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PROGNOSIS OF MECHANICAL STABILITY OF STRUCTURAL PARTICLEBOARDS BASED ON MODIFIED PHENOL-FORMALDEHYDE RESINS DURING LONG-LASTING STAY IN THE OPEN IN REAL CLIMATIC CONDITIONS

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ABSTRACT

Mechanical stability – relative reduction of modulus of elasticity and stiffness in bending, of structural particleboards (SPBs) based on modified phenol-formaldehyde resins (PFRs) during long-lasting stay in the open in natural climatic conditions has been determined experimentally. The impact of atmospheric effects by varying climatic factors, such as heating, wetting, freezing, insolation, etc., on strain-strength characteristic of SPBs has been established under field conditions.

To assess the mechanical stability of SPBs during long-lasting stay in the open in natural climatic conditions, respective algorithms and a diagram have been proposed. The traditionally used $K_a^E \geq 50$ %, and for the stiffness – $K_a^{St} \geq 65$ %, at a board thickness of 18 ± 2 mm, have been adopted as permissible rate of reduction of the relative modulus of elasticity. SPBs based on PFR modified with aluminium sulphate, in which $K_a^E \geq 50$ % for a 10-year period of exposure in the open has been attained, have shown relatively highest weather resistance. For the boards based on PFR and aluminium sulphate, $K_a^E \geq 50$ % for a 5-year period of stay in the open, but with respect to stiffness, the permissible duration of exposure is considerably lower – under 1.5 years.

Key words: structural particleboards (SPBs); atmospheric effects; long-lasting stay; modified resin; stiffness in bending; module of elasticity in bending.

INTRODUCTION

In recent years, due to the use of binders with increased water and weather resistance, the production of structural composite particleboards (SPBs) of category “3” with respect to use conditions pursuant to ENV 12872:2000 is increasingly expanding. For the purpose, mainly the use of relatively cheap modified phenol-formaldehyde resins (PFRs) is recommended. The weather-resistant SPBs are intended above all for use in building structures exposed to open air, such as: linings under the roof and wall linings, structural members in temporary or mobile residential, farm and storage buildings of short durability, vehicle bodies, containers, etc.

The main reason limiting the wide use of SPBs in the capacity of adequate structural material in construction is the insufficient study of their mechanical resistance to the impact of atmospheric factors.

In view of the above, subject of this investigation is the establishment of the prognostic mechanical stability of SPBs based on modified PFR during long-lasting stay in real climatic conditions. At the same time, this paper is a contribution to the already published investigations by the author et al. on the weather resistance of wood-based composite boards.

1. THEORETICAL PREMISES

Structural particleboards are essentially a technologically formed wood-based polymer product with prevalent participation (more than 80 %) of a wood-based component in the form of adhesively bonded wood particles, synthetic binder and water. The physical essence of SPBs may be defined as a lignocellulosic composite with set hygroscopic and mechanical properties. The participation of the polymer component as a binder ensures, besides the adhesion between the wood particles, to a great extent the water and weather resistance of the composite. For the time being, the production of SPBs with increased weather resistance is most often achieved by densification of their structure and the use as a binder of the relatively cheap resol phenol-formaldehyde resin (PFR) and its modifications. Aluminium sulphate $Al_2(SO_4)_3$ that contains the active complexing agent Al^{+3} intensifying the process of polycondensation of the resin is recommended (Elbert).

The chemical interaction between the synthetic resin and the wood is determined by the reaction of the functional groups of the main components of wood (mainly hydroxyl groups) with the reaction groups of the binder (mainly methylol groups) in the course of which transverse ethereal bonds of methylene bridges related to the reaction of polycondensation of the adhesive (Albert) are formed. At the same time the strength, water and weather resistance of the composite depend above all on the degree of polycondensation of the adhesive.

The mechanical stability of SPBs during long-lasting stay in the open in real climatic conditions is directly related to their weather resistance, i.e. their resistance to different atmospheric effects, such as: insolation, heating, wetting, freezing, etc. The duration and alternation of these effects is of accidental nature depending on the season and the geographic region.

