INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 1/2014 (5): 137–146

PROGNOSTICATION OF STRAIN-STRENGTH CHARACTERISTICS OF STRUCTURAL PARTICLEBOARDS DURING CONTINUOUS STATIC BENDING LOAD

Nikolay Yosifov[1], Stefan Delin[2]
[1]University of Forestry, 10 Kliment Ohridski blvd, 1797 Sofia, Bulgaria,
e-mail: nikyosif@mail.bg
[2]Los Angeles, USA, e-mail: deltica@aol.com

ABSTRACT

Subject of the investigation is the prognostication of the resistance of structural three- and multilayer particleboards (SPB) to continuous static bending load under the conditions of relatively dry environment. The theoretical prerequisites of the development are the rheological model of SPB and the schematic diagram of their deformation during continuous load, the algorithm and the nomogram to determine the stiffness of SPB on the basis of their simulation model of a “double T-beam” and the regression dependences of the moduli of elasticity of SPB with various thicknesses on their volumetric density.

An algorithm and a nomogram to determine the continuous load factor of SPB to prognosticate their resistance as structural elements in furniture and building structures have been proposed. The creep coefficient of composite particleboards under operating conditions has been determined.

Key words: structural particleboards (SPB), continuous load, creep coefficient, elastic deformation

INTRODUCTION

Structural particleboards (SPB) a widely used composite materials in furniture and building structures. Under operating conditions, the horizontal structural elements of SPB are most often subjected to continuous static bending load. In the course of time, the strain-strength indices of the structural elements and, above all, their stiffness (*EI*) are continuously reduced as a result of which they sag. The deflection is a result of the development of the process of “creeping” in the material, which depends on the type, microstructural and strain-strength characteristics of the composite board, the value and the duration of the load and the climatic-operating conditions. Under given operating conditions and sufficiently big loads and duration, a process of destruction of the composite material begins.

Of big interest to the practice is the prognostication of strain-strength properties of SPB during continuous static bending load. It should be noted, however, that, for the time being, it is difficult to offer a universal, and with the necessary accuracy, solution of the above problem because of the presence of many conventionalities related to the differences in the specific structure of these heterogeneous composite materials and their technologically formed properties. That is why, in this case it is more appropriate to apply differential approach for the prognostication of strain-strength characteristics of SPB according to their type (morphological characteristic) and climatic-operating conditions.

In view of the above, subject of the present study is the prognostication of strain-strength characteristics of three- and multilayer SPB during continuous static bending by uniformly distributed load under the conditions of operating class SC1 according to ENV 1156:1998 (20 °C air temperature and 65 % relative air humidity). At the same time, the indices: stiffness and moduli of elasticity during continuous load E_τ; the factors of continuous load K_d and creeping K_c are adopted as evaluation criteria for the strain characteristics during continuous static bending load.

1. THEORETICAL PART

Investigations of a number of authors (Bryan 1960, Terentyev 1964, Artyuhovskiy 1965, Kollmann et al. 1975, Kyuchukov and Nikolaeva 1980, Potashev and Lapshin 1982, Dinwoodie et al. 1990, Panayotov et al. 2000, etc.) prove that the continuously acting load leads to irrevocable deflection and destruction of the composite boards. This is a result of the loss of strength and, above all, of the reduction of the modulus of elasticity, i.e. $E = f(\tau)$.

The strain-strength characteristics of SPB as structural elements in furniture and building structures are directly dependent on the conditions of their operating load. The physical essence of the deformations emerging during their loading ensues from the rheological model of the composites made of wood particles (Yosifov and Delin 2012).

On the basis of the rheological model and the investigations by Artyuhovskiy, a schematic diagram of the deformation behaviour of a structural element of SPB during continuous static bending load is presented in Fig. 1.

