DESIGNING A NEW WOOD-COMPOSITE MATERIAL MADE FROM LOGGING WASTE

O. Pinchevska  
Doctor of Technical Sciences, Professor*  
E-mail: olenapinchevska@nubip.edu.ua

Yu. Lakyda  
PhD*

O. Baranova  
PhD*

M. Biletskyi  
PhD*

V. Holovach  
PhD, Senior Researcher  
Department of Energy Audit and Energy Saving  
Ukrainian State Research Institute «Resource»  
Malevich str., 84, Kyiv, Ukraine, 03150

R. Oliinyk  
PhD, Associate Professor  
Department of Meteorology and Climatology Department  
Taras Shevchenko National University of Kyiv  
Volodymyrska str., 64/13, Kyiv, Ukraine, 01033

A. Yeroshenko  
PhD  
Department of Mechanical Engineering and Wood Technology  
Chernihiv National University of Technology  
Shevchenka str., 95, Chernihiv, Ukraine, 14035

*Department of Technology and Design of Wood Products  
National University of Life and Environmental Sciences of Ukraine  
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041

Copyright © 2020, O. Pinchevska, Yu. Lakyda, O. Baranova, M. Biletskyi, V. Holovach, R. Oliinyk, A. Yeroshenko
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0)

1. Introduction

One of the biggest environmental problems, which has been particularly acute in any industry in recent years, is the formation of significant volumes of different types of wastes and, therefore, the necessity of their storage, processing, and utilize.

At present, woodworking and logging enterprises also face the issue related to the disposal of wood waste because timber harvesting leaves up to 25 % of the biomass in the felling area; its use is a pressing problem.

Over years, there is an increasingly acute task to efficiently and completely utilize wood, including timber waste. In 2019 alone, the amount of waste from timber harvesting operations in Ukraine amounted to about 9 million m³; it was mostly piled in felling areas (tree tops, knots, branches, rotten parts of trees, etc.) and subsequently burned.

One of the most effective ways to utilize the wastes of logging and woodworking is to use them in the production of wood-composite materials. The manufacturing technology of fiberboards of different densities, particle boards, oriented strand boards involves the crushed fibers of wood waste [1].

This predetermines their use in the furniture industry and in the carpentry and construction sector. Production of the latter in Ukraine is insignificant because of the difficulties related to equipment and the inability to directly utilize all the waste from timber-woodworking enterprises, which requires the search for alternative solutions. Another way to use wood waste is the production of fuel briquettes and granules. This is relevant due to the high cost and non-sustainability of traditional heat sources. However, this production is currently unprofitable as there is fierce competition among the manufacturers of timber-based panels and energy to purchase the raw materials [2]. As regards logging waste,
its significant part is those branches that are not used in the manufacture of fuel due to the large content of bark. The development of a technology for the rational use of branches as a wood component for wood-plate materials may be an alternative to structural materials available in the market, given that the raw materials' cost in the felling area is negligible.

Therefore, determining the technological features in the manufacture of a wood-composite material from logging waste is not only of the scientific and practical significance but could also ensure the rational utilization of wood resources to produce products with a high added value.

2. Literature review and problem statement

The utilization of wood waste is addressed in the studies that consider the production of plate materials by pressing when using various binders [3–5]. Their authors established the possibility to receive plate materials using environmentally-friendly adhesives. However, the wood component used was crushed timber, which makes it impossible to apply these results for other types of wood raw materials. Work [6] describes a manufacturing technology and the properties of wood particle boards (WPB) while defining the requirements to the size of a wood component – chips. It is recommended to use chips of the following sizes: thickness, 0.2–0.5 mm; width, 1–10 mm; length, 5–40 mm. In addition, the authors determined the physical and mechanical properties and examined the advantages of WPB and the medium density fiberboards (MDF). They compared their properties with massive timber. However, such issues as the environmental friendliness, low tensile strength, moisture- and thermolability, which restrict their use in construction, remained unresolved. The use of certain additives to the binder, contributing to binding formaldehyde and various types of finishing, which enhance environmental friendliness, contributed to the wide application of WPB and MDF in the production of structural furniture. However, given an insignificant value of the tensile strength limit (10–27 MPa), the use of WPB and MDF plates as countertops is limited to the corresponding dimensions and requires reinforcement in the form of additional supports [7].

