UDC 674.815

Tambov State Technical University
D. Sc. in Engineering, Prof. of Department of Structures of Buildings and Constructions
V. P. Yartsev
Postgraduate Student of Department of Structures of Buildings and Constructions
D. V. Antipov
Ph. D. in Engineering,
Assoc. Prof. of Department of Structures of Buildings and Constructions
O. A. Kiselyova
Russia, Tambov, tel.: +7(4752)63-03-80;e-mail: kiseleva_oa@rambler.ru

V. P. Yartsev, D. V. Antipov, O. A. Kiselyova

INFLUENCE OF TEMPERATURE AND ULTRAVIOLET IRRADIATION ON DEFORMATION CAPACITY OF GLUED WOOD

Problem statement. The presence of polymer glued interlayer causes changes in a glued wood structure and its properties. Consequently, using laminated constructions it is necessary to make corrections in estimated characteristics of wooden items and constructions.

Results and conclusions. Influence of quantity of layers on bearing capacity of glued wood is established. Strength dependencies of glued wood on temperature and loading are obtained in accordance with thermal fluctuations theory. Thermal fluctuations approach is applied to lateral bending deformation of glued wood. Physical constants for the analytical description of these processes at temperature variation and operation time are calculated from the results. Differences in pattern of change in strength of whole and glued wood are revealed under climate influence on them.

Keywords: glued wood, strength, deformability, temperature-humidity exposures, thermal fluctuations theory.

Introduction. Glued wood has been intensively used in building constructions (columns, beams, frames, arches, etc.). Its use offers savings in large-size wood.

According to present standards [1], glued wood constructions are designed as solid ones with the introduction of a coefficient taking into account only the thickness of layers. However, the presence of polymer glued interlayer causes changes in a glued wood structure and its properties. Consequently, using laminated constructions it is necessary to make corrections in estimated characteristics of wooden items and constructions. During an operating process a material may be affected by climatic factors (temperature, hostile liquid and gas mediums, ultraviolet irradiation, etc.) and long-time loads which are to be considered while designing a construction.

1. The effect of a number of layers, an adhesive type and temperature on glued wood failure mechanisms under a short- and long-time load

For a present study, samples of glued wood were designed with a varying number of layers on the basis of polyvinyl acetate (PVA), acrylic, casein and UFD (based on urea-formaldehyde gums) glue. During the cross-bending trials the function between strength and temperature was obtained (Fig. 1). The function for whole wood was plotted according to the equation $\sigma_w = \sigma_{12} / \left[1 + \alpha \ W - 12 \right]$ [2] on the basis of a strength value at the temperature of +20 °C obtained experimentally.

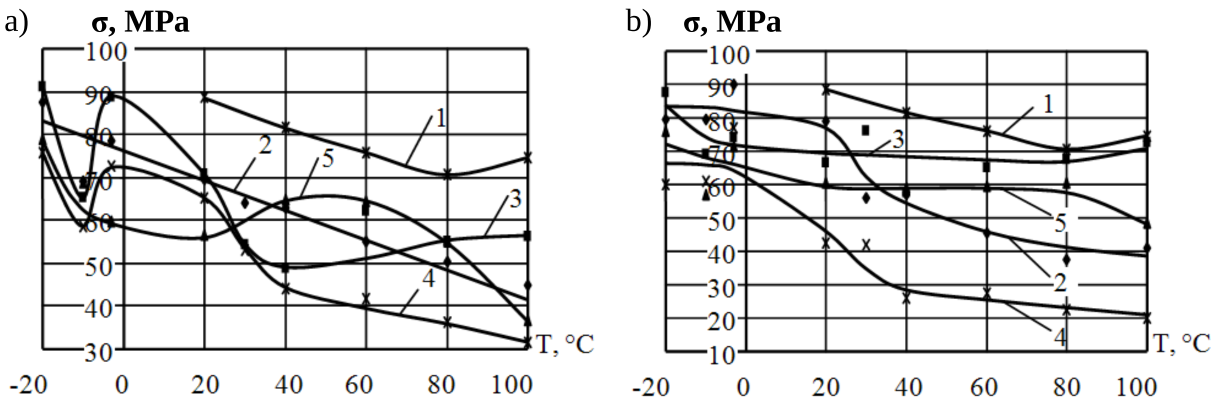

Fig. 1. The function between two-layer *(a)* and four-layer *(b)* whole glued wood and temperature:
1 — whole wood; 2 — PVA glue wood; 3 — UFD glued wood;
4 —acrylic glue wood; 5 — casein glue wood

It is seen from Fig. 1 that PVA and UFD glue samples were found to be the strongest ones in normal conditions. Glued wood performs in a high-temperature mode worse than whole one. In this case acrylic glue is most vulnerable to temperature, while UFD glue is most immune to it. Temperature affects the failure mechanism as well. Hence, as temperature increases up to 80 °C, the percentage of adhesive failure increases. Most of the glued wood samples failed in glue, which is unacceptable. The exception is PVA glue samples. While using acrylic glue, adhesive failure appears to be crucial already at 30 °C.

