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У статтях збірника містяться матеріали наукових досліджень і проектно-конструкторських робіт, спрямованих на вдосконалення технології та техніки лісового господарства, лісової, паперової, деревообробної промисловості та економіки.

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ЗМІСТ

UDC 674.815:631.572 *Assoc. prof. R.O. Kozak – UNFU*

DETERMINATION OF THE EQUIVALENT DIAMETER AND SPECIFIC STRAW PARTICLES SURFACE

The values of the equivalent diameter and specific straw particles surface based on their dimensions, shape and average diameter of sieve holes after sieve analysis of particles were determined. It was graphically described the dependencies of specific straw particles surface of their longitudinal comminution degree, the ratio of length to diameter of particles and the multiplicity coefficient of this ratio.

Keywords: equivalent diameter, specific surface, straw particle, sphericity factor.

Formulation of the problem. When you are making the research of technological processes of drying, pneumatic transportation, resination of crushed particles the great importance is the size, shape and the area of particles, which are expressed of their equivalent diameter (d_e) and specific surface (a), according to formulas [1-4]:

$$d_e = \varphi \cdot d_{\kappa V} = \frac{d_{\kappa V}}{f} = \varphi \cdot \sqrt[3]{\frac{6 \cdot V_ч}{\pi}} = \varphi \cdot \sqrt[3]{1{,}91 \cdot V_ч} \qquad (1)$$

$$a = \frac{6 \cdot \pi \cdot d_{\kappa V}^2 \cdot f}{\pi \cdot d_{\kappa V}^3} = \frac{6 \cdot f}{d_{\kappa V}} = \frac{6}{d_e} \qquad (2)$$

where: φ – sphericity factor; f – a geometric shape factor; $d_{\kappa V}$ – diameter of the sphere, whose volume (V_κ) is equivalent to the volume of the particle ($V_ч$), m.

However, for straw particles which are different in shape from wood particles the values of these parameters are not available. That's why the determination of the equivalent diameter and specific surface of straw particles for further use in technological calculations of straw particleboard production processes is relevant.

Results. The volume of straw particles of certain size can be written as follows:

$$V_ч = n \cdot (V_c - V_n) = 0{,}25 \cdot \pi \cdot n \cdot l \cdot \left(d_c^2 - d_n^2\right) \qquad (3)$$

where: V_c – volume of straw without internal cavity; V_n – volume of the cavity of straw; n – coefficient which taking into account the longitudinal degree of straw particles (n = 1 for tube-shaped particle; n = 1/2 for half tube-shaped particle, etc.); l – length of the straw particle; d_c and d_n – respectively the outer and inner diameters of the straw particles body.

The sphericity factor for straw particles is [5]:

- for tube-shaped straw particles:

$$\varphi = \frac{\left(1{,}5 \cdot l \cdot \left(d_c^2 - d_{ï}^2\right)\right)^{2/3}}{0{,}5 \cdot \left(d_{ñ} + d_{ï}\right) \cdot \left(2 \cdot l + d_{ñ} - d_{ï}\right)} \qquad (4)$$

- for non tube-shaped straw particles:

$$\varphi = \frac{\pi \cdot \left(1{,}5 \cdot n \cdot l \cdot \left(d_c^2 - d_n^2\right)\right)^{2/3}}{0{,}5 \cdot n \cdot \pi \cdot \left(d_c + d_n\right) \cdot \left(2 \cdot l + d_c - d_n\right) + d_c - d_n} \qquad (5)$$

Taking into account formulas (1) – (5) equivalent diameter and specific surface of straw particles respectively is:

- for tube-shaped straw particles:

$$d_e = \frac{3 \cdot l \cdot \left(d_c - d_n\right)}{2 \cdot l + d_c - d_n} \qquad (6)$$

$$a = \frac{4}{d_c - d_n} + \frac{2}{l} \qquad (7)$$

- for non tube-shaped straw particles:

$$d_e = \frac{1{,}5 \cdot \pi \cdot n \cdot l \cdot \left(d_c^2 - d_n^2\right)}{0{,}5 \cdot n \cdot \pi \cdot \left(d_c + d_n\right) \cdot \left(2 \cdot l + d_c - d_n\right) + d_c - d_n} \quad (8)$$

$$a = \frac{2 \cdot \pi \cdot n \cdot \left(d_c + d_n\right) \cdot \left(2 \cdot l + d_c - d_n\right) + 4 \cdot \left(d_c - d_n\right)}{\pi \cdot n \cdot l \cdot \left(d_c^2 - d_n^2\right)} \quad (9)$$

According to formulas (6) and (8) the values of equivalent diameter of straw particles depending on their longitudinal comminution degree (form), the length of the particle, the maximum and minimum diameters of straw and its cavities, which are submitted in Table 1 were calculated. According to formulas (7) and (9) the graphical dependency of diameters influence, length and coefficient of longitudinal comminution degree of straw particles on its specific surface (Fig. 1) were obtained.

According to Fig. 1 the particles with the ratio of length to diameter which is equal to unity when the coefficient of longitudinal degree is minimal have the most specific surface. When the coefficient of longitudinal degree of straw particles increases, its specific surface decreases and reaches a minimum when this coefficient is equal to unity, which corresponds to the tube-shaped straw particle.

Table 1. The value of the equivalent diameter (d_e) of straw particles for certain dimensions and their longitudinal comminution degree

Length of the straw particles, mm	The longitudinal comminution degree of straw particles							
	$n = 1$ (tube-shaped)		$n = 0{,}5$ (half tube-shaped)		$n = 0{,}25$ (1/4 of tube-shaped)		$n = 0{,}125$ (1/8 of tube shaped)	
	max	min	max	min	max	min	max	min
2	2,000	0,667	1,899	0,609	1,808	0,561	1,650	0,484
5	2,500	0,714	2,435	0,687	2,374	0,661	2,260	0,615
10	2,727	0,732	2,688	0,717	2,651	0,703	2,578	0,676
15	2,813	0,738	2,785	0,728	2,758	0,718	2,705	0,699
20	2,857	0,741	2,836	0,733	2,814	0,726	2,773	0,711
25	2,885	0,743	2,867	0,736	2,850	0,730	2,816	0,718
30	2,903	0,744	2,888	0,739	2,874	0,734	2,845	0,723

Note. Diameter of straw: max – 5 mm, min – 1 mm; diameter of straw cavity: max – 3 mm, min – 0,5 mm [6].

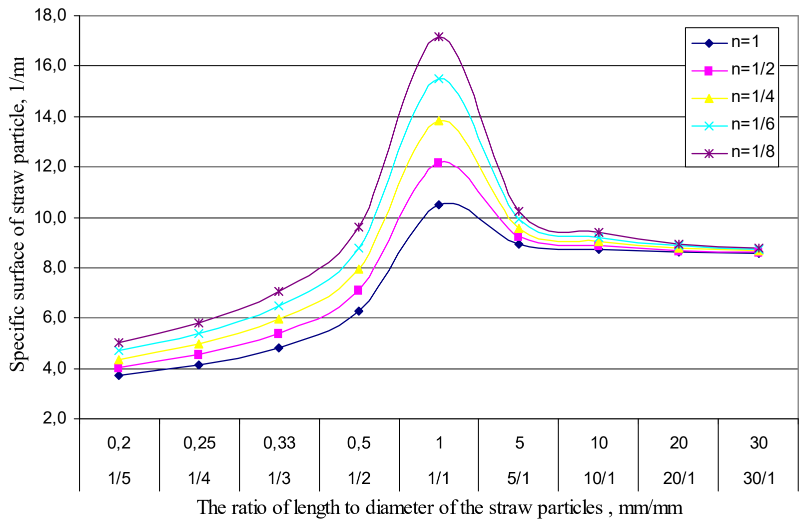

Fig. 1. Dependence of specific straw particles surface of their sizes and longitudinal comminution degree

The increasing of the straw particles diameter when the other parameters are constant causes a rapid decrease of its specific surface. Herewith the ratio of the length to particles diameter is less than unity. When the value of the ratio of the length to its particle diameter increases greater than unity, which corresponds to the particles length increase at constant other parameters, the value of the specific straw particles surface decreases. However, this decrease is less significant than the straw particles diameter increase. An example is the dependence of specific straw particles surface from the multiplicity of its dimensions when the coefficient of longitudinal comminution degree is constant (Fig. 2). According to Fig. 2 specific particles surface decreases with the increasing of their sizes when the coefficient of straw particles longitudinal comminution degree and the ratio of length to diameter of straw particles is constant. Furthermore, the diameter of the particle has greater impact on specific surface then the length of the particle. This dependence is described by the power function.

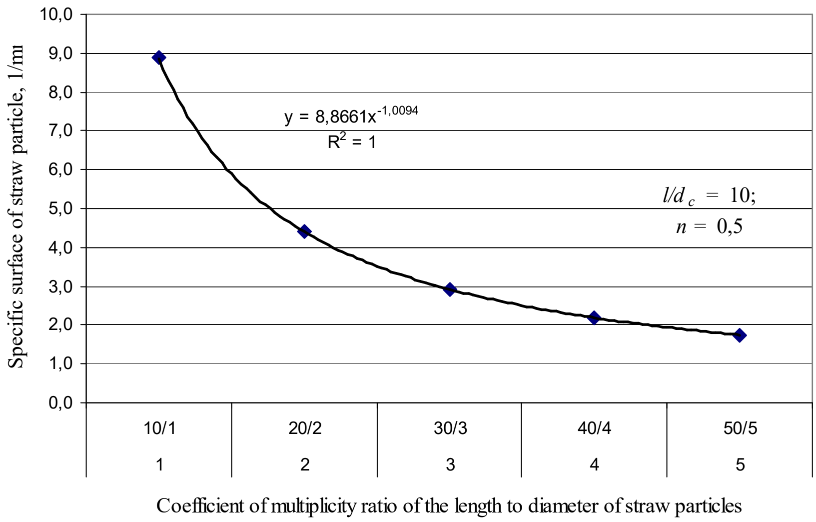

Fig. 2. The dependence of specific straw particles surface from the multiplicity of its ratio of length to straw particles diameter when the coefficient of longitudinal comminution degree is constant

In working conditions of particle boards production is not always possible to determine the size of particle. It is used to operate the fractional composition parameter of the particles, which is determined by sorting. That's why the determination of equivalent diameter and the specific surface of straw particles through the particle properties of separate fraction are important. The equivalent diameter and specific straw particles surface of separate fractions can be calculated by the average diameter of sieve holes where the particles pass, and where the particles are delayed [4, 5]:

$$d_e = \frac{k_V^3}{k_F^2} \cdot d_{o.c} \tag{10}$$

$$a = \frac{6 \cdot k_F^2}{k_V^3 \cdot d_{o.c}} \tag{11}$$

where: k_F – proportionality coefficient between the diameter of the ball which is equivalent to the particle with the same surface ($d_{\kappa\ F}$) and the average diameter of sieve holes where the particles pass, and where the particles are delayed ($d_{o.c}$); k_V – proportionality factor between the diameter of the ball (with the same volume as particle) ($d_{\kappa\ V}$) and the arithmetic mean of two sieves holes diameter through the first sieve particles pass, and on the second one - delays ($d_{o.c}$). Proportionality factors k_F and k_V are defined by the formulas [5]:

$$k_F = 2{,}5387 - 0{,}2762 \cdot d_{o.c} + \frac{0{,}3416}{d_{o.c}}, \qquad (12)$$

$$k_V = 1{,}2491 - 0{,}0527 \cdot d_{o.c} + \frac{0{,}2446}{d_{o.c}}. \qquad (13)$$

Using the formulas (10)-(13) the values of equivalent diameter and specific straw particles surface of the separate factions which are listed in the Table 2 were calculated.

Table 2. The value of the arithmetic mean of two sieves holes diameter, equivalent diameter and specific straw particles surface of the separate fractions

Parameters	Fractions				
	5,0/3,15	3,15/2,0	2,0/1,25	1,25/0,63	0,63/0,315
$d_{o.c}$	4,075	2,575	1,625	0,940	0,473
d_e	2,3833	1,1826	0,6968	0,4188	0,2547
a	2,5176	5,0738	8,6103	14,3281	23,5565

Conclusions. The particles, whose ratio of length to diameter is equal to the unit at a minimum longitudinal degree, have the largest specific surface. By increasing the coefficient of the longitudinal degree, the specific surface of straw particles decreases. When this coefficient is equal to unity, that is the characteristic of tube-shaped straw particle, it reaches a minimum. Increasing the straw particles diameter when the other parameters are constant causes a rapid decrease of its specific surface.

Also found that decreasing of straw particle fractions size causes the increasing of its specific surface. In particular, the decreasing of fraction from 5.0 / 3.15 to 0.63 / 0,315 causes the specific surface increasing of more than 9 times. The obtained values of equivalent diameter and specific straw particles surface, based on the results of calculations of the sieve analysis are equal to the results of the calculations of these parameters by the size and particles form. However, the method of determining the equivalent diameter based on the results of sieve analysis is technically much simpler.

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УДК 674.815:631.572 ***Доц. Р.О. Козак, канд. техн. наук – НЛТУ України***

Визначення еквівалентного діаметра та питомої поверхні солом'яних частинок

Визначенні значення еквівалентного діаметра й питомої поверхні солом'яних частинок за їх розмірами, формою та середньоарифметичним діаметром отворів сит після ситового аналізу частинок. Графічно описано залежності питомої поверхні солом'яних частинок від частки їх поздовжнього поділу, співвідношення довжини до діаметра солом'яних частинок та коефіцієнта кратності цього співвідношення.

Ключові слова: еквівалентний діаметр, питома поверхня, солом'яна частинка, коефіцієнт сферичності.

UDC 674.028.9 ***Assist. V.R. Solonynka, assoc. prof. B.Ya. Kshyvetskyy – UNFU***

WATER EFFECT ON THE STRUCTURE OF ADHESIVE FILMS FORMED BY PVA DISPERSION-BASED COMPOSITION

The results of studies of water effect on the structure of polymeric films formed by modified and non-modified polyvinylacetate dispersion-based adhesives (PVAD-51P trade mark) are given. Also, conclusions have been drawn concerning applicability of PVA adhesives, modified with Fenton reagent or acid-salt complex, for glueing wood parts depending on the usage environment for the produced articles.

Key words: modifying agent, polyvinylacetate (PVA) dispersion, polyvinyl alcohol, spectrophotometer, infrared (IR) spectroscopy, absorption rate, transmission capacity.

Problem formulation. The manufacture of products in joinery, furniture making and other branches of woodworking industry involves application of glueing operations, proper choice of adhesive compositions being of great importance. The choice is primarily influenced, along with economic factors, by the product's intended use and service conditions. However, it is not unfrequent practice in furniture industry to brush aside demands for ensuring appropriate water- and heat resistance of adhesive joints when making articles for indoor area service. It should be noted that such an approach is unacceptable for kitchen furniture, bathrooms as well as wares to be used in unheated housekeeping areas.

For the purpose of ensuring appropriate service characteristics of glued articles, a great variety of PVA dispersion-based composition have been developed in woodworking industry, while a large number of researchers all over the world are engaged in finding ways of enhancing operational performance of adhesive joints [3,4,6,7]. However, despite the fixed interest in this direction of investigations, the majority of the research works give little attention to the study of aggressive environment effects on polymeric films. That is why the objective of this work is to investigate the direct water effect on polymeric films which are formed by modified and non-modified PVA dispersions. This is to be done by studying chemical transformations of their composition by means of infrared spectral characterization of adhesive films transmission capacity.

Methods and materials. The dibutyl phthalate-plasticized PVAD-51P dispersion was chosen as the basis composition to conduct the experiments. Fenton reagent was used as a modifying agent (an oxidation-reduction complex composed of ferrous sulphate (II)($FeSO_4$)) and hydrogen peroxide (H_2O_2, 35%), alternatively was used the mixture of a 30% aqueous solution of nitric acid (HNO_3) and Aluminium nitrate ($Al(NO_3)_3$) as modifying agent. The infrared spectra within the range of wavenumbers of 4000–400 cm^{-1} were measured by means of a Specord – M80 spectrophotometer (produced by Karl Zeiss, Jena, Germany), which made it possible to record changes in the transmission capacity of polymeric films 0.1…0.2 mm thick formed by adhesive compositions under study.

In order to reveal changes in chemical composition of the polymeric films and, as a consequence, changes in their transmission capacity, part of the test specimens had been kept in a water-filled reservoir for 24 hours at a temperature of 20±2°C prior to measuring IR-spectra. The rest of the specimens, designed to taking check measurements, were used to determine transmission capacity of the films without preliminary water-soaking.

Results and discussion. In order to make effective use of modified adhesive compositions, it is essential to know the mechanism of joints formation at the glueing stage, similarly important is a knowledge of glued joint failure mechanism while in operation. A certain information on this area can be obtained not only by way of destructive or non-destructive joint testing [2], but also by investigating adhesive films in conditions similar to the environment in which these adhesive films are to be operated.

When analyzing the mechanism of wood joint formation by PVA dispersion-based compositions, of primary importance are both the number of contact points and the number of groups available for forming hydrogen bonds [1, 4, 5]. This is precisely why compositions containing polyvinyl alcohol which acts as protective colloid (emulsifying agent) have found widespread application in woodworking industry. Polyvinyl alcohol is a substance that contains a large number of easy-to-interact hydroxyl groups (–OH). However, the presence of a certain quantity of such emulsifying agent also leads to negative effects the most important of which is low resistance to direct water contact and high ambient humidity.

To obtain initial data, testing at the first stage was performed on polymeric films formed by PVA-51P dispersion of domestic production. The results of determining transmission capacity of the films prior and after water-soaking for 24 hours are presented in Fig.1.

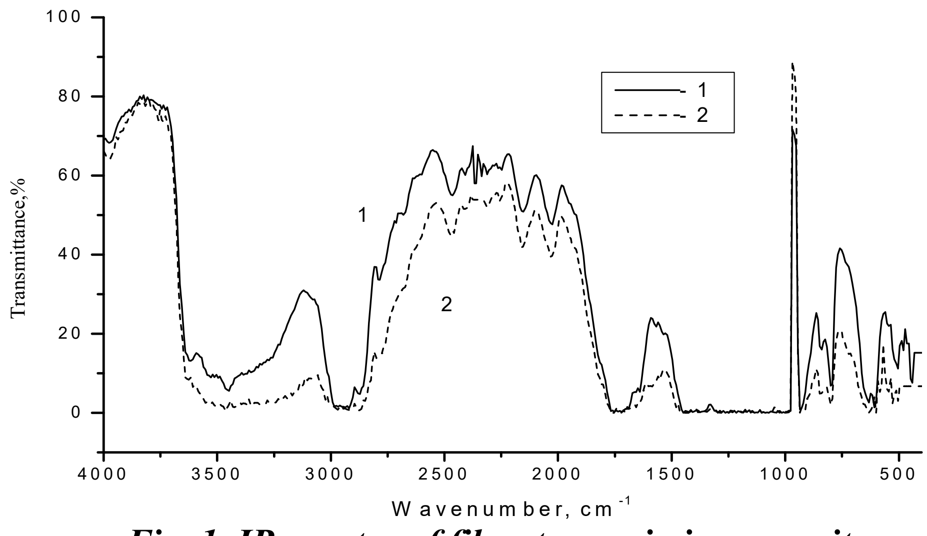

Fig. 1. IR-spectra of films transmission capacity:
1 – PVAD-51P-formed films soaked in water environment at a temperature of 20±2°C for 24 hours; 2 – adhesive films of a check specimens formed by PVAD-51P

From characteristic curves 1 and 2 one can observe a decrease in absorption capacity of films at the wavenumber of 3700–3600 cm^{-1}. Such processes are attributed to the reduction in the number of non-associated alcohol groups (–C–OH) which belong to a great extent to polyvinyl alcohol macromolecules. When comparing the wider portion of IR-spectrum within the wavenumber of 3700–3600 cm^{-1}, one can observe an increase in transmission capacity of the films after water-soaking. This corresponds to a decrease in the share of associated alcohol groups (–OH), which is also confirmed by narrowing half width of the aggregate absorption band at the wavenumber of 3700–2500 cm^{-1}.

Besides, when examining spectral dependences at the wavelength of 3100–3000 cm^{-1}, one can observe an increase in transmission capacity of water-soaked films. Since this zone of the absorption band is conditioned by the presence of (=C–H) groups of dibutylphthalate aromatic rings in the solution, it may be concluded that the quantity of plasticizer in the films after testing also diminishes. Moreover, a spectral analysis at the wavenumber value of 1900–1600 cm^{-1} has shown that the obtained absorption band is decreasing. Such phenomenon can be attributed to a slight decrease in the share of carbonyl groups that enter into the composition of PVAD-51P. Furthermore, since butyl phthalate groups of the plasticizer belong to carbonyl compounds, the increase in transmission capability at the wavenumber of 1900–1600 cm^{-1} is also a confirmation of decrease in its share in the water-soaked films.

Consequently, it may be concluded that the direct contact with water of polymeric films formed by PVAD-51P results in washing-out of hydrophilous emulsifying agent – polyvinyl alcohol (mostly these are macromolecules in the surface layers of the film and are accessible for interaction, as well as macromolecules from the boundary layer), this occurring due to interaction of alcohol groups (–OH) with H_2O molecules. The process of washing-out of polyvinyl alcohol macromolecules favours the removal of plasticizer not only from the surface, but from inner layers as well.

The analysis of the results of spectral studies of adhesive films formed by PVAD-51P and modified with Fenton reagent (Fig.2) show that the pattern of change in absorption capacity prior and after specimens water-soaking is somewhat different for the specimens of non-modified dispersion.

The examination of characteristic curves 1 and 2 (Fig.2) shows no evidence of substantial decrease in films absorption capacity at the wavenumber value of 3700–3600 cm^{-1} (except for the end part of the band absorption arm at wavenumber up to 3600 cm^{-1}), yet the spectral region of the 3700–3300 cm^{-1}wavenumber still shows an increase in the film transmission capacity, while the region of 3700–2500 cm^{-1}shows narrowing halfwidth of the aggregate absorption band for the water-soaked specimens. Such change in spectra pattern points to a decrease in the number of associated groups (–OH) as well as slight decrease in the number of non-associated alcohol groups.

On examination of IR-spectra within the wavenumber of 3100–3000 cm^{-1} (absorption band zone is conditioned by the presence of (=C–H) groups of dibutyl phthalate aromatic ring in the mixture), no decrease is observed in the absorption capacity of the water-soaked films (with the exception of the initial part of the absorption band arm at wavenumber up to 3100 cm^{-1}). Similarly, no substantial increase in transmission capacity is observed for the region within 1900–1600cm^{-1}. This is attributable to the retention in the mixture of the most part of macromolecules with (–C=O) groups which enter into the composition of PVA and dibutyl phthalate, this being true even under the action of water. Therefore, the introduction of Fenton reagent into adhesive composition can produce adhesive films that have better strength characteristics for glued joints with short-term contact with water. This is due to the fact that the rate of film transmission capacity increase in the regions associated with valent oscillation of hydroxyl or other oxygen-containing compounds capable of formation hydrogen bonds is far lower than similar characteristics of films formed by non-modified PVA dispersion.

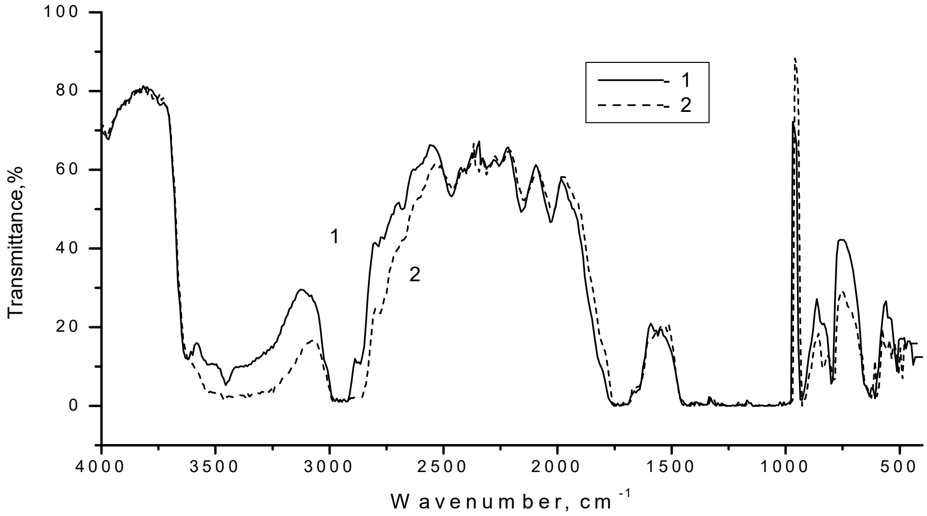

Fig.2. IR-spectra of film transmission capacity:

1 – adhesive film formed by PVAD-51P modified with Fenton reagent and water-soaked at a 20±2°C temperature for 24 hours; 2 – adhesive film of check specimens formed by PVAD-51P and modified by Fenton reagent

That is, even after the direct contact of polymeric films with water, there remain a large number of groups that are capable of chemical interaction (first of all to form hydrogen bonds) with wood components. Practical application of such compositions favors strength retention of glued joints in service. Besides, the direct contact of polymeric films with water does not cause the plasticizer washing-out, which ensures high elasticity of the films. Technologically, plasticizer retention in the film has a positive effect since this prevents from accumulating strains in adhesive joints at alternating loads thus enhancing their durability and operating strength.

The best results, from the standpoint of ensuring high strength characteristics of adhesive wood and wood-based joints glued with PVA dispersions, are obtained by films formed by PVAD-51P compositions modified with a 30% aqueous solution of nitric acid (HNO_3) and Aluminium nitrate ($Al(NO_3)_3$) (see Fig.3).

The examination of characteristic curves 1and 2 (Fig. 3) as well as comparison with the results of similar investigation of other adhesive formulations presented in Figs.1-2 point out that the decrease in the absorption rate of films formed by dispersion modified with acid-salt complex at the wavenumbers of 3700–3300 cm^{-1} is lower than that for the two previous formulations. The narrowing halfwidth of the aggregate absorption band in the region with the wavenumbers of 3700–2500 cm^{-1} is also less due to water action as compared with all other adhesive formulations. Initial characteristic figures when determining absorption capacity of PVAD-51P modified with nitric acid (NHO_3) and Aluminium nitrate ($Al(NO_3)_3$) are the highest of all the three study compositions, while the rate of increase in the films transmission capacity due to water action is the least. Hence, it can be assumed that there is a small portion of oxygen-containing compounds that are capable of forming hydrogen bonds both at the stage of wood adhesive joint formation and during these joints service. Besides, both the films formed by PVAD-51P and modified with Fenton reagent, and those formed by the same dispersion but modified with HNO_3 and $Al(NO_3)_3$ at the wavenumbers values of 3100–3000 cm^{-1} and 1900–1600 cm^{-1}show no decrease in the film absorption capacity. This points to the absence or a slight washing-out of plasticizer from the mixture, which has a positive influence on the strength and performance of adhesive wood joints.

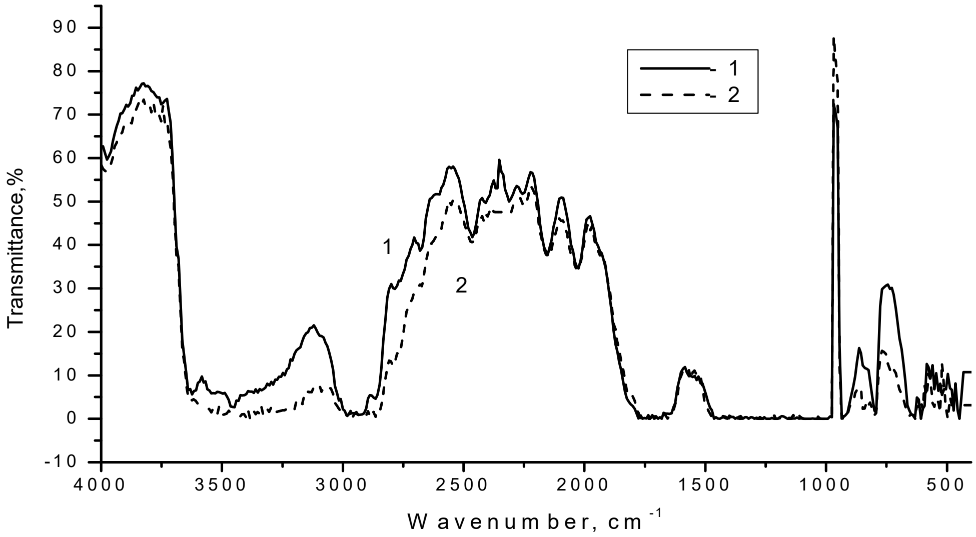

Fig. 3. IR-spectra of film transmission capacity:
1 – adhesive films formed by PVAD-51P composition modified with nitric acid (HNO_3) and Aluminium nitrate ($Al(NO_3)_3$), water-soaked at a 20±2°C temperature for 24 hours; 2 – adhesive films of check specimens formed by PVAD-51P composition and modified with nitric acid (HNO_3) and Aluminium nitrate ($Al(NO_3)_3$)

Conclusions. Based on the examination of the IR-spectroscopy of specimens formed by PVAD-51P prior and after water-soaking at a 20±2°C temperature for 24 hours, it was established that there occurs washing-out of hydrophilous emulsifying agent (polyvinyl alcohol) during its interaction with water molecules, the process taking place both in the surface layers and in the inner layers of the films. This is favored by partial soaking of polyvinylacetate macromolecules. In addition, along with the removal of the emulsifying agent macromolecules, there occurs washing-out of the plasticizer. This results in increasing rigidity and decreased elasticity of the films due to reduced mobility of polymeric basis chains (PVA). The above- described processes, which take place when glueing wood with non-modified PVA dispersion is characterized by a drastic reduction of joints strength resulted from direct contact with water, increased rigidity and brittleness, which is also due to accumulated stress set in the glue line.