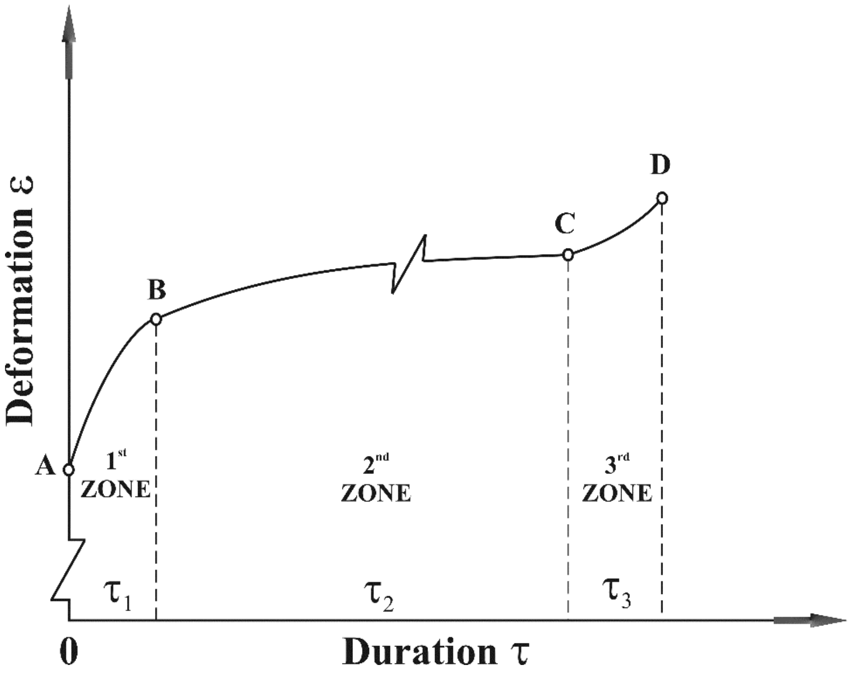


Figure 1: Schematic diagram of the deformation of SPB during continuous static bending load: 1st zone *AB* – highly elastic deformation; 2nd zone *BC* – elastic-viscous deformation; 3rd zone *CD* – plastic deformation; *D* – destruction

From the graph in Fig. 1 is seen that the total deformation $\varepsilon = f(\tau)$ of the structural elements made of SPB during continuously acting static bending load consists of the following deformations by time zones: *OA* – linear part characterising the immediate elastic deformation at the moment of loading; *AB* – a curve describing the deformation during short-time load (1st zone), which is a consequence of the highly elastic and elastic properties of the composite and is quickly recoverable; *BC* – a curve with an approximation to a straight line, characterised by delayed elastic deformation with viscous flow during the applied continuous stress (2nd zone); *CD* – a curve that characterises the plastic deformation (3rd zone) and the destruction at a given moment (point D) as an end of a relatively slow process. At the same time, unlike solid wood, the destruction of SPB is due, besides the destructive physicochemical processes in the lignocellulose composite during continuous load, mostly also to the accumulation and increase of the microcracks in its conglomeration structure.

In principle, at constant level of stress σ_0, the functional dependence of the deformation ε versus time τ (at $\tau \to \infty$) is expressed with the rheological equation:

$$\varepsilon(\tau)=\frac{\sigma_0}{E_b}\left[1+\int_0^{\infty} R(\tau-\tau_0)d\tau\right], \qquad \textbf{(1)}$$

where E_b is the modulus of elasticity in bending;

$R(\tau-\tau_0)$ – relaxation kernel or deformation rate.

According to the Wolter theorem, the continuous modulus of elasticity is determined by the rheological equation:

$$E(\tau)=E_0/(1+k), \qquad \textbf{(2)}$$

where E_0 is the initial modulus of elasticity;

k – experimental constant that depends on the elastic deflection during short-time (f_0) and continuous (f_τ).

According to the energetic theory (Toshev 1967), the deformation potential Ω for normal one-dimensional stress σ_x of an element of SPB may be determined by the formula:

$$\Omega=\sigma_x/2E \qquad \textbf{(3)}$$

The work of deformation A during simple bending is expressed with the equation:

$$A=\int_V \Omega dV=\frac{1}{2EI_Y}\int_0^{\ell} M_Y^2 dV=\frac{1}{2St}\int_0^{\ell} M_Y^2 dV, \qquad (4)$$

where $EI_Y = St$ – material stiffness;

ℓ – span;

M_Y – bending moment.

Therefore, the stiffness is a determining index for the strain-strength resistance of composite particleboards. In principle, the value of this index is functionally dependent on the modulus of elasticity in bending (E_b) and the geometric parameters of the cross-section of the structural element, i.e. on the inertia moment I_x.