Glued wood failure mechanisms under a long-time load and temperature variations were examined in cross-bending, compression and spalling. The experimental results obtained are presented in Fig. 2. It is seen from Fig. 2 that glued wood in the examined range of temperatures has a complex failure mechanism. The function between the durability logarithm and stress for two-layer glued wood is a family of intersecting straight lines forming an inverse sheaf in the temperature range 8—40 °C and a direct sheaf at the temperature of more than 40 °C. The corresponding function for three-layer glued wood in the examined range has the form of a direct sheaf [5]. Such a pattern of behaviour for glued wood is connected to its layered macrostructure. In the temperature range 8—40 °C the load-carrying capacity with one glue stitch is determined by wood dowels. At the temperature more than 40 °C as a glue interlayer increases (for three-layer wood) it is determined by glue.

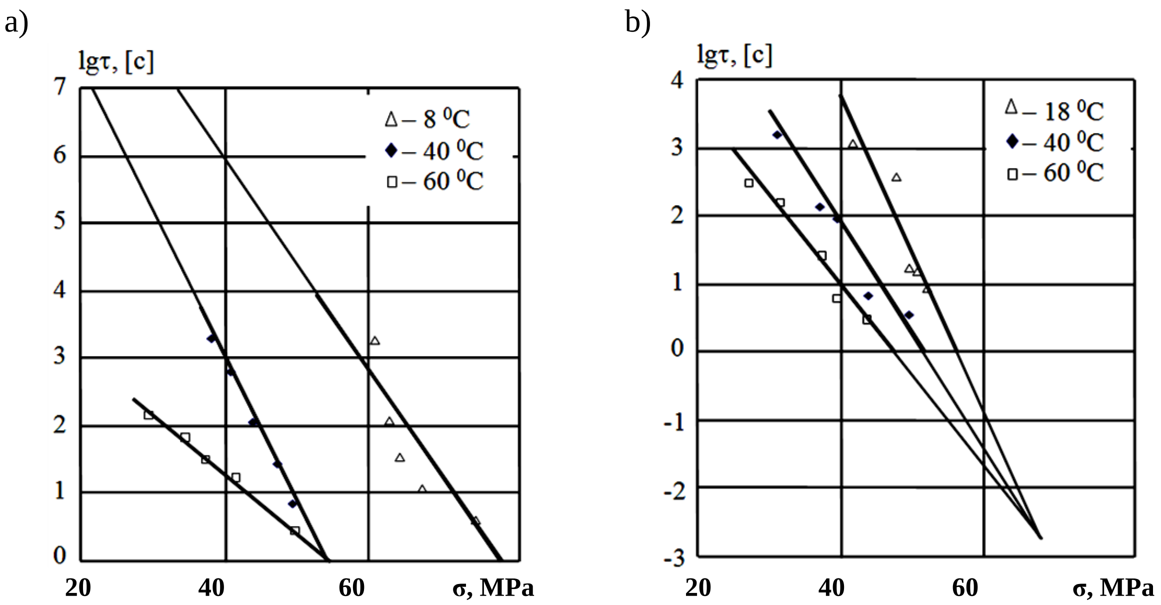

Fig. 2. The functions between durability and stress during glued wood cross-bending: *a* — two-layer glued wood, *b* — three-layer glued wood

A glue-stitch effect on the load-carrying capacity during spalling shows itself in the whole temperature range. At the temperature of 18 °C 50 % of the samples fail in glued places, the rest fail in the boundary between glue and wood, which is unacceptable during a performance of glued wood. When the temperature increases (up to 40 °C and more) the failure takes place only in a glue stitch, which is unacceptable. As this takes place, the durability drops by 3…4 points. The experimental functions (lgτ-σ) have the form of a direct sheaf [4], which supports the conclusion that a glue stitch plays a crucial role in the glued wood load-carrying capacity.