On analyzing IR-spectroscopy curves for films formed by PVA dispersions and modified with Fenton reagent or with the mixture of nitric acid and Aluminium nitrate, it was found that although the specimens water-soaking for 24 hours results in polyvinyl alcohol washing-out, this rate of washing-out is lower than that for non-modified specimens, while the plasticizer removal from the mixture, except for the surface layers, does not take place. That is why modified PVA dispersions are useful in formation of wood and wood-based joints for those articles which are to be used in the environment with possible short-term water influence or ambient long-term high relative humidity. Also, the comparison study of different adhesive composition formulations, whether the study films were exposed to water or not, has shown that the best indexes of absorption capacity within the range from 3700 cm^{-1} to 2500 cm^{-1} in the regions with the presence of associated and non-associated (–OH) hydroxyl groups in the layers are referred to those specimens that are formed by PVAD-51P dispersion modified with 30% aqueous solutions of nitric acid (NHO_3) and Aluminium nitrate ($Al(NO_3)_3$). In practical terms this means it is precisely this kind of composition that is able of forming the most durable and water-resistant adhesive joints.

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Вплив води на структуру клейових плівок сформованих за допомогою композицій на основі ПВА дисперсій

Наведені результати досліджень впливу води на структуру полімерних плівок отриманих з модифікованих і немодифікованих клеїв на основі полівінілацетатної дисперсії марки ПВАД-51П. Зроблені висновки щодо можливостей використання ПВА клеїв модифікованих реактивом Фентона або кислотно-соляним комплексом в залежності від можливих умов експлуатації сформованих ними виробів.

Ключові слова:модифікуючі добавки, полівінілацетат, дисперсія, полівініловий спирт, спектрофотометр, ІЧ-спектроскопія, інтенсивність поглинання, пропускна здатність.

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OPTIMIZATION OF MOISTURE AND TEMPERATURE EFFECTS ON STRENGTH AND DURABILITY OF THERMOPLASTIC ADHESIVE WOOD JOINTS

Presented is optimization methodology, also a gradient method is proposed to estimate optimum values of atmospheric moisture and ambient temperature effects on strength and durability of thermoplastic adhesive wood joints. By means of the proposed gradient method and methodology as well as mathematical modeling stress-strain state of bonded wood joints, the optimization of atmospheric moisture and ambient temperature influence on strength and durability of thermoplastic adhesive wood joints under operating conditions has been carried out. Optimum values for atmospheric moisture content and ambient temperature have been established for operation of thermoplastic polyvynilacetate-based adhesive wood joints.

Keywords: thermoplastic polyvvynilacetate glues, glue connection, mathematical model, optimization, durability, longevity.

Thermoplastic polyvvynilacetate-based adhesives are widely used for bonding wood parts in fabricating millwork and structural members, furniture items, parquet work and furniture panels as these types of adhesive have good gluing properties concerning wood and wood-based material, they form non-dense netted and elastic glue line which is environmentally safe and easier to make bonding. Wood joints obtained by means of such adhesive can take loads of D3-D4 degrees according to the European standard EN DIN 204. In Ukraine, thermoplastic polyvvynilacetate-based adhesive with D3-D4 degrees of load came into use for gluing wood and wood-based material comparatively not long ago. It should be noted, however, that the level of their usage, both in Ukraine and abroad, is rapidly rising and, as of today, is equal to 25 % of the total amount of adhesives used for glueing wood and wood-based material. That is why the studies and prediction of strength and durability of thermoplastic polyvvynilacetate-based adhesive wood joints are of importance today.

The author of the article has proposed mathematical models for prediction (1) strength and (2) durability of thermoplastic adhesive wood joints depending on atmospheric moisture and ambient temperature [1, 2, 3]

$$\sigma = -A^{(i)}\Delta T^{(i)} + B^{(i)}\Delta W^{(i)} \exp(-\alpha^{(i)}\tau^{(i)}); \tag{1}$$

$$\tau^{(i)} = \frac{1}{C^{(i)}} \cdot \ln\left(\frac{B^{(i)} \cdot \Delta W^{(i)}}{\sigma_{гран.} + A^{(i)} \cdot \Delta T^{(i)}}\right), \tag{2}$$

where: $\Delta T^{(i)}$ – the average ambient temperature, °C; $\Delta W^{(i)}$ – the average atmospheric moisture, %; $\sigma_{\text{гран. (boundary)}}$ – the boundary strength of wood joint; the parameters $A^{(i)}$, $B^{(i)}$, $C^{(i)}$ are dependent on the temperature and moisture variation.

In order to construct the mathematical model, methods of mathematical modeling heat-and-mass transfer, the results of studies on physical-and-mechanical characteristics of thermoplastic polyvvynilacetate glue film were applied. Performed was modeling the process of moisture transfer in wood as a basic structural material of adhesive joints, which is dependent on cyclic effect of atmospheric moisture. Moisture content change in glued wood was mathematically described for varying and harmonic conditions of the environment, also it was established that such changes depend on the specimen geometry, thermal-and-physical properties of the wood as well as the atmospheric moisture and ambient temperature [4, 5].

The proposed model provides means of predicting strength and durability of thermoplastic adhesive wood joints taking into account the cyclic effect of atmospheric moisture and ambient temperature irrespective of the adhesive type used and trade mark of the producer and regardless of the specific temporal rate and the particular moisture-temperature environmental conditions [6, 7, 8]. Also, the prediction of strength and durability of thermoplastic adhesive wood joints by means of mathematical modeling makes it possible to identify the change in strength or durability for thermoplastic adhesive wood joints during the service time, but it does not allow for determining optimum parameter values of operational conditions of glued wood joints.

Therefore, in order to determine the optimum effect of atmospheric moisture and ambient temperature on strength and durability by means of mathematical modeling, optimization of the temperature and moisture effects on strength and durability of thermoplastic adhesive wood joints under operating conditions has been performed.

A gradient method was applied to solve the task in hand [9, 10].

It is a difficult task to perform optimization of the temperature and moisture influence on strength and durability of thermoplastic adhesive wood joints as it is difficult to describe moisture and temperature measuring of the environment in various regions.

That is why the optimization was performed according to the results of the obtained mathematical model and prolonged experimental studies.

$$\sigma_{op} = -A_1^{(i)}\Delta T^{(i)} + B_1^{(i)}\Delta W^{(i)}\exp(-C_1^{(i)}\tau^{(i)}); \tag{3}$$

where: $A_1^{(i)} = \alpha_1 \exp(-\beta_1\tau^{(i)}) + \gamma_1$; $B_1^{(i)} = \alpha_2 \exp(-\beta_2\tau^{(i)}) + \gamma_2$; $C_1^{(i)} = \alpha_3 \exp(-\beta_3\tau^{(i)}) + \gamma_3$;

The objective function $R = \sum_{k=0}^{\tau(i} \left(\sigma_{op}^{(k)} - \sigma^{(k)}\right)^2 \to \min$; (4)

where $k = (\tau_{поч.}^{(i)} - \tau_{кін.}^{(i)})$

The following restrictions are imposed: The strength at the beginning of each $\Delta\tau^{i}$ – time interval is to be higher than the final one in this time interval.

$$\sigma_{op} = (\alpha_{k^*}^{(i)}, \beta_{k^*}^{(i)}, \gamma_{k^*}^{(i)} \geq \sigma^{(i)}), k^* = 1,2,3; \tag{5}$$

At each next moment, the strength is not to be higher than the set boundary strength in the previous interval $\sigma_{op} = (\alpha_{k^*}^{(i)}, \beta_{k^*}^{(i)}, \gamma_{k^*}^{(i)} \geq \sigma^{(i-1)}, k^n = 1,2,3.$ (6)

The task is solved by gradient method for the time interval $\tau_{поч.}^{(i)} \leq \tau \leq \tau_{кін.}^{(i)}$ for each i-set.

The realization of optimization task involves:

- a choice of initial parameter values of the optimization $R(\alpha_k, \beta_k, \gamma_k)$, which corresponds to the value $A_1^{(i)}, B_1^{(i)}, C_1^{(i)}$; at the initial instant $\tau^{(i)}$, obtained by the mathematical model;
- determination of components $\frac{\partial R}{\partial \alpha_k}; \frac{\partial R}{\partial \beta_k}; \frac{\partial R}{\partial \gamma_k}$ of gradient vector of function $R(\alpha_k, \beta_k, \gamma_k)$;
- computing the values $R(\alpha_k, \beta_k, \gamma_k)$ and the components of gradient vector of $R(\alpha_k, \beta_k, \gamma_k)$ for initial values;
- set parameter λ to find descending pitch to the optimum of function $R(\alpha_k, \beta_k, \gamma_k)$;
- realization of locating algorithm α_k, β_k, γ_k $R(\alpha_k, \beta_k, \gamma_k)$ in the iteration process

$$R^{(j)}(\alpha_k, \beta_k, \gamma_k) = R^{(j-1)}(\alpha_k, \beta_k, \gamma_k) + \lambda \cdot \text{grad } R^{(j-1)}(\alpha_k, \beta_k, \gamma_k), \tag{7}$$

where (j) is the initial number of the iteration:

- determination of components of vector $R(\alpha_k, \beta_k, \gamma_k)$ at the previous points of the iteration process.

In order to calculate partial derivatives in each j-iteration, approximation relation are employed:

$$\frac{\partial R}{\partial x_k} \approx \frac{\Delta R}{\Delta x_i} = \frac{R(x_i + \Delta x_i, y_1, \ldots y_m) - R(x_1, \ldots, x_n, y_1, \ldots y_m)}{\Delta x_i} \tag{8}$$

$$\frac{\partial R}{\partial y_k} \approx \frac{\Delta R}{\Delta y_i} = \frac{R(x_i + \Delta x_i, y_1, \ldots y_m) - R(x_1, \ldots, x_n, y_1, \ldots y_m)}{\Delta y_i} \tag{9}$$

In the gradient method, the absolute value of parameter λ is set arbitrary and is constant for all k-iterations. However, with decrease in values |λ| the accuracy of the problem solution is higher, and number k is high.

The sigh of value λ is determined by the character of the unknown extreme value of function $R(\alpha_k, \beta_k, \gamma_k)$ / To calculate max $R(\alpha_k, \beta_k, \gamma_k)$ a positive number λ is taken, while to find min $R(\alpha_k, \beta_k, \gamma_k)$ – negative number.

An expression for finding vector grad $R(\alpha_k, \beta_k, \gamma_k)$ can be written as follows

$$\frac{\partial R}{\partial \alpha_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)}) \exp(-\beta_1 \tau^{(i)}); \quad \frac{\partial R}{\partial \beta_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)})(-\tau^{(i)}) \exp(-\beta_k \tau^{(i)}); \quad \frac{\partial R}{\partial j_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)}).$$

Thus, the algorithm of the optimization of temperature-moisture influence on strength and durability of thermoplastic adhesive wood joints has been constructed based on gradient method.

Optimum values of atmospheric moisture content and ambient temperature, at which thermoplastic adhesive wood joints will have the highest durability, have been calculated, a diagram of the moisture content and temperature effects on thermoplastic adhesive wood joints has been constructed.

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УДК 674.028.9.004.15:519.216.3 *Доц. Б.Я. Кишивецький, д-р техн. наук – НЛТУ України*

Оптимізація впливу вологості і температури на міцність і довговічність термопластичних клейових з'єднань деревини

Наведено методику оптимізаційної задачі та запропоновано градієнтний метод для розрахунку оптимальних показників впливу вологості та температури навколишнього середовища на міцність і довговічність термопластичних клейових з'єднань. За допомогою запропонованого методу і методики та математичного моделювання напружено-деформаційного стану з'єднань деревини, здійснено оптимізацію впливу вологості і температури навколишнього середовища на міцності та довговічність термопластичних клейових з'єднань деревини під час експлуатації. Встановлено оптимальну вологість і температуру навколишнього середовища для експлуатації термопластичних полівінілацетатних клейових з'єднань деревини.

Ключові слова: термопластичні полівінілацетатні клеї, клейове з'єднання, математична модель, оптимізація, міцність, довговічність.

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DEVELOPING SOFTWARE FOR MODELLING THE STRENGTH OF BIAXIALLY STRESSED WOOD

An algorithm and the software for modelling the strength of biaxially stressed composite materials have been developed.

Keywords: algorithm, strength criterion.

Introduction. An important problem when rationalizing the selection of the criterion for the short-term strength of wood is constructing the curves of the short-term strength of biaxially stressed material according to the given strength criteria for the purpose of their verification in the particular case. Nowadays, for composite anisotropic materials, the class of which includes wood, there are more than 10 criteria of strength, namely those of R. Mises, A. K. Malmeister, K. V. Zakharov, Goldenblatt-Kopnov, E. K. Ashkenazi etc. However, the main criterion tested on wood is Ashkenazi's criterion, which does not fully reflect the strength peculiarities of materials under combined stress. According to the data in [1], this criterion adequately describes mainly the limit stress state of hardwood. It cannot be employed to define the strength of softwood.

The problem is therefore relevant. One way of solving it is analyzing the curves of strength constructed for each of the abovementioned criteria from such viewpoints: a) the strength surface in case of the combined stress state of the composite material, namely wood, in stress space should be gradual, closed, smooth and convex; b) the correlations between the strength characteristics of the composite material should satisfy the so-called Goldenblatt-Kopnov's heuristic principle according to which, if at least one constant of the material changes, the new surface of strength should be located inside or outside the initial one.

These are the crucial conditions for the verification of the existing strength criteria. If during the adaptation of some of the criteria at least one of these conditions is not satisfied, then such a criterion is unreliable and deserves no further attention.

Problem. The analysis of the existing strength criteria for biaxially stressed composite anisotropic materials has shown that their mathematical models are the implicit functions of two variables:

$$F_m(\sigma_t, \sigma_r) - F_m^* = 0, \quad (1)$$

where: σ_t , σ_r are the main components of the stress tensor; F^*_m – the threshold limit value of the function $F_m(\sigma_t , \sigma_r)$.

Therefore, the problem of constructing the curves of strength according to the given criteria of strength (1) consists in constructing the lines (contour lines) of the function of two variables.

The algorithm of constructing the contour lines of the function of two variables. In order to solve the problem, an algorithm has been suggested, the application of which involves the following steps:

- tabulating the function of two variables

$$f(\sigma_t, \sigma_r) = A\sigma_t^2 + B\sigma_t\sigma_r + C\sigma_r^2 + D\sigma_t + E\sigma_r, \quad (2)$$

- with tabulation steps $\Delta\sigma_t$ and $\Delta\sigma_r$;
- finding for the fixed values σ_t such values of argument σ_r for which the following conditions are satisfied:

$$f(\sigma_t, \sigma_r) > 0, \text{ and } f(\sigma_t, \sigma_r + \Delta\sigma_r) < 0, \quad (3)$$

$$f(\sigma_t, \sigma_r) < 0, \text{ and } f(\sigma_t, \sigma_r + \Delta\sigma_r) > 0; \quad (4)$$

- choosing from the pair of numbers σ_r and $\sigma_r + \Delta\sigma_r$ such a number for which the absolute value of function $f(\sigma_t , \sigma_r)$ is minimal;
- constructing the curves of strength by the obtained coordinates of points (σ_t , σ_r).

The results of the practical application of the algorithm and their analysis. The suggested algorithm is applied as program code in development environment Microsoft Visual Studio 2010, and the results of its practical application are shown in Fig. 1.

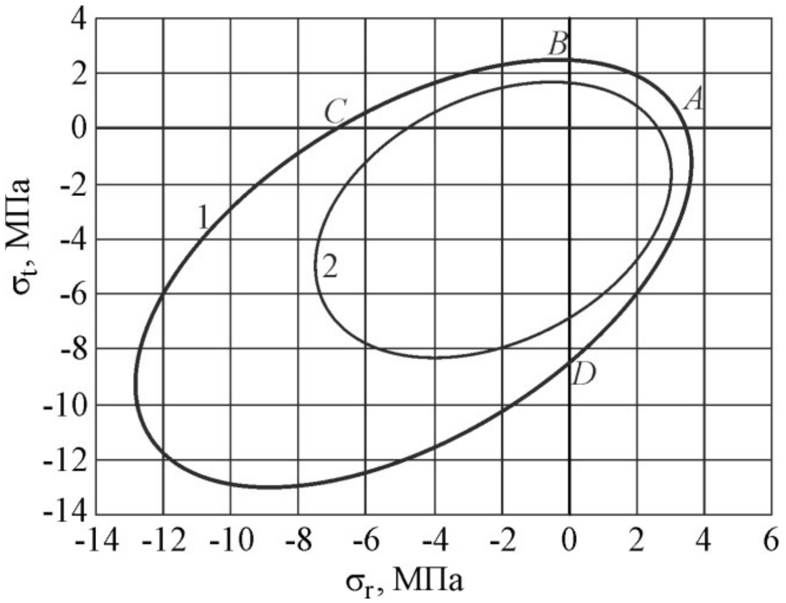

Fig. 1. The curves of the short-term strength of pine wood with temperature T=20°C, relative humidity W, and biaxial stress states in the radial-tangential plane of structural symmetry: *1 – W=12%; 2 – W=18%*

Conclusions:

1. An algorithm and the respective software for constructing the curves of strength of biaxially stressed wood have been developed.

2. Based on the analysis of the software application results, it has been shown that the strength of pine wood is adequately described by Goldenblatt-Kopnov’s criterion.

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Розроблення програмного забезпечення для моделювання міцності деревини з двовісним напруженим станом

Розроблено алгоритм та програмне забезпечення для моделювання міцності композитних матеріалів з двовісним напруженим станом.

Ключові слова: алгоритм, критерій міцності.

UDC 674.023.0 ***Assoc. prof. M.M. Kopanskyy – UNFU***

PRODUCTION OF WOOD-BASED COMPOSITES MADE FROM RAPE STRAW WASTES

The article deals with the analysis of the component structure, the structure of plant material made from rape stems in terms of prospects of their use in the manufacture of particle board or other composite-based materials. It has been presented the basic technological aspects of production of wood-based composite materials using rape raw materials and some of their physical and mechanical property indicators.

Keywords: wood-based composites, particle boards, plant based raw materials, physical and mechanical properties, rape stem.

The current state of the issue. Wood is considered to be a traditional raw material for production of wood-based composites. The intensity of global deforestation and its impact on the environment has been forced manufacturers of these products to search for alternative sources of raw materials. This is mainly lignocellulosic raw materials of agricultural production, straw in particular. One of the main factors that hinder the use of straw as a raw material for the production of wood-based panels is the presence of wax with a rather complex chemical composition. The fact is that wax is not scattered throughout straw mass as it is in the case of wood but it is almost entirely spread on the surface of the stem. The formation of such a layer of adhesive coatings on the surface of the straw prevents wetting of the particle surface and impede bonding.

Research results. Equally with the use of straw as one of the most promising types of plant material for the production of wood-based composite materials (WCM) there is a stalk of rape. Rape raw is an extremely valuable oil crop but it can be also as one of the elements of resources in the manufacture of these materials. The chemical composition of the stalks of rape is like wheat straw but they have a number of ***peculiarities*** (Table 1). It should be noted that stalks of rape are differ from the straw of different crops by their increased thickness and stiffness, and because of that fact they are not applied for traditional agricultural purposes. In contrast to the hollow stalks of rye, rape stalk axial channel is filled with a porous white parenchyma tissue. The shape of the cells in cross section is close to the hexagonal one and transverse dimensions of the cells do not greatly exceed the longitudinal ones. Cellular structure of the parenchymal tissue with its shape and size of cells is different from the stalk wall, so it is can be easily determined the boundaries between the components. In the rape stalk wall capillaries are narrower than in the straw, their diameter is less than 50 microns, with the difference size of 20 microns, that there is less than in the peripheral layer of rye stalks.

Table 1. Component Composition of Different Types of Wood and Plant Raw Materials

Material	Cellulose	Lignin	Pentosin	Resin, Fat, Wax	Ash
Wheat straw	44.3	16.5	26.7	5.22	6.65
Rye straw	45.2	19.3	26.2	5.86	4.63
Rape straw	39.3	18.5	20.2	3.12	10.9
Sawdust	46.1	28.5	10.7	2.93	0.18

Wheat-rye straw is characterized by greater uniformity along the length of the stalk. The most homogenous material is rye raw. The volume of its axial channel is the most part of the stalk volume, its diameter is almost the same along the all length. As for rape, it depends on the part of the stalk (basal, central, top) axial channel capacity is 38.0-54.0% of the total volume of the stalk, density of parenchyma tissue that fills the axial channel is extremely small. The internal parenchyma structure of the rape stalk is characterized by extremely high porosity. The composition of pentosin in the rape parenchyma tissue is 15.3-17.3%. According to general indicators of porosity rape stalks are only slightly inferior to the straw.

Thus, it is presented the comparative analysis of rape and wheat stalks, wheat straw and some properties that allows arrive to the following conclusions: The ripe stalk tissue is characterized by denser and harder structure compared with straw. Based on type and quantitative composition components, rape stalks are close to the rye-wheat straw. In contrast to straw, rape stalks contain a small amount of wax substances. Inner parenchyma tissue of the rape stalk has very high porosity (is considered to be a natural foam plastic). Close to the composition and properties of rape stalks, wheat-rye straw and wood proves its use as a raw material for production wood-based composites. It can be assumed that the low content of wax substances in rape stalks can have a positive impact on the degree of bonding of chipped particles with a binder, i.e. adhesion increases. Because of the fact that rape stalks contain fewer amount of wax substances compared with straw and they are spread throughout the whole volume, the value of adhesion is much larger that positively affects the physical and mechanical properties of composites; that is expanded the raw resources for the production of and save valuable wood material. The manufacture of wood-based composites includes the following operations such as chipping, drying, mixing with glue, mat forming and composite pressing. Raw wood and ripe stalks are separately chipped to obtain wood and rape particles. The particles are fed to the drying operation. The mass ratio between the wood particles and the rape one is 70:30. Prepared mass of wood and rape particles mixed with the glue of urea and phenol formaldehyde resins. Content of resin in the composites is 14% of the absolutely dry particle mass. As for a hardener, ammonium chloride is used. It is in an aqueous solution of 20% concentration in the amount of 1%. After mixing with the glue, a single layer chip mat is formed. The mat is pressed of 3 MPa and a normal air temperature within 1 min and then is fed to the operation of pressing composite. Pressing single layer boards of density 650 kg/m^3 and a thickness of 16 mm is performed under the following schedule: pressure of 2.2 MPa, temperature of 170 °C, duration of 0.38 min / mm (6.14 min). Humidity of finished composites was 8%.

It is experimentally proved that WCM produced by traditional technology with adding layers up to 30% of rape particles have mechanical properties that meet the National Standard of Ukraine (DSSU EN 312-2:2003) (Table 2).

Table 2. Properties of WCM

Tensile strength in static bending, MPa	12,3
Tensile strength perpendicular to the plane of a surface, MPa	0,28
Water, %	85
Swelling, %	32

Wood-based materials produced manufactured with adding more than 30% of the filler material from rape raw of coarse fraction are characterized by a high aesthetic quality and low surface roughness and can be used as faced wall panels without additional mechanical conversion.

Conclusions. Thus, proving rape waste into the manufacture of wood composites allows to expand the raw resources and to reduce the cost of materials and consequently save valuable wood raw material, that is extremely important for rarely forestry regions of Ukraine.

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УДК 674.023.0 ***Доц. М.М. Копанський, канд. техн. наук – НЛТУ України***

Виготовлення деревинних композитів з використанням відходів ріпаку

Проаналізовано компонентний склад, будову рослинної сировини виготовленої із стебел ріпаку з точки зору перспективності їх використання у виробництві стружкових плит та інших композиційних матеріалів. Наведено основні технологічні аспекти виготовлення деревинних композитів з використанням ріпакової сировини та деякі їх фізико-механічні показники.

Ключові слова: деревинні композиційні матеріали, стружкові плити, рослинна сировина, фізико-механічні властивості, стебла ріпаку.

UDC 691.11:674.8:531.717.8 ***Post-graduate I.O. Kiyko – UNFU***

INFLUENCE OF THE STRUCTURAL ELEMENTS’ PLACEMENT OF THE FURNITURE BOARDS ON THEIR SHAPE STABILITY

Furniture boards made from wooden wastes have a number of the significant economic and environmental benefits in relation to their use in furniture and woodworking industries in comparison to the usual furniture boards made from wooden timber which are connecting into furniture boards in size of length using finger ironings and in size to the width – using adhesive on the smooth puffer. One of the possible disadvantages of the furniture boards made from structural elements of small size is a deviation from flatness that sometimes exceeds the permissible value. Comparison of deviation from flatness of furniture boards with directions along and across the fibers for two different schemes for placement of structural elements – parallel and perpendicular was done. Conclusion about better shape

stability for the furniture boards, in which there is perpendicular scheme of the structural elements' location, was suggested.

Keywords: furniture boards made from wooden wastes, deviation from flatness, parallel and perpendicular schemes of structural elements placement.

Rationale. The author of this researches has suggested the design and manufacturing process of furniture boards made from wood waste accumulated during woodworking [1, 2 , 3]. Previous studies have also found [3] that the change in the linear dimensions of the structural elements of furniture board has a significant impact on the deviation from flatness of such board. It is likely that the structural placement of the wooden items in the furniture boards made from wood waste will make the impact on the shape stability of furniture boards [4-7].

Therefore, the objectives of the research presented in this paper are the following.

- Comparison of the absolute values of deviations from flatness defined in direction A and direction B for experimental samples of the furniture boards produced by parallel and perpendicular schemes.
- Comparison of the occasional deviations from flatness defined in direction A and direction B for experimental samples of the furniture boards produced by parallel and perpendicular schemes by testing statistical hypotheses about the homogeneity of variances and homogeneity of the medium values and establish the presence of correlation relations between them.
- Making conclusion in regard to shape stability of the furniture boards produced by parallel and perpendicular schemes.

Methodology of the researching. During the researching, according to the technology [3] furniture boards with various schemes of the structural elements placing were produced with respect to the direction of the fibers (Fig. 1 and Fig. 2).

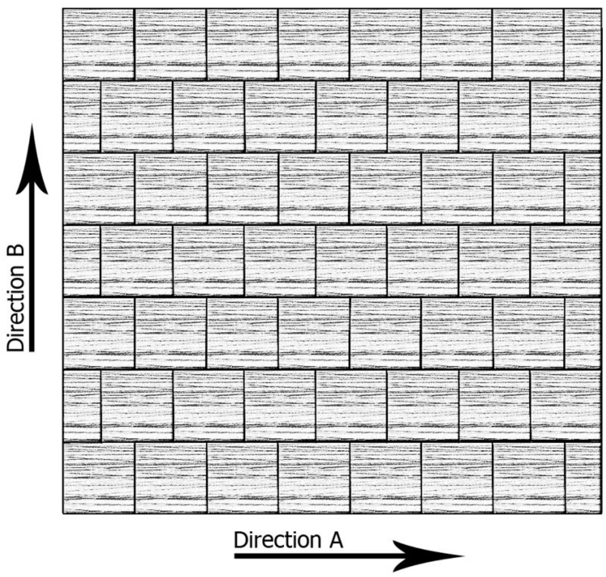

Fig. 1. General view of the furniture board sample №1 *with parallel scheme of structural elements placement*

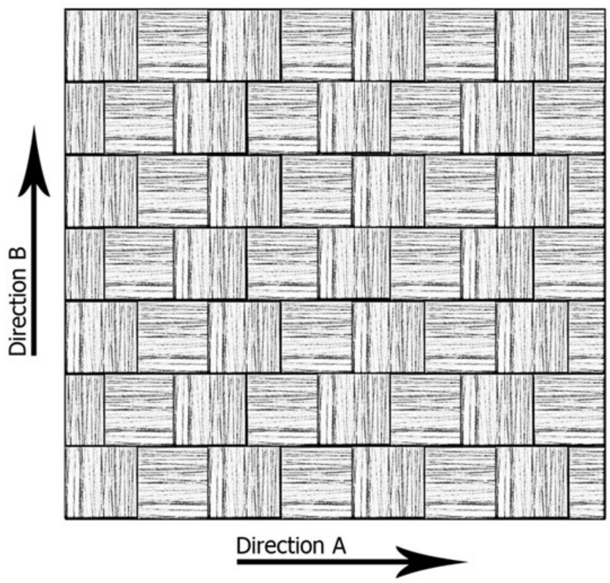

Fig. 2.General view of the furniture board sample №2 *with perpendicular scheme of structural elements placement*

(dimensions of structural elements: L = 40 mm B = 40 mm)

In order to implement experimental studies it was made three samples of two sizes of experimental models of furniture boards produced from solid wood waste of alder (Fig. 1 and Fig. 2) using size 300 × 300 mm. Deviation from flatness measurement was carried out using a numerical indicator ICHTS (3)-25-0,01 (measurement accuracy – 0.001 mm). These data were read by the software produced by the Microtech

(Ukraine)company type UYS-P1-COM and transferred to Microsoft Excel environment for recording and processing. Measurements were removed from the experimental sample furniture boards in two directions (along the fiber direction – direction A, across the fibers direction – direction B). In each of the directions of furniture board measurements were carried out in 6-th conditional lines. As a result, measurements on each line it was recorded from 300 to 360 points. Thus the results of one measurement it received sample of volume from 1800 to 2160 (6 × (300 ... 360)). The experimental deviation from flatness estimated using a mean value of the sample.