Experimentally proven are (Yosifov 1981 and 1997) functional dependencies of E_b on the main structural parameter of SPB – the density ρ_b.

The common form of the regression equation is:

$$\mathbf{E_b = a + a_1\rho + a_{11}\rho^2} \qquad \textbf{(5)}$$

The values of the regression coefficients for five of the most often manufactured thicknesses of SPB are given in Table 1.

Table 1: Values of regression coefficients of the equations for $E_b = f(\rho)$

Board thickness [mm]	**Regression coefficients**			**Statistical relative error Δy [%]**
	a	***a*₁**	***a*₁₁**	
12	-5.11×10^3	10.04	1.80×10^{-3}	1.52
16	-4.80×10^3	9.48	1.41×10^{-3}	1.44
18	-4.30×10^3	8.60	1.25×10^{-3}	1.56
22	-4.16×10^3	8.28	1.12×10^{-3}	1.65
25	-4.02×10^3	7.97	1.04×10^{-3}	1.33

Established also are (Yosifov 1981) functional dependencies of the modulus of elasticity in bending on the bending strength σ_b of SPB with different thicknesses h_b and densities, which are expressed with the summarised equation:

$$\boldsymbol{E_b = k_\rho \times \sigma_b, \text{ at } \Delta y = \pm 110} \qquad \textbf{(6)}$$

where k_ρ is a coefficient taking into account the density of a board with a given thickness h_b.

The approximate values of k_ρ are respectively: 80 for 550 kg/m^3; 120 for 650 kg/m^3; 160 for 750 kg/m^3 and 200 for 850 kg/m^3.

According to the theory of hazardous and allowable stresses, the energetic theory and the investigations of the strength-strain characteristics of composite particleboards (Bryan 1960, Toshev 1967, Küne 1980, Potashev 1982, Nikolaeva 1982, Yosifov et al. 1981, 1997, 2012, etc.), it has been proved that the deformation resistance of SPB is directly dependent on their main structural parameter – density, but also on the geometry of their cross-section, i.e. on the inertia moment *I*.

The optimum macrostructural characteristic of the SPB cross-section is a five-layer composite (Yosifov and Delin 2012). At the same time, the outer layers (surface ones) of the composite board are less than 0.2 mm thick, on account of which they may be ignored in the strength calculations. Therefore, the optimisation of the three-layer macrostructure of SPB is related to the determination of the optimum thickness of the layers. For the purpose, Kolev and Yosifov (1968) propose a solution of one conditional extremum problem related to the determination of the maximum inertia moment *max* I_y with respect to the Y-Y axis of an element of the cross-section of a three-layer SPB (Fig. 2). In Fig. 2, a, the real section is presented as a three-layer rectangle with a base h_b and a height $h_b = 2h_F + h_C$, and in Fig. 2, *b* – the fictitiously transformed rectangle into an equal-area double T-profile.

The maximum inertia moment of the simulation double T-profile of the cross-section of SPB (Fig. 2, *c*) is determined by the equation:

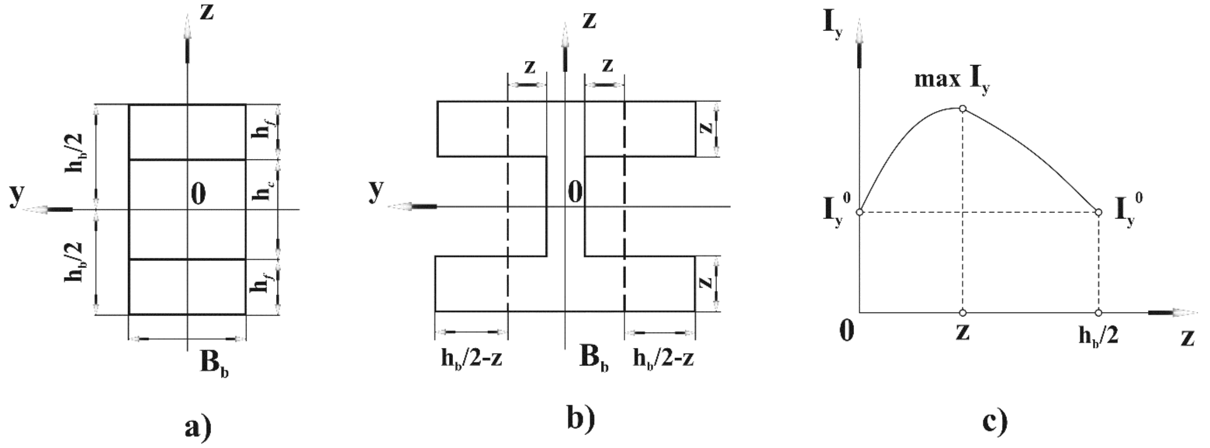
$$I_y = I_y^0 + h_b z\left(2z^2 - 3h_b z + h_b^2\right) \qquad \textbf{(7)}$$

