976. 416 p. (rus)
25. Khrulev V.M. *Dolgovechnost kleyenoy drevesiny* [Durability of glued wood]. Moscow: Lesnaya promyshlennost, 1971. 160 p. (rus)
26. Khrulev V.M., Mashkin N.A. Novyye kontseptsii v teorii i tekhnologii kompozitsionnykh drevesno-polimernykh materialov [New concepts in the theory and technology of composite wood-polymer materials]. *Izvestiya vysshikh uchebnykh zavedeniy. Stroitelstvo.* 1999. No. 7. Pp. 61–64.

Известия высших учебных заведений. Строительство. 1997. № 9. С. 62–67.

18. Покровская Е.Н. Влияние старения на структуру и свойства полимерного композита древесины // Материалы международной научно-технической конференции «Актуальные проблемы и перспективы развития лесопромышленного комплекса». Кострома: КГТУ, 2012. С. 29–31.
19. Zhu J., Zhu H., Njuguna J., Abhyankar H. Recent development of flax fibres and their reinforced composites based on different polymeric matrices // Materials. 2013. № 6. Pp. 5171–5198
20. Baiardo M., Zini E., Scandola M. Flax fibre–polyester composites // Composites: Part A. 2004. Vol. 35. Pp. 703–710.
21. Saxena M., Pappu A., Sharma A., Haque R., Wankhede S. Composite materials from natural resources: recent trends and future potentials // Advances in Composite Materials – Analysis of Natural and Man-Made Materials. 2011. Vol. 09. Pp. 121–157.
22. Хрулев В.М., Мальцев М.Г., Хасанов Р.Ш. Цементностружечные плиты в строительстве. Уфа: УГНТУ, 2001. 96 с.
23. Хрулев В.М., Машкин Н.А., Мальцев Н.Г. Современные представления о стуктурообразовании древесных композиционных материалов // Материалы Международной конференции «Композиционные строительные материалы. Теория и практика» Ч. 2. Пенза: Приволжский дом знаний, 2000. С. 138–140.,
24. Ван Кревелен Д.В. Свойства и химическое строение полимеров. Пер. с англ. М.: Химия, 1976. 416 с.
25. Хрулев В. М. Долговечность клееной древесины. М.: Лесная промышленность, 1971. 160 с.
26. Хрулев В.М., Машкин Н.А. Новые концепции в теории и технологии композиционных древесно-полимерных материалов // Известия высших учебных заведений. Строительство. 1999. № 7. С. 61–64.
27. Мартынов К.Я., Хрулев В.М. Исследование ускоренного старения древесностружечных плит методом математического планирования эксперимента // Известия вузов. Строительство. 1984. № 12. С. 78–81.
28. ГОСТ 19100-73. Древесина клееная. Метод испытания клеевых соединений на атмосферостойкость.
29. ГОСТ 17580-82. Конструкции деревянные клееные. Метод определения стойкости клеевых соединений к цикличным температурно-влажностным воздействиям.
30. ГОСТ 33121-2014. Конструкции деревянные клееные. Методы определения стойкости клеевых соединений к температурно-влажностным воздействиям.
31. ГОСТ 32399-2013. Плиты древесно-стружечные влагостойкие. Технические условия
32. DIN EN 321 Wood-based panels – Determination of moisture resistance under cyclic test conditions.
33. Мамонтов С.А. Естественное старение древесных композитов в условиях умеренного климата // Актуальные направления фундаментальных и прикладных исследований. Материалы VI Международной научно-практической конференции. North Charlecton, USA, 2015. Т. I. С. 96–98.
34. Ярцев В. П., Киселева О. А. Прогнозирование поведения строительных материалов при неблагоприятных условиях эксплуатации. Тамбов: ТГТУ, 2009. 124 с.
35. Обливин А.Н., Сапожников И.В., Лопатников М.В. Моделирование длительной прочности композиционных материалов на древесных наполнителях // Лесной вестник. 2015. № 1 С. 6–12.
36. Сулейманов А.М. Принципы разработки методов

Susoeva I.V., Vahnina T.N., Titunin A.A., Asatkina J.A. The performance of composites from vegetable raw materials with changes in temperature and humidity. *Magazine of Civil Engineering*. 2017. No. 3. Pp. 39–50. doi: 10.18720/MCE.71.5.