Experimental values of the output value (table 1) were obtained as the difference between the mean values of samples obtained for the first and last measurement (in absolute value),moreover the first measurement was carried out after approximately two weeks from the date of the experimental sample furniture board manufacturing and the last measurement was determined by invariance of the deflection (deflection measurement is not continued if the value of the last boom deflection measurement differs from the previous one by no more than 5%). It was conducted four series of measurements in the experiment and deflection value is defined as the difference between the first and fourth experiments. During the researching also tested the statistical hypothesis about dispersion homogeneity and sample averages homogeneity for two samples – a deviation from flatness that was defined in the direction along the fibers (sample 1) and across the fibers (sample 2). The samples were obtained by averaging of the results for each of the six conventional lines for each of the direction of furniture boards with parallel and perpendicular arrangement scheme of structural elements. Testing of the statistical hypotheses about the homogeneity of two dispersions was performed in that order.

1. For two samples with volumes N_1 and N_2it was calculated their dispersion S_1^2 and S_2^2 ($N_1 = N_2 = 355$).

2. The calculated value of the Fisher criterion was calculated as the ratio of more dispersion to less one:

$$F_{cal} = \frac{S_1^2}{S_2^2}, \text{ if } S_1^2 > S_2^2. \tag{1}$$

3. The tabulated values of the Fisher criterion F_{tabl} was selected using distribution tables with Fisher for the selected significance level q and the number of freedom degrees f_1 and f_2.

4. It was compared values of the calculated and tabulated criteria. If $F_{cal} < F_{tabl}$,then the sample dispersionsS_1^2 and S_2^2 were considered as homogeneous and otherwise – it was believed that the difference between them was significant.

Testing of the statistical hypotheses about the homogeneity of average values was performed as follows.

1. It was calculated mean values $\bar{y}_1$and$\bar{y}_2$ for two samples and their dispersion S_1^2andS_2^2.

2. It was calculated the estimated value of Student's criteria:

$$t_{cal} = \frac{\left|\bar{y}_1 - \bar{y}_2\right|}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}, \tag{2}$$

3. It was selected value of the tabulated criteria t_{tabl} from Student's distribution tables using the accepted significance level q and the number of the freedom degrees $f=N_1+N_2-2$.

4. It was compared values of the calculated and the tabulated criteria. If $t_{cal}<t_{tabl}$, the hypothesis of homogeneity of the medium was assumed. Otherwise –it was concluded there is a significant difference between the averages of two samples.

Also it was established the presence of correlation between the magnitude of the deviation from flatness defined in two directions: along and across the fibers using correlation coefficient. Selective correlation coefficient r was calculated from the expression (3) after calculating the average values $\overline{y_1}$ ($y_1=S_l$) and $\overline{y_2}$ ($y_2=S_b$), their dispersion S_1^2 and S_2^2 and standard deviation S_1 and S_2.

$$r = \frac{\sum_{i=1}^{N} (y_{1i} - \overline{y_1}) \cdot (y_{2i} - \overline{y_2})}{(N-1) \cdot S_1 \cdot S_2}. \tag{3}$$

For the determination of correlation relation absence it was calculated value of the calculated Student criteria:

$$t_{cal} = |r| \cdot \sqrt{\frac{N-2}{1-r^2}}, \tag{4}$$

The calculated value t_{cal} was compared with the tabulated value of the Student's criteria t_{tabl}, which was chosen due to significance level q and the number of the freedom degrees of $f = N-2$. If $t_{cal}<t_{tabl}$, the hypothesis about absence of the correlation between two random variables was assumed. If $t_{cal}>t_{tabl}$, it was considered that a sample correlation coefficient is significantly different from zero or in other words, there is a linear statistical relationship between two random variables.

Researching results. Researching results for samples of furniture boards with parallel and perpendicular placement schemes are presented in Fig. 3 and Fig. 4.

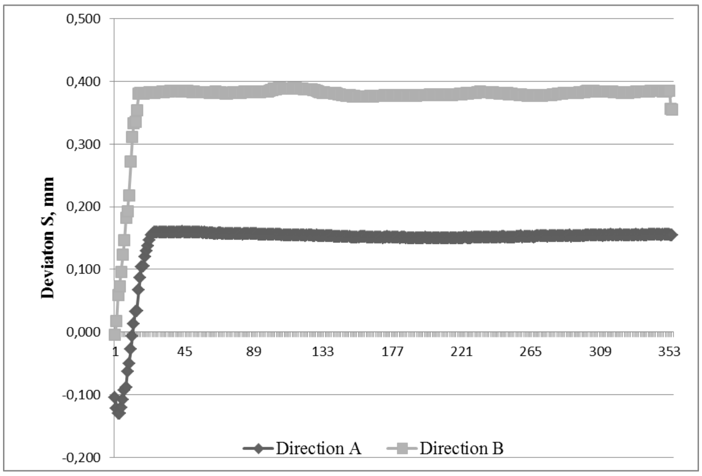

Fig. 3. Value of the deflection (deviation S) for the experimental sample number 1 *(the length of the structural element L = 40 mm, width of the structural element B = 40 mm; placement scheme of the structural elements – parallel in such directions: along (direction A) and across (direction B) fibers)*

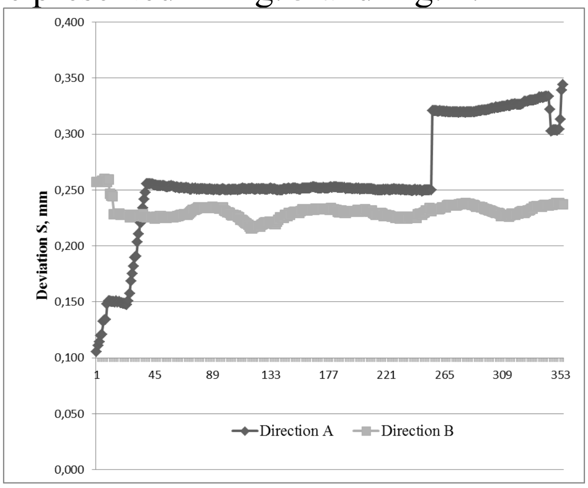

Fig. 4. Value of the deflection (deviation S) for the experimental sample number 2 *(the length of the structural element L = 40 mm, width of the structural element B = 40 mm; placement scheme of the structural elements – perpendicular in such directions: along (direction A) and across (direction B) fibers)*

The results of the statistical test of the hypothesis of homogeneity of the medium of two random variables (deviation from flatness defined in direction A and direction B), which received two aggregate sample which are presented in Table 1.

Table 1. Results of testing of the hypothesis of homogeneity of average of two samples (S_l deviation in the longitudinal and transverse directions S_b)

№ of the experimental sample of the furniture board	Dimensions of the structural elements of the furniture board		Average value of the deviation from flatness S, mm		The relative difference between the values of the deviations in the direction A and Direction B, %	Testing of the hypotheses about the homogeneity of the means for two samples (S_l deviation in the longitudinal and transverse directions S_b)		
						calculated and tabulated value of Student criteria		conclusion about homage of two means
	L, mm	B, mm	in the direction along fibers (dir. A), S_l	in the direction across fibers (dir. B), S_b		t_{cal}	t_{tabl}	
1	40	40	0,144	0,373	160	65,5	1,96	difference between the averages is significant
2	40	40	0,261	0,230	12	12,03	1,96	

As it is shown in the Table 1, in two cases, for various schemes of the structural elements placing the calculated value of Student criterion is more than the tabular value of this criterion and therefore we concluded that the differences between the means of the random deviations from flatness in the directions along and across the fibers is significant and these average values cannot be considered as homogeneous. It should also be noted that the relative difference between the deviations in the directions A and B for furniture boards of the perpendicular placement (sample number 2, Fig. 2) is substantially less than the same difference for furniture boards of the perpendicular placement(sample number 1, Fig. 1.) – 12 and 160%, respectively. The results of the statistical test of the hypothesis of homogeneity of the dispersions (Table 2) showed that the difference between the sample means of two random variables deviations from flatness in different directions is significant for both: for furniture board with parallel arrangement scheme of structural elements and for furniture board with a perpendicular arrangement scheme of these elements.

Table 2. Results of testing in regard to the hypothesis of homogeneity of variances of the two samples (S_l deviation in the longitudinal and transverse directions S_b)

№ of the experimental sample of the furniture board	Dimensions of the structural elements of the furniture board		The average value of the dispersion for deviation from flatness		Testing hypotheses about the homogeneity of the dispersions for the two samples (deviation in the longitudinal and transverse directions)		
					calculated and tabulated values of the Fisher criteria		conclusion about the homogeneity of the two dispersions
	L, mm	B, mm	in the direction along fibers (dir. A), S_l, mm	in the direction across fibers (dir. B), S_b, mm	F_{cal}	F_{tabl}	
1	40	40	0,0021	0,0022	1,06	1,00	heterogeneous
2	40	40	0,0023	0,00005	51,1	1,00	heterogeneous

It should be noted that the relative difference between the average values of the deviations from flatness in different directions in the case of parallel placement makes up 160 %, while a similar difference for perpendicular arrangements of the structural elements makes up only 12 % (Table 1). However, as a result, we concluded that the two samples (for deviation S_l and for deviation S_b) are not the members of the sane total population and the difference between two sample means and sample dispersions cannot be explained by random errors. Obviously, the above described difference is related to the influence of certain non-random factors. Therefore it is logical to assume that the deviation from flatness in the direction along the fibers and the deviation from flatness in the direction across the fibers for furniture boards with different placement schemes – these are two different random variables, characterized by different nature and causes. As shown in Table 3, for the pilot sample furniture board with parallel in regard to the direction of fiber placement of structural elements (sample number 1) between two random variables (deviation from flatness toward the direction A and B) there is a statistical relationship, namely by changing a random variable it will change the distribution of the other one. Also for the experimental sample is likely to assume the presence of a direct line of communication, as the sample correlation coefficient value is positive (Table 3).

Table.3. Results of testing of the hypothesis about the presence of the statistical (correlation) connection between two random variables (S_l deviation in the longitudinal and transverse directions S_b)

№ of the experimental sample of the furniture board	Dimensions of the structural elements of the furniture board		Value of the selective correlation coefficient r for two random values: S_l deviation in the longitudinal and transverse directions S_b	Testing hypotheses about the correlation connection for the two values (deviation in the longitudinal and transverse directions)		
				calculated and tabulated value of Student criteria		Decision about a statistical (correlation) connection
	L, mm	B, mm		t_{cal}	t_{tabl}	
1	40	40	0,94	53,2	1,96	there is linear statistical connection
2	40	40	-0,11	2,05	1,96	

The presence of a linear inverse statistical relation (negative sample correlation coefficient) between the magnitude of the deviation from flatness specified in the direction along the fibers and the corresponding deflection specified in the direction across the fibers it can observe for the experimental sample of the furniture board number 2 (perpendicular to the placement of structural elements). For sample of the furniture board with perpendicular placement of structural elements (Table 2), the calculated value of Student criterion makes up t_{cal} = 2,05which is more than the tabular value of the Student criterion (t_{tabl}.=1,96), which is defined for a significance level q = 0,05 (on the basis of this comparison it was concluded that there is a correlation). It is interestingly, if we take q = 0,01 (to increase uncertainty in the decision of statistical hypotheses from 5 to10%), the value of the tabular value of the Student criterion will increase and will make up t_{tabl}. = 2,58, which will allow in this case to conclude that there is no statistical relationship between deviations from flatness of the furniture boards specified in the directions along and across the fibers.

Conclusions. Thus, as a result of the comparing the deviations from flatness for furniture boards for parallel and perpendicular placement of the structural elements (Fig. 1) it was made the following conclusions.

1. Two samples (deviation from flatness of the furniture board in direction along the fibers S_l and deviation from flatness across the fibers S_b), the two placing schemes of the structural elements (parallel and perpendicular) does not belong to the same total population and the difference between two sample means and two selective variances of these variables cannot be explained by random errors.

2. Relative difference between the average values of the deviations from flatness in different directions (A and B) in the case of parallel placement makes up 160 %, while a similar difference for perpendicular arrangements of the structural elements makes up only 12%.

3. For the experimental samples of the furniture boards with perpendicular arrangement scheme of structural elements, with a significance level q = 0,01, it can accept the hypothesis that there is no statistical correlation between the two these values of the deviations from flatness in the direction A and direction B, that together with conclusion 2 may indicate a better shape stability of furniture

boards with perpendicular placement of structural elements in comparison with similar furniture boards that are made by the parallel scheme.

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УДК 691.11:674.8:531.717.8 ***Аспір. І.О. Кійко – НЛТУ України***

Вплив розміщенняструктурних елементів клеєних щитів на їх формостійкість

Меблеві щити, виготовлені з кускових відходів деревини, мають ряд суттєвих економічних та екологічних переваг щодо використання їх у меблевому і деревооброблювальному виробництвах у порівнянні із класичним меблевими щитами, виготовлених з ламелей шляхом з'єднання у меблевий щит у розмір за довжиною за допомогою зубчастих шипів і у розмір за шириною – за допомогою склеювання на гладку фугу. Одним із імовірних недоліків меблевих щитів, виготовлених із структурних елементів невеликих розмірів є відхилення від площинності, що інколи може перевищувати допустимі значення. дійснено порівняння величини відхилення меблевих щитів від площинності у напрямках вздовж і поперек волокон для двох різних схем розміщення структурних елементів – паралельної і перпендикулярної. Здійснено висновок про кращу формостійкість меблевих щитів, у яких структурні елементи розміщені за перпендикулярною схемою.

Ключові слова: клеєний щит із кускових відходів, відхилення від площинності, паралельна і перпендикулярна схеми розміщення структурних елементів.

UDC 674:630 ***Senior teacher I.Z. Pylypiv; assoc. prof. O.I. Dumanskyy – UNFU***

BUILDING MATHEMATICAL MODELS DEPENDING ON BEND RADIUS FIBER BOARDS CONCERNING ITS THICKNESS AND HYDRATION TIME

Submitted by processing experimental studies necessary for the production of curved pieces of furniture with fiberboard. Found a mathematical dependence studied processes using methods of interpolation and approximation. Presented minimum radius curved pieces of furniture in the thickness of plates and different moisture conditions adhesive.

Keywords: curved furniture element, fiberboard, minimum radius, interpolation, approximation.

Recently, the development of design and construction in order to improve consumer properties of furniture products significantly changed the approach to the formation processes of production and management domain-spatial environment of human life. The design of contemporary furniture unacceptable standard solutions. The important here, individual and small batch projects, the implementation of which must be based on new technologies. Essential in the production of modern furniture elements becomes artistic design, one of the areas in the production of curved furniture items.

To solve the problem of forming the set of bends in furniture elements, currently, we have a very limited number of theoretical - experimental studies. This is due to the fact that the phenomenon that leads to reshape the curved block, you cannot clearly describe the mathematical model, and they are determined to unmanageable, often forcing manufacturers forced condone the advent of low-quality product even in strict compliance with a given technology and accordingly plan the cost of production. In the present work the treatment of experimental studies conducted to construct curved furniture items from fiberboard panels, according to which the mathematical model in the form of empirical formulas for setting minimum permissible bending radii of the furniture elements with different thickness plates [1-16].

For the treatment of experimental studies and construction mathematical dependences, studied processes used methods of interpolation and approximation. In particular, interpolation method is that in most cases to show the functional dependence of the investigated process using polynomials of Lagrange and Newton. However, these formulas have certain disadvantages. In particular, Lagrange's formula is rather cumbersome and not so common, because if there is a need for improved precision interpolation, then the increased experimental values, you must re-perform all calculations, because one of the variables Lagrange's formula does not apply. With respect to Newton formula - there no such problems, it is quite comfortable. However, if the value of the experimental data, which are variables formula arguments, form an arithmetic progression is not always able to get them. We believe that in some cases, do not require high precision convergence of functional dependencies built with experimental, we can interpolate these dependences as a simple polynomial of a certain order, but no higher than fifth, because of the increasing number of nodes is growing and the degree of interpolation polynomial. However, this interpolation polynomial becomes more accurate approximation table function. Moreover, such a polynomial harder to work through his awkwardness. It is important to use the Taylor polynomial interpolation to build dependencies, which can more precisely express a mathematical model of the process. Experimentally investigated fiberboard bending it with the following geometrical characteristics: l-length, h-width, d-thickness of the plate. In addition, $l >> h$ and $l >> d$, that is a plate form the core of certain geometrical dimensions (Fig. 1).

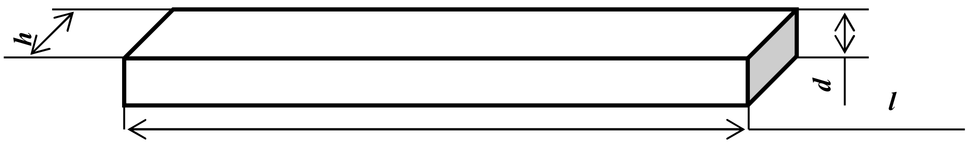

Fig. 1. Experimentally investigated fiberboard

Plate is hinge-reliance and under the influence of the horizontal point load force (Fig. 2).

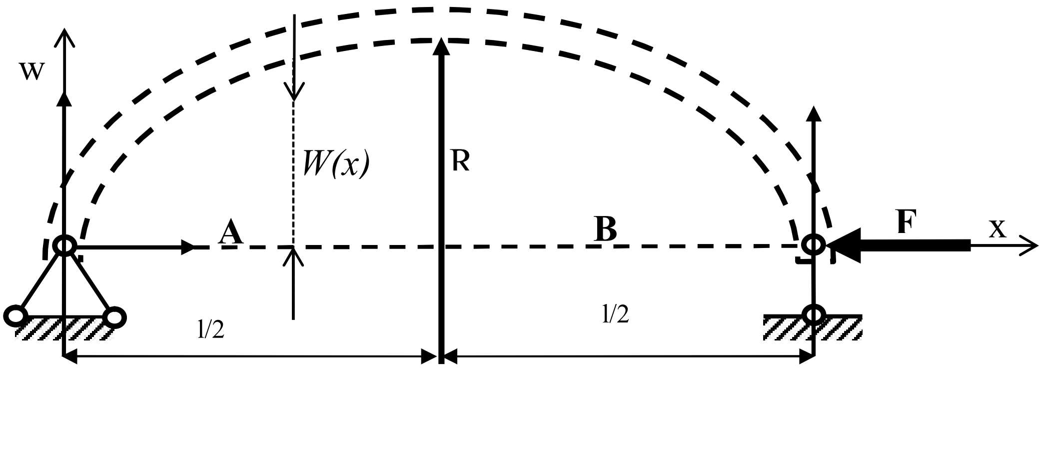

Fig. 2. Plate is hinge-reliance

Are the two processes of wetting adhesive layer plates: a) on the one hand, and b) on both sides. According to experimental studies set the radius R of bending plate depending on the thickness d and time t wetting glue plates, which presented graphically in Fig. 3.

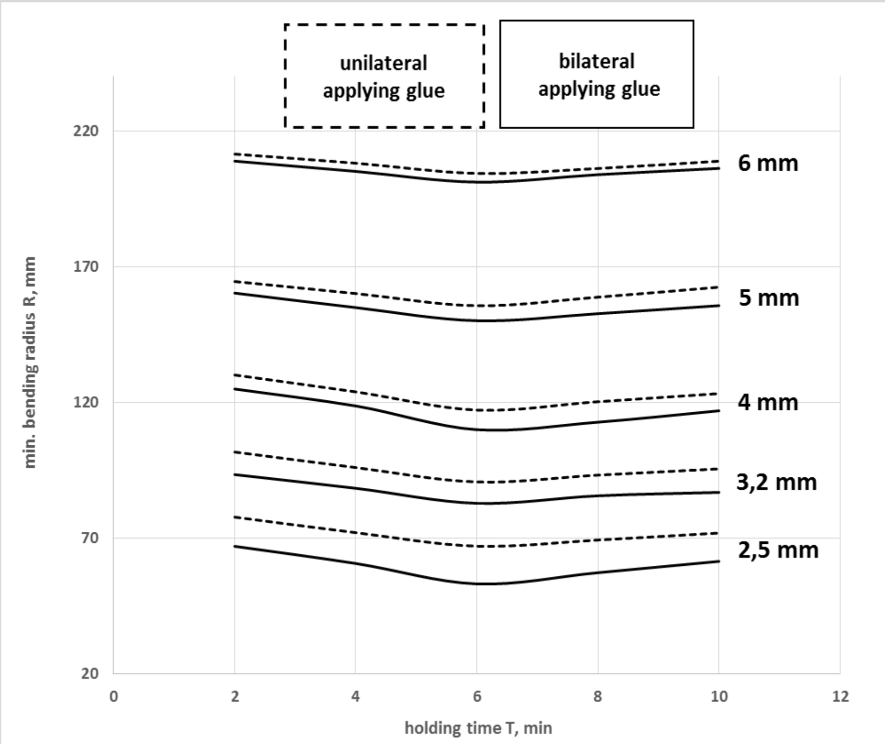

Fig. 3. Minimum bending radius fiberboard panels of different thicknesses

To construct the empirical formula dependencies plate-bending radius R of time t changes wetting glued at the appropriate thickness d of used methods of interpolation and approximation. For polynomial interpolation, used Taylor 4-th order polynomial is the following form:

$$g[x] = a_0 + a_1 \frac{x}{1!} + a_2 \frac{x^2}{2!} + a_3 \frac{x^3}{3!} + a_4 \frac{x^4}{4!} \tag{1}$$

Or for our research in appropriate thickness plates

$$R(t) = a_0 + a_1 \frac{t}{1!} + a_2 \frac{t^2}{2!} + a_3 \frac{t^3}{3!} + a_4 \frac{t^4}{4!} \tag{2}$$

Coefficients a_i ($i=0$-4) approximating polynomial (2) placed under the following system of equations:

$$\begin{cases} a_0 + a_1 \frac{t_1}{1!} + a_2 \frac{t_1^2}{2!} + a_3 \frac{t_1^3}{3!} + a_4 \frac{t_1^4}{4!} = R_1, \\ a_0 + a_1 \frac{t_2}{1!} + a_2 \frac{t_2^2}{2!} + a_3 \frac{t_2^3}{3!} + a_4 \frac{t_2^4}{4!} = R_2, \\ a_0 + a_1 \frac{t_3}{1!} + a_2 \frac{t_3^2}{2!} + a_3 \frac{t_3^3}{3!} + a_4 \frac{t_3^4}{4!} = R_3 \\ a_0 + a_1 \frac{t_4}{1!} + a_2 \frac{t_4^2}{2!} + a_3 \frac{t_4^3}{3!} + a_4 \frac{t_{14}^4}{4!} = R_4. \end{cases} \tag{3}$$

Thus, the following empirical formula (mathematical models) changes the radius of bending plates with unilateral glue wetting:

- ✓ at $d=2,5mm,$ $R = 59.470 + 16.333t - 12.707t^2 + 4.95t^3 - 0.829t^4$;
- ✓ at $d=3,2mm,$ $R = 89.633 + 6.325t - 6.401t^2 + 2.638t^3 - 0.446t^4$;
- ✓ at $d=4mm,$ $R = 115.3 + 35.749t - 25.019t^2 + 9.44t^3 - 1.569t^4$; (4)
- ✓ at $d=5mm,$ $R = 154.733 + 20.042t - 14.462t^2 + 5.513t^3 - 0.913t^4$;

When two sided, adhesive application built following empirical formula:

- ✓ at $d=2,5mm,$ $R = 34.733 + 35.155t - 24.647t^2 + 9.279t^3 - 1.533t^4$;
- ✓ at $d=3,2mm,$ $R = 79.6 + 7.601t - 7.556t^2 + 3.123t^3 - 0.531t^4$;
- ✓ at $d=4mm,$ $R = 96.667 + 37.242t - 26.039t^2 + 9.688t^3 - 1.583t^4$; (5)
- ✓ at $d=5mm,$ $R = 145.3 + 17.897t - 13.55t^2 + 5.242t^3 - 0.875t^4$;
- ✓ at $d=6mm,$ $R = 220.7 + 19.019t - 13.618t^2 + 5.208t^3 - 0.871t^4$.

According built empirical formulas of these relationships by the method of approximation. In this case, these dependences built into a Taylor polynomial, but the second order, as experimentally constructed curves correspond to the form of the quadratic function, according to what was selected approximant as follows:

$$R=c+bt+at^2/(2!) \tag{6}$$

The system of equations for the coefficients of the approximant based on the method of least squares, as a result, received the following system of equations for finding them:

$$\begin{cases} a\sum_{i=1}^{n} t_i^4 + b\sum_{i=1}^{n} t_i^3 + c\sum_{i=1}^{n} t_i^2 = \sum_{i=1}^{n} R_i t_i^2, \\ a\sum_{i=1}^{n} t_i^3 + b\sum_{i=1}^{n} t_i^2 + c\sum_{i=1}^{n} t_i = \sum_{i=1}^{n} R_i t_i, \\ a\sum_{i=1}^{n} t_i^2 + b\sum_{i=1}^{n} t_i + nc = \sum_{i=1}^{n} R_i. \end{cases} \tag{7}$$

Thus, the following empirical formula (mathematical models) changes the radius of bending plates with unilateral glue wetting:

- ✓ at $d=2,5mm,$ $R = 82{,}787 - 5{,}779t + 0.422t^2$;
- ✓ at $d=3,2mm,$ $R = 101.633 - 5.186t + 0.370t^2$;
- ✓ at $d=4mm,$ $R = 161.087 - 7.258t + 0.533t^2$; (8)
- ✓ at $d=5mm,$ $R = 181.853 - 5.316t + 0.42t^2$;
- ✓ at $d=6mm,$ $R = 254.547 - 4.073t + 0.31t^2$.

When two sided, glue application built following empirical formula:

- ✓ at $d=2,5mm,$ $R = 80{,}667 - 7{,}709t + 0.582t^2$;
- ✓ at $d=3,2mm,$ $R = 93.453 - 5.802t + 0.417t^2$;
- ✓ at $d=4mm,$ $R = 146.467 - 8.684t + 0.624t^2$; (9)
- ✓ at $d=5mm,$ $R = 170.213 - 5.722t + 0.429t^2$;
- ✓ at $d=6mm,$ $R = 245.407 - 4.355t + 0.336t^2$.

Deviation values empirical formula as the method of interpolation (formula 4, 5) and the method of approximation (formula 8, 9) is in the range of 3 to 5%.

By the method of approximation was constructed empirical formula depending on the radius R of bending plate, depending on the thickness of the plate d_i at a constant time of exposure coated with glue. In Fig. 4 The geometric interpretation of these relationships at time t = 6 and 10 min.

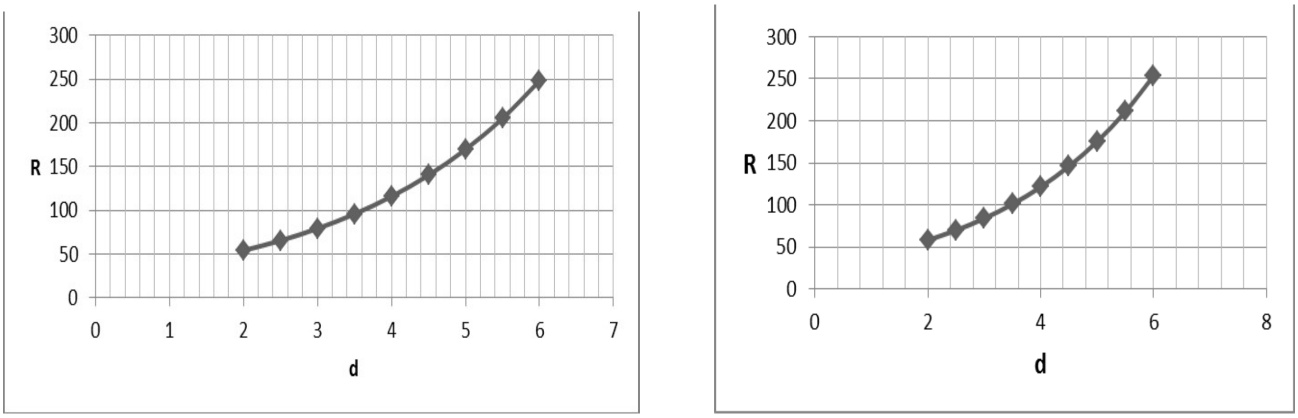

Fig. 4. Radius dependence on the thickness of plate at t = 6 min and t = 10 min

This dependence of the radius *R* of the bending plate of thickness *d* has exponential dependence: $R=be^{ad}$, (10)

Where the coefficients *a* and *b* were approximant according to the following system of equations:

$$\begin{cases} a\sum_{i=1}^{n} t_i^2 + B\sum_{i=1}^{n} t_i = \sum_{i=1}^{n} t_i \ln R_i, \\ a\sum_{i=1}^{n} t_i + nB = \sum_{i=1}^{n} \ln R_i. \end{cases} \quad B = \ln b \tag{11}$$

Thus, the following empirical formula change the radius of bending plates of thickness at a constant exposure time of glue:

- ✓ at *t=6min,* $R = 25.309 \cdot e^{0.381d}$ (12)
- ✓ at *t=10min,* $R = 27.877 \cdot e^{0.368d}$

As we see both qualitative and quantitative changes in radius at various time of exposure of the coated glue did not significantly differ.