The extremum of I_y as a function of the parameter *z* that is part of the height $h_b/2$ $(0 \le z \le h_b/2)$ is obtained at:

$$z = 1/2h_b\left(1 - \frac{\sqrt{3}}{3}\right) = 0.211 \qquad \textbf{(8)}$$

Then

$$\max I_y = I_y^0 + 0.0962h_b^4 . \qquad \textbf{(9)}$$



a) b) c)

Figure 2: Diagram of construction of a fictitious T-profile of the cross-section of a three-layer SPB: a) three-layer rectangle; b) double T-profile; c) schematic diagram of the dependence of I_y on z

To determine the optimum thickness of the face and middle layers of the composite boards, the established (Yosifov et al. 1997) cover ratio $\lambda_R = 2h_F / h_b = 0.422$ is used. Then, $h_F = 0.211\ h_b$ is obtained for the thickness of the face layers h_F, and $h_C = 0.578\ h_b$ for the thickness of the middle layer, respectively.

The resultant modulus of elasticity in bending of the three-layer SPB may be determined by the Calvert equation (Yosifov et al. 1997):

$$E_b = E_C + (1-\lambda_R)^3 (E_F - E_C), \qquad \textbf{(10)}$$

E_C and E_F are respectively the moduli of elasticity of the middle and face layers.

Under operating conditions, the strain-strength indices of the composite boards vary in the course of time (τ). To assess the deformation resistance of the structural elements made of SPB, the criteria pursuant to EN 1156:1998, viz. continuous load coefficient K_d and creep coefficient K_c, were adopted. The coefficient K_d takes into account the loss of strength during continuously acting load, and the coefficient K_c takes into account the creep of the material and is used to calculate the bending deflection during continuously acting loads with respect to the initial elastic deflection f_0. The determination of the coefficient values is performed graphically.

MAIN CONCLUSIONS FROM THE THEORETICAL PART

- On the basis of the rheological model of SPB, a schematic diagram of the deformations during continuous load was proposed.
- It has been proved that during load in ordinary bending, the stiffness EI_y is a determining index for the strain-strength characteristics of the composite particleboards.
- Functional dependencies of the modulus of elasticity in bending E_L on the density, thickness and layered structure of SPB were presented.
- Dependence of the maximum inertia moment max I_y of an equal-area double T-profile of the cross-section and of the optimum thickness of the face layers h_F of SPB was derived.
- Pursuant to EN 1156:1998, the resistance of SPB against the loss of strength and deflection during continuous load is characterised by the coefficients K_d and K_c, but, simultaneously, there are difficulties during the practical determination of the values of those coefficients.
- Reliable methods for calculation of the stiffness of structural elements made of SPB are missing.

2. AIM AND TASKS OF THE INVESTIGATIONS

The aim and tasks of the investigations have been formulated on the basis of the theoretical treatment in this field and the requirements of the practice.

The aim of this paper is to determine the prognostic strain-strength resistance of SPB during continuous load in a dry environment by means of improved methods.

Subject of the investigations are the following main tasks:

- Development of an adequate and easily accessible algorithm for determination stiffness of SPB.
- Determination of the coefficient K_d for resistance of SPB (minimum loss of strength) during continuously acting bending load.
- Establishment of the creep coefficient K_c, i.e. of the ratio between the prognostic deflection of SPB during continuously acting bending load and the initial elastic deflection.

3. RESULTS OF THE INVESTIGATIONS

3.1. DETERMINATION OF THE STIFFNESS OF SPB

The stiffness is the most important characteristic of SPB, reflecting their suitability as structural materials for application under various operating conditions. It should be noted, however, that there are a number of difficulties for adequate assessment of that index, related both to the macrostructural and morphological characteristic of the composite as a technologically formed heterogeneous material and to the lack of easily accessible methods for its determination. Even in the standardisation documents (EN 19986:2004 – Wood-based panels for use in construction), it is allowed that the stiffness is interpreted as a modulus of elasticity in bending.