The obtained functions are described by the following equations [4]:

– for a direct sheaf: $$\tau = \tau_m \exp\left[\frac{U_0 - \gamma\sigma}{RT}\left(1 - \frac{T}{T_m}\right)\right], \qquad (1)$$

– for an inverse sheaf: $$\tau = \tau_m^* \exp\left[\frac{U_0^* - \gamma^*\sigma}{RT}\left(\frac{T_m^*}{T} - 1\right)\right], \qquad (2)$$

where τ_m is a minimal durability (oscillation period of kinetic units), sec; U_0 is a maximum energy of a failure activation or deformation, kJ/ mol; γ is a structural mechanical constant, kJ/(mol×MPa); T_m is a pole temperature (limiting temperature of solid body existence), *K;* U_0*, γ*, T_m* — are empirical constants; R — is the universal gas constant, kJ per (mole×К); τ is the durability (deformational or strength one), sec; σ — is the stress, MPa; T — is the temperature, К.

The constants included in Equations (1) and (2) were determined by a grapho-analytical method using *Constanta.exe* software. Their values are presented in Table 1.

Table 1

Values of empiral and physical constants for wood of whole [5]
and glued section under various loads

Type of load	Type of section	Number of stitches	Temperature interval, ºC	Physical constants			
				θ_m, θ_m^*, sec	T_m, T_m^*, K	U_0, U_0^*, kJ/mol	γ, γ^*, kJ/ (mol×MPa)
Cross-bending	Whole	-	18-100	10^{7}	160	-131	-1.7
	Glued	1	8-40	10^{18}	200	-65	-2.24
			40-60	$10^{0.612}$	343	752	14.64
		2	18-60	$10^{-2.601}$	438	301	4.38
Spalling	Whole	-	18-40	10^{7}	200	-80	-21.6
	Glued	1	16-100	$10^{-4.8}$	348	623	86.27
Compression [3]	Whole	-	16-100	$10^{0.317}$	566	120	4.08
	Glued	1	18-40	$10^{6.18}$	276	-927	-36.9
			40-100	$10^{0.98}$	418	342	10.71

2. Wood deformation description from the thermal fluctuational point of view

In order to reveal the deformation mechanisms (in the second group of limiting states), glued wood with a varying number of wood layers was tested during a long-time cross-bending and compression in the mode of constant temperatures and stresses.

The changes in deformation were noted through the course of the tests. The kinetic curves experimentally obtained by the method of grapho-analytical differentiation were redrawn depending on the function between the velocity logarithm and the inverse temperature.

An example is illustrated in Fig. 3—4.

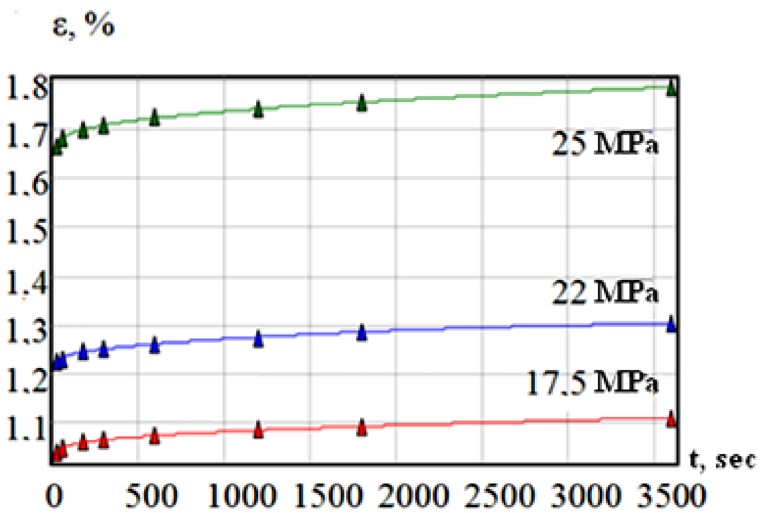

Fig. 3. The function between deformation and time of the load effect

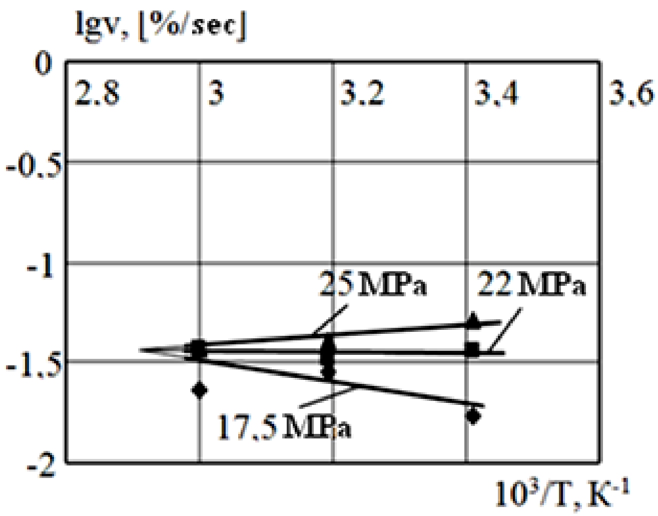

Fig. 4. The deformation velocity logarithm from the inverse temperature

The obtained functions are described by the following equations:

$$v = v_{m(\partial)} \exp\left[-\frac{U_{0(\partial)} - \gamma_{(\partial)}\sigma}{RT} \left(1 - \frac{T}{T_{m(\partial)}} \right) \right], \quad (3)$$

$$v = v^*_{m(\partial)} \exp\left[-\frac{U^*_{0(\partial)} - \gamma^*_{(\partial)}\sigma}{RT} \left(\frac{T^*_{m(\partial)}}{T} - 1 \right) \right], \quad (4)$$

where v is a material deformation velocity, %/sec; $v_{m\ (d)}$ is the initial apparent material deformation velocity, %/sec; $U_{0(d)}$ is the maximum energy of the velocity activation, kJ/mol; $\gamma_{(d)}$ is a structural-mechanical factor, kJ/(mol×MPa); $T_{m\ (d)}$ is the limiting temperature of the existence of the materials, K; R, σ, T are the same as in (1)-(2); $v^*_{m\ (d)}$, $T^*_{\ m\ (d)}$, $U^*_{0(d)}$ and $\gamma^*_{(d)}$ are empirical constants.

The values of physical and empirical constants calculated by the grapho-analytical method are presented in Table 2.

Table 2

The values of deformation constants for whole and glued wood

Type of load	Number of layers	$lgv_{m\ (d)}$ ($lgv^*_{m\ (d)}$), [%/sec]	$T_{m\ (d)}$ ($T^*_{m\ (d)}$), K	$U_{0(d)}$ ($U^*_{0(d)}$), kJ/mol	$\gamma_{(d)}$ ($\gamma^*_{(d)}$), kJ/(mol×MPa)
Compression	1	-2.085	276	4.7	-15.3
	2	2.479	2545	50.269	5.973
Compression	4	-0.361	4000	23.171	0.346
Cross-bending	1	-2	268	-23	-1.26
	2	-1.45	370	34	1.47
Penetration	1	-1.4	337	58	0.094

3. The change of glued wood strength after cyclic temperature-humidity exposures

The tests were performed on glued wood samples with a varying number of layers. The research of effect of the cycles of freezing and defrosting on strength showed that the functions of strengths for glued wood, unlike those for whole one, are of linear character (Fig. 5). A double drop in strength was as well observed already after 35 cycles.

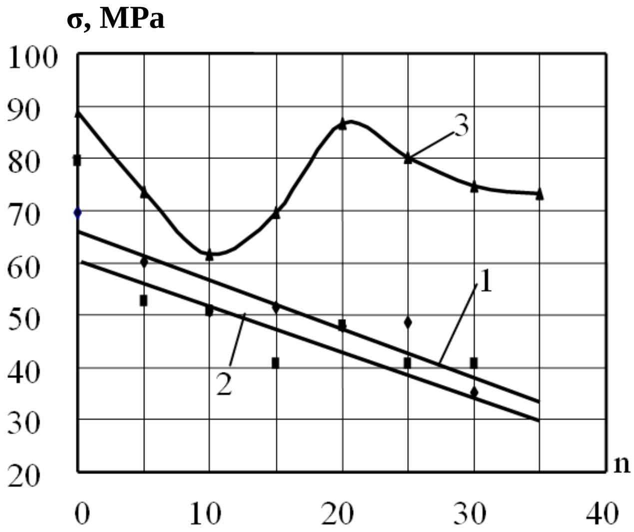

Fig. 5. The function between glued wood strength and number of the cycles of freezing and defrosting:
1 — for two-layer wood, 2 — for four-layer wood, 3 — for whole wood [5]

Temperature and photoaging have a great effect on the mechanical properties of glued wood. Thermal aging (at +80 ^{0}C) and ultraviolet irradiation of the samples were performed for 10…400 hours. The samples were tested on strength after the given time of effect.

The results of the effects are presented in Table 3.