According to the methods of differential calculus were set value of time *t* soak glued with unilateral application (Formula 13), and two sided - (Formula 14), in which the obtained minimum value of bending radius *R* plates in their respective thickness *d:*

Sided glue application

- ✓ at *d=2,5mm, t=6,85min, R=63mm,*
- ✓ at *d=3,2mm, t=7min, R=76,95м,*
- ✓ at *d=4mm, t=6,81min, R=136,38mm,* (13)
- ✓ at *d=5mm, t=6,33min, R=165,03mm,*
- ✓ at *d=6mm, t=6,57min, R=241,17mm.*

- double-sided glue application

- ✓ at *d=2,5mm, t=6,62min, R=55,14mm,*
- ✓ at *d=3,2mm, t=6,96min, R=73,27м,*
- ✓ at *d=4mm, t=6,96min, R=116,25mm,* (14)
- ✓ at *d=5mm, t=6,67min, R=151,13mm,*
- ✓ at *d=6mm, t=6,48min, R=231,30mm.*

Analyzing value, we can state that the length of time wetting as one-sided and double-sided and did not differ significantly on the average 7,14 min. With this timing will have the best minimum value of bending radius plates. It should be noted that these values are almost identical with those obtained experimentally; the deviation is about 1 - 2%. For bilateral applying glue on a plate thickness of 2.5 and 3.2 mm. there is a positive change in the minimum bending radius of 6 and 4 mm. respectively, compared with one-sided.

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УДК 674:630

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Побудова математичних моделей залежності радіусу вигину ДВП стосовно її товщини та часу зволоження

Представлено обробке експериментальних досліджень, необхідних для виробництва вигнутих предметів меблів з ДВП. Знайдено математичну залежність, яка вивчає процеси, використовуючи методи інтерполяція і наближення. Представлено мінімальний радіус вигину предметів меблів залежно від товщині пластин при різних умовах вологості клею.

Ключові слова: різьблені елементи меблів, ДВП, мінімальний радіус, інтерполяція, апроксимація.

UDC 674.047

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ANALYSIS OF PHYSICAL FACTORS AFFECTING THE DRYING PROCESS OF LUMBER

An analysis of physical factors affecting the drying process of lumber has been done. Considered is their influence upon the drying rate and qualitative characteristics of the dried wood material. Also methods of moisture removal from wood have been examined. Described are equations for heat-

moisture conduction. Also an analysis of these equations has been carried out. The characteristic patterns of moisture movement within wood have been considered.

Keywords: wood, lumber, humidity, pressure, gradient, temperature, heat conduction, evaporation, moisture, moisture transfer, moisture content.

Introduction. Green lumber that has not been properly dried is not suitable for further use. To facilitate effective use of wood material, excess water should be removed from the wood, that is, a drying process is to take place the purpose of which is changes in the lumber's physical and service properties due to its moisture content change. Drying of lumber is a physical process of moisture removal based on the process of heat-moisture exchange. When warm air comes into contact with moist wood material, the thermal energy is transmitted to the wood and the moisture is changed into water vapour for evaporation process to take place. As a result of this process, the performance figures of lumber change making this lumber suitable for furniture making and construction purposes [5-13].

Dry lumber has higher mechanical strength, it is more resistant to the attack of fungi and insects, and wood products have good shape and dimensional stability.

Drying of lumber is a complex physical process whose peculiarities and characteristics are conditioned by a number of physical phenomena. Drying of lumber requires energy to evaporate the moisture from the lumber and the environment which would be capable of absorbing the water vapour, also it is necessary to ensure air circulation for transferring the vapour. Free water is the first to evaporate during the process of lumber drying. All the free water having been evaporated, the lumber reaches the so-called the fiber saturation point (FSP). The moisture content at FSP ranges from 20 to 35% depending on wood species. The moisture remaining in wood below FSP is called bound water. The removal of bound water from lumber requires much higher consumption of energy than evaporation of free water.

Discussion and results. Lumber drying results from moisture movement from the inner layers towards the surface layers. Drying of lumber consists of the following processes:

- evaporation of water from the surface of the lumber into the environment;
- moisture movement from the inner layers towards the surface layers.

The drying process starts with the surface moisture evaporation immediately after the wood comes to be exposed to the ambient air. The surface evaporation creates moisture gradient that increases in the direction towards the centre.

Green wood, in addition to hygroscopic water which is chemically and physically bound with the cell walls, normally contains free water which is held in the cell cavities (Lumina) and intercellular spaces [2]. Heartwood of conifers has a moderate moisture content (W=31-35%), sapwood is noted for its high moisture content (W=120-160%). Lumber of hardwood has higher moisture content (W=80-90%, for example poplar wood has W=212%), while there is no pronounced difference in moisture content between sapwood and heartwood [3]. Moisture content in lumber of softwoods is higher for upper parts of the tree due to a predominance of sapwood there, while lumber of hardwoods does not exhibit essential distinction in moisture content in this respect. Normally, the moisture content in wood is lower as the tree grows older, that is why lumber produced from young trees has higher moisture content than that produced from mature trees. As a rule, uneven-aged forests yield lumber of higher moisture content than even-aged forests do, while lumber from coppice forests is of higher moisture content than that of high forests [4].

Anisotropic nature and anatomic structure of wood influence the moisture movement in different directions relative to the wood grain. Moisture conduction is the least in the tangential-to-the grain direction. Moisture conduction in the parallel-to-the grain direction is 15-20 times higher than in the tangential-to-the grain direction [1].

By using expression (1), it is possible to determine the relationship between water conduction in the tangential (a_T) and radial (a_r) directions:

$$\frac{a_r^{'}}{a_T^{'}} = 1 + \frac{2L}{100\%} , \qquad (1)$$

where L is the volume of woodrays voids.

For water evaporation to take place, it is necessary that the surrounding air should be unsaturated, while to ensure internal moisture movement toward the surface layers, as well as toward the inner layers moisture gradient should be maintained. The evaporation process occurs by Dalton's Law according to which vapour (like all gases) moves in the air in the direction toward the region of minimum pressure, and the evaporation rate is proportional to the pressure difference of water vapour at the surface zone [5]. The law (2) for the total pressure of gas mixture

$$P = \sum_{i-1}^{n} p_i = p_1 + p_2 + ... + p_n . \qquad (2)$$

The law (3) for solubility of gas mixture components $m_i = \frac{p_i}{P}$, (3)

where P is the pressure.

But Dalton's formula for determining the amount of evaporated (condensed) moisture in capillars is unsuitable to use due to considerable difficulties associated with determination of mass-transfer coefficient and mass-exchanger area.

The moisture gradient ensures the movement of water and water vapour within lumber from zones of higher to zones of lower moisture content. The patterns (4) of such movement are called moisture conduction

$$i_H = -a^{'} \rho_0 \frac{dU}{dX} , \qquad (4)$$

where $a^{'}$ is the coefficient of moisture conduction; ρ_0 is the density of oven dry wood.

Moreover, the moisture conduction inside lumber can be caused by temperature gradient due to which moisture moves from warmer towards cooler layers of wood. The movement rate grows up as the temperature gradient increases.

The rate of internal moisture movement is controlled by the moisture and temperature gradients inside the lumber. In most cases, this rate, except for wood with very high moisture content, is conditioned by moisture gradient, wood density, temperature. On the other hand, elevated temperatures lead to lower mechanical strength and counter stresses that occur in lumber during the drying process, these are minimal at moisture content above the FSP. The movement of moisture inside lumber depends on its permeability for moisture and vapour, that is, the structure of wood. Moisture can be transported through cell lumina, through vessels of hardwoods and also through intervessel pitting with opening in the membranes [3].

The driving force for moisture movement is due to the presence of force gradient of surface tension in wood capillary meniscus and, at time, this mechanism is due to manifestation of liquid osmosis, as well as gas diffusion in the direction of vapour pressure gradient in the cavities of the surrounding cells.

The presence of pressure gradient inside lumber is responsible for molar vapour movement. This pressure gradient causes no uniform distribution of the movement rate. The occurrence of such pressure is attributed to moisture evaporation from capillary and vessel voids at elevated temperatures [5]. The capillary and vessel voids present rather a confined (sealed) space and, therefore, the water vapour is not easy to get into the atmosphere, which result in pressure build-up. The movement (5) of water vapour and liquid water due to the pressure inside the capillars and vessels as well as the movement intensity can be described by the following equation:

$$i_p = -b\frac{dP}{dX}, \quad (5)$$

where: b is the coefficient of moisture molar transfer; $\frac{dP}{dX}$ is the pressure gradient in wood material.

Provided that all the three driving forces (6) are involved, the expression will take the following form:

$$i_\Sigma = -a' \rho_0 \left(\frac{dU}{dX} + \delta \frac{dT}{dX} \right) - b\frac{dP}{dX} \ . \quad (6)$$

The diffusion rate of vapour through cell lumina, open vessels and pores is thousands times greater than that for other types of flow, thus ensuring a very high rate of drying green lumber, this is especially true when interior boiling occurs.

Moisture movement is going on as long as free water is present in the surrounding cells [4]. After the removal of free water, the cell walls will contain only bound water (hygroscopic water) the movement of which occurs at the expense of water molecules transfer through the cell walls in the direction of moisture concentration gradient as well as due to water vapour diffusion through cell lumina in the direction of vapour pressure gradient [2]. Free water and vapour contained in cell lumina and intercellular spaces also move in accordance with the mechanism for molecular movement through cell walls. Permeability of wood by gases and liquid decreases with wood's higher density, increased number of growth rings, with presence of secreting gums and resins [4].

The increase in diffusion rate at the expense of moisture concentration gradient is somewhat limited due to reduced wet ability of oven dry wood, which might block the moisture permeability, that is, occurrence of casehardening and formation of water pockets. Diffusion rate increases with temperature rise, while lower temperatures slow down the diffusion rate. The evaporation rate is a function of the ambient temperature and relative humidity. The evaporation rate increases with increasing temperature and decreased atmospheric relative humidity [3]. The evaporation rate remains steady provided that the temperature and moisture conditions are constant. The heat-moisture conduction is a complex physical process. The moisture movement occurs in the liquid and gaseous states and the driving forces are vapour partial pressure as well as the liquid pressure in capillars.

The equation for heat-moisture conduction (7) takes the following form:

$$i_t = -a' \rho_0 \delta \frac{dT}{dX}, \quad (7)$$

where δ is the coefficient of heat – moisture conduction; dT/dX is the temperature gradient in wood.

Heat-moisture conduction in capillary-porous substances consists of capillary heat-moisture permeability, relative thermal diffusion of liquid and vapour.

The coefficient of heat-moisture conduction is linearly proportional to temperature rise. The absolute value of the heat-moisture coefficient decreases with increased moisture diffusivity or molecular diffusion. The moisture gradient, which is produced by heat-moisture conduction, varies proportionally with the temperature gradient [5]. The water flow caused by heat-moisture conduction will also take in additional amount of heat to move in the direction of the main heat flux.

Conclusions. Based on the literature source, the analysis of the drying process of lumber has shown that moisture movement within lumber is due to the presence of three driving forces: moisture content gradient, temperature gradient, internal pressure.

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Аналіз фізичних закономірностей процесу сушіння пиломатеріалів

Проведено аналіз фізичних закономірностей, які впливають на процес сушіння пиломатеріалів. Розглянуто їх вплив на швидкість на якість висушеного матеріалу. Розглянуто методи видалення вологи з деревини. Описано рівняння вологопровідності та термовологопровідності. Проведено аналіз цих рівнянь. Розглянуто принципи руху вологи в середині вологої деревини.

Ключові слова: деревина, пиломатеріал, вологість, тиск, градієнт, температура, теплопровідність, випаровування, волога, вологоперенесення, вологовміст.

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SOFTWARE DEVELOPMENT FOR DETERMINATION OF STRESS FIELDS IN THE WOOD WITH A PARABOLIC DISTRIBUTION OF MOISTURE

The task of determination of the flat tense consisting is in-process decided of radiality-tangentiality plane of anisotropy of wood with the uneven distributing of moisture. On the basis of method of Ritca an algorithm and software is developed for the calculation of components of tensor of tensions in saw-timbers with the parabolic distributing of moisture. The algorithm of description is given in it is given in a verbal form. The program is realized in the environment C++ with the use of visual components.

Keywords: Ritz method, the stress field.

At the stage of constant rate drying saw in the plain stress state is flat , the value of the axial component of the stress tensor is almost negligible. Therefore, to determine the allowable differences in moisture drying saw limited mathematical model of stress in plain board with plane stress condition in the radial plain structural symmetry. The components of this model are:

equilibrium equation
$$\begin{cases} \dfrac{d\sigma_x}{dx} + \dfrac{d\tau_{xy}}{dy} = 0 \\ \dfrac{d\sigma_y}{dy} + \dfrac{d\tau_{xy}}{dx} = 0 \end{cases} \qquad (1)$$

adjacency equation
$$\frac{d^2\varepsilon_x}{dy^2} + \frac{d^2\varepsilon_y}{dx^2} = \frac{d^2\Upsilon_{xy}}{d_x d_y} \qquad (2)$$

Hooke's law for incompressible and compressible materials
$$\begin{cases} \varepsilon_x = \dfrac{\sigma_x}{E_x} - \dfrac{\mu_{yx}\sigma_y}{E_y} + \beta_x \Delta w; \\ \varepsilon_y - \dfrac{\sigma_y}{E_y} - \dfrac{\mu_{xy}\sigma_x}{E_x} + \beta_y \Delta w; \\ \Upsilon_{xy} = \dfrac{\tau_{xy}}{G_{xy}}, \end{cases} \qquad (3)$$

boundary conditions σ_x=0 для $x=\pm R$; σ_y=0 для $y=\pm a$; τ_{xy} =0 для $x=\pm R$ та $y=\pm a$ (4)

Here E_x, E_y – modulus of elasticity; G_{xy} – shear modulus; μ_{xy}, μ_{yx} – Carbon Poisson; β_x, β_y – shrinkage factor; Δw – feature changes in humidity for toschynoyu material; ε_x, ε_y – the main components of strain; σ_x, σ_y – the main components of the stress tensor; τ_{xy}, γ_{xy} – related stress and shear strain; *a* – half-plane board; R – half board thickness, x, y – the coordinates of the points of the cross-section board.

Practical implementation of a mathematical model of the Ritz method is represented as:
$$\sigma_x(x,y) = \frac{\partial^2 F(x,y)}{\partial y^2};\ \sigma_y(x,y) = \frac{\partial^2 F(xy)}{\partial x^2};\sigma_{xy}(x,y) = -\frac{\partial^2 F(x,y)}{\partial x dy} \qquad (5)$$

Here F (x, y) - any two differentiated, which is a solution of the equation:
$$\frac{1}{E_2}\frac{\partial^4 F}{\partial x^4} + \left(\frac{1}{G_{xy}} - \frac{\mu_{yx}}{E_y} - \frac{\mu_{xy}}{E_x}\right)\frac{\partial^4 F}{\partial x^2 \partial y_2} + \frac{1}{E_y}\frac{\partial^4 F}{\partial x^4} = -\frac{\partial^2}{\partial x^2}\left(\beta_y \Delta w(x,y)\right) - \frac{\partial^2}{\partial y^2}\left(\beta_x \Delta w(x,y)\right), \qquad (6)$$

obtained substituting the relations (3) into (2) and subsequent replacement σ_x, σ_y, σ_{xy} – to $\dfrac{\partial^2 F(x,y)}{\partial y^2}, \dfrac{\partial^2 F(xy)}{\partial x^2}; \sigma_{xy}(x,y) = -\dfrac{\partial^2 F(x,y)}{\partial x dy}$ respectively.

So, the problem of calculating the stress fields in cross-section timber uneven distribution of water equivalent to the problem of finding the solution of equation (6) which satisfies the boundary conditions (4).

Approximate solution of equation (6) look as $F = d_1\varphi_1 + d_2\varphi_2 + d_3\varphi_3$ (7)
де $\varphi = (x^2-a^2)^2(y^2-R^2)^2$; $\varphi_2 = \varphi_1 x^2$; $\varphi_3 = \varphi_1 y^2$.

The unknown coefficients d_1, d_2, d_3 – Ritz coefficients of a system of linear algebraic equations:
$$\sum_{k=1}^{3}\left(\bar{\Delta}\varphi_k, \varphi_n\right)d_k = \left(\left[-\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2}\right]\beta_y W(x,y), \varphi_n\right), \qquad (8)$$

де

$$\bar{\Delta} = \frac{1}{E^2}\frac{\partial^4}{\partial x^4} + \left(\frac{1}{G_{12}} - 2\frac{\nu_{21}}{E_2}\right)\frac{\partial^4}{\partial x^2 \partial y^2} + \frac{1}{E_1}\frac{\partial^4}{\partial x^4};$$

$\left(\bar{\Delta}\varphi_k,\ \varphi_n\right)$, $\left(\left[-\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2}\right]\beta_y \Delta W(x,y),\ \varphi_n\right)$ – corresponding scalar product:

$$\left(\bar{\Delta}\varphi_k,\ \varphi_n\right) = \int_{-a}^{a}\int_{-R}^{R}\bar{\Delta}\varphi_k\varphi_n\,dxdy\ ,$$

$$k = 1,2,3. \qquad (9)$$

$$\Delta W = \frac{W_{max}}{R^2}x^2 \qquad (10)$$

For timber with a parabolic distribution of moisture

The system of equations (8) has the form:

$$\begin{cases} A_{11}d_1 + A_{12}S_{пр}d_2 + A_{13}S_{пр}d_3 = \frac{7\varsigma}{64}\beta_y\Delta W; \\ A_{21}d_1 + A_{22}S_{пр}d_2 + A_{23}S_{пр}d_3 = \frac{13}{12}\beta_y\Delta W; \\ A_{31}d_1 + A_{32}S_{пр}d_2 + A_{33}S_{пр}d_3 = \frac{13\varsigma}{12}\beta_y\Delta W, \end{cases} \qquad (11)$$

where:

$$A_{11} = \left(\frac{\varsigma^2}{E_y} + \frac{2}{7}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{1}{7\varsigma^2 E_x}\right)S_{пр}^3;\ A_{12} = \left(\frac{\varsigma}{7E_y} + \frac{1}{11\varsigma^3 E_x}\right)S_{пр}^4;$$

$$A_{13} = \left(\frac{\varsigma^3}{11E_y} + \frac{1}{7\varsigma E_x}\right)S_{пр}^4; \qquad A_{21} = \frac{16}{3}\left(\frac{13\varsigma}{7E_y} + \frac{1}{33\varsigma^3 E_x}\right)S_{пр}^3;$$

$$A_{22} = \left(\frac{64}{21E_y} + \frac{1376}{2079\varsigma^2}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{1647}{143\varsigma^4 E_x}\right)S_{пр}^4;$$

$$A_{23} = \frac{16}{23}1\left(\frac{13\varsigma^2}{E_y} + \frac{4}{3\varsigma^2 E_x}\right)S_{пр}^4;\ A_{31} = \frac{16}{3}\left(\frac{4\varsigma^3}{33E_y} + \frac{13}{7\varsigma E_x}\right)S_{пр}^3;$$

$$A_{32} = \frac{16}{3}\left(\frac{7\varsigma^2}{3E_y} + \frac{13}{\varsigma^2 E_x}\right)S_{пр}^4; \qquad (12)$$

$$A_{33} = \left(-\frac{1674\varsigma^4}{143E_y} + \frac{1376}{2079}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{64}{21E_x}\right)S_{пр}^4;$$

$\varsigma = a/b$ – relation of width to the length of the board, $S_{пр} = aR$ – quarter of the cross-sectional area board, W_{max} – the difference of moisture content in the central layer and the surface of the board.

Coefficients d_1, d_2, d_3 –dependent on the geometrical characteristics of a material and drop of moisture on his thick. Indeed, according to (11):

$$d_1 = D_1\beta_y\Delta W;\ d_2 = D_2\beta_y\Delta W;\ d_3 = D_3\beta_y\Delta W \qquad (13)$$

where $D_1 = \frac{\Delta_1}{\Delta};\quad D_2 = \frac{\Delta_2}{\Delta};\quad D_3 = \frac{\Delta_3}{\Delta};$

$$\Delta = \begin{vmatrix} A_{11} & A_{21} & A_{31} \\ A_{21} & A_{22} & A_{32} \\ A_{31} & A_{23} & A_{33} \end{vmatrix};\ \Delta_1 = \begin{vmatrix} B_1 & A_{21} & A_{31} \\ B_2 & A_{22} & A_{32} \\ B_3 & A_{23} & A_{33} \end{vmatrix};\ \Delta_2 = \begin{vmatrix} A_{11} & B_1 & A_{31} \\ A_{21} & B_2 & A_{32} \\ A_{31} & B_3 & A_{33} \end{vmatrix};\ \Delta_3 = \begin{vmatrix} A_{11} & A_{21} & B_1 \\ A_{21} & A_{22} & B_2 \\ A_{31} & A_{23} & B_3 \end{vmatrix}. \qquad (14)$$

Substituting (13) and (7) and formula (5) determine the components of the stress tensor:

$$\sigma_x = \Phi_x\beta_y\Delta W;\ \sigma_y = \Phi_y\beta_y\Delta W;\ \tau_{xy} = \Phi_{xy}\beta_y\Delta W \qquad (15)$$

where

$$
\begin{aligned}
\Phi_x &= 2\{2D_1(3y^2-a^2)+2D_2(3y^2-a^2)x^2 \\
&\qquad + D_3(15y^4-12a^2y^2+a^4)\}(x^2-R^2)^2; \\
\Phi_y &= 2\{2D_1(3x^2-R^2)+D_2(15x^2-6R^2x^2+R^4) \\
&\qquad + 2D_3(3x^2-R^2)y^2\}(y^2-a^2)^2; \\
\Phi_{xy} &= 16D_1(x^3-R^2)(y^3-a^2y) \quad +8(y^3-a^2y)(3x^5-4R^2x^3+R^4x)D_2 \\
&\qquad + 8D_3(x^3-R^2x)(3y^5-4a^2y^3+a^4y).
\end{aligned}
\tag{16}
$$

In this work in C + + Builder it is developed software that allows modeling distributions of stress fields in the component timber parabolic distribution of moisture. The result of practical testing of the software on the plain pine boards are shown in Fig. 1.

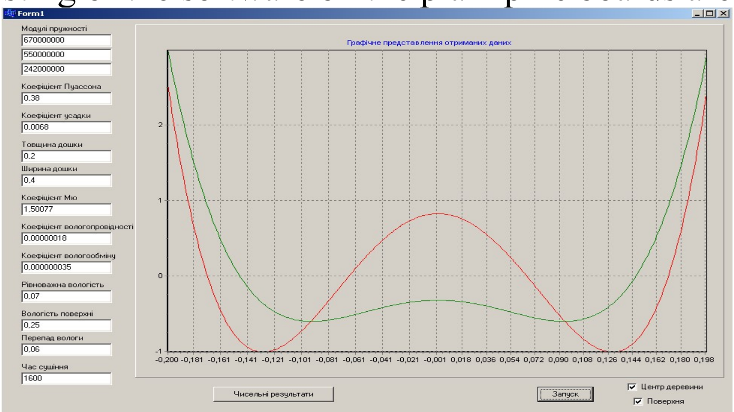

Fig. 1. Software for determining the stress fields in the wood

So in the work it is done the mathematical formulation of the problem of determining the stress state of the wood. The developed automated system for calculating the stress state of timber with non-uniform distribution of moisture fields can be used in modern systems of early detection and control of hazardous on forming and fracture in drying boards stresses.

Conclusions. An algorithm and the respective software for constructing the curves of strength of biaxially stressed wood have been developed. Based on the analysis of the software application results, it has been shown that the strength of pine wood is adequately described by Goldenblatt-Kopnov's criterion.

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Розробка програмного забезпечення для визначення полів напружень у деревині з параболічним розподілом вологи

Вирішено задачу визначення плоского напруженого стану у радіально-тангентальній площині анізотропії деревини з нерівномірним розподілом вологи. На основі методу Рітца розроблено алгоритм та програмне забезпечення для розрахунку компонентів тензора напружень у пиломатеріалах з параболічним розподілом вологи. Програма реалізована у середовищі Builder C++ з використанням візуальних компонентів.

Ключові слова: метод Рітца, поля напружень.

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TECHNIQUES FOR RECYCLED OF POST-CONSUMER WOOD IN THE PRODUCTION OF QUALITY PARTICLEBOARD

Summary. It is found that post-consumer wood (PCW) is as yet non utilized resource of wood waste that is suitable for manufacturing wood particleboards (PB). The study reveals a problem the point of which is the absence of resource-saving and environmentally benign technologies; also practical recommendations have been given as to the use of PCW in woodworking industry. It has been suggested that the given problem could be solved in several steps: evaluation of the current state of the problem; justification of PCW classification and estimation of its potential; development of the procedure for conducting experimental investigations; modelling technological processes; analysing results of the experimental investigations; development of technological processes and practical recommendations as to the PCW utilization; implementation of the investigation results into practice. A system approach to PCW recycling was used. Investigated was the influence of the PCW and binder contents in each of the layers on physical and mechanical properties of three-layer particleboards: bending strength, tensile strength perpendicular to plane, and thickness swelling. Obtained were adequate mathematical models of dependence of WPB physical and mechanical properties on the PCW contents in each layer and the binder. It was proposed to establish an area for PCW preparation. Production techniques for PCW-containing three-layer particleboards were developed.

Keywords: post-consumer wood, PCW potential, particleboard, chips, physical and mechanical properties of panels, mechanical models, woodworking techniques, practical recommendations.

Introduction. The demand for wood composites from waste wood has been increasing as timber resources in natural forests decline. The use of renewable biomass as a raw material in composites production was one approach and the use of renewable biomass may result in several benefits such as environmental and socioeconomic. Today renewable biomass are mostly accepted as waste materials and are mostly ploughed into the soil or burnt in the field. According to the end uses of wood-wastes and their possible reuse products, PB has found typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops, and it seems that the manufacture of PB from recycled wood-based wastes is the most common way to reuse such waste materials [10]. The PB is a panel product manufactured under pressure from particles of wood or other lignocelluloses materials and an adhesive. PB has been widely used throughout the world for furniture manufacture and house construction, including flooring systems, etc. Recently, the demand for the PB has continued to increase for housing construction and furniture manufacturing.

Large-scale cutting down of forests and the resulting environmental impacts, wood resource scarcity – all these force the woodworking industry to seek for alternative sources of raw material. The prospective resource that could be used as the raw material base for wood PB manufacture, is PCW. This category of wood waste has been making successfully a sort of «career» over the last several decades, especially in West European countries. PCW includes all kinds of wooden material that is available at the end of its use as a wooden product. Such wood mainly comprises demolition wood, packaging material, used furniture. PCW may contain fire retardant material, wood preservatives, paints, varnishes, glues, artificial films, metal, and even glass. Because of its very different composition, the presence of various kinds of impurity as well as the lack of appropriate machines for its conversion into valuable raw material, the industries of many countries do not always display great interest in this promising source of wood raw material. That is why, PCW, like other industrial wood waste is mainly landfilled.

Millions of tons of wood waste have accumulated on the long-standing refuse dumps. The amount of the accumulated waste is too large to be naturally decomposed.

Thus, the present study is devoted to solving the problem which is important and pressing both for industry and the environment: replenishment of the raw material base.

Topicality of the study – provision of woodworking industry with alternative additional resource by away of recycling and utilization of post-consumer wood (PCW) to manufacture products such as PB from disintegrated wood.

Problem formulation. This paper covers the issues of generating energy from additional wood resources, in particular PCW, by way of converting this into PB. As of now, the problems of raw material and waste are sure to remain the "hottest" problems in the woodworking industry all over the world and in Ukraine [1-8].

At least partial solution of the latter problem is a rational and holistic approach to settle the first problem – the problem of raw material. PCW reserves are potential resources and untapped base for wood raw material whose supplies are in-creasing with the development of wood-processing industry and the economy as a whole.

The problem of the study – the absence of resource-saving and environmentally benign technologies with practical recommendation as to PCW utilization in woodworking industry.

The objective of the study: investigation on technological capability and studying the peculiarities of PCW utilization in woodworking production processes; to develop production techniques and improve the existing equipment for manufacturing PB from PCW; to develop a science-based, technical-and-technological, basis for effective prediction of the PB properties as well as to work out hands-on guidelines for quality assurance of PCW-produced PB.