(rus)

27. Martynov K.Ya., Khrulev V.M. Issledovaniye uskorennogo stareniya drevesnostruzhechnykh plit metodom matematicheskogo planirovaniya eksperimenta [Investigation of the accelerated aging of particle boards by the method of mathematical experiment planning] *Izvestiya vuzov. Stroitelstvo.* 1984. No. 12. Pp. 78–81. (rus)
28. *Russian State Standard GOST 19100-73.* Drevesina kleyenaya. Metod ispytaniya kleyevykh soyedineniy na atmosferostoykost [Wood glued. The method of testing adhesive compounds for weather resistance]. (rus)
29. *Russian State Standard GOST 17580-82.* Konstruktsii derevyannyye kleyenyye. Metod opredeleniya stoykosti kleyevykh soyedineniy k tsiklichnym temperaturno-vlazhnostnym vozdeystviyam [Structures wooden glued. Method for determining the resistance of adhesive joints to cyclic temperature and humidity influences]. (rus)
30. *Russian State Standard GOST 33121-2014.* Konstruktsii derevyannyye kleyenyye. Metody opredeleniya stoykosti kleyevykh soyedineniy k temperaturno-vlazhnostnym vozdeystviyam [Structures wooden glued. Methods for determining the resistance of adhesive joints to temperature-humidity influences]. (rus)
31. *Russian State Standard GOST 32399-2013.* Plity drevesno-struzhechnyye vlagostoykiye. Tekhnicheskiye usloviya [Wood-particle board moisture-proof. Specifications] (rus)
32. *DIN EN 321* Wood-based panels – Determination of moisture resistance under cyclic test conditions.
33. Mamontov S.A. Yestestvennoye stareniye drevesnykh kompozitov v usloviyakh umerennogo klimata [Natural aging of wood composites in a temperate climate]. *Aktualnyye napravleniya fundamentalnykh i prikladnykh issledovaniy. Materialy VI Mezhdunarodnoy nauchno-prakticheskoy konferentsii* [Actual directions of fundamental and applied research. Materials of the VI International Scientific and Practical Conference.]. North Charlecton, USA, 2015. Vol. I. Pp. 96–98. (rus)
34. Yartsev V.P., Kiseleva O.A. *Prognozirovaniye povedeniya stroitelnykh materialov pri neblagopriyatnykh usloviyakh ekspluatatsii* [Forecasting the behavior of building materials under adverse operating conditions]. Tambov: TGTU, 2009. 124 p. (rus)
35. Oblivin A.N., Sapozhnikov I.V., Lopatnikov M.V. Modelirovaniye dlitelnoy prochnosti kompozitsionnykh materialov na drevesnykh napolnitelyakh [Modeling the long-term strength of composite materials on wood fillers]. *Lesnoy vestnik.* 2015. No. 1 Pp. 6–12. (rus)
36. Suleymanov A.M. Printsipy razrabotki metodov uskorennykh ispytaniy na dolgovechnost polimernykh stroitelnykh materialov [Principles for the development of methods for accelerated tests for the durability of polymer building materials]. *Academia. Arkhitektura i stroitelstvo.* 2010. No. 3. Pp. 602–603. (rus)
37. Vydrina T.S., Artemov A.V., Dedyukhin V.G., Buryndin V.G. Teplovoye stareniye izdeliy na osnove drevesnykh kompozitsionnykh materialov [Thermal aging of products based on wood composite materials]. *Khimiya rastitelnogo syrya.* 2007. No. 2. Pp. 101–106. (rus)
38. Mehta G., Drzal L.T., Mohanty A.K., Misra M. Effect of fiber surface treatment on the properties of biocomposites from nonwoven industrial hemp fiber mats and unsaturated polyester resin. *Journal of Applied Polymer Science.* 2006. Vol. 99. No. 3. Pp. 1055–1068.
39. Dibaba H.D. Permeability barriers for composites ageing mechanisms and surface treatment of polymeric matrix composites under cyclic load. *Materials Processing Technology*. 2016. [Electronic resource] URL: http:// www.theseus.fi (date of reference: 10.03.2017).
40. Goretyy V.V., Nagda S.Yu. Otsenka vliyaniya nanostruktury modifitsirovannoy drevesiny na prochnost' pri staticheskom ускоренных испытаний на долговечность полимерных строительных материалов // Academia. Архитектура и строительство. 2010. № 3. С. 602–603.
37. Выдрина Т.С., Артёмов А.В., Дедюхин В.Г., Бурындин В.Г. Тепловое старение изделий на основе древесных композиционных материалов // Химия растительного сырья. 2007. № 2. С. 101–106.
38. Mehta G., Drzal L.T., Mohanty A.K., Misra M. Effect of fiber surface treatment on the properties of biocomposites from nonwoven industrial hemp fiber mats and unsaturated polyester resin // Journal of Applied Polymer Science. 2006. Vol. 99. № 3. Pp. 1055–1068.
39. Dibaba H.D. Permeability barriers for composites ageing mechanisms and surface treatment of polymeric matrix composites under cyclic load. Materials Processing Technology. 2016. [Электронный ресурс] URL: http:// www.theseus.fi (дата обращения 10.03.2017)
40. Горетый В.В., Нагда С.Ю. Оценка влияния наноструктуры модифицированной древесины на прочность при статическом изгибе // Материалы 45-й Международной конференции «Актуальные проблемы прочности». Белгород: БелГУ, 2006. С. 95–96.
41. Cantero G., Arbelaiz A., Llano-Ponte R., Mondragon I. Effects of fiber treatment on wettability and mechanical behaviour of flax/polypropylene composites // Compos. Sci. Technol. 2003. Vol. 63. Pp. 1247–1254.
42. La Rosa A.D., Recca G., Summerscales J., Latteri A., Cozzo G., Cicala G. Bio-based versus traditional polymer composites. A life cycle assessment perspective // Journal of Cleaner Production. 2014. Vol. 74. Pp.135–144.
43. Wang B., Panigrahi S., Tabil L., Crerar W. Pre-treatment of flax fibers for use in rotationally molded biocomposites // Journal of Reinforced Plastics and Composites. 2007. Vol 26. № 5. Pp. 447–463.
44. Копылова А.И., Ватин Н.И., Пестряков И.И. Экспериментальное сравнение характеристик паропроницаемости основных строительных материалов // Строительство уникальных зданий и сооружений. 2014. № 10(25). С. 98–108.
45. Сусоева И.В., Вахнина Т.Н., Ибрагимов А.М. Исследование интенсивности образования пылевидных отходов текстильных предприятий, используемых для производства строительных лигноцеллюлозных композиционных материалов // Технология текстильной промышленности. 2016. № 2(362). С. 219–222.
46. Боровиков А.М., Уголев Б.Н. Справочник по древесине. М.: Лесная промышленность, 1989. 296 с.