Table 3

The effect of aging on glued wood strength in cross-bending

Type of effect	Number of layers	Residual strength of the samples,%, after thermal aging for, h						
		10	20	40	80	120	200	350
Thermal aging	1	96.3	93.5	90.5	88.7	88.0	77.5	-
	2	100	100	98.9	94.0	88.8	86.6	65.8
	4	86.7	78.9	89.6	97.9	98.3	90.3	62.0
Ultraviolet irradiation	1	107.8	112.6	112.0	110.7	109.2	129.9	-
	2	100.0	100.0	100.0	100.0	97.7	92.3	39.46
	4	99.0	97.9	96.1	93.7	92.5	90.7	87.5

It is seen from the table that thermal aging clearly tells on glued wood strength after 120 h:strength drops by 12 %, more than 30% of the samples fail in glued places. The process stabilizes itself through further aging. However, 66% of the samples already fail in a glued interlayer. A change in the colour of the glued interlayer and of the glued wood itself are as well observed under the thermal aging effect. They had a dark-brown colouring.

A growth in the whole-wood strength was noted after a long-time ultraviolet irradiation effect [5]. Glued wood strength gradually drops. After 470 h of ultraviolet irradiation the strength is 85 % of the initial one. Apparently, it is related the glued interlayer aging. During the process the colour of the glued interlayer did not change, up to 17% of the samples failed in glued places.

Conclusions

1. All the constants change when glued wood, unlike whole one, fails. Their values depend on the number of stitches in a section. For a direct sheaf in cross-bending and spalling in the temperature range of 40…60 °C T_m is close to the softening temperatur of polymer glue, while U_0 corresponds with the energy of the split of intermolecular [4] but not of chemical bonds. This points to the crucial role of deformation processes during the failure, which was supported by visual observations, i.e. the samples were strongly deformed before the failure. For three-layer wood T_m corresponds with the temperature of a glue stitch decomposition, while U_0 is close to the energy of polyvinyl acetate failure activation.

2. The functions between short-time strength and temperature may be used in order to estimate long-time strength of glued wood samples (in the first group of limiting states). If a construction strength, while changing at an elevated temperature, is higher than that of the other within the whole temperature range, its operating capacity may be expected to remain the same through the operating process according to the temperature-time equivalence principle.

3. The change of all the constants is observed for glued wood during cross-bending deformation. Hence, $v_{m\ (d)}$, $T_{m\ (d)}$ increase, while $\gamma_{(d)}$ drops. The behaviour of the fourth constant $U_{0(d)}$ depends on the type of load: during compression its value increases, while it drops in bending. This proves that it is wooden dowels not a polymer interlayer that play the crucial role during deformation.

4. The present approach with the use of the constants allows to prognosticate more reliably the long-time strength and deformability of glued wood in the physical context. Unlike the other methods where long-time strength limit at constant and variable temperatures is prognosticated, the present method considers the constantly changing glued wood strength with the account to the temperature and additional external actions (humidity, ultraviolet irradiation, cyclic freezing and defrosting).

References

1. **СНиП II-25-80.** Деревянные конструкции. — Взамен СНиП II-В.4-71; введ. 01.01.1982. — М.: ГП ЦПП, 1995. —34 с. = **Code of Practice (SNiP) II-25-80.** Wooden constructions. Instead of Code of Practice (SNiP) II-B.4-71; enacted on 01.01.1982. Moscow, 1995.
2. **ГОСТ 16483.3-84.** Древесина. Метод определения предела прочности при статическом изгибе. — Взамен ГОСТ 16483.3-73; введ. 01.07.1985 до 01.01.87. — М.: Изд-во стандартов, 1999. — 4 с. = **State Standard (GOST) 16483.3-84**. Wood. Method of ultimate strength determination under static bending. Instead of State Standard (GOST) 16483.3-73; enacted on 01.07.1985 until 01.01.87. Moscow, 1999.
3. **Ярцев, В. П.** Термоактивационные закономерности разрушения и деформирования клееной древесины / В. П. Ярцев, О. А. Киселева // Строительные материалы, оборудование, технологии XXI века. — 2007. — № 8. – С. 74—75. = **Yartsev, V. P.,** Kiselyova, O. A. Thermo-activation laws of destruction and deformation of glued wood. Building materials, equipment, and technologies of XXI century. 2007. № 8. P. 74—75.
4. **Ратнер, С. Б.** Физическая механика пластмасс. Как прогнозируют работоспособность? / С. Б. Ратнер, В. П. Ярцев. — М.: Химия, 1992. — 320 с. = **Ratner, S. B.,** Yartsev, V. P. The physical mechanics of plastics. How to predict operability? Moscow, 1992. 320 pp.
5. **Сашин, М. А.** Прогнозирование и повышение долговечности и длительной прочности древесины в строительных изделиях и конструкциях: автореф. дис…канд. техн. наук / М. А. Жуков. — Воронеж, 2006. — 22 с. = **Sashin, M. A.** Forecasting and increase of durability and long strength of wood in building products and constructions: Ph. D. in Engineering thesis’ abstract. Voronezh, 2006. 22 pp.