The object of the study: resource-saving technologies of PCW utilization; the production process of PB from PCW by using upgraded and improved equipment.

The subject of the study: the patterns of technological parameters influence on the properties of PCW-produced PB in terms of predicting and quality assurance; physical-and-mathematical models and practical recommendations on PCW utilization in woodworking production techniques

The methods of the study. Theoretical and experimental investigation were carried out with the application of a system approach involving computer engineering.

The study of potential of PCW. The determination of potential for wood biomass was done on the basis of statistical data from the state agency of forest resources in Ukraine concerning timber harvest (12.76 million tonnes (18.23 million m^3)) in 2013 (Table 1). Taking into account that the level of wood consumption is dependent on export-import, which compensate each other in the total balance of raw materials, the level of available PCW was calculated as 13% of the total harvested volume, which made up 1.659 million tonnes in 2013.

In addition, an average of 50 to 60 million tonnes of solid residential waste (SRW) is available in Ukraine each year, in which the share of PCW amounts to 2 to 4%. According to the data from the ministry of regional development, housing construction, residential and public utility services, about 13 million tonnes of SRW was available in 2013, of which 0.441 million tonnes (3,4%) was PCW.

Available quantity of PCW per capita in Ukraine amounts to 49 kg (with Ukraine's population of 43 million people, as of 01.06.2014).

Table 1. The potential of PCW in Ukraine in 2013

Wood biomass	W-%	PCW, million tons	Energy potential / year		
			million t f.e.	PJ	billion kWh
Commerce (package)	15	0,315	0,173	5,077	1,410
Construction waste	18	0,483	0,255	7,482	2,078
Wood-processing industry	20	0,126	0,065	1,899	0,528
Furniture	10	0,273	0,160	4,686	1,302
Municipal waste	40	0,357	0,121	3,542	0,984
Solid residential waste	35	0,441	0,164	4,800	1,333
Other	30	0,105	0,043	1,262	0,350
Total used wood mixtures	25	**2,100**	**0,981**	**28,749**	**7,986**

PCW utilization technologies according to the objective of the paper: investigations on technological capability and studying the peculiarities of PCW utilization in woodworking production processes, on the basis of a system analysis, it has been proposed to use PCW: (1) in the solid form for manufacturing curved blanks, batten blocks, and furniture panels; (2) in the form of chipped wood for manufacturing PBs, and fuel pellets and briquettes (Fig. 1). In order to prepare PCW for resource-saving production processes to manufacture the abovementioned products, the following technological flow diagram has been developed: for the use in the solid form-a layout of the workshop for sorting, segregation and cleaning; for the use in the clipped-wood from-a layout of the workshop for chipping, stepwise cleaning, and crushing (re-chipping).

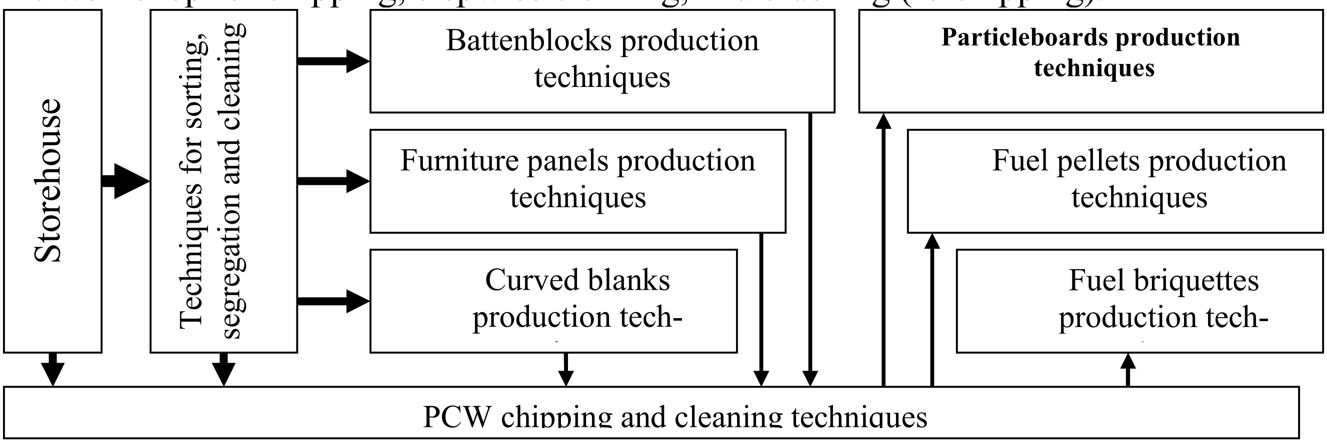

Fig. 1. System approach to PCW utilization [6]

Methods of study. A number of methods were used in the study, namely, experiments, measuring and comparison. The wood particles from conventional wood and PCW were obtained by way of cutting and chipping. The test specimens of panels from PCW were made by way of flat pressing in the hydraulic press. In order to reduce the number of systematic errors during the experiments, the method of randomization was used. During the determination of wood particles from green wood and PCW, the following research methods were applied: physical research methods to determine fractional composition of the particle, the particles moisture content, density, and thickness swelling; mechanical methods to determine the bending strength and tensile strength perpendicular to plane. The experimental data were processed by method of statistical analysis. Also, a comparison was made between the panels made from PCW and the panels made from conventional wood to check the conformity to the standards.

Scientific novelty of the findings. On the basis of the experimental results obtained, the feasibility of PCW utilization for manufacturing flat-pressed PBs with adequate physical and mechanical qualities was substantiated.

The optimal ratio of the components of the chips-glue furnish with the addition of PCW was developed, which ensures the production of P-A type of WPB according to DSTU 10632:2009 [9]. Regression dependences were obtained for bending strength, tensile strength perpendicular to plane, thickness swelling versus PCW content in the face layers and the core, various glue consumption as well as pressing parameters (temperature, pressing time, and pressure); these can be used for calculating technological parameters of PB manufacture.

Comparative analysis of chips. Depending on the factor of cutting and the degree of its effect, the process of wood chipping is characterized by the quality of chips obtained and the operating parameters of chipping. The shape of PCW particles should be characterized above all qualitatively (pin-shaped, twisted, cube-shaped, fibrous particles) rather than quantitatively (PCW species, density, bulk density, size distribution curve, etc). There are methods of screen analysis for measuring sample particle size and calculation of arithmetical mean length, width and thickness. However, in actual practice, the methods of qualitative estimate of wood particles are dominant.

The parameters that provide quantitative characteristics (particles size, their ratio, specific surface, "ends area") are not controlled accurately and are not related to each other, the methods of measuring them do not allow for accurate quantitative values that could be used to calculate composite material composition and to develop techniques for manufacturing panels with prescribed qualities with a minimum of glue and energy consumption. Therefore, the critical characteristics of PCW particles are the chips fractional size and composition. In order to compare the geometry and fractional composition of chips, we used primary conventional wood and PCW.

On a 5-minute sifting, the material obtained was divided into eight fractions: –/10, 10/7, 7/5, 5/3, 3/2, 2/1, 1/0.5, 0.5/0. The results of the study of wood particles geometric dimensions show that fraction content practically does not vary with respect to wood particles from conventional wood (Table 2), although the amount of fine fraction (fraction content 1/0) is two time as much.

Table 2. Comparative analysis of chip fractional composition

Type of wood	Fraction content, %							
	–/10	10/7	7/5	5/3	3/2	2/1	1/0,5	0,5/0
Conventional wood	0,5	2,3	2,6	32,1	28,9	20,6	10,6	2,4
PCW	0,4	1,0	1,8	28,3	25,2	19,3	19,1	4,9

The impact of structural and technological parameters on panels' strength values is demonstrated through the mediation of dimension less geometrical characteristic of chip formation: degree of contact area. It was found that the degree of contact area is dependent on the size of wood particles, namely, the values of bending strength and tensile strength perpendicular to plane as chip fractional composition changes from fraction 5/3 to fraction 10/7. Wood particles from conventional wood and PCW do not have a significant deviation of the fractional content.

Investigation planning. Since the process of manufacturing and testing WPB made from PCW was investigated under laboratory conditions, multifactor planning was applied: full-factorial plan. During the experiments, the following factors were taken as variable factors: the contents of the binder and PCW particles both in the core (P_c) and the face layers (P_f). The values for PCW chips content for each layer varied from 20 to 100 % – the rest were standard technological chips; the binder content in each layer was within the average consumption norm ranging from 7 to 16 % (K).

For the purpose of reducing the number of systematic errors, the method of randomization was applied which allowed for establishing random sequence of the experiments conducting. The following factors characteristic of panel manufacture, were noted at the fixed levels: density – 700 kg/m; specific pressure – 2.5 MPa; press temperature – 200 ºC; pressing time – 0.35 min/mm moistures content of the particles for the core – 2 %; moistures content for the face layers – 4 %; the ratio of the layers – 50/50; three-layer panels of 16 mm thick.

Physical and mechanical testing. The determination of the WPB physical and mechanical properties was carried out 5 days after the panels were pressed. The PCW-made panels were cut on the circular saw bench to size specified for specimens testing according to GOSTs 10634-88; 10635-88; 10636-90. The tests for the bending strength and the tensile strength perpendicular to plane were conducted on the WOLPERT machine according to GOST 7855-84. The motion speed of the load-carrying head – 60 mm/min, the scale division – 1 kg/sm^2; deviation from the actual value made up – 1%.

The results of experimental investigation. A thorough study has been conducted on the biomass raw material base including PCW for manufacturing PB. A multifactorial experiment has been performed according to the procedure of the study. The data obtained from physical and mechanical testing of pilot PCW-containing PB for bending strength (**σ_b**), tensile strength perpendicular to plane (**σ_t**), and thickness swelling (**Δh**) are shown in Fig. 2-4.

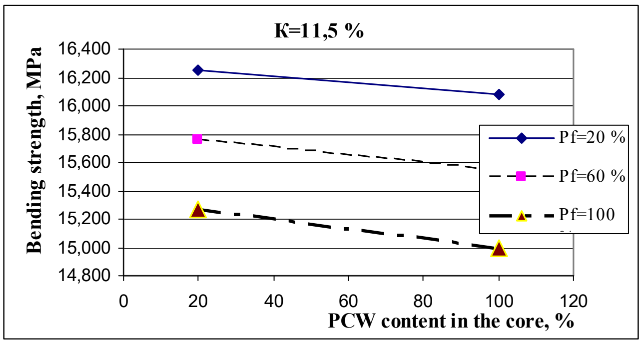

Fig. 2. Relationship between panel's bending strength and the content of PCW both in the core and face layers as well as the binder content: *К=11,5 %*

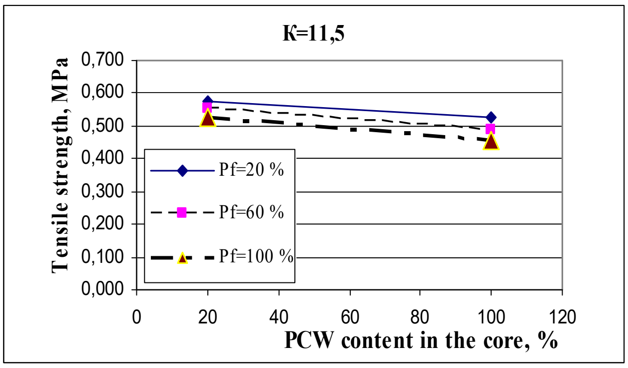

Fig. 3. Relationship between panel's tensile strength and PCW content both in the core and face layers as well as the binder content: *К=11,5 %*

Graphical representation of the relationships obtained allows for revealing character of variable factors influence on the properties of the resulting PB, since the full-factorial plan was realized here, all the dependences have linear character. As is seen from the diagrams, the PCW content in the PB behaves equally at different binder content levels that is the bending strength is decreasing within from 19.469 to 12.030 MPa range, the tensile strength is decreasing within the range of 0.646 to 0.344 MPa, while the thickness swelling is also decreasing from 17.22 to 13.93 %. The diagrams also show that the lines do not run parallel to one another, and the angle of their slope varies as certain variable factors change. This points to the fact that the influence of factors interaction is just as significant as the influence of the individual factors.

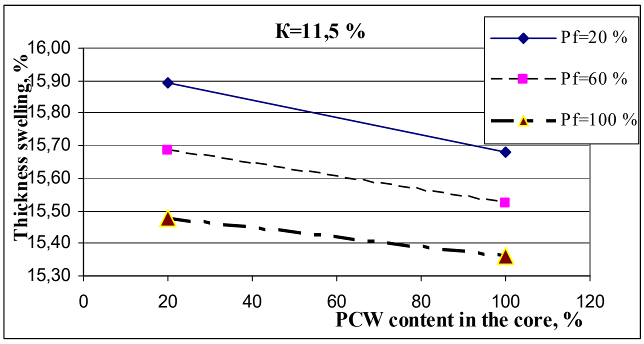

Fig. 4. Relationship between panel's strength at swelling and PCW content both in the core and the face layers as well as the binder content: *К=11,5 %*

Our study has demonstrated that for a given 700 kg/m^3 PB density and an average glue consumption of 11.5 %, an increase in PCW chips content in the face layers from 20 to 100 % results in decreased bending strength by 6 % while the same increase in PCW content in the core makes up only 1 %. The use of a 100 % PCW particles content and glue consumption of 11.5 % both in the core and the face layers results in the bending strength of 15 MPa, which is 8 % smaller than for the case of a 20 % PCW content.

The conditions being the same, it was found that the tensile strength is essentially influenced by the increased content of PCW particles in the core an decrease in the tensile strength amounted to 9 %. The physical and mechanical properties of the PB are most influenced by the glue content. With increasing the glue content, the strength is also increasing (by 30 %) while the thickness swelling is decreasing (by 15 %). The reason for this lies in the fact that there is a greater amount of adhesive spread per unit surface area of the wood particles, and this glue film prevents the water from penetration into the interior of wood particles. Also, due to the absence of bark from PCW particles, there is an increase in the strength by 2 to 5 % in the PCW-containing PB compared to panels made from conventional wood.

Thus, WPB that has a 60 % PCW particles content and the glue consumption of 11.5 % produces composite materials that meet the requirements for the P-A type of PB according to DSTU 10632:2009 [9]. Thus, the calculations done made it possible to obtain the following regression equations of the full-factorial plan with actual factor values for physical and mechanical properties:

$$\boldsymbol{\sigma_b} = 8{,}145 - 0{,}00039 \cdot P_c - 0{,}0053 \cdot P_f + 0{,}729 \cdot К;$$
$$\boldsymbol{\sigma_t} = 0{,}442 - 0{,}00088 \cdot P_c - 0{,}0015 \cdot P_f + 0{,}0136 \cdot К - 0{,}000083 \cdot P_f \cdot К;$$
$$\boldsymbol{\Delta h} = 19{,}37 - 0{,}0021 \cdot P_c - 0{,}0031 \cdot P_f + 0{,}288 \cdot К.$$

A standard layout of the workshop for sorting, segregation and cleaning of PCW. Once the PCW is delivered and accumulated in adequate quantities at the plant (factory), the following operations are to be conducted: identification according to the categories; sorting according to the type of materials, species etc.; segregation according to moisture content, impurities etc.; revealing possible toxic chemicals. A standard layout of the workshop measuring 36×24 m has been designed where PCW sorting is to be done according to 4 categories: the type of material – solid wood, panels; segregation according to moisture content, impurities and toxic chemicals (Fig. 5). A special feature of the workshop is its division into four lines. The first and the second lines deal with solid PCW (according to the categories): clean PCW-I and contaminated PCW-IV. The other part of the shop deals with panel materials. The third line deals with PCW-II that is coated with finishing, chemically untreated and without halogenated organic compounds; the fourth line deals with PCW-III which is coated with finishing, chemically untreated but containing halogenated organic compounds in the coating. After sorting according to the type of material and quality statement the PCW is segregated from foreign materials such as tramp metal and other impurities. The detection of metal particles is done by means of metal detectors which are installed for each type of material at the both sides of the entrance to the workshop. The impurity-contained spots are sawn out of the PCW and removed from the workshop by side belt conveyors to be farther transported by traversing carriages to the other area for chipping and cleaning. The main feature of this area are machine tools for longitudinal surface treatment (cleaning). In particular, a four-sided grinding machine is used for PCW-I; a two-sided grinding machine is used for PCW-II; a two-sided needle milling machine is used for PCW-III; a four-sided needle milling machine is used for PCW-IV. After surface treatment operation, the PCW is re-inspected for possible detecting metal impurities by means of metal detectors which are installed at each of the four lines. Defect-free PCW becomes suitable for obtaining blanks by means of secondary machining. The PCW so treated (Table 3, 4) is an additional source of raw material for manufacturing fuel pellets and briquettes.

Table. 3. Recommendations on techniques for PCW sorting and segregation

№	Stages and operations	Equipment
1	Collection, accumulation according to the type	Place of origin, the plant
2	Delivery to the plant	Transportation facilities
3	PCW identification according to the category	Visual inspection, instruments
4	Sorting according to the type of material and species	By hand, automatically
5	Segregation according to moisture content	Visual inspection, instruments
6	Revealing possible toxic chemicals	Indicator, testing
7	Removal of foreign inclusions	With tools, physically
8	Removal of visible metal particles	Metal detector, physically
9	Removal of coatings (films)	Machine tools for cleaning
10	Distribution according to technology	Recycling process

Table 4. Recommendations on techniques for chipping and cleaning of PCW

№	Stages and operations	Equipment
1	Chipping, particles	Chipper, shredder
2	Transportation	Belt conveyor
3	Removal of metal inclusions	Suspended magnetic conveyor
4	Removal of coarse inclusions	Disc separator
5	Repeat removal of metal	Suspended magnetic conveyor
6	Separation of fane fraction	Swinging sieve
7	Sucktion of foil, films etc.	Aspiration system
8	Removal of non-ferrous metals	Non-ferrous metals separator
9	Separation of flow into fractions	Mehanical classifier
10	Pneumatic sorting	Inertial separator
11	Gravimetric cleaning	Bunker, collector cyclone
12	Crushing	Hammer mill
13	Removal of sand particles from fine fraction	Vibrating sieve
14	Mehanical cleaning of chips	Disc separator
15	Transportation to bunker	Pneumatic transport, proportioned

Project PB plant with PCW. “PCW” mills based on recycled wood have had varying success. However there is apparently a growing market from some who want to make an environmental point. Described PCW Panels, as the project PB plant to operate successfully with 100 % recycled post-consumer waste wood. Annual input is 35,000 tons. The mill uses pallets, crates, cable reels, construction and industrial wood. One of the keys is compaction of the residues, such as pallets and reels, to allow more material per truck load and consequent lower raw material transportation costs. Pallets come from within a 150-200 km radius. Another key is a stringent cleaning process with nine points where debris and metal are removed from the raw material. Fig. 6 shows the project designed and engineered the plant. Crushing, cleaning, metal and debris removal were by Pal of Italy. Drying, conveying, blending and pressing with continuous Berndorf bands and sanding were by Module System of Germany. Drying is fairly conventional except for two more wind sifters after drying – one for core and the other for surface. Drying costs are lower because the wood is generally at or below 20 % moisture content. The objective is to remove the last bit of ash and other contaminants from the furnish. However, the material requires about 1 % higher resin content. New researches was to separate the dirty steam coming from the refiner, together with most of the volatiles from fiber processing. The dirty steam is condensed and treated in a conventional water treatment plant. The fibers are then conveyed from the steam separator, helped by fresh steam to allow for conventional blow line blending in a secondary blow line ahead of the dryer. Dryer emissions are mainly volatiles from the resin added in the blow line and are managed by control devices such as RTOs.

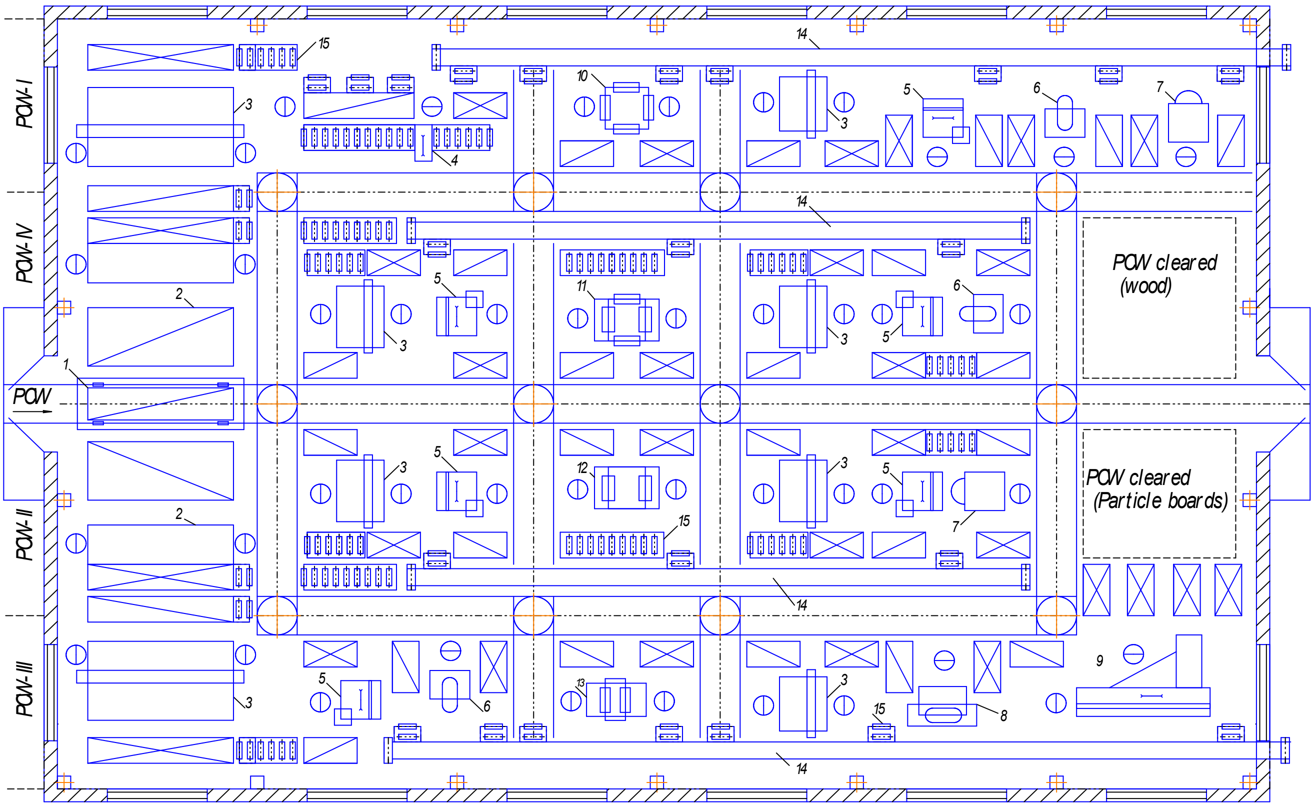

Fig. 5. Equipment for PCW preparation – sorting, segregation and cleaning: *1 – traversing carriage; 2 – bench, worktable; 3 – metal detector; 4 – trimmer; 5 – circular saw; 6 – band mill; 7 – milling machine; 8 – enge sander; 9 – sizing machine; 10 – four-sided sander; 11 – four-sided needle milling machine; 12 – double-needle milling machine; 13 – double milling machine; 14 – conveyor; 15 – roller conveyor sections*

Conclusions and Recommendations:

1. Monitoring of PCW in Ukraine has been fulfilled. It has been estimated that about 2,1 million tonnes of PCW was produced in 2013 in Ukraine.
2. A thorough study has been conducted on the biomass raw material base including PCW for manufacturing PB. The sources and PCW origin have been examined: solid domestic waste, municipal waste, commerce (package, pallets), construction waste, wood-processing industry by-products and residue, and others. The rising cost of raw materials, ever tighter legislation about waste disposal, and the fierce competition between PB manufacturers has led to the increasing use of recycled wood. It is possible to use any source of recycled wood to reduce raw material costs by between 40-70 % and the resulting boards will have even surfaces and post-soft formable core layers. There are advantages apart from the obvious one of being a sustainable alternative to using virgin timber. Recycled wood has a moisture content of around 20 % compared to the 60-70 % moisture in virgin wood, so it makes economic sense to buy recycled wood chip; it also lasts longer and utilizes less energy during processing.

3. Obtained are adequate mathematical models of the PB parameters depending on the three variable factors: PCW content and binder content. The PCW suitable for PB manufacturing should be cleaned by one of the following ways: surface cleaning (for solid PCW) on machine tools such as brushing machine, milling machine, grinding machine, sandblast machine and other; internal cleaning (for chipped PCW) by equipment such as air separator, vibratory feeder, air cleaner, magnetic strip, metal detector, swinging sieve. The development of the technological process for converting PCW into PB. Accordingly, it was proposed to establish an area for PCW preparation which will involve: PCW sorting for contamination, wood species, the type of the used construction material, etc.; removal of impurities and various foreign material; removal of plastics, non-ferrous and ferrous metals from both solid (unshipped) and chipped PCW.

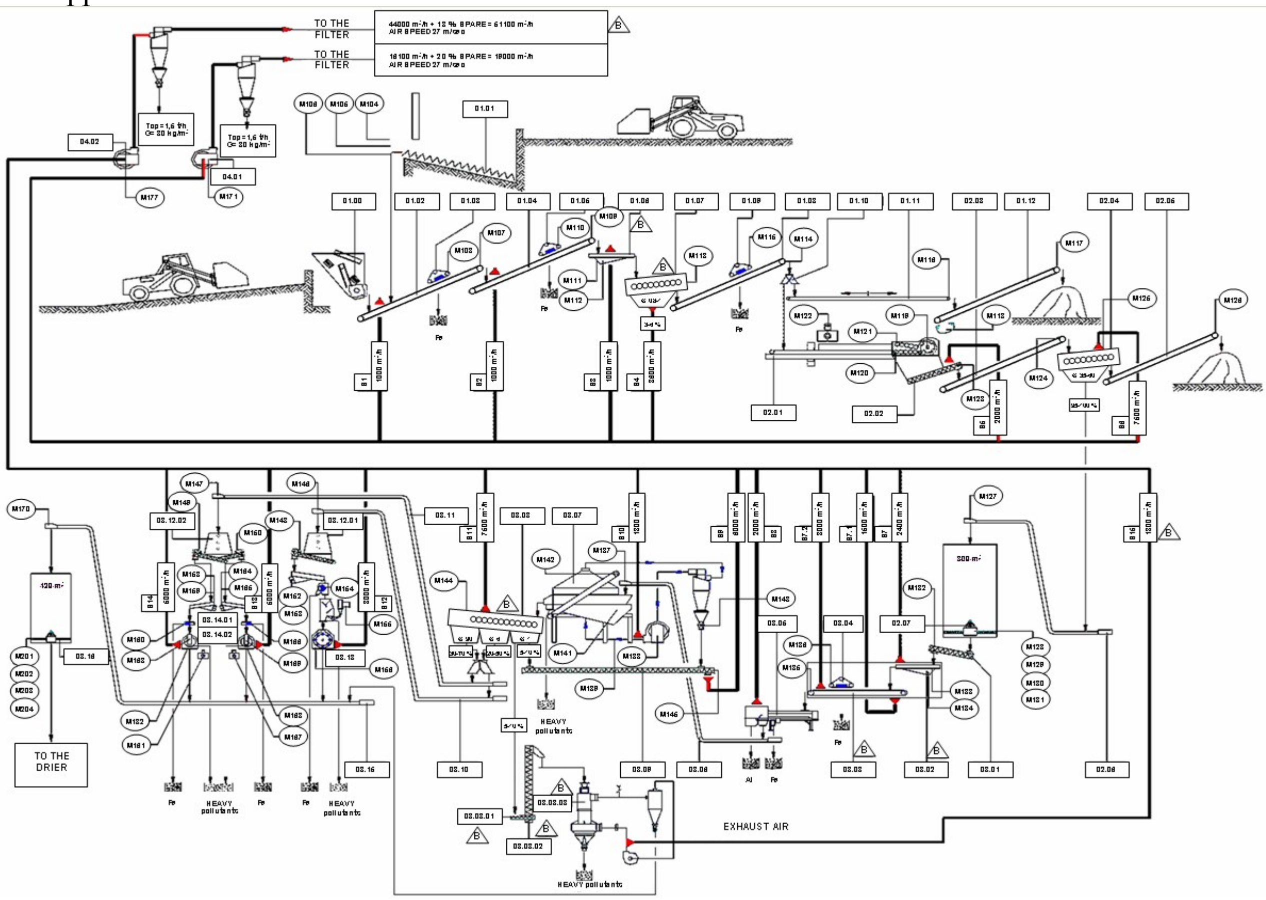

Fig. 6. Flow of wood preparation area of post-consumer wood

4. It has been found that the optimum conditions for manufacturing boards of standard quality (DSTU 10632:2009) are as follows: for P-A type (13 MPa) – PCW particles content in the core and the face layers may amount to 60 % with an average glue consumption of 11.5 %; for P-B type of boards (11.5 MPa) – PCW particles content in the core amounts to 100 % and 80 to 100 % in the face layers with glue consumption in the core being 7 to 8 % and 10 to 11 % in the face layers.