In the investigations by a number of authors (Hann and extr. 1963, Bersenev 1969, Neusser 1970, Kollmann, Kuenzi, Stamm 1975, Khrulev, Martynov 1977, Elbert and extr. 1982, 1984, 1989, Yosifov et al. 1986, 1989, Sedliačik 1995 et al.), it is proved that the atmospheric effects have an adverse effect on the physicomechanical characteristic of SPBs and in the course of time it comes even to destruction of their structure. At the same time, stronger is the effect of combined effects, such as: insolation and heating, wetting and freezing, etc. These effects cause the emergence of moisture stresses, deformations, weakening of the adhesive bonds between the particles, surface cracks, intensive ageing of the polymer and other disturbances in the structure of the wood-based composite materials. Therefore, as a result of the atmospheric effects during long-lasting stay of SPBs in the open, destructive processes that lead to decrease of their mechanical stability emerge and advance in them. Pursuant to the American standard ASTM 1037-64 and according to the investigations by Neusser, Kollmann, Khrulev, Elbert etc., the wood-based panels are considered fit for use in outdoor structures if after a 30-month stay their retain more than 50 % of their initial strength.

It is necessary to note that, irrespective of the numerous investigations on the weather resistance of the wood-based composites, for the time being there are no systematized prognostic evaluation of their mechanical stability (bending strength and modulus of elasticity in bending) during long-lasting stay in outdoor climatic conditions. This is mainly due to the accidental nature of the atmospheric effects in a given area both with respect to duration and with respect to intensity. There are also no investigations on the stability of the stiffness of the composites exposed to outdoor atmospheric conditions.

The prognosis of the mechanical stability of wood-based composites in structures in the open is determined above all by the prognostic stability of their strain-strength indices – stiffness, strength and modulus of elasticity in bending. But, because of lack so far of standardized methods for prognostication of the mechanical stability of SPBs in outdoor atmospheric conditions, we think that it is expedient for the purpose to adopt the main principles pursuant to ENV 1156:1998, i.e. the criterion of relative loss of strength K_a at set duration of the stay τ. In view of the presence of experimentally established (Yosifov 1981) correlation dependence between the bending strength f_m and the modulus of elasticity in bending E_b, valid for calculation of K_a are the relations

$$K_a = (f_m / f_0) \cdot 100 = (E_b / E_0) \cdot 100\%, \quad \textbf{(1)}$$

where f_0 and E_0 are the initial values for the bending strength and the modulus of elasticity in bending.

To determine the prognostic mechanical stability of SPBs during long-lasting stay in real climatic conditions, we propose to use with accuracy sufficient for the practice the linear logarithmic dependence of Khrulev and Martynov

$$K_{a\tau} = a_0 - a_1\ lg\ \tau, \quad \textbf{(2)}$$

where τ is the time of the long-lasting stay in the open, expressed in minutes on a logarithmic scale $lg\ \tau$.

Then, the prognostic time to reach given relative mechanical stability will be

$$lg\ \tau = b_0 - b_1 \cdot K_{a\tau}, \quad \textbf{(3)}$$

where $b_0 = a_0 / a_1$ and $b_1 = 1 / a_1$ are regression coefficients.

1.1. CONCLUSIONS FROM THE THEORETICAL PREMISES

1. The atmospheric effects on SPBs lead to decrease of their mechanical stability and, in the course of time, to their complete destruction.
2. It has been proven that the optimum duration of the stay of SPBs in the open in real atmospheric conditions depends mainly on the binder type.
3. So far, there are no regulatory documents for the determination of the prognostic stability of SPBs during long-lasting stay in the open.
4. It is proposed to adopt the relative loss of strength and stiffness in bending as an evaluation criterion for the prognostication of the mechanical stability of SPBs exposed in the open to real atmospheric conditions.

2. AIM OF THE INVESTIGATION

The aim of this investigation is to propose a method and to make an evaluation of the prognostic value of the decreased mechanical stability of SPBs exposed to long-lasting stay in real atmospheric conditions in case of set period of time and of the time to reach their critical values.

The aim set has been realized with the carrying out of the following main tasks:

- Determination of a suitable criterion for evaluation of the of the prognostic mechanical stability of SPBs exposed in the open in real atmospheric conditions.
- On the basis of experimental data, to make an algorithm for determination of the prognostic stability.
- To develop a nomogram for express evaluation of the prognostic duration of the stay in the open for SPBs on the basis of resol phenol-formaldehyde resin.

3. WORK METHOD

A method and a nomogram for evaluation of the prognostic value of the decreased mechanical stability of SPBs exposed in the open in real atmospheric conditions, which are based on experimental data about the weather resistance of SPBs based on resol PFR, with an average share of 10%, have been developed. The experimental data used related to industrially manufactured SPBs made of hard hardwood (Yosifov et al. 1989). The test pieces were tested on a testing ground facing south, specialized for such investigations, on the land of the training-experimental forestry enterprise in Yundola for 5 years (1984–1989).