Сусоева И.В., Вахнина Т.Н., Титунин А.А., Асаткина Я.А. Показатели композитов из растительного сырья при изменениях температуры и влажности // Инженерно-строительный журнал. 2017. № 3(71). С. 39–50.

izgibe [Estimation of the influence of modified wood nanostructure on the strength at static bending]. *Materialy 45-y Mezhdunarodnoy konferentsii "Aktualnyye problemy prochnosti"* [Proceedings of 45th International conference "Actual problems of strength]. Belgorod: BelGU, 2006. Pp. 95–96. (rus)

41. Cantero G., Arbelaiz A., Llano-Ponte R., Mondragon I. Effects of fiber treatment on wettability and mechanical behaviour of flax/polypropylene composites. *Compos. Sci. Technol.* 2003. Vol. 63. Pp. 1247–1254.
42. La Rosa A.D., Recca G., Summerscales J., Latteri A., Cozzo G., Cicala G. Bio-based versus traditional polymer composites. A life cycle assessment perspective. *Journal of Cleaner Production.* 2014. Vol. 74. Pp. 135–144.
43. Wang B., Panigrahi S., Tabil L., Crerar W. Pre-treatment of flax fibers for use in rotationally molded biocomposites. *Journal of Reinforced Plastics and Composites.* 2007. Vol. 26. No. 5. Pp. 447–463.
44. Kopylova A.I., Vatin N.I., Pestryakov I.I. Eksperimentalnoye sravneniye kharakteristik paropronitsayemosti osnovnykh stroitelnykh materialov. *Construction of Unique Buildings and Structures.* 2014. No. 10(25). Pp. 98–108. (rus)
45. Susoyeva I.V., Vakhnina T.N., Ibragimov A.M. Issledovaniye intensivnosti obrazovaniya pylevidnykh otkhodov tekstilnykh predpriyatiy, ispolzuyemykh dlya proizvodstva stroitelnykh lignotsellyuloznykh kompozitsionnykh materialov [Investigation of the intensity of formation of pulverized waste of textile enterprises used for the production of building lignocellulosic composite materials]. *Tekhnologiya Tekstilnoy Promyshlennosti.* 2016, No. 2(362). Pp. 219–222. (rus)
46. Borovikov A.M., Ugolev B.N. *Spravochnik po drevesine* [Handbook of wood]. M.: Lesnaya promyshlennost, 1989. 296 p. (rus)

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