5. An estimation has been made for socio-economic efficiency resulting from the implementation of the practical recommendations for manufacturing PB from PCW. Estimated was the effect of introducing the results obtained in practice at the Swisspan Ltd. Enterprise, which lies in the fact that the use of PCW in the PB manufacture leads' to the reduction of costs for conventional wood by 9.4 % [2].

6. Future Ukraine and Europe should focus on efficient recovery of recovered wood.

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УДК 674.81:662.638 ***Доц. С.В. Гайда, канд. техн. наук – НЛТУ України***

Технології пероблення вживаної деревини для виробництва якісних деревинностружкових плит

Обґрунтовано, що вживана деревина (ВЖД), як додатковий ресурс деревної маси, через відсутність технологічних розробок та практичних рекомендацій не знайшла ще належного використання деревообробними підприємствами України. А також ВЖД поки що, не ефективно

використовується для виготовлення деревинностружкових плит (ДСП). Розроблено практичні рекомендації щодо використання ВЖД у виробництві ДСП. Досліджено проблему, вирішення якої забезпечить утворення ресурсозберігаючих та екологічно безпечних технологій на основі використання ВЖД. Встановлено, що дана проблема може бути вирішена в кілька етапів: оцінка поточного стану проблеми; обґрунтування класифікації ВЖД та оцінки її потенціалу; розроблення методики для проведення експериментальних досліджень; моделювання технологічних процесів; аналіз результатів експериментальних досліджень; розроблення технологічних процесів і практичних рекомендацій щодо використання ВЖД; здійснення досліджень у виробничих умовах. Використано системний підхід і до утилізації ВЖД. Досліджено вплив вмісту ВЖД у кожному із шарів та в'яжучого на фізико-механічні властивості тришарових ДСП – міцність при статичному згині, розтягу перпендикулярно до площини плити та набрякання. Отримано адекватні математичні моделі залежності фізико-механічних властивостей ДСП від вмісту ВЖД в кожному шарі і в'яжучого. Було запропоновано створити дільницю для підготовки ВЖД. розроблено методику виробництва тришарових ДСП із ВЖД.

Ключові слова: вживана деревина, потенціал ВЖД, ДСП, стружка, властивості плит, математичні моделі, дерево оброблювальні технології, практичні рекомендації.

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LOCATION OF SAWING PATTERN ON THE COVERING WORKING ZONE OF SEGMENT AND SECTOR WITH CONSIDERATION OF THEIR REAL SHAPE

The simulation method for variants of location of sawing pattern on the working zone covering by sawing pattern of segment and sector was considered. Consideration of real shape for log (segment) based on results of scanning for shape surface of log cross sections was provided for simulation process.

Keywords: log, segment, sector, covering working zone, location of sawing pattern, real shape, simulation, volume, log rotation.

Statement of problems and research currency. During the work [1] the topicality of research is proven and the simulation method for variants of location of sawing pattern on the working coverage zone of log is developed with the consideration of natural fluctuations of its real size characteristics, the usage of which will provide the lumber sawing of minimally acceptable and larger sizes. Given method is mathematically proven, experimentally confirmed and applicable to the determination of all possible variants of location of sawing pattern on the working coverage zone of log. It is also applicable to the determining of optimal variant which is characterized by the dimension of step displacement of working coverage zone and turn angle of log around the linear regressive axis. Instead, a similar problem on simulation of variants of location of sawing pattern on the working coverage zone of segments and sector with the consideration of natural fluctuations of its real size characteristics is almost undiscovered. Therefore, it is actual line of research, which requires scientific argumentation and solution.

The analysis of existing researches. It is important to mention that despite the detailed researches in the sawmill technology that were carried out in order to solve the problem of rational sawing of logs (cants, segments) on sawn timber by sawing process simulation, this issue is not fully solved [1-3]. Therefore, in the present paper the development of theoretical and practical approach to the process of log sawing is suggested, in particular the method of simulation of variants of location of sawing pattern on the working coverage zone of segment and sector with the consideration of its real size.

The features of simulation for variants of location of sawing pattern on the working zone covering of segment and sector with the consideration of its real size. The determining method of width of the working coverage zone of segment and sector with the consideration of its real size is provided in the paper [2].

The freedom of location of sawing pattern on the working coverage zone of segment and sector is defined as:

$$\lambda_{\max} = A + pr - \sum_{g=1}^{G}\left(t_g + d_{t_g} + pr\right), \tag{1}$$

where: A – width of working coverage zone of sawing pattern of segment and sector; pr – thickness of saw cut; t_g – thickness of g^{th} lumber; d_{tg} – drying of g^{th} lumber; g – an serial number of lumber on the sawing pattern (lumber must be renumber from left to right for the logical presentation of information); G – the amount of lumber in the sawing pattern.

The displacement step of sawing pattern on the working coverage zone is presented as:

$$\lambda_q = \frac{q\lambda_{\max}}{p}, \quad q = \overline{0, p}, \tag{2}$$

where p – a number of variants of sawing pattern location on the working coverage zone (defined *a priori*).

On purpose to evaluation of sawing pattern of logs (segments, sectors) the comparison of lumber volume received by various variants of sawing pattern on the working coverage zone is provided. Determination of lumber volume, which along with volume recovery (yield) is one of the determinant criteria for evaluation of sawing pattern was conducted as for the lumber with the consideration of its type (unedged lumber, one-sided edged lumber, combined lumber, one-sided wedged and two-sided wedged lumber), as well for the process of sawing of edged lumber from unedged lumber, one-sided edged lumber, combined lumber, one-sided wedged and two-sided wedged lumber).

In the process of lumber size determining, sawed from a log (segment, sector), for each of meanings λ_q, that characterizes the variant of location of sawing pattern on the working coverage zone, it is necessary to make a calculations of the width of internal and external faces at each cross section $\left(i = \overline{0, N}\right)$ and acceptable lumber lengths. The thickness of lumber is taken from sawing pattern of segment and sector, received by the exhaustive method of all acceptable variants.

The simulation for variants of location of sawing pattern on the working coverage zone of segment. The width of sawn timber face on each cross section $\left(i = \overline{0, N}\right)$ of g^{th} one-sided edged lumber $\left(g = \overline{1, G}\right)$ from the sawing pattern of segment (Fig.1) is defined as:

- Left $R_i(\varphi)\cos\varphi = -{}^{SEG}A^L + \lambda_q + \sum_{s=1}^{g-1}\left(t_s + d_{t_s} + pr\right), \quad \varphi \in (0, \pi);$ (3)
- Right $R_i(\varphi)\cos\varphi = -{}^{SEG}A^L + \lambda_q + \sum_{s=1}^{g}\left(t_s + d_{t_s} + pr\right) - pr, \quad \varphi \in (0, \pi).$ (4)

According to the solutions $\varphi_L^{(g)}$ of equation (3) and $\varphi_R^{(g)}$ (4) we will find the width of left (${}_L b_i^{(g)}$) and right (${}_R b_i^{(g)}$) faces of one-sided edged lumber on i^{th} cross section:

$$ {}_L b_i^{(g)} = \chi\left(R_i\left(\varphi_L^{(g)}\right)\sin\left(\varphi_L^{(g)}\right) - \sigma\right); \tag{5}$$

$$ {}_R b_i^{(g)} = \chi\left(R_i\left(\varphi_R^{(g)}\right)\sin\left(\varphi_R^{(g)}\right) - \sigma\right), \tag{6}$$

where: χ is a characteristic function $\left(\chi(\beta)=\begin{cases}\beta, & \beta\ge b_{\min}\\ 0, & ELSE.\end{cases}\right)$; σ is the distance from linear regressive axis of log to the sawed part of segment.

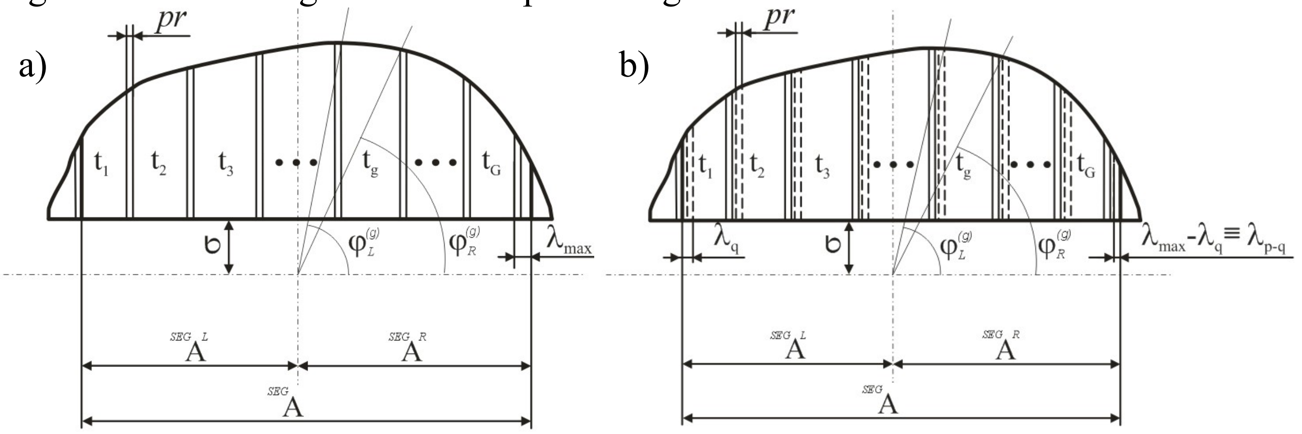

Fig.1. The location of sawing pattern on the working coverage zone of segment (i^{th} cross section): a) initial (leftmost) locating of sawing pattern; b) displacement of sawing pattern on a step λ_q

Note if there is at least one of the meanings ${}_{L}b_i^{(g)}$ or ${}_{R}b_i^{(g)}$ of the width of face on some cross section is less than $b_{\min}$, then it accepts as equal to zero.

Let us additionally set ${}_{L}b_{-1}^{(g)}={}_{R}b_{-1}^{(g)}={}_{L}b_{N+1}^{(g)}={}_{R}b_{N+1}^{(g)}=0$ (on both sides of the log ends) and ${}_{L}b_i^{(g)}$, ${}_{R}b_i^{(g)}$ simultaneously equal to zero, if at least one of the equations (3) or (4) does not have solution. Then, it is necessary to define acceptable length of fragment of g^{th} lumber according to the fixed meanings ${}_{L}b_i^{(g)}$ and ${}_{R}b_i^{(g)}$.

The terms "left" and "right" sawn timber faces characterize g^{th} lumber with the numeration of lumber location in the sawing pattern from the left to the right. It is necessary to mention that the identification of internal and external faces in the sawing pattern is realized depend on their location with regard to the linear regressive axis of log.

The conditions of acceptability of g^{th} lumber fragment ($l_{fr}\ge l_{\min}$ and $b_{fr}\ge b_{\min}$ along the full length of fragment), if it is located between known edge cross of log $i_{1j}^{(g)}$ and $i_{2j}^{(g)}$ (j is an serial number of g^{th} lumber fragment), can be written as follows:

$$\begin{cases} {}_{in}b^{(g)}_{i_{1j}-1}=0 \;\; OR \;\; {}_{ex}b^{(g)}_{i_{1j}-1}=0;\\ {}_{in}b^{(g)}_{i_{2j}+1}=0 \;\; OR \;\; {}_{ex}b^{(g)}_{i_{2j}+1}=0;\\ {}_{in}b^{(g)}_{i}\ge b_{\min},\; {}_{ex}b^{(g)}_{i}\ge b_{\min}\;\left(i_{1j}\le i\le i_{2j}\right)\; AND\;\left(i_{2j}-i_{1j}\right)h\ge l_{\min}, \end{cases} \tag{7}$$

where h is the step of scanning.

Simultaneous performance of mentioned below conditions is an indicator of the presence of acceptable g^{th} lumber fragment:

$$\begin{cases} {}_{in}b^{(g)}_{i_{1j}-1}\cdot{}_{ex}b^{(g)}_{i_{1j}-1}=0;\\ {}_{in}b^{(g)}_{i_{1j}}\cdot{}_{ex}b^{(g)}_{i_{1j}}>0;\\ {}_{in}b^{(g)}_{i_{2j}}\cdot{}_{ex}b^{(g)}_{i_{2j}}>0;\\ {}_{in}b^{(g)}_{i_{2j}+1}\cdot{}_{ex}b^{(g)}_{i_{2j}+1}=0;\\ \left(i_{2j}-i_{1j}\right)h\ge l_{\min}. \end{cases} \tag{8}$$

The volume of identified acceptable g^{th} lumber fragment is defined as:

- one-sided edged lumber $V_j^{(g)(o.s)} = \sum_{k=i_{1j}}^{i_{2j}-1} \frac{\left({}_{in}b_k^{(g)} + {}_{ex}b_k^{(g)}\right)/2 + \left({}_{in}b_{k+1}^{(g)} + {}_{ex}b_{k+1}^{(g)}\right)/2}{2} ht_g$; (9)
- edged lumber (with parallel edges) $V_j^{(g)(e)} = \left(i_{2j} - i_{1j}\right) \min_{k\in\left[i_{1j}, i_{2j}\right]} \left({}_{in}b_k^{(g)}, {}_{ex}b_k^{(g)}\right) ht_g$; (10)
- edged lumber (of maximal volume) $V_j^{(g)(e.\max)} = \max_{0\le i\le n\text{-}m}\ \max_{i+m\le j\le n} (j-i) \min_{i\le k\le j}\left({}_{in}b_k^{(g)}, {}_{ex}b_k^{(g)}\right) ht_g$, (11)

where i, j are an serial number of running scan (see [1])

The solving method for sawing of edged sawn timber of maximal volume is provided in the paper [1].

The total volume of acceptable g[th] lumber fragments is defined as:

- one-sided edged lumber $V^{(g)(o.s)} = \sum_{i_{1j}=0}^{N-1} \sum_{i_{2j}=i_{1j}+1}^{N} \xi_{(*)} \cdot V_j^{(g)(o.s)}$, (12)
- where $\xi_{(*)}$ is a characteristic function of conditions (8) $\begin{cases} \xi_{(*)} = 1, & IF \ \ {}_{(*)} - TRUE \\ \xi_{(*)} = 0, & IF \ \ {}_{(*)} - FALSE \end{cases}$; (13)
- edged lumber (with parallel edges) $V^{(g)(e)} = \sum_{i_{1j}=0}^{N-1} \sum_{i_{2j}=i_{1j}+1}^{N} \xi_{(*)} \cdot V_j^{(g)(e)}$; (14)
- edged lumber (of maximum volume) $V^{(g)(e.\max)} = \sum_{i_{1j}=0}^{N-1} \sum_{i_{2j}=i_{1j}+1}^{N} \xi_{(*)} \cdot V_j^{(g)(e.\max)}$. (15)

The total volume of lumber sawed from the segment is defined as:

- one-sided edged lumber $V^{(o.s)} = \sum_{g=1}^{G} V^{(g)(o.s)}$; (16)
- edged lumber (with parallel edges) $V^{(e)} = \sum_{g=1}^{G} V^{(g)(e)}$; (17)
- edged lumber (of maximum volume) $V^{(e.\max)} = \sum_{g=1}^{G} V^{(g)(e.\max)}$. (18)

The simulation for location of sawing pattern on the working coverage zone of sector by sawing of radial sawn lumber. The width of face on each cross section $\left(i = \overline{0, N}\right)$ of g[th] one-sided edged lumber $\left(g = \overline{1, G}\right)$ from the sawing pattern of sector (Fig.2) is defined as:

- Left $R_i(\varphi)\cos\varphi = -{}^{S}A^{L} + \lambda_q + \sum_{s=1}^{g-1}\left(t_s + d_{t_s} + pr\right),\ \ \varphi \in \left(\frac{\pi}{4} < \varphi < \frac{3\pi}{4}\right)$; (19)
- Right $R_i(\varphi)\cos\varphi = -{}^{S}A^{L} + \lambda_q + \sum_{s=1}^{g}\left(t_s + d_{t_s} + pr\right) - pr,\ \ \varphi \in \left(\frac{\pi}{4} < \varphi < \frac{3\pi}{4}\right)$. (20)

According to the solutions $\varphi_L^{(g)}$ of the equation (19) and $\varphi_R^{(g)}$ of the equation (20) we will find the width of left (${}_L b_i^{(g)}$) and right (${}_R b_i^{(g)}$) faces of one-sided wedged lumber on i^{th} cross section:

$$ {}_L b_i^{(g)} = \chi\left(R_i\left(\varphi_L^{(g)}\right)\left(\sin\left(\varphi_L^{(g)}\right) - \cos\left(\varphi_L^{(g)}\right)\right) - \frac{pr}{\sqrt{2}} \right); \quad (21) $$

$$ {}_R b_i^{(g)} = \chi\left(R_i\left(\varphi_R^{(g)}\right)\left(\sin\left(\varphi_R^{(g)}\right) - \cos\left(\varphi_R^{(g)}\right)\right) - \frac{pr}{\sqrt{2}} \right). \quad (22) $$

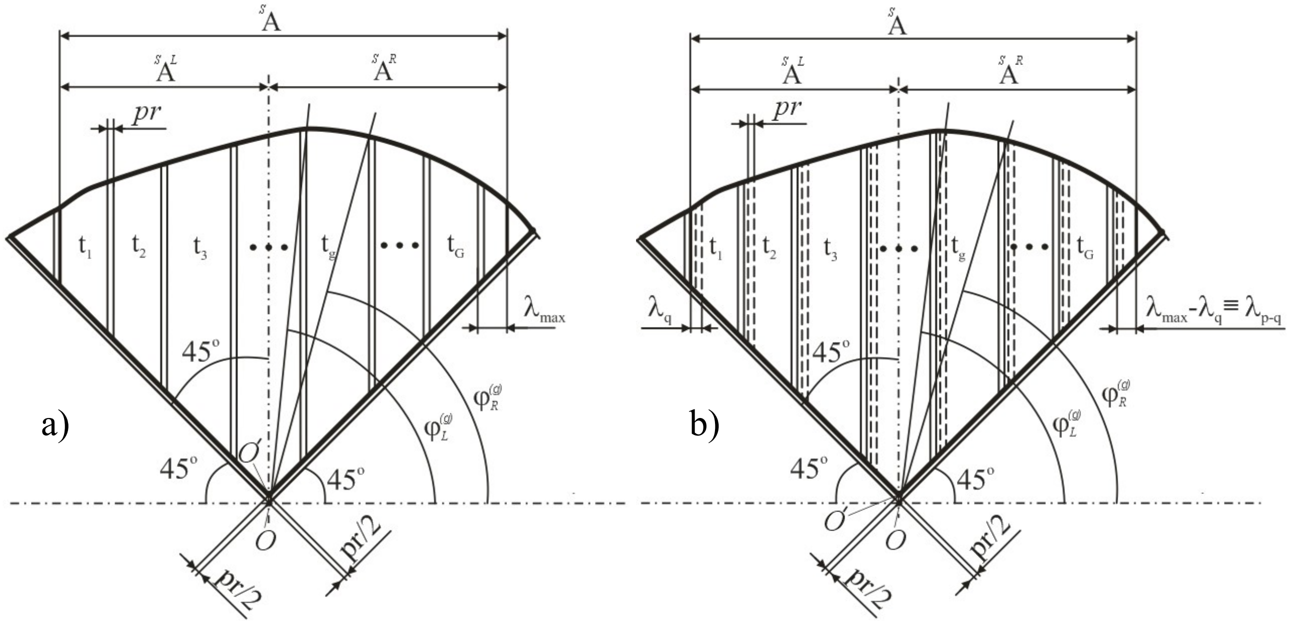

Fig. 2. The location of sawing pattern on the working coverage zone of sector by sawing of radial lumber (ith cross section): *a) initial (leftmost) locating of sawing pattern; b) displacement of sawing pattern on a step* λ_q

There are additional conditions such as the condition of acceptability of g^{th} lumber fragment (7) and existence indicator (8). Both are similar for one-sided wedged lumber and one-sided edged lumber. The volume of identified and acceptable g^{th} lumber fragment is defined as: one-sided wedged lumber (9), edged lumber (with parallel edges) (10), edged lumber (with maximum volume) (11).

The total volume of acceptable fragments of g^{th} lumber is defined as: one-sided wedged lumber (12), edged lumber (with parallel edges) (13), edged lumber (with maximum volume) (14). Then, the total volume of radial lumber sawed from the sector is defined as: one-sided wedged lumber (16), edged lumber (with parallel edges) (17), edged lumber (with maximum volume) (18).

The simulation of variants for location of sawing pattern on the working coverage zone of sector by sawing of tangential lumber. The width of face on each cross section $\left(i=\overline{0,N}\right)$ of g^{th} two-sided wedged lumber (unedged in curvilinear zone of sector) $\left(g=\overline{1,G}\right)$ from the sawing pattern of sector (Fig.3) is defined as:

- internal $R_i(\varphi)\cos\varphi={}^{s}A^{L}+\lambda_q+\sum_{s=1}^{g-1}\left(t_s+d_{t_s}+pr\right),\ \ \varphi\in\left(-\frac{\pi}{4},\frac{\pi}{4}\right);$ (23)
- external $R_i(\varphi)\cos\varphi={}^{s}A^{L}+\lambda_q+\sum_{s=1}^{g}\left(t_s+d_{t_s}+pr\right)-pr,\ \ \varphi\in\left(-\frac{\pi}{4},\frac{\pi}{4}\right).$ (24)

According to the solutions $\varphi_{1a}^{(g)},\ \varphi_{2a}^{(g)}$ $\left(-\frac{\pi}{4}<\varphi_{1a}^{(g)}<0<\varphi_{2a}^{(g)}<\frac{\pi}{4}\right)$ of the equation (23) we will find the width of "upper" and "lower" part of internal sawn timber face of g^{th} lumber depending on the hit of cutting plane (saw cut plane) on edged plane or curvilinear zone of sector, in particular:

$$ {}^{up}_{in}b_i^{(g)}=\chi\left(\min\left(R_i\left(\varphi_{2a}^{(g)}\right)\cdot\left|\sin\left(\varphi_{2a}^{(g)}\right)\right|,\ d_a-\frac{pr}{\sqrt{2}}\right)\right); \qquad (25) $$

$$ {}^{low}_{in}b_i^{(g)}=\chi\left(\min\left(R_i\left(\varphi_{1a}^{(g)}\right)\cdot\left|\sin\left(\varphi_{1a}^{(g)}\right)\right|,\ d_a-\frac{pr}{\sqrt{2}}\right)\right). \qquad (26) $$

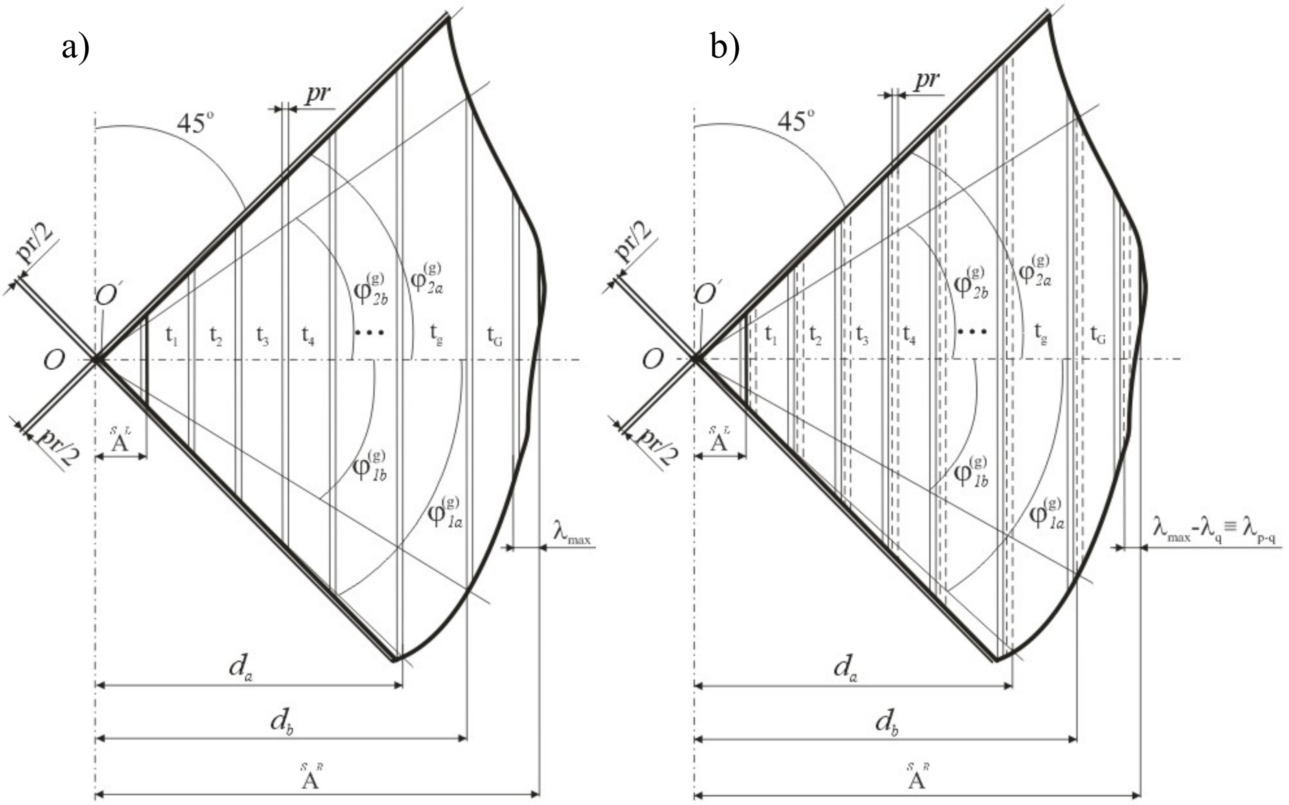

Fig. 3. The location of sawing pattern on the working coverage zone of sector by sawing of tangential lumber (i^{th} cross section): *a) initial (leftmost) locating of sawing pattern; b) displacement of sawing pattern on a step λ_q.*

Similarly, according to the solutions $\varphi_{1b}^{(g)}$, $\varphi_{2b}^{(g)}$ $\left(-\frac{\pi}{4} < \varphi_{1b}^{(g)} < 0 < \varphi_{2b}^{(g)} < \frac{\pi}{4}\right)$ of the equation (24) we will find the width of "upper" and "lower" part of external face of g[th] lumber depending on the hit of cutting plane (saw cut plane) on edged plane or curvilinear zone of sector, including:

$$ {}_{ex}^{up}b_i^{(g)} = \chi\left(\min\left(R_i\left(\varphi_{2b}^{(g)}\right)\cdot\left|\sin\left(\varphi_{2b}^{(g)}\right)\right|,\ d_b - \frac{pr}{\sqrt{2}}\right)\right); \qquad (27)$$

$$ {}_{ex}^{low}b_i^{(g)} = \chi\left(\min\left(R_i\left(\varphi_{1b}^{(g)}\right)\cdot\left|\sin\left(\varphi_{1b}^{(g)}\right)\right|,\ d_b - \frac{pr}{\sqrt{2}}\right)\right). \qquad (28)$$

Then, according to the solutions (25) and (26) we will find the width of internal face. According to the solutions of the equation (27) and (28) we will find the width of external faces of side lumber on i^{th} cross section:

$$ {}_{in}b_i^{(g)} = \chi\left({}_{in}^{up}b_i^{(g)} + {}_{in}^{low}b_i^{(g)}\right); \qquad (29)$$

$$ {}_{ex}b_i^{(g)} = \chi\left({}_{ex}^{up}b_i^{(g)} + {}_{ex}^{low}b_i^{(g)}\right). \qquad (30)$$

There are additional conditions such as the condition of fragment acceptability for g[th] lumber (7) and existence indicator (8). Both are similar for two-sided wedged lumber and one-sided edged lumber.