The decrease of the modulus of elasticity and the stiffness in bending, expressed with the relations

$$K_a^E = (E_\tau / E_0) \cdot 100\% \text{ and}$$

$$K_a^{St} = (St_\tau / St_0) \cdot 100\% . \quad \textbf{(4)}$$

have been chosen as suitable criteria for evaluation of the prognostic mechanical stability of SPBs in the open in real atmospheric conditions.

To determine the moduli of elasticity E_0 and E_τ, methods standardized pursuant to EN 310 are used.

The stiffness in bending (St_0 and St_τ) has been determined through calculation of an algorithm developed with the use of known formulas from the handbooks of "Strength of Materials" and the specific considerations about their application for SPBs (Yosifov, Delin 2013):

$$St = max\ I_y \cdot E_b, \quad \textbf{(5)}$$

where $max\ I_y$ s the maximum inertia moment of the cross-section of SPBs, modelled in terms of simulation as an I-beam;

E_b – modulus of elasticity in bending.

On the basis of the logarithmic equation (3), a nomogram for express determination of the prognostic duration of the stay of SPBs with a thickness of 18 mm in the open has been developed, taking into account the decrease of the relative percentage loss of mechanical stability with respect to the: 1) modulus of elasticity in bending (K_a^E) of SPBs based on PFRs; 2) modulus of elasticity in bending (K_a^E) of SPBs based on PFRs with hardening system $Al_2(SO_4)_3$; 3) stiffness in bending (K_a^{St}) of SPBs based on PFRs with hardening system $Al_2(SO_4)_3$.

The values of the regression coefficients for the three equations are as follows: for the 1st one – b_0 = 14.4 and b_1 = 0.170; for the 2nd one – b_0 = 15.3 and b_1 = 0.180; for the 3rd one – b_0 = 14.6 и b_1 = 0.167.

Criterion limitations $K_a^E \geq$ 50% and $K_a^{St} \geq$ 65% have been introduced in the nomogram.

4. RESULTS

The results of the performed investigations to forecast the mechanical stability of SPBs in the open in real atmospheric conditions are presented by means of the nomogram in Fig. 1. The prognostic duration of the stay in the open is presented through linear logarithmic dependences of the percentage decrease of the modulus of elasticity in bending for SPBs based on PFRs without and with the use of hardening system $Al_2(SO_4)_3$, and also for the percentage decrease of their stiffness in bending.

The starting initial points of the descending straight lines for the prognostic duration have been conformed to the condition to ensure the necessary time (about 3 months) for stabilization of the sharp changes in the shape and size (mainly in thickness) of the test pieces exposed on the stand. These points correspond to the values of the relative losses of mechanical stability K_a^E and K_a^{St} as follows: K_{a1}^E = 84% for SPBs based on PFRs without hardener; K_{a2}^{E} = 86 % for SPBs based on PFRs with hardening system $Al_2(SO_4)_3$; K_{a3}^{St} = 87 % for the stiffness in bending.

As seen from the graph, the straight lines reflecting the prognostic decrease of the mechanical stability (modulus of elasticity and stiffness in bending) of SPBs are quickly convergent and reach for relatively short time the critical levels 50 % for K_a^E and K_a^{St}. At the same time, the composite boards based on PFRs with hardening system $Al_2(SO_4)_3$ show considerably higher mechanical stability in comparison with the boards based on PFRs without hardener, which is due to the difference in the degree of hardening of the resin, and, moreover, to the action of the active complexing agent Al^{+3}. The thus prognosed duration of the stay of SPBs in the open with the use of PFRs with hardening system $Al_2(SO_4)_3$ reaches 5 years at critical level for K_a^E with 50%, whereas for SPBs with PFRs without hardener the prognostic duration of the stay is only 2 years and 7 months.

At critical level for the stiffness in bending for SPBs based on PFRs with hardening system at K_a^{St} = 65 % the prognostic duration of the stay in the open is 1 year and 4 months, and at K_a^{St} = 50 % it reaches more than 4 years.