It is the usual practice that the stiffness during simple bending *St* is expressed as a product of the indices modulus of elasticity in bending E_b and inertia moment I_y with respect to the co-ordinate axis Y-Y, i.e. $St = E_b \times I_y$. Therefore, the resistance of a structural element made of SPB against deformation stresses during continuously acting load depends both on the nature of the material (E_b) and the geometry of its cross-section (I_y).

The calculated values for the stiffness $St = E_b \times max\ I_y$ of SPB with standard thicknesses of 12, 16, 18, 22 and 25 mm at test piece width of 50 and 280 mm are given in Table 2. The values of the moduli of elasticity in bending have been determined on the basis of the regression equation (5) and the data from Table 1. The maximum inertia moments have been calculated by formula (9) for a simulation T-profile of the cross-section of the boards.

Table 2: Values of inertia moments (*max* I_y) and stiffness (*St*) of structural elements made of SPB

Thickness h_b [mm]	***max* I_y [mm^4]**		**Stiffness *St* [MN.mm^2]**			
	Test piece width *b* [mm]		**At modulus of elasticity in bending E_b [N/mm^2]**			
			for b = 50 mm			**b = 280 mm**
	50	**280**	**2000**	**3000**	**4000**	**6000**
12	9 152	45 112	18.3	27.5	36.6	243
16	23 106	108 442	46.2	69.3	92.4	576
18	34 397	155 898	68.8	103.2	137.6	820
22	65 957	287 800	131.2	197.8	263.8	1 497
25	101 109	426 640	202.2	303.3	404.4	2 196

The data from the table show that the geometric parameters of the cross-section of SPB and, before all their thickness, exercise very strong influence on *max* I_y and *St*. Thus for example, the medium-density boards (ρ = 750 kg/m^3 and E_b = 3000 N/mm^2) with a thickness of 25 mm have more than 10 times higher stiffness in comparison with the boards 12 mm thick.

3.2. DETERMINATION OF THE COEFFICIENT OF RESIS-TANCE OF SPB DURING CONTINUOUS STATIC LOAD

Pursuant to the requirements of ENV 1156:1998, the resistance of SPB to continuous load at a given moment τ is determined through the coefficient K_d expressing the ratio between the level of the breaking stress at that moment $\sigma_{b\tau}$ and the stiffness in short-time bending σ_b, i.e. the relative loss of strength during continuously acting load:

$$K_{d\tau} = [(\sigma_b - \sigma_{b\tau})/\sigma_b]\cdot 100\%, \qquad \textbf{(11)}$$

whereby the following conditions are valid:

- K_d is 50 to 80 % on a scale with a graduation mark of 5 % and refers to a dry environment, i.e. operating class SC1 (20°C temperature and 65% relative air humidity);
- σ_b is an experimentally determinable quantity or with a value corresponding to the standard requirements for SPB with a given type and thickness;
- $\sigma_{b\tau}$ is a quantity with prognostic value that is functionally dependent on the size of the breaking stress at given duration of loading of a structural element made of the composite, with the respective stiffness.

The total duration of the acting breaking load τ, according to the graph in Fig. 1 for the deformation behaviour of the structural elements made of SPB, includes the times of the highly elastic deformation during the short-time starting load $\tau_1 < 60$ min and that of the delayed elastic deformation with viscous flow in the 2nd zone τ_2. For technical calculations with approximate accuracy, it may be assumed that the deformation in this zone is of linear nature. Is has been adopted (EN 1156) that the time of the continuous static load, expressed in minutes, is determined in a logarithmic scale $lg\ \tau$.

According to the investigations by Bryan 1960, Terentyev 1964, Artyuhovskiy 1965, Khrulev 1977, etc., the process of reduction of $\sigma_{b\tau}$ during continuously acting load has two characteristic stages. Initial one – at starting the loading, in which the process takes place with at a very high rate and has a duration of up to 60 min, with $\sigma_{b\tau}$ being reduced to about 80%. The process of reduction of $\sigma_{b\tau}$ during the second stage is relatively slow, with the prognosticated duration being able to exceed 27 years. The stiffness of the composite exercises essential influence on the duration of the breaking load. It has been proved that the prognostic level of stress of composites also depends on their density. Thus, for composite boards with a density of 750 kg/m^3, prognostic level of 50 % is achieved in 10 years, and for boards with a density of 650 kg/m^3 – in about 6 years. For SPB with a density of 850 kg/m^3 – in about 15 years.