The volume of identified and acceptable fragment for g[th] lumber is defined as:

- two-sided wedgeg $\qquad V_j^{(g)} = V_{j1}^{(g)} + V_{j2}^{(g)}$; $\qquad$ (31)

$$V_{j1}^{(g)} = \sum_{k=i_{1j}}^{i_{2j}-1} \frac{\left({}_{in}b_{1k}^{(g)} + {}_{ex}b_{1k}^{(g)}\right)/2 + \left({}_{in}b_{1k+1}^{(g)} + {}_{ex}b_{1k+1}^{(g)}\right)/2}{2} ht_g\ ;$$

$$V_{j2}^{(g)} = \sum_{k=i_{1j}}^{i_{2j}-1} \frac{\left({}_{in}b_{2k}^{(g)} + {}_{ex}b_{2k}^{(g)}\right)/2 + \left({}_{in}b_{2k+1}^{(g)} + {}_{ex}b_{2k+1}^{(g)}\right)/2}{2} ht_g\ ,$$

where: ${}_{in}b_{1k}^{(g)}$, ${}_{ex}b_{1k}^{(g)}$ are the width of internal and external sawn timber faces of lower part of g[th] two-sided wedged lumber respectively; ${}_{in}b_{2k}^{(g)}$, ${}_{ex}b_{2k}^{(g)}$ are the width of internal and external sawn timber faces of upper part of g[th] two-sided wedged lumber respectively;

- edged lumber (with parallel edges)

$$V_j^{(g)(e)} = V_{j1}^{(g)(e)} + V_{j2}^{(g)(e)}; \tag{32}$$

$$V_{j1}^{(g)(e)} = \sum_{k=i_{1j}}^{i_{2j}-1} \min\left({}_{in}b_{1k}^{(g)}, {}_{ex}b_{1k}^{(g)}\right) ht_g\ ;$$

$$V_{j2}^{(g)(e)} = \sum_{k=i_{1j}}^{i_{2j}-1} \min\left({}_{in}b_{2k}^{(g)}, {}_{ex}b_{2k}^{(g)}\right) ht_g\ .$$

- edged lumber (of maximum volume)

$$V_j^{(g)(e.\max)} = \max_{0 \le i \le n-m}\ \max_{i+m \le j \le n} (j-i)\chi\left(\min_{i \le k \le j}\left({}_{ex}b_{1k}^{(g)},\ {}_{in}b_{1k}^{(g)}\right) + \min_{i \le k \le j}\left({}_{ex}b_{2k}^{(g)},\ {}_{in}b_{2k}^{(g)}\right)\right) ht_g\ . \tag{33}$$

The total volume of acceptable fragments of g[th] lumber is defined as: two-sided wedged lumber (12), edged lumber (with parallel edges) (13), edged lumber (with maximum volume) (14). Then, the total volume of tangential lumber sawed from the sector is defined as: two-sided wedged lumber, edged lumber (with parallel edges) (17), edged lumber (with maximum volume) (18). It is necessary to mention, that during the process of quarter (sector) sawing method into tangential lumber from curvilinear sector zone, except two-sided wedged lumber we could also get unedged and conventionally unedged (combined) lumber [4], the calculation method of which is analogues to the calculation method of unedged lumber taken from the simulation process for variants of location of sawing pattern on the working coverage zone of log [1].

The features of simulation for variants of location of sawing pattern on the working coverage zone of segment and sector by their rotation around the log axis at defined angle. It is known [2] that the width of working coverage zone of sawing pattern of log (cant, segment and sector) depends on different variants of log rotation around its axis at defined angle. Consequently, the calculation of location of sawing pattern on this zone for each rotation angle of log gives us the possibility to find the variants which will provide the optimal recovery (yield) of lumber.

In a case of usage of sawing methods which provide sawing of segments and sectors that are further sawn up into lumber, the lumber volume for each rotation angle and for each its part (cant, segment and sector) should be calculated. For example, the optimal recovery (yield) of lumber from a log for the quarter (sector) sawing method is defined as:

$$V_{\max} = \max_{\varphi}\left(\max_{S_1}\left(\max_{q_1} V_1\right) + \max_{S_2}\left(\max_{q_2} V_2\right) + \max_{S_3}\left(\max_{q_3} V_3\right) + \max_{S_4}\left(\max_{q_4} V_4\right)\right), \tag{34}$$

where: φ the rotation angle of log around its axis; V_1, V_2, V_3, V_4 the volumes of lumbers from 1[st], 2[nd], 3[rd] or 4[th] sectors; S_1, S_2, S_3, S_4 sawing patterns that are used for the sawing of related sectors; q_1, q_2, q_3, q_4 the quantity of displacement steps for sawing patterns on the coverage zones of related sectors.

In case of technological need to use one of the sawing patterns for all sectors, the formula (34) can be written as follows:

$$V_{\max} = \max_{\varphi}\left(\max_{S}\left(\max_{q_1} V_1 + \max_{q_2} V_2 + \max_{q_3} V_3 + \max_{q_4} V_4 \right)\right). \quad (35)$$

Conclusions:

1. The simulation method for variants of location of sawing pattern on the working coverage zone of segment and sector with the consideration of natural fluctuations of its real size characteristics is developed. The usage of it will provide the lumber sawing of minimally acceptable and larger sizes. Given method is mathematically proven, experimentally confirmed and applicable to the determination of all possible variants of location of sawing pattern on the working coverage zone of segment and sector.

2. The approach towards the simulation for variants of location of sawing pattern on the working coverage zone of segment and sector applicable for main industrial processes of log sawing into lumber.

3. The comparison of lumber volumes, sawed from log, segment(s) and sector(s), by various variants of location of sawing pattern on the working coverage zone depending on log rotation around its axis at defined angle, gives the possibility to determine an optimal variant, which is characterized by the displacement step of sawing pattern on the working coverage zone and angle of log rotation around the linear regressive axis.

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Розміщення схеми розпилювання на робочій зоні охоплення сегмента та сектора з урахуванням їх реальної форми

Наведено методику моделювання варіантів розміщення схеми розпилювання на робочій зоні охоплення сегмента та сектора. У процесі моделювання передбачено урахування реальної форми колоди (сегмента, сектора), отриманої за результатами сканування форми поверхонь поперечних перетинів. З метою оцінювання схем розпилювання колод (сегментів, секторів) передбачено порівняння об'єму пиломатеріалів, отриманого за різними варіантами розміщення схем розпилювання на робочій зоні охоплення сегмента (сектора) та залежно від обертання колоди навколо лінійної регресійної осі на заданий кут.

Ключові слова: колода, сегмент, сектор, робоча зона охоплення, розміщення схеми розпилювання, реальна форма, моделювання, об'єм, обертання колоди.

UDC 674.047 ***Senior teacher Z.P. Kopynets, assist. R.B. Shchupakivskyy – UNFU***

INVESTIGATION OF BEECH LUMBER DRYING PROCESS BY THE LOW TEMPERATURE MULTI-STAGE REGIMES

This paper presents the results of experimental study of convective drying process of beech lumber under production conditions. Processed drying process cards, built drying curves and drying rate curves for beech lumber with the actual thickness 32mm. Duration of drying process for multi-stage low-temperature regime of beech timber have been investigated; obtained the value of moisture conduction coefficient at given conditions.

Keywords: wood drying, low-temperature drying regime, beech timber, drying curve, moisture conduction.

The current state of the issue. Convective chamber drying of lumber is complex, energy-intensive process. Modern production realities require obtaining high quality products as a result of drying. However, there is a need for efficient use of heat and electricity. Therefore, the research process of timber drying does not lose its relevance. The experimental investigations in the laboratory are important, but equally important is the generalization of manufacture experience for timber drying to further improvement of drying regimes, increasing resource and energy effectiveness [5-8].

The aim of the investigation. The aim of the study is to establish the duration of the convective drying of beech lumber with the actual thickness 32 mm for the studied low-temperature multi-mode regime under production conditions; identifying of drying coefficient and moisture conductivity.

Investigation methodology. Experimental production studies were conducted in convective drying chamber with a vertical transverse circulation of drying agent.

The chamber was loaded by stacks of length 6.5 m, width 1.8 m, height 3 m. Six experimental drying process of beech lumber with thickness of 32 mm, width 200 mm and length 3.5m have done. The use of adaptive automatic control process allowed to obtain the results of moisture content in stack at 6 points. The rate of circulation drying agent in the chamber was near 3 m/s.

During the drying process change of regime parameters occurred stepwise depending on the change of the current moisture content. Process of drying from the initial moisture content up to 25% moisture content was carried out by the rate of the sample with the highest moisture content, due to decline the current moisture content of the sample down to 25% – with average estimated moisture on the stack.

Ambient temperature during the drying process in the first stage at a dry bulb was $t = 53°C$, relative humidity – $\varphi = 84\%$; at the last stage – $t = 64°C$ and $\varphi = 30\%$ accordingly.

Results and Disscutions. According to the results of the drying process of beech lumber, drying curves and drying rate curves for each experiment at all points of measurement of humidity were built.

In Fig. 1 shows the drying curves in six points of the stack (experiment №2), from which is also visible regime parameters of drying agent. In Fig. 2 illustrated the curves of drying rate, which shows that the process occurs in a period of slowing down rate of drying.

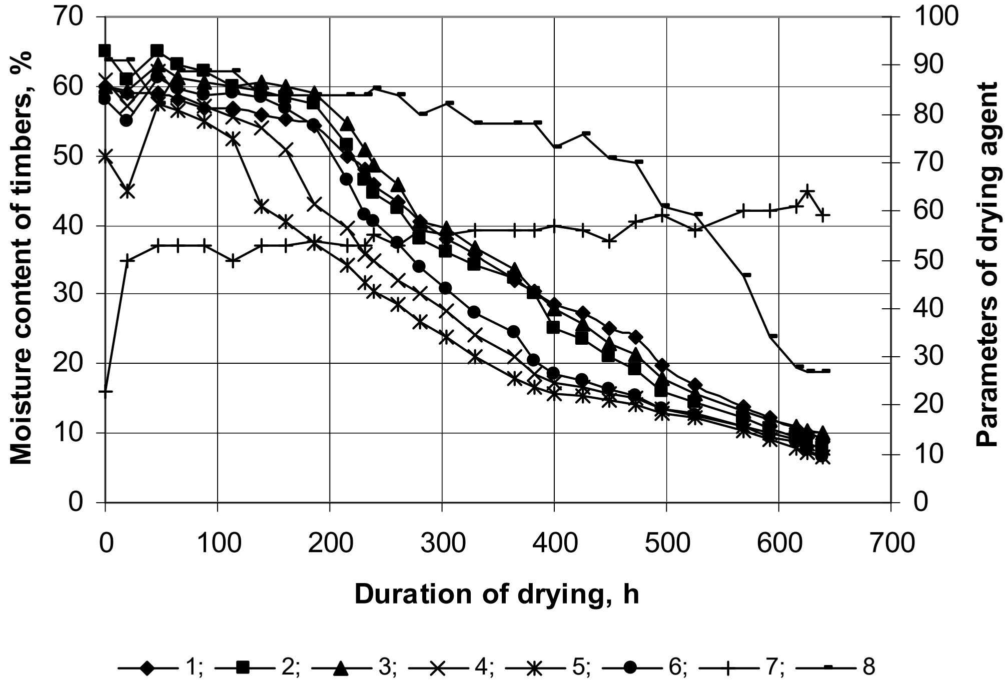

Fig. 1. Drying curves (study number 2) in stacks of six points:
1, 2, 3, 4, 5, 6 – drying curves under measurement at points 1, 2, 3, 4, 5, 6;
6 – temperature of drying agent, °C; 7 – relative humidity og drying agent, %.

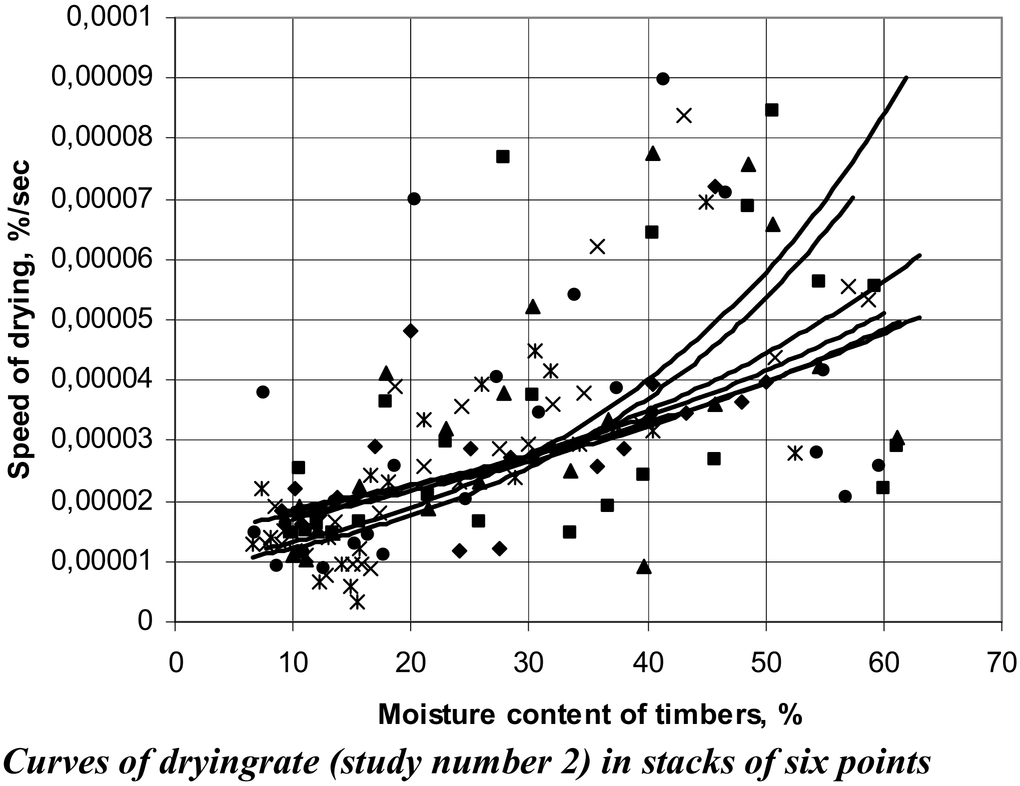

Fig. 2. Curves of dryingrate (study number 2) in stacks of six points

Since under industrial conditions the initial humidity of lumber, which are loaded into the chamber, varies considerably the drying curves were built in moisture at which the process was carried out reduced to the same initial moisture content by moving them along the x-axis as long as they cross the y-axis at the point at the initial moisture content.

Experimental drying curves are given at initial moisture content of about 60% and the final moisture content about 8% (see Fig. 3).

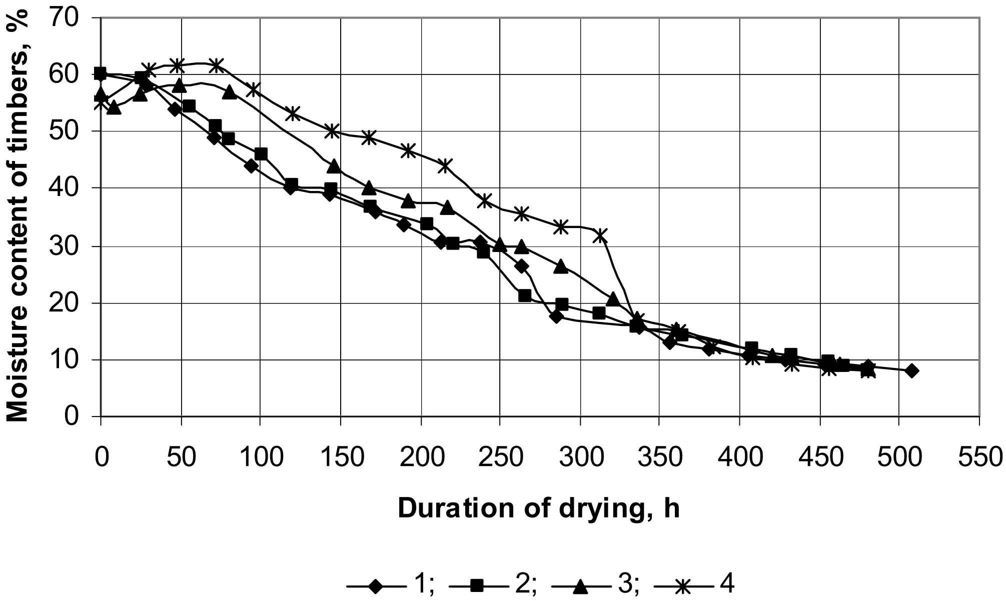

Fig. 3. Drying curves fitted to the same initial moisture content:
1, 2, 3, 4 – drying curves for experiments № 1, 2, 3, and 5.

Thus, the duration of beech lumber chamber drying after correction to the same initial moisture content are as follows: 1st experiment - 507,3 hours; 2nd – 479,92 h; 3rd – 480,5 h; 4th– 429,9 h; 5 th – 480 h; and 6 th – 447,75 hours. The arithmetic mean value of the duration of drying process is 470.9 hours. The accuracy of the experiment, according to [1] is 2.39%. Since in woodworking the reliability of the experiment accuracy rate does not exceed more than 5%, found average duration can be considered a reliable result. With the drying curves mass transfer coefficients can be investigated.

Approximate equation of drying curve for a period of slowing down rate expressed as follows [2, 3]:

$$\ln \frac{W_i - W_{eq}}{W_f - W_{eq}} = -K \cdot \tau \;, \qquad (1)$$

where: W_i, W_f, W_{eq}–respectively the initial, final and equilibrium moisture content,%; K – coefficient of drying (depends of the type and size of material, mass transfer, slowing downrate of the drying process) s^{-1}; τ – the drying period, s.

From equation (1) can determine the rate of drying:

$$K = \frac{\ln\left[(W_i - W_{eq}) / (W_f - W_{eq}) \right]}{\tau}, \qquad (2)$$

According to the investigated multi-mode regime average rate of drying coefficient is = $2{,}332 \cdot 10^{-6}$, s^{-1}.

The coefficient of moisture conductivity was determined by the method of pilot dryers. Duration of the low-temperature drying process by graphoanalitical method determined at each stage mode by the formula [3]:

$$\tau_{1\ldots n} = C_{\tau 1\ldots n} \cdot \frac{65 \cdot S_1^2}{a'_{1\ldots n} \cdot 10^6} \cdot C_{1\ldots n} \cdot A_{c.} \cdot \lg\left(\frac{W_{i1\ldots n} - W_{eq.1\ldots n}}{W_{f1\ldots n} - W_{eq.1\ldots n}}\right), \qquad (3)$$

where: $W_{i1\ldots n}$, $W_{f1\ldots n}$, $W_{eq.1\ldots n}$– initial, final and equilibrium moisture content of lumber at each of drying stages; C_τ –amendment to the multidimensionality that takes into account the width of the lumber; S_1 –width of the lumber; C –factor of the slowdown of drying process in stacks of different widths; A_c – coefficient for the reversibility circulation (for reverse circulation – 1.0); $a`_{1..n}$– coefficient of moisture conductivity of wood at each of the stages of the drying, cm^2/s. The amendment to the multidimensionality accepted - 1 as the width of lumber were 200 mm and more, as well as the ratio of thickness to width ratio is 0.16 or less. Factor considering slowing the drying process in the stacks was took according to the method described in [4]. According to our calculations for the study of these conditions it is 1.04. The average coefficient of moisture conductivity for these drying conditions is $2{,}526 \cdot 10^{-6}$ cm^2/s.

Conclusions. By the results of this study in a production environment and statistical processing of the experimental data the average time for the convective drying process of edged beech lumber with thickness 32 mm have been obtained.According to the investigated multi-mode low-temperature regime average duration of drying is ≈ 470,9 hours. Obtained the value of drying coefficient – $2{,}332 \cdot 10^{-6}$ s^{-1}, and the coefficient of moisture conductivity –$2{,}526 \cdot 10^{-6}$ cm^2/s undergiven conditions.

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Дослідження* процесу *сушіння букових пиломатеріалів низькотемпературним багатоступеневим режимом

Проведено експериментальні дослідження конвективного низькотемпературного сушіння букових пиломатеріалів у виробничих умовах. Опрацьовано картки обліку процесу сушіння і побудовано криві сушіння та швидкості сушіння для букових обрізних пиломатеріалів товщиною 32 мм. Досліджено тривалість процесу сушіння букових пиломатеріалів низькотемпературним багатоступеневим режимом; встановлено коефіцієнти сушіння та вологопровідності для даних умов дослідження.

Ключові слова: сушіння деревини, низькотемпературний режим сушіння, деревина бука, крива сушіння, коефіцієнт сушіння, вологоперенесення

UDC 639.1
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RE-ACCLIMATIZATION OF EUROPEAN BISON (*BISON BONASUS* L.) IN THE SKOLE BESKIDS (THE EASTERN CARPATHIANS)

The outcomes of bison re-acclimatization in the Skole Beskids (the Eastern Carpathians) undertaken in the period 1965-2013 have been examined. 10 bisons were first brought to the Skole Beskids in May 1965. They became founders of the Maydan sub-population. The bison numbers reached their peak in the 1980s. In 1990s, adecline in this population was recorded. The last bison of the Maydan sub-population died during the 2008-2009 period. The causes of their death were food shortage in winter, poaching, diseases and others. In 2005, the Large Herbivore Foundation (Holland), in collaboration with the European Bison Friends Society (Poland), [Stowarzysyenie Miłośników Zubrów, Polska] developed the program «Restoration of the European Bison population in the Eastern Ukrainian Carpathians». Under this project, 6 bison were brought from the Thüringen Waldzoo Gera (Germany) to be placed in an enclosure in the Skole Beskids in June 2009. In Nowember 2010, five individuals were brought from the Bavaria Forest National Park (Germany) and the breeding centre «Marschfeld Castles» (Austria). The two groups of animals created a herd. During winter time, the animals are provided with supplementary food. The bison numbers in the herd have increased during the 2009-2013 period amounting to 15 individuals at present time.

Keywords: re-acclimatization, sub-population, population numbers.

Introduction. The re-acclimatization of bison (*Bison bonasus* L.) in the Skole Beskids began in the latter part of the 20th century. In 1965, a group of bison was brought to the mountainous part of Lviv region (the Skole Beskids), these became founders of the Maydan sub-population [4, 7, 9, 11]. There were no systematic observations made about the process of re-acclimatization of the Maydan sub-population bison. On establishing the Skole Beskids National Nature Park and thus including the bison biotopes into the protected zone, the study on the species vital activities in mountain conditions began: feeding behavior, spatial distribution, migration patterns etc. In the course of the study, migration routes, summer and winter biotopes frequented by the bison, peculiarities of their nutrition were identified, as well as forage supplies available in winter time were estimated [3]. The 1990s saw a decline in bison numbers in the Skole Beskids. The causes of the population decline were analyzed in the literature [3, 5, 8, 9, 10]. Early in the 21st century the Maydan sub-population did not exceed 10 individuals and continued to decrease.

In view of the fact that the bison numbers of the Maydan sub-population declined precipitously in 2005, the Large Herbivore Foundation (Holland), in collaboration with the European Bison Friends Society (Poland), developed the program «Restoration of the European Bison population in the Eastern Ukrainian Carpathians» [11]. Under this program, the first animals were brought to the Skole Beskids in 2009, the next group of animals was brought in 2010. Therefore, there is a need for considering and analyzing the outcomes of bison re-acclimatization in the Skole Beskids.

Material and methods. The studies of bison vital activities in the Skole Beskids have been conducted during the 1999-2013 period . In estimating the bison numbers, statistical data on bison inventory from the Ministry for Environmental protection as well as the author's own investigations were used [8].

For the purpose of establishing the causes and determining the time of bison death, forest wardens, hunters, forest employees were interviewed and surveyed by questionnaires [2]. In analyzing the causes of animals death, the reports on post-mortem examination of dead animals carried out by vet laboratories specialists were used.

Results and discussion. In May 1965, ten bison were brought to the Maydan game enterprise (the Skole Beskids) from the Belovezhskaya Forest (Belarus). The ancestors of the Skole bison were 3 males and 9 females of the Lowland-Caucasian Line [12].

Table 1. Register of *Bison bonasus* brought to the Skole Beskids (May 1965)

Parents		Name of the animal	Date of birth	Gender
male	female			
Pustosz	Pliszka	Byegonia	August 22, 1952	female
Pustosz	Byeta	Byezdna	May 3, 1955	female
	Purpura	Byesiedka	May 3, 1955	female
Puchatek	Byeza	Byerendej	November 7, 1960	male
Pul	Byegonia	Byezsmertnyi	June 21, 1960	male
Pul	Byeljanka	Byelena	May 11, 1962	female
-	Byeloczka	Byeloglazka	June 1963	female
Puchatek	Byezumnaja	Byezumiec	May 17, 1963	male
Puchatek	Byerdanka	Byerdiansk	May 11, 1963	male
-	Byerdanka	Beha	1965	female

The analysis of age-sex structure of the bison population points to a satisfactory selection of the animals brought to the Skole Beskids. The researchers who studied the bison biology noted that bison females become sexually mature at the age of 3 to 5 years, while males are already sexually mature when they are 3 years old; however, in the wild, young males are not allowed by older bulls to participate in breeding until the young bulls are physically strong, which occurs at the age of 5 or 6 years [6]. Taking into account the fact that of all bison animals, only 2 males and 4 females attained sexual maturity and that cows under natural conditions produce calves once in every 2 or 3 years, the population growth rate during the first years may be considered as being satisfactory. The period from 1965 to 1971 saw the birth of 14 calves. Under natural conditions, bison females commonly give birth to one calf and rarely to twins. In the Skole Beskids 2 calves were born each year, only 1 calf was born in 1967, and 3 calves in 1971. During a 7-year period (1965-1971), 11 bison died. As of January 1, 1972 there were 13 individuals (4 males and 7 females) in the Skole Beskids [7]. In the late 1970s, all the bison became sexually mature; yet the bison numbers growth was slow: two individuals per year, which is accounted for by bison's essentially high death rate.

The bison that had been brought to the Skole Beskids were kept for about 2 years in an enclosure of area about 4 ha. Since feeding them with beetroot and potato caused health problems, the animals were released into the wild in 1967. The increase in the Maydan sub-population was recorded until the late 1980s (Fig. 1).

The average annual increase in the bison numbers amounted to 12.4±1.8%. In 1980, thirty-one individuals were recorded (14 males and 17 females). In the period from 1980 to 1984, eight calves were born, and seven adult animals died, mostly in winter. In the 1990s, birth and death rates in various years varied greatly: 1 to 7 calves were born while 2 to 4 individuals died each year. There were years when no calves were born at all. In 1995, over 35 bison were recorded in the Skole Beskids, the main herd amounting to 17 or 18 individuals. The sexual structure of the Skole population varied from year to year. The share of males made up 38-48%, accordingly the share of females was – 52-62%. The bison population was getting old. In 1993, adult animals made up 48% of the total number, in 1998 – 64%. In the late 1990s, the main herd numbered 14 individuals, while the early 21st century counted 10 individuals. In was in this period that the sub-population declined dramatically. The last bison of the Maydan sub-population died, presumably, within the 2008-2009 period.

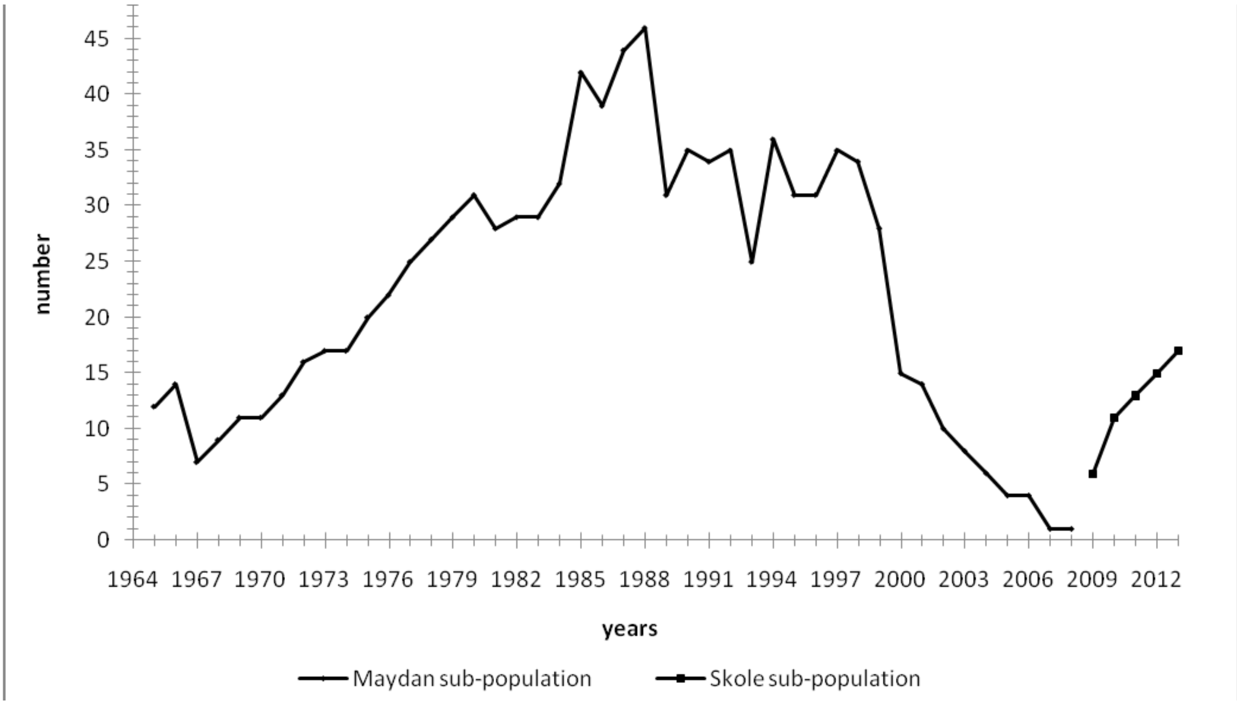

Fig. 1. Dynamics of Bison bonasus numbers in the Skole Beskids

We have identified 7 causes of the bison death. The population numbers were affected by snowy winters: a thick blanket of snow made in difficult for the animals to access forage, which led to their exhaustion and, consequently, to death. 34.5% of bison death cases was due to forage shortage in winter period. It is usually difficult to discover a dead animal under natural conditions. Very often, on discovering a dead animal, the state of this dead animal body made it impossible to identify the cause of death. That is why in 17.2% of cases, the cause of death could not be identified. A considerable number of animals (20.7%) died due to accidents. Illegal hunting was responsible for 13.8% of bison death cases. The other causes (13.8%) that led to the bison numbers decline were transport, old age, diseases.