The low bending strength of the above plate materials is due to the insignificant size of wood particles, which, unlike timber whose structure is formed during the natural growth, lose their strength characteristics [8]. The influence of the shape and size of wood particles, as well as their arrangement in the plate, on the mechanical properties of wood-composite materials was tackled by many studies [8, 9], whose authors made a conclusion about the expediency of choosing an orientation way and increasing the size of wood particles (for length, 75–150 mm; for width, 15–25 mm). That was implemented in the oriented strand boards (OSB), which made it possible to increase their tensile strength to 18–28 MPa [10]; however, the tensile strength compared to massive timber was not achieved. In addition, the manufacturing technology of WPB, MDF, and OSB restricts the use of bark – up to 4%.

The desire to preserve the natural strength of wood fibers was reproduced in such materials as Ultraspen, Strucuture-frame, Scribner [11], and «Monodrev» [12], which allowed a three-time increase in rigidity compared to WPB. However, in all the materials for the production of a wood component used tree trunks of small diameters, which does not solve the issue of the use of logging waste, namely branches.

The uncertainty related to the utilization of branches, whose specific content of bark is significant, and the necessity to develop a technological regulation on the production of wood-composite material from them, predetermine our research in this area.

3. The aim and objectives of the study

The aim of this study is to scientifically substantiate the composition of a new composite material that includes a wood component to preserve the integrity of the fibers. To accomplish the aim, the following tasks have been set:

- to determine a priority binder for the production of a new composite material from flattened branches;
- to define the parameters of a wood component obtained by a flattening method and the technological stages in the manufacture of wood-composite material based on them;
- to determine a shape stabilization time of the panels made from the new composite material.

4. Materials and methods of research in the development of a wood-composite material from logging waste

4.1. The study materials used in the experiment

To perform the research, we used the following materials:

- the samples of poplar wood, 1 m long, a diameter from 15 mm to 30 mm, a 95% moisture content;
- the urea formaldehyde low-toxic resin, brand KFM-MT-15;
- phenol-formaldehyde resin, brand Lignofen. To flatten branches, we used an experimental modernized installation (Fig. 1), where the branches were flattened to obtain the weaving of fibers, conditionally divided into the «thin» fibers with a thickness of 1 to 5 mm and the «thick» ones, a thickness of 6 to 10 mm (Fig. 2).

Fig. 1. Experimental installation to flatten branches [13]

Fig. 2. The weaving of fibers obtained after flattening: a – «thin» fibers, b – «thick» fibers [13]
The samples of fibers in the weave were dried to a moisture content of 4%, tanned by the contact method with a binder content of 12% (% to the mass of a wood component), and placed in a mold. Assembled packages were first pressed in the press with cold plates PMM-125, followed by pressing in the press with heating plates MS-2000. The pressing pressure was \( p = 8 \text{ MPa} \), the temperature and holding time of the urea formaldehyde-based resin were \( t = 180 \, ^\circ C \), \( \tau = 7 \text{ min} \); for panels that contained phenol-formaldehyde resin, correspondingly, \( t = 200 \, ^\circ C \), \( \tau = 8 \text{ min} \). The result of the pressing process was the new wood-composite material in the form of panels, the size of 330x330 mm. The panels had different orientations, and dimensions of the fibers in the weave, as well as the number of layers. These panels were then used to manufacture the samples for determining the physical and mechanical properties.

The density and water absorption experiments, according to \([14, 15]\), were conducted using samples of the following size: length, 100 mm; width, 100 mm; thickness, 15 mm. To determine the tensile strength and elasticity module at bending, \( a \) single-layer panel made from «thick» fibers (6–10 mm); \( b \) double-layer panel made from «thin» fibers, perpendicular arrangement; \( c \) a single-layer panel made from «thin» fibers (1–5 mm); \( d \) a three-layer panel made from «thin» fibers (1–5 mm).

The panels fabricated by the pressing method were used to obtain a new composite material with the same physical and mechanical properties both in the direction of the longitudinal axis and in the direction of the perpendicular axis.

### 5. Research results

#### 5.1. The study results on determining a priority binder

The experimental results were statistically treated according to the procedure given in \([17]\). The results of the statistical treatment of measuring the density of the obtained panels are given in Table 2.

| Binder type | Mean density, \( \rho_{av} \), kg/m\(^3\) | Standard error, \( P \), % | Standard deviation, \( S \), kg/m\(^3\) | Variance factor, \( V \), % |
|-------------|--------------------------------|----------------|----------------|----------------|
| UF          | 640                            | 5.424          | 50.29          | 7.42           |
| PF          | 665                            | 5.739          | 51.33          | 7.72           |

The average density of the composite material is close to the OSB panels (\( \rho_{OSB} = 650 \text{ kg/m}^3 \)). This has allowed us to further compare the physical and mechanical properties of the obtained wood-composite material and OSB panels.