To determine the relative loss of strength, i.e. the coefficient of continuously acting load K_d, the regression linear dependence is used:

$$\boldsymbol{K_d = a_0 - a_1\, lg\ \tau}, \qquad \textbf{(12)}$$

where a_0 и a_1 are regression coefficients that, depending on the stiffness of the composites, have values respectively of a_0 = 78 ÷ 80 and a_1 = 2.7 ÷ 3.0 (Khrulev and Martynov 1977).

It is necessary to note that the determined values of K_d refer to loads both along and across the board length at a degree of orientation of particles of up to 15 %.

Of interest for the practice is the prognostic durability of SPB in furniture and building structures depending on the level of stress. For the purpose, most appropriate is to use the graphic dependencies. That is why, a graphic method for quick determination of the approximate prognostic durability of SPB with different densities of SC1 class is presented in Fig. 3.

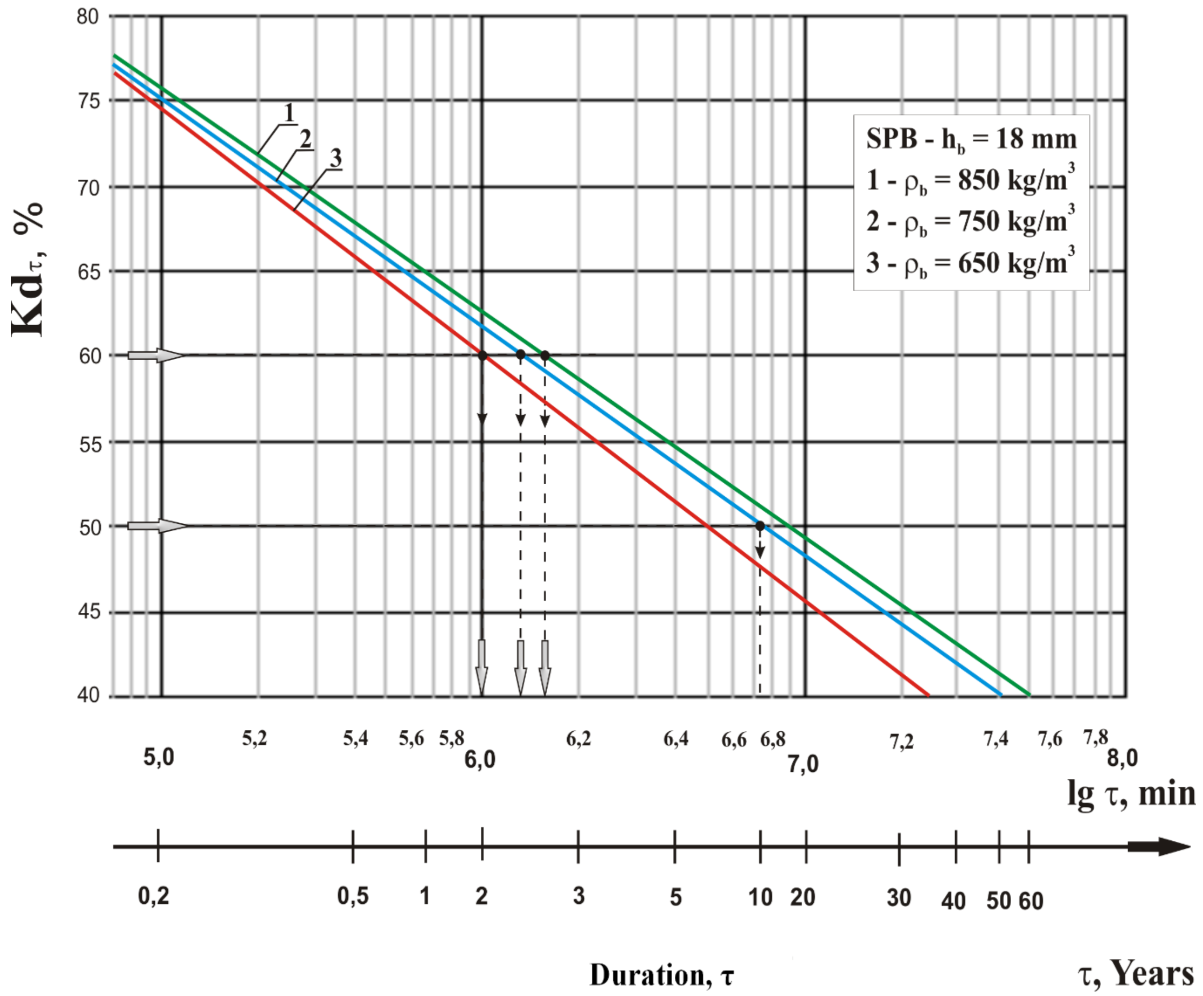


Figure 3: Approximate prognostic durability of SPB of SC1 class at levels of stress K_d of 40 to 80% and board density P5: 1 – 850 kg /m^3; 2 – 750 kg/m^3; 3 – 650 kg/m^3

3.3. DETERMINATION OF THE CREEP COEFFICIENT

One can judge of the variations of deformation over the time by the increase of deflection (material creep), i.e. by the maximum deflection f in the middle of the span at constant continuously acting load q. The dimensionless quantity – creep coefficient K_c, serves to assess the value of the creep pursuant to ENV 1156.

$$K_c = \frac{\left(f_\tau - f_1\right)}{\left(f_1 - f_0\right)}, \qquad (13)$$

where $(f_\tau - f_1)$ is the difference between the deflection after a definite time f_τ and the deflection after one minute f_1 in mm;

$(f_1 - f_0)$ – initial elastic deflection after one minute since the application of the load, in mm;

f_0 – deflection of the test piece without load, in mm.

The prognostic value of the creep coefficient, respectively the deflection during deformation in bending during continuously acting load of SPB depends on the factors: level of stress, load duration, type, stiffness and thickness of the material under the conditions of operation class SC1. An example for a prognostic value of K_c for a duration of 1 year – set span l and level of stress 25 %, is written as K_c, 1Y, SC1, 25 %.