In keeping with the project of bison re-acclimatization, there was established a 3 ha-sized enclosure in the Skole Beskids in 2007 for temporary keeping bison in the lands of the Maydan forest unit of the Skole Beskids National Park. Forest lands occupied about 60% of the enclosure area, small clearings – 40%. The predominant vegetation within the enclosure area was beech-spruce-fir associations which grew on the slopes of western exposure, the undergrowth was sparse formed with *Corylus avellana* (L.), *Populus tremula* (L.), *Salix triandra* (L.), *Sorbus aucuparia* (L.), *Betula pendula* (R.). The herbaceous cover was well-developed represented by *Potentilla erecta* (L.), *Pteridium aquilinum* (K.), *Polygonatum officinale* (L.), *Carex acuta* (L.) and others. Two streamlines ran across the area of the enclosure.

In June 2009, six bison belonging to the Lowland-Caucasian line were brought to the enclosure from the Thüringen Waldzoo Gera (Germany). All the females from the introduced bison group were of reproductive age, while the oldest of the males was only 3 years old, the other two males – 1 and 2 years old, respectively (Table 2).

Table 2. Register of *Bison bonasus* brought to the Skole Beskids (June 2009)

Parents		Name of animal	No.	Date of birth	Gender
male	female				
Orion	Zwetschke	Theo	10711	October 9, 2006	male
Orion	Lina	Thunderbird	10983	April 30, 2007	male
Orion	Thyra	Thasidos	11182	May 31, 2008	male
Orion	Lina	Thyra	9773	June 21, 2002	female
Orion	Thyra	Thalia	10710	October 5, 2006	female
Orion	Zwetschke	Thoska	9774	July 11, 2002	female

Naturally, the rut with bison occurs late in August – early in September. Pregnancy duration averages 9 months, therefore bison calves in natural conditions are born in spring or early in summer. In the Gera Waldzoo where the bison were supple mentally fed up and their living conditions did not vary much over the year compared to those in the wild, the rut period was much longer and calves were born at different times in the year. 3 bison which were brought to the Skole Beskids were born in May-June, which is the most favorable period for calf birth. In July, the birth of Thoska was recorded, in October – Theo and Thalia were born. As bison become wild – in their passing to living in the wild without feeding up – the rut period will become shorter and, in the course of time, the rut will occur in August-September with further birth of calves in May-June. Thus, in 2013, the huntsman guard registered bison rut in September. As is seen from Table 2, the introduced individuals descend from 1 male and 3 females. 1 male and 1 female are direct descendants of 1 female from the herd. Already at the initial stage of its formation, the herd was featured by a considerably high level of inbreeding. The genetic variability was essentially low. Close-related crossbreeding in highly-inbreeding herds is inadmissible because this results in essentially high incidence of various congenital anomalies the bearers of which were relatives who themselves did not have such abnormalities. In particular, among major problems are the following: fetal death of calves due to abnormal development of embryo (which is incompatible with further development of embryo) [7]; early post-natal death of calves become of frequent occurrence, their birth weight decreases. They are slow to gain in weight and are susceptible to various diseases during their lifetime, they often suffer from sexual disorders and are characterized by a shorter lifespan; that is, close inbreeding results in decline of general viability of progeny. Thus, on September 26, 2009 the female Thyra gave birth to a calf, however the calf died in October owing to poorly healed navel string. The calve Tymko, that was born by the female Thoska, has survived.

The breeders' practical experience shows that prolonged inbreeding which takes place from generation to generation commonly results in reduced reproductive ability (fecundity) and productive performance, and other negative effects.

Close-related breeding causes substantial reduction in the variability of inbreeding lines, animals may lose their ability to be adapted to changing environmental conditions. The improperly formed herd, in which close relatives were found (brother-sister), was a cause of bison death of the Nadvirna sub-population (the Eastern Carpathians). The mean inbreeding coefficient of the sub-population was 40%, which resulted in decreased genetic variability, particularly for genes responsible for resistance to diseases.

Hereditary diseases emerged and became widespread among the animals of the herd caused by lethal and semi-lethal genes, in particular, stillbirth, cryptorchism (undeveloped testicles). Also common in the animals are infectious genitor-urinary diseases caused by staphylococci and purulent actinomycetes. Some males suffered from acute form of purulent balanoposthitis [3].

In October 2009, the male Thasidos died of exhaustion, although the animal had enough forage: they were regularly provided with supplementary feeding by game wardens of the Skole Beskids National Nature Park. The first several months (between 4 to 5 months) of the animals dwelling in the enclosure was the period of the herd's formation. The period of lactation in bison females lasts for about 1.5 to 1.8 years up to the next rut and calving. The animal's rank is known to depend on its age and weight, so calves benefit from their mother's hierarchical status for a prolonged time. The calf Thasidos was weaned from its mother (Thyra) at the point when breaking blood and social ties led to the calf's stress state the cause of which was the female's next calving (in September 2009). Repeated manifestation of aggression against Thasidos from the side of other animals in the herd made the calf keep away from the herd. Gradually, Thasidos integrated into the herd; however its lowest rank was responsible for food shortage. Under conditions of nutrition competition with larger and older individuals the calf had to content itself with food of the lowest energy value. Therefore, the cause of Thasido's death was the excessively high density of animals within the small area and the lack of full value nutrition during the stage of herd's formation.

In November 2010, five individuals of the Lowland-Caucasus line were brought from the Bavaria Forest National Park (Germany) and the breeding centre «Marschfeld Castles« (Austria) (Table 3). The animals behaved rather quietly during the transportation except for the male Aboko which showed aggressiveness during the transportation and also at the time of releasing into the enclosure.

Table 3. Register of *Bison bonasus* brought to the Skole Beskids (November 2010)

Parents		Name of animal	No.	Date of birth	Gender
male	female				
Scharan	Pomroka	Schah	11426	August 1, 2009	male
Abkes	Aboka	Aboko	11334	June 27, 2008	male
Abkes	Abtei	Abtebo	11518	September 28, 2009	male
Abkes	Abalu	Aballa	11519	November 6, 2009	female
Abkes	Aboka	Aboker	11520	November 27, 2009	male

The other group of animals was kept in the enclosure from November 12, 2010 till February 2011 when they were released into the wild after one of the males (Schah) managed to break out of the fenced area to join a free-ranging herd. This free-ranging herd often had come near up to the enclosure. After the animals were released from the enclosure the two groups came together to form a single herd. In March 2011, Thyra gave birth to twins (a male and a female). In May 2012, Thalia gave birth to a male calf, and in July a female from the second group gave birth to a female calf. In spring 2013, only male bison were born: the female Thoska gave birth to one calf while the female Thalia gave birth to one calf in May. In winter, the herd usually ranges within a limited area not far from the enclosure; this has resulted in depletion of natural forage supplies. The bison intensively fed on twigs and bark of *Corylus avellana*, *Populus tremula*, *Salix triandra, Salix daphnoides*.

From time to time, some males which were introduced in Nowember 2010 (Schah, Abtebo and Tymko) move off the herd to a distance of 3 to 5 km (Fig. 2), while the male Aboko would move to a greater distance and for a longer period of time. Thus, Aboko left the herd in autumn 2011 to rejoin the herd only late in February 2012. The male was exhausted but, in general, its state of health was satisfactory. The 2009-2013 period in the Skole Beskids saw the most severe and long winter of 2012-2013, a deep and dense blanket of snow formed in December 2012 and did not melt until mid-April. In winter the bison are additionally fed up with hay, beetroot, cabbage, and mixed fodder. The feeding ground is situated not far from the enclosure (Fig. 2). During the feeding up process it was possible for the visitors come nearer to the feeding ground within a distance of 3 to 5 m.

Fig. 2. The main herd of Bison bonasus in the Skole Beskids

Conclusions:

1. The process of bison re-acclimatization in the Skole Beskids is proceeding successfully. The animals were introduced at different times from various bison breeding centers. They have integrated into a single herd and reproduction of bison has been recorded. During a 4-year period, 6 calves were born, 1 calf and 1 young male have died. The current bison numbers amount to 15 individuals.

2. It is registered that male individuals prevail in the herd, the sexual ratio is 1.8 : 1.0.

3. In winter the game wardens of the Skole Beskids National Nature Park provide the animals with supplementary feeding; proper guarding and protection of the bison herd are organized.

4. The Maydan bison sub-population, which was established in 1965, ceased to exist, presumably in 2008-2009. Therefore, the present herd is appropriate to call the Skole sub-population.

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Реакліматизація зубра у Сколівських Бескидах (Східні Карпати)

Реакліматизацію зубра у Східних Карпатах проводять з 1965 р. На початку 90-х років XX ст. чисельність поголів'я досягло максимальної чисельності – близько 270 особин. Тут існувало три субпопуляції зубра (Майданська, Надвірнянська, Буковинська). З 90-х років минулого століття зареєстроване зменшення чисельності. Останніх зубрів Надвірнянської субпопуляції реєстрували в кінці 90-х років минулого століття, останні звірі Майданської субпопуляції ймовірно загинули зимою 2008-2009 рр., зменшується чисельність Буковинської субпопуляції. Сучасна чисельність поголів'я Буковинської і Майданської субпопуляцій є незначною і становить понад 40 голів, що зумовлює необхідність здійснення заходів з охорони і відтворення поголів'я зубрів. Перспективи реакліматизації зубра у Східних Карпатах полягають: у створенні розплідників на території НПП «Сколівські Бескиди», Вижницького НПП; у завезенні особин із Уладівської субпопуляції (Україна), Білорусії, Польщі, Росії та інших європейських країн для формування у новостворених розплідниках стад зубра; створенні двох нових місць оселення звірів у Східних Карпатах на території Івано-Франківської областей; завезення зубрів у біотопи поширення Буковинської субпопуляції.

Ключові слова: реакліматизація, субпопуляція, чисельність, розплідник.

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TRANSFORMATION OF ENERGY BASE IN POLAND. ENERGY CONSERVATION AND USE OF RENEWABLE ENERGY

The article is about the energy transformation of the Polish economy over the last 25 years. The basic steps of transformation, mechanisms of white certificates, energy audits, energy conservation processes in the industry. Also, the article focuses on the use of renewable energy sources in Poland, such as biomass, hydropower engineering, wind power engineering, etc., as well as mechanisms for financing projects in the field.

Keywords: energy efficiency, renewable energy sources, biomass, energy audit.

Introduction. Continuing increase in the cost of energy (economic aspect), and the need to conduct business with minimal damage to the environment (environmental aspect) requires implementation of energy-saving technologies and the use of renewable forms of energy. The energy consumption efficiency is an important economic factor. Increased energy efficiency is of benefit to the economy, namely:

- It is an important factor of the country's energy security due to the decreased energy resources import;
- It enhances the economy's competitive capacity by cheapening production cost, it improves financial condition of enterprises and households;
- It contributes to creation of additional jobs;
- It creates the basis for innovative economy;
- It reduces harmful atmospheric emissions and improves the air quality.

The history of the transformation period. The last 25 years were a turning point for Poland's economy. The nondemocratic political system and administrative-command economy, whose characteristic features were wastage of natural resources, lack of modern technologies, considerably high level of energy consumption and atmospheric emission, were replaced by market economy. Since 2004, Poland has been a member state of the European Union, which has offered strong possibilities for further development. Beginning in the latter part of the 1990s, restructuring of the energy sector of the economy has been started in Poland. On the one hand, this was compelled by requirements of market economy which the then Poland's energy industry was not tailored to meet, and, on the other hand, there were demands concerning the reduction in harmful atmospheric emission, first of all, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) [4, 16-20]. Starting in 1994, the main instrument which aimed at promoting modernisation of the energy sector was long-term contracts. These were signed between energy enterprises and Polish electric power supply network. The contracts specified volumes of sales, prices, and the term of power supply (ranging from 10 to 20 years).

This enabled funds to be raised and invested for the purpose of re-equipment of energy enterprises. On 17 September 1996, Poland's Council of Ministers adopted the programme of demonopolization and privatisation of the energy sector, which also implied promotion of environmentally benign modernisation of energy enterprises. As from 1st January 1998, the prices for heat energy have been raised to the market level, which allowed for installation of environmental protection facilities at enterprises.

The energy legislation that was adopted on 5 December 1997 obliged the energy enterprises to prepare development plans which were to be adjusted to environmental requirements as well as to the possibility of obtaining energy from renewable sources. The producers of energy from renewable sources were granted tax relief and preferential prices for "green energy" [4]. Along with this, a paradigm dominated in the latter part of the 1990s according to which economic growth was associated with increased energy consumption. Such an approach led to increased energy consumption, in particular gas that was supplied from Russia; this also resulted in freezing investment into energy efficiency projects and renewable energy sources development, and, consequently, to waste of time needed for radical modernization of the energy industry. It was not until 2008 that this paradigm (development = consumption) was abandoned and a demand for zero energy development for Poland was first emphasized in the document "Polish energy policy up to the year 2030". The energy efficiency is a top priority in Poland's energy policy up to 2030 according to the document adopted by the Government in 2009.

This concept has received support among the most influential political parties in the country. Poland's government has taken on obligations to improve the energy efficiency by 9 % by the year 2016 in reference to the forecast of primary energy consumption, yet the potentials for further improving energy efficiency remain still great. The energy consumption in

Polish economy is twice as much as the average in the European Union countries. This factor should be taken into consideration to improve competitiveness of Polish economy and create new jobs. The financial prospects of the European Commission for the period 2014-2020 provide for as much as 20 % of funds to be allotted from the mutual fund for supporting and promotion of energy efficiency as well as the development of the renewable energy sources (RES).

In recent years, the energy efficiency in Poland has improved. During the period 1998-2009, the energy consumption in the economy decreased by roughly 30 %. The most drastic decline in energy consumption occurred in the industrial sector as a result of the privatization and modernization processes. The reduction of energy consumption in the households is largely influenced by the growth of prices for energy carriers and investments into heat engineering modernization.

White certificates. White certificates were presented in Directive 2006/32 WE by the European Parliament and Council of Europe as one of the mechanism necessary to achieve the objective: enhancing energy efficiency of end power consumption by 9 % by the year 2016, and 20 % by the year 2020.

The main addressee of the certificates is companies that supply electric power, gas and heat (energy service companies) to end-users. These companies must receive a certain number of certificates according to the amount of energy sold. If the sellers do not receive the necessary number of certificates, they will have to pay for them.

As to the instruction, the energy companies that sell electric power, heat and gas are to obtain energy efficiency certification which corresponds to, at least, a 1.5 % amount of energy saved per year. The mechanism of white certificates is an innovative market instrument which provides a system-based support for projects aimed at energy saving such as heat engineering modernization, insulation of industrial installations and others [2, 3-15]. Energy saving is possible to occur only when we have an accurate knowledge of "where, how much and when" this energy was consumed.

The **energy audit** makes it possible to trace at a certain enterprise all operations associated with energy consumption and then to draw up a plan of reducing energy consumption. The analysis made by the auditor allows for all-round examination of the equipment, installations, technological lines, thermal insulation condition, as well as the condition of machinery at the time under review. The energy audit specifies methods by means of which the energy consumption can be reduced, it defines necessary measures to bring about the most effect, and estimates cost budgeting for each action taken, also it determines expected time of cost recovery. The next mechanism for increasing energy efficiency is the Fund for heat engineering modernization and repairs which was established in 1998. The Fund supports projects for replacing household heating boilers, heat insulation of walls, heat pipelines and others. An important instrument for promotion of energy efficiency is targeted additional financing of measures to reduce energy consumption which comes from the State's Fund for Environmental Protection and Water Management, in particular within the framework of Green Investment Scheme (GIS). This originates from the mechanism of greenhouse gas trading. Worthy of notice is the program for financing the development of sustainable energy, this is to support small and medium-sized enterprises by granting them soft loans for investments into new technologies and equipment that reduce energy consumption.

Energy conservation at industrial enterprises. The reduction in energy consumption at industrial enterprises implies carrying out various measures beginning with ensuring proper maintenance and operation of the equipment as well as appropriate production arrangement, including minor modification of the equipment, and ending with investments into new energy-saving equipment and technologies.

The introduction of new technologies, that allow energy consumption to be significantly reduced, results in decreased energy consumption for the whole branches of industry. The application of the method for "dry" manufacture of cement is an example. As a rule, these are measures which require sizable capital investments and are possible to be carried out in a selected group of enterprises. As is evident from the experience of most countries, a notable advance can also be achieved when making modifications in standard equipment that is widely used in industry and which does not necessarily require heavy capital investments.

This clearly points to the availability of essentially simple alternative means for energy conservation, this being true for the areas of energy use such as lighting, ventilation, creation of indoor climate, air compression, heat exchange, steam generation, power distribution etc.

The possible ways of energy saving at industrial enterprises are as follows:

- Gaging the energy consumed, energy consumption monitoring;
- Lighting installation (making the most use of natural lighting, replacement of lamps by energy-saving ones);
- Monitoring of the operation of compressed-air system, lowering their costs;
- The application of energy-saving pneumatic systems (e.g. pneumatic guns);
- The use of energy-saving engines, fans, pumps;
- Monitoring the operation of heating boilers: lowering steam pressure in the boilers, improving heat insulation, elimination of steam and heat loss in transferring;
- Heat insulation of piping;
- Up-to-date insulated entrance doors to workshops;
- The use of air recuperators;
- Properly adjusted system of indoor climate [9-27].

Renewable energy sources (RES). Renewable energy sources can make a significant share of the energy balance, assist the growth of energy security, including improving energy investment in areas with poorly developed energy infrastructure. Potentially the largest consumer of renewable energy sources may be agriculture, houses and transport. Especially for regions with high unemployment, renewable energy sources create new possibilities, including the emergence of new jobs[2, 5].

The development of RES-based energy industry can be helpful in handling many environmental problems caused by the traditional energy industry.

Supporting RES has become an important objective of the European Union's policy. In 1997, the RES development strategy for the EU countries was presented, this forming the basis for taking actions on the EU territory. The strategy provides for a 20 % share of RES to be achieved in the fuel-and-power balance by the year 2020. The share of RES in the energy consumption for Poland in 2020 is to make 15 %.

Biomass. The most important renewable energy source in Poland is biomass. It has a 98% share in the renewable energy market and its use will continue to grow. Biomass resources for energy purposes in Poland are the highest among all other renewable sources. Its use, in comparison to other renewable energy sources, is also dominant in all energy sectors.

About 20 000 people are employed in Polish enterprises engaged in biomass supply to the energy market and several thousands more is engaged in cooperating companies. The majority of plants are located in areas with above-average level of unemployment and less industrialized regions where is no alternative employment. But in Poland biomass was used mostly for "co-burning". In 2011, Poland's power engineering used more than 90% of "co-burning" technology.

Hydropower engineering. Hydropower engineering in Poland has a long tradition of practice. Water-power resources of Poland are rather modest, taking into consideration not-too-heavy precipitations, high water-absorbing capacity of the soils, and small differences in heights. The capacity of now operating hydroelectric stations can be raised by 20-30 % through upgrading power-generating units. Poland's water-power industry, despite rather moderate level of exploiting the now existent potential, has considerable opportunities for further development. The number of small hydroelectric stations, which are largely built at natural elevations, is increasing at the expense of private investments.

Geothermal energy. The main resources of geothermal waters are concentrated in the lowlands, in particular in the region between Szczecin and Lodz, in the Grudzionsko-Warsaw region and also in the Precarpathian region. A characteristic feature of all geothermal investments is high start-up expenditures, which is attributed to the necessity of conducting drilling works, the cost of which amount to 50-60 % of all investment expenses. Financing drilling-based geological works from the Fund for Environmental Protection and Water Management was a contributory factor to bring into existence several geothermal heat stations in Pyzytsy and Podkhaliu.

Wind power engineering. Wind power engineering in Poland began to evolve in the early 1990s, mainly along the coast line. The most favourable conditions for wind energy use are found in the following regions: the Baltic Sea coastline, Suvalshchyzna and Mazovian plain. Towards the end of 1999, 14 network wind power farms with the total registered capacity of 3.5 MW were put into operation. In addition, there operate more than 50 small autonomous wind-driven power installations. Great interest has been shown by investors in wind-driven power installations, especially in north-western Poland where new projects are arising.

Solar power engineering. Solar energy is the least used form of energy in Poland. The meteorological conditions in Poland are characterized by rather uneven distribution of solar radiation throughout the year, about 80 % of the year's amount of solar radiation falls within six months of the spring-summer period. The character and structure of the solar radiation suggest low potentials for its usage, especially during the winter time. An increase in solar energy use in Poland would be possible due to more extensive application of solar heat collectors of flat liquid type for heating water and houses. Photocells which convert solar energy into electricity are few in Poland.

Financing of projects in the RES field. The following financial institutions that support the use of RES are operative in Poland: State Fund for Environmental Protection and Water Management, Ecofund, Thermal Engineering Modernization Fund, Regional funds for nature protection and water management. There also exist financial institutions which can provide financial support for RES projects in rural areas (for agricultural development): Agricultural Programmes Foundation, Agency for Agricultural Property of the Treasury, Agricultural Foundation. These institutions give soft loans and subsidies that usually make no more than 50 % of the credit costs. There also exist great opportunities for the use of foreign support in this sphere. In addition to the World Bank and well-known European financial institutions, of increasing importance in the sphere of financing of projects are target programmes of the European Commission such as Altener II, Synergy, Life, and Framework programme on technological cooperation and preferences. In most cases, these funds and programmes allow for funding subsidies to prepare investment projects and construct model installations. In the context of further integration into the EU, the following funds may be of importance: PHARE, ISPA, SARARD. In addition to the international funds for financing of RES, there are funds that can be used within the framework of bilateral cooperation with western states such as Denmark, Sweden, and Germany.

Conclusions. Meeting demands of the EU as to the 50 % share of RES in Poland's power balance up to 2020 would be impossible without the government assistance. The current practice in Poland is granting certificates of origin which are issued by President of the administration of energy industry management in accordance with the energy industry law. The main proof of origin is "green certificate" which came to be granted in the late 2004 – the early 2005 to the producers of energy from renewable sources. Their introduction into National Legislation emerged from Directive 2001/77/EC on green energy promotion. The producers of energy, in additional to the money from selling the energy, receive certificates which they sell at the Polish energy exchange. The energy companies which sell energy to end-users have to purchase the certificates or just pay money instead.

In the nearest future, the energy from renewable sources will make up a significant share in the world and European power balance. The integration into the EU, on the one hand, compels Poland to take actions which promote the development of RES and, on the other hand, makes it possible to make use of the EU's assistance in this field. Until the present time, the reduction in energy consumption of Poland's economy has resulted from the transformation of the economic system as well as due to the availability of simple reserves for increasing energy efficiency. Although the situation in the sphere of energy efficiency has significantly improved, there is still much to be done and the potential for further improvement is promisingly high. The increase in the share of RES in Poland's power balance has been made possible due to the obligations resulting from the EU Directive 2009/28/EC that provides for an increase in the share of RES by 15 % in the year 2020. However much has been done as for now (about 11 % RES in the power balance), Poland, as many other countries, is facing a challenge of further transformation of the energy sector and, consequently, its economy. Energy efficiency and the use of RES should become priority tasks for the society, business and the state.

This is the only way to ensure the country's energy security and competitiveness of its economy. To do this would require creation of long-range government's strategy for energy efficiency, conducting an active information campaign for promotion of energy saving among citizens, businessman and jobholders; it is necessary to set ambitious objectives as to reduction in energy consumption followed by continuous monitoring of attaining these objectives.

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Трансформація енергетичної бази Польщі. Енергозбереження та використання відновлюваних джерел енергії

Проаналізовано енергетичну трансформацію польської економіки за останніх 25 років. Описано основні кроки трансформації, механізми білих сертифікатів, енергетичного аудиту, процеси енергозбереження на промислових підприємствах. Розглянуто використання відновлюваних джерел енергії в Польщі, таких як біомаса, гідроенергетика, вітрова енергетика та інші, а також механізми фінансування проектів в галузі.

Ключові слова: енергозбереження, відновлювальні джерела енергії, трансформація, біомаса, енергетичний аудит.

ДО ВІДОМА АВТОРІВ СТАТЕЙ

При підготовці статей для міжвідомчого науково-технічного збірника "**Лісове господарство, лісова, паперова і деревообробна промисловість"** радимо авторам дотримуватись таких рекомендацій.

Автор поданої до друку статті повинен чітко уявити коло читачів, на яке він розраховує. Рекомендуємо дотримуватись деяких загальних правил побудови науково-технічної статті: чітко і зрозуміло сформулювати постановку задачі; доступно викласти методику її розв'язання; зробити висновки науковцям або дати практичні рекомендації виробничникам.

Наукова праця повинна містити необхідні характеристики описаних конструкцій чи схем, але в ній не має бути ні зайвого опису історії питання, ні відомих з підручників ілюстрацій, даних, математичних викладок.

Текст статті обсягом 5-20 сторінок необхідно подавати українською чи будь-якою іншою мовою, друкувати на папері формату А4 за допомогою комп'ютера у редакторі MS Word (шрифт – Times New Roman, розмір – 14 points, рядки – через 1.5 інтервали, поля – 2 см по периметру) без присвоєння жодних стилів і оформляти в такій послідовності. На початку статті **ОБОВ'ЯЗКОВО** проставляється індекс УДК (Універсальної десяткової класифікації), в заголовку українською мовою вказуються: вчене звання, ініціали і прізвище автора (або авторів), науковий ступінь, скорочена назва закладу, в якому виконана робота, назва статті, анотація (500 знаків) та ключові слова. Далі – англійською мовою: ініціали і прізвище автора (або авторів), скорочена назва закладу, в якому виконана робота, назва статті, анотація та ключові слова.

Сторінки рукопису нумеруються, а на полях олівцем вказуються місця ілюстрацій і таблиць, якщо останні додаються до статті на окремих аркушах. Особливу увагу необхідно звернути на акуратний набір формул, індексів і показників, з використанням можливостей редактора MS Equation.

При підготовці рукопису необхідно користуватися науково-технічними термінами відповідно до діючих стандартів на термінологію, наведений матеріал не повинен дублювати таблиці. Скорочення слів, імен, назв у тексті статті не допускаються. Можливе використання тільки загальноприйнятих скорочень - мір (тільки після цифр), хімічних, фізичних і математичних величин. Назви установ, підприємств, марки механізмів і т.д., що згадуються в тексті статті вперше, необхідно писати повністю (вказуючи в дужках скорочену назву); надалі ця назва може зустрічатися у скороченому вигляді.

У таблицях необхідно точно вказувати одиниці фізичних величин, у назвах граф слова скорочувати небажано. Таблиці необхідно виконувати переважно вздовж листа з максимальною насиченістю інформації в рядках. Надто громіздких таблиць складати не рекомендується.

Ілюстрації (фотографії та рисунки) до статті подаються в одному примірнику. Фотографії повинні бути контрастні, розміром не менше 9x12 см, рисунки розміром не більше стандартного листка, виконані чорною тушшю пером на якісному папері. Допускається подання рисунків у форматі *.cdr (редактор CorelDRAW), у форматі *.tif або *.jpg (редактор PhotoShop, 300 dpi, b/w або Grayscale) чи оформлених у середовищі MS Excel. У тексті статті посилання на ілюстрації беруться в круглі дужки, позиції на рисунках розташовуються за годинниковою стрілкою і повинні відповідати наведеним у тексті. Окремо подані ілюстрації на зворотній стороні нумеруються і підписуються олівцем.

При посиланні в тексті статті на роботи інших авторів у квадратних дужках вказують номер позиції списку літератури, яка подається в кінці статті. Список літератури оформляється згідно з вимогами і правилами складання бібліографічного опису документа. У випадку наведення цитати необхідно вказати, звідки вона взята (автор, назва роботи, номер тому, рік видання, сторінки).

У кінці статті додаються такі матеріали: **прізвища та ініціали авторів, назва статті; заява зі вказуванням для кожного автора вченого звання та наукового ступеня, посади, повної та скороченої назви закладу, де виконана робота, службової чи домашньої адреси, номери телефонів, E-mail, прізвища авторів для листування.** Окрім того, необхідно подати витяг з протоколу засідання кафедри про можливість публікації статті, експертний висновок, дві рецензії - внутрішню і зовнішню. Також вказується кількість примірників збірника, які автор хотів би отримати з опублікованою його статтею.

Старанно вивірений текст статті підписується автором, проставляється дата відправлення чи подання. Редакція може повернути авторові неохайно оформлену статтю, має право проводити редакційні виправлення. До редакції надсилається (приноситься) один роздрукований примірник статті та CD-диск з її текстом. Авторові (авторам) однієї статті видається один збірник з публікацією.

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ЛІСОВЕ ГОСПОДАРСТВО, ЛІСОВА, ПАПЕРОВА І ДЕРЕВООБРОБНА ПРОМИСЛОВІСТЬ

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Свідоцтво про державну реєстрацію друкованого засобу масової інформації
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Згідно з переліком №19, «Лісове господарство, лісова, паперова і деревообробна промисловість» належить до наукових фахових видань України, в яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора і кандидата технічних наук за такими напрямами: технічні науки, сільськогосподарські науки, економічні науки (Додаток до постанови президії ВАК України від 15.02.2007 р. № 1-05/2)

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