When studying moisture absorption, the panels based on UF were destroyed (Fig. 4).

![Fig. 4. Samples of a new composite material based on the UF binder after holding in water: \( a \) – over 2 hours ± 5 minutes; the sample size, 25x25x15 mm; \( b \) – over 24 hours ± 15 min; the sample size, 100x100x15 mm](image)
An analysis of the obtained results has proven the inappropriate use of a UF binder and the parallel fiber arrangement in a panel. Therefore, it was decided to carry out a second stage of the experimental study, which implied determining a combination of the sizes of weaving in the three-layer panels with a perpendicular arrangement of fibers, as well as defining their mechanical properties.

5. 2. Results of studying the parameters of the wood component obtained by a flattening method and the technological stages in manufacturing the wood-composite material on their basis

In the second stage of our study, we determined the expediency of using different sizes of fibers in the panels based on PF. To this end, we experimentally studied the strength and elasticity module at bending, Fig. 8.

The wood of a trunk and the branches is a set of natural polymers, which consist of long flexible chain molecules. This feature of the polymer structure determines the special character of their behavior under load at pressing. When applying efforts, a polymer during pressing undergoes the following types of deformations: elastic – due to a reverse change in the average values of interparticle distances; plastic – connected with a reversible regrouping of particles (the links of the chain molecules), thus the volume of the body does not change; the elastic ones are due to the irreversible displacement of the molecular chains, the body volume also does not change in this case.

The rheological processes in wood occur as follows – at the instantaneous loading by a constant force, there occur, at the same time, the elastic, and plastic deformations.

The total deformation of wood due to loading can be represented as the sum of the deformations $\epsilon_\text{e}, \epsilon_\text{p}, \epsilon_\text{f},$:

$$\epsilon = \epsilon_\text{e} + \epsilon_\text{p} + \epsilon_\text{f},$$

where $\epsilon_\text{e} = \sigma/E$ are the elastic deformations; $\epsilon_\text{p} = \sigma/E'$ are the plastic deformations;

$$\epsilon_\text{f} = \frac{\sigma}{E_2} \left(1 - e^{-\frac{E_2}{E}} \right)$$

flexible deformations; $\sigma$ – loading, N/m²; $\tau$ – the time a wood sample is exposed to loading, s; $E$ – elasticity module, N/m²; $E'$ – plastic deformation module, N/m²; $E_2$ – flexible deformation module; $\eta_2$ – flexibility factor.

According to [18], the magnitude of plastic deformation is insignificant and is not more than 3 % of the total deformation magnitude, so it can be neglected.
Given that the magnitude of deformation is influenced by the pressing modes: \( p \) – pressure; \( t \) – temperature; \( \tau \) – aging time under pressure, the rheological model of the pressed material takes the following form:

\[
\varepsilon = \varepsilon(P,T,\tau_{\text{avg}}) + \int_{t_{\text{start}}}^{t_{\text{end}}} (P,T,\tau_{\text{avg}}) dt.
\]

To determine the rational parameters of pressing modes that provide for the minimal panel deformity, the intervals of factor variability were selected (Table 3) and a series of experimental studies were performed according to the matrix of the complete factor planning (CFP) of experiment 23 (Table 4).

### Table 3

| Factor          | Factor variance interval |
|-----------------|--------------------------|
| Natural         | Normalized               |
| \( t, \ ^\circ \mathrm{C} \) | \( x_1 \) | 160 | 180 | 200 |
| \( p, \ \text{MPa} \)       | \( x_2 \) | 8 | 10 | 12 |
| \( \tau, \ \text{min} \)     | \( x_3 \) | 6 | 7 | 8 |

### Table 4

Matrix of the complete factor planning (CFP) of experiment 2

| No | X₁ | X₂ | X₃ | X₄ | X₅ | X₆ | X₇ | X₈ | X₉ | X₁₀ | X₁₁ | X₁₂ | X₁₃ | X₁₄ | X₁₅ | X₁₆ | X₁₇ | X₁₈ | \( \tau, \ ^\circ \mathrm{C} \) | \( p, \ \text{MPa} \) | \( \tau, \ \text{min} \) | \( \varepsilon_{\text{av}}, \ \text{mm} \) |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------------------|------------------|------------------|------------------|
| 1  | 1  | 1  | 1  | 1  | -1 | 1  | -1 | 1  | -1 | 200 | 12  | 8  | 3.75 |
| 2  | 1  | -1 | -1 | -1 | 1  | 1  | 1  | 1  | 1  | 160 | 12  | 8  | 3.46 |
| 3  | 1  | 1  | -1 | -1 | 1  | 1  | 1  | 1  | 1  | 200 | 12  | 8  | 2.4 |
| 4  | 1  | -1 | -1 | -1 | 1  | 1  | 1  | 1  | 1  | 160 | 8  | 8  | 4.27 |
| 5  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 200 | 12  | 6  | 3.74 |
| 6  | 1  | -1 | 1  | -1 | 1  | -1 | 1  | -1 | 1  | 160 | 12  | 6  | 6.23 |
| 7  | 1  | 1  | 1  | -1 | -1 | 1  | -1 | -1 | 1  | 200 | 8  | 6  | 2.17 |
| 8  | 1  | -1 | -1 | 1  | -1 | -1 | 1  | -1 | 1  | 160 | 8  | 6  | 3.36 |

A regression equation was built:

\[
\varepsilon = 3.67 - 0.66x_1 + 0.62x_2 + 0.49x_3 - 0.43x_4 - 0.48x_5 + 0.49x_6 - 0.43x_7 - 0.43x_8 - 0.43x_9, \quad (4)
\]

The coefficient \( b_j \) in the regression equation was considered insignificant when the condition [17] was met:

\[
|b_j| \leq t_{n-1} \cdot S\{b_j\},
\]

where \( t_{n-1} = 1.99 \) is the Student \( t \)-criterion at the significance level \( q = 0.05 \) and the number of degrees of freedom \( f_n = N_p - 8 - 5 = 3 \) and \( f_n = N(n - 1) = 72 \), derived the value \( F = 2.74 \) [17].

Using the \( F \)-distribution tables for \( q = 0.05 \) and at the number of degrees of freedom \( f_n = N - p = 8 - 5 = 3 \) and \( q = 0.05 \), we derived the Fisher value \( F = 2.60 \) [17].

The adequacy test of regression equation (4) found the correspondence of the regression model to the experimental data. The results of calculating the panel deformation magnitude after pressing under different schedules are shown in Fig. 9.

![Fig. 9. Dependence of the deformation magnitude of composite material on temperature and pressure for the following holding: a – 7 min; b – 8 min](image)

At the same pressure and temperature of the press panels, smaller deformations are observed in the case of a less holding time under load.

### 5.3. Determining a shape stabilization time of the panels made from a new wood-composite material

To determine the rational schedule of pressing the wood-composite material, one must know the duration of a material’s shape stabilization after the stresses arising at pressing. Because elastic deformations disappear quickly enough, the residual deformation magnitude is determined mainly by flexible deformations. Given (2), it is possible to determine the thermal stabilization time.

To calculate \( \tau = f(\varepsilon) \), we performed a transformation.
Denote:

\[ \frac{\sigma}{E} = A; \quad \frac{E_s}{\eta_2} = B, \]

where \( \eta_2 \) is the coefficient of flexibility equal to the ratio of the thickness \( h \) to the length \( l \) of the sample and is \( \eta_2 = 0.05: \)

\[ \eta_1 = \frac{h}{l} \quad (10) \]

Then:

\[ \epsilon_s = A(1 - e^{-Bt}), \quad (11) \]

where \( \epsilon_s \) is the relative elasticity, which equals \( \epsilon_{\text{max}}/\epsilon_{\text{res}} \).

The time of shape stabilization can be determined from the following expression:

\[ \tau = \ln \left( \frac{1 - \epsilon_{\text{res}}/\epsilon_{\text{max}}}{\eta_2} \right) = \ln \left( \frac{1}{1 - \frac{\epsilon_{\text{res}}}{\epsilon_{\text{max}}}} \right). \quad (12) \]

Thus, depending on the schedule of pressing, it is possible to determine a material’s shape stabilization time (Fig. 10) and choose the schedule that provides for the minimum holding.

Equation (12) was used to calculate the value of a shape stabilization time for the panels made from wood-composite material for different modes of pressing – Fig. 11.

**Fig. 10.** The principle of determining the time of shape stabilization \( \epsilon_{\text{res}} \)

**Fig. 11.** Mean values of a shape stabilization duration of the wood-composite material under different schedules of pressing

The smallest shape stabilization time, 7 days, was demonstrated by the samples of panels pressed at temperature \( t = 200 ^\circ \text{C} \) and pressure \( p = 8 \text{ MPa} \), which agrees with the results obtained when determining the deformity of a panel as a result of pressing.

6. Discussion of results of determining the properties of the new wood-composite material made from logging waste

Based on the results of our experimental study, a new wood-composite material was obtained [13] with the similar physical, and even better mechanical, properties compared to OSB panels. Thus, the density of the new material is \( \rho_{\text{com}} = 665 \text{ kg/m}^3 \) (Table 3), the density of OSB panels is \( \rho = 650 \text{ kg/m}^3 \) [10]. The tensile strength at bending of the new material was \( 29.8^-37.6 \text{ MPa} \) (Fig. 8, b), that of the OSB panels of general purpose \( 9^-17 \text{ MPa} \) and \( 26^-30 \text{ MPa} \) (for panels of increased strength). The elasticity module of the new composite material at bending was 6,962–8,932 MPa (Fig. 8, a), that of the OSB panels of general purpose \( 2,500 \text{ MPa} \) and \( 4,800 \text{ MPa} \) (for panels of increased strength). It is found that the values of the tensile strength and the elasticity module for the first three groups of sample panels are approximately the same. In the fourth sample group, these indicators are 20 % lower (Table 2). This is due to the use of thin fibers in the middle layer of the material that do not provide the adequate strength and elasticity of the material. Therefore, to facilitate the technological process and reduce its cost in the manufacture of the new wood-composite material, one can recommend the use of fibers of equal thickness, 6–10 mm.

The high values of the mechanical properties of the new wood-composite material are explained by the properties of a wood components. In contrast to OSB panels and other wood-composite materials, it is proposed to fabricate a wood component not by crushing but flattering. Wood fibers when flattened are not crushed along the length, as is the case in the production of OSB panels, they retain their natural strength, which ensures the high mechanical properties of a material, similar to massive timber. To obtain a wood fiber of the predefined parameter, branches are flattened, that is, they are rolled through the profiled rollers under pressure at a special installation. Because the weave thickness of 6–10 mm is considerably larger than the wood particles used in the manufacture of OSB panels, 2–6 mm, the energy consumption for the wood component production is smaller. In addition, the technological process of OSB panel fabrication requires the use of wood raw materials in the form of trunks, which are used in other technological processes – the manufacture of paper, cellulose, fuel materials, which is accompanied by competition in the acquisition of the raw materials. Meanwhile, in the felling areas, there remains a significant amount of logging waste: branches, knots, tree tops, which are still not utilized in the industry.

Our study involved the branches of poplar as a fast-growing wood species. Meanwhile, it does not belong to industrial timber and its plantations are still insignificant. Therefore, further research will employ the branches of pine as the most widespread wood type in our country. In addition, it is a relevant task to search for a non-harmful binder to achieve the complete environmental friendliness of the proposed material.

As regards the peculiarities of the technological process of manufacturing the new wood-composite material, which is a little shorter compared to the production of OSB panels, it eliminates such stages as peeling ridges, cutting of splinters, chip sorting. Further technological operations, such as drying, tarring, carpet forming and pressing, as well as the equipment for their implementation, are similar.

Thus, by using the wood raw materials unclaimed by the industry, one can obtain such wood-composite panels that are not inferior in its properties to the OSB panels.
7. Conclusions

1. The result of our study is the established possibility to use logging waste for the manufacture of wood-composite panels. The peculiarity of the new wood-composite material is the application of a wood component made from whole woody fibers obtained by flattening the poplar branches. Based on the experimental research into the techniques for arranging fibers with different sizes of the weaving elements and the type of a binder, it is determined that the use of the urea formaldehyde binder is inappropriate. It is explained by the fact that the products made from it are not water-resistant and have 20% lower rates of mechanical properties than the panels containing phenol-formaldehyde resin. In addition, we determined the inappropriate use of the single-layer and double-layer materials for the manufacture of panels because they lose their flat shape immediately after pressing.

2. The experimental study of the physical, mechanical, and technological properties of the new wood-composite material allowed us to determine its rational parameters: the thickness of a wood fiber, 6–10 mm; the type of a binder – phenol-formaldehyde resin; a three-layer structure with mutually