CONCLUSION

- The results of the performed investigations show that the effect of the climatic factors during long-lasting stay of SPBs in the open leads to considerable decrease of their mechanical stability – modulus of elasticity and stiffness in bending.
- The mechanical stability of SPBs in the open against atmospheric effects depends to a great extent on the adhesive type and the respective additives. Relatively high mechanical stability of the composite boards based on phenol-formaldehyde resin with hardening system $Al_2(SO_4)_3$ has been established – more than 5 years until reaching the critical level for K_a^E = 50 %.
- Algorithms for calculation of the values of the criteria for evaluation of the mechanical stability of SPBs have been proposed – K_a^E for the relative decrease of the modulus of elasticity and K_a^{St} for the relative loss of stiffness in bending.
- An algorithm and a nomogram for determination of the prognostic duration of the stay of SPBs in the open in real atmospheric conditions have been proposed.

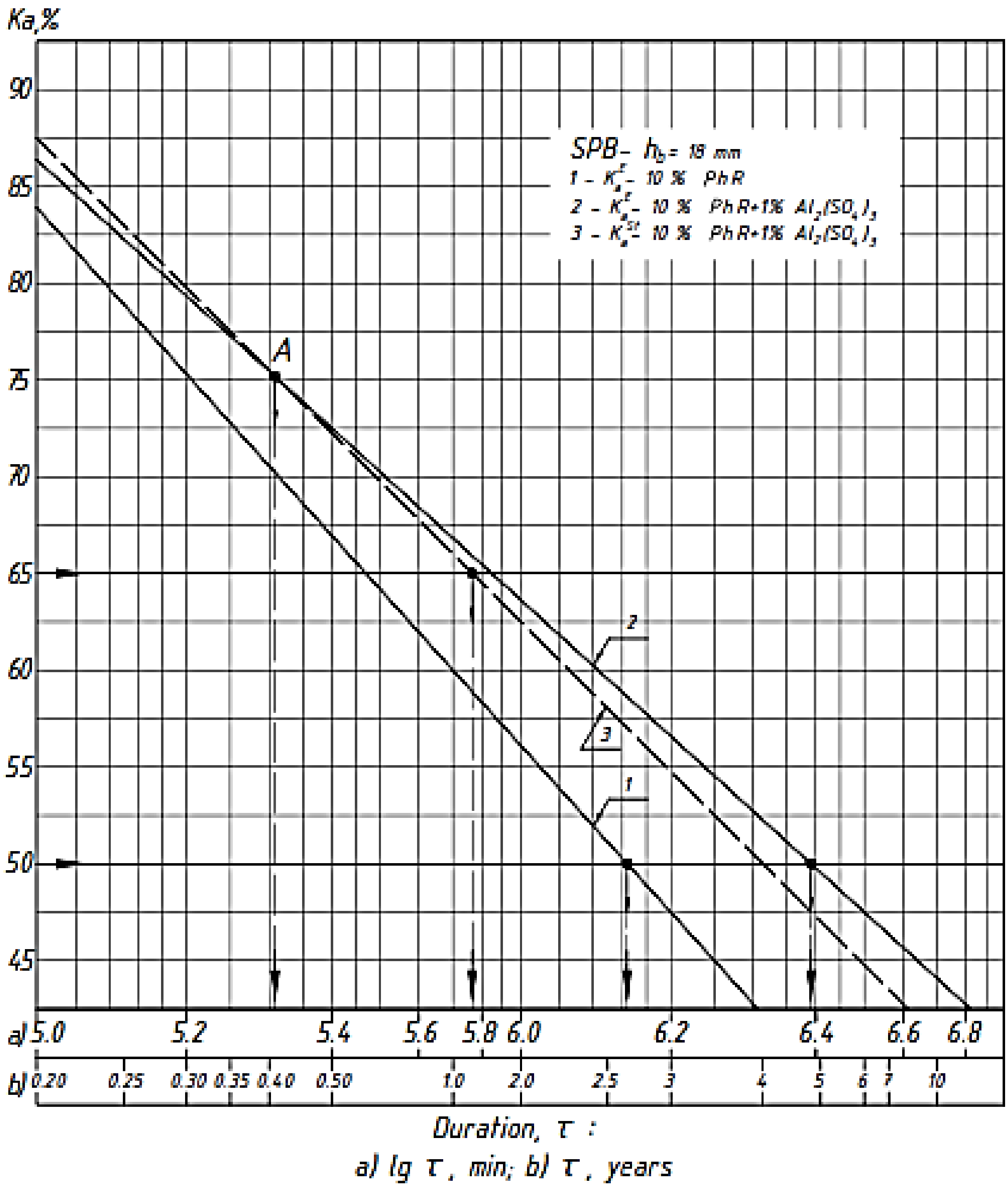

Figure 1: Nomogram for determination of prognostical stay time for structural particleboards during long-lasting stay in theopen under real climatic conditions.

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