As a result of experimental investigations by Artyuhovskiy 1965, Khrulev and Martynov 1977, Nikolaeva 1981, it has been established that the composite boards, as an elastic body, are slowly destroyed under the impact of continuous static load with a level of stress below 30 % of the short-time one. That is why, the determination of the prognostic value of K_c must be for a level of stress below 25 %, which ensures more smooth, and of attenuating nature, increase of the deformation in bending, which is closer to the real operating conditions.

It has been proved (Kyuchukov and Nikolaeva 1980) that in the horizontal elements of furniture (mostly bookshelves, etc.), subjected to bending load under operating conditions, a process of creep takes place, as a result which the elements sag. The tests have been performed for shelves with a length of 900 mm and a thickness of 18 mm at a loading with a distributed load q = 400 N/m for a duration of 120 days (172 800 min). It has been established the maximum deflection reaches a maximum value of up to 3 mm.

The prognostic maximum deflection f_{max} for 52 weeks of SPB with a density of 750 kg/m^3 and a thickness of 18 mm may be calculated by means of extrapolation from that for 120 days. Grounds for this are the established (Nikolaeva 1981 and Panayotov et al. 2000) very low increase of the deflection rate after the 86th day – below 0.002 mm/day. That is why, with approximate accuracy, it may be assumed that the prognostic deflection for a 1-year period of loading of a horizontal element made of SPB with a density of 750 kg/m^3 with a uniformly distributed load of 400 N/m can be take $f \leq 3$ mm. Moreover, for this composite, the value of the deflection after one minute since the application of the load f_1 = 0.93 mm has been established, and also the deflection without load f_0 = 0.34 mm.

Then, the example value of the creep coefficient K_c for SPB for the conditions 1Y, SC1 and level of stress of 25% according to the calculation (equation 12) is K_c = 3.51.

MAIN INFERENCES FROM THE EXPERIMENTAL INVESTIGATIONS

- An algorithm for determination of the stiffness of SPB has been developed;
- An algorithm and a nomogram for determination of the resistance coefficient of SPB during continuous load – K_d for dry environment, have been developed;
- The value of the creep coefficient K_c of SPB with a density of 750 kg/m^3 and a thickness of 18 mm for operating conditions – dry environment SC1, level of stress of 25 % and duration of 1 year, has been determined.

CONCLUSION

The investigation presented is a contribution to the theory and practice for clarification of the strain-strength characteristics of SPB during continuously acting bending load under operating conditions SC1 (dry environment). The developed mathematical algorithms and graphic methods for determination of the stiffness, coefficients of continuously acting load and creep in static bending may be successfully used in the calculation of the building and furniture structures with application of SPB, as well as for scientific and technical justification of the structural solutions when using these composites.

The investigations may be used with success in the future revision of the standard ENV 1156.

REFERENCES

1. Artyuhovskiy N. K. (1965). Experimental investigation of long-time strength and deformability of particleboards in tension, compression and bending. Scientific papers of Voronezh Institute of Construction Engineering, Voronezh.
2. Yosifov N. (1981). Investigation on the dependence of the modulus of elasticity in bending on the density of different types of industrially manufactured particleboards. Proceedings – 30 Years of the Mechanical Wood Technology (MWT) Speciality, S.

3. Yosifov N. (1984). Optimisation of the density of particleboards. Balkan Scientific-technical Conference (STC), S.
4. Yosifov N. (1987). Effect of process factors on the density of particleboards. STC “Wood-based pressed materials”.
5. Yosifov N. (1990). Investigation on the maximum difference in the layer density of particleboards.
6. Yosifov N., Delin St. (2012). Rational macrostructure of board-type composites made of particleboards. STC, Faculty of Forest Industry, S.
7. Kolev D., Yosifov N. (1968). One optimum problem. Scientific papers of the University of Forestry, S.
8. Kyuchukov G., Yosifov N. (1967). On the bending strength and modulus of elasticity in bending of the particleboards manufactured in our country. Scientific papers of the Higher Institute of Forestry (HIF), Ser. MWT, S.
9. Kyuchukov G., Nikolaeva R. (1980). Investigation on the deflection of shelves made of uncoated and laminated particleboards during long-time static bending load. Journal of Woodworking and Furniture Manufacturing, No. 9, S.
10. Nikolaeva R. (1982). On the behaviour of structural elements of furniture made of particleboards during long-time static bending load. Scientific papers of HIF, S.
11. Panayotov P., Hristova Yu., Rusanov H., Marinova A. (2000). Deformation properties of wood composites made of glued layers. Scientific papers of the Bulgarian Academy of Sciences – Physicochemical Mechanics, S.
12. Potashev O. E, Lapshin Yu. G. 1982. Mechanics of wood-based panels. Forest Industry (FI), M.
13. Toshev B. (1967). Theoretical mechanics. Technica, S.
14. Terentyev V. Ya. (1964). Investigation of mechanical properties of particleboards during impact of short- and long-time loads. STC, Leningrad Institute of Construction Engineering, L.
15. Khrulev V. M., Martynov K. Ya. (1977). Durability of particleboards. FI, M.
16. Bryan E. L. (1960). Bending Strength of Particle Board under Long-term Load. FPJ, No. 4, USA.
17. Dinwoodie J. M., Higgins J. A., Robson D. J., Paxton B. H. 1990. Creep in chipboard. WSci. Techn., USA.
18. Kollmann F., Kuenzi E., Stamm A. (1975). Principles of Wood Science and Technology. N.Y.
19. Küne G., Niemz P. (1980). Untersuchungen zur Struktur von Spanplatten. –Leipzig.
20. Yossifov N., Dinkov B., Miljkovic J., Todorovic P. (1997). Theoretical and experimental prerequisites for optimizing layers thickness of three-layer particle board. 3rd CFWST, Belgrade.
21. ENV 1156. Wood-based panels – Determination of duration of load and creep factors.
22. EN 309. Particleboards – Definition and classification.
23. EN 310. Wood-based panels – Determination of modulus of elasticity in bending and of bending strength.
24. EN 312. Particleboards – Specifications.
25. EN 789. Timber structures – Test methods – Determination of mechanical properties of wood-based panels.
26. EN 1058. Wood-based panels – Determination of characteristic values of mechanical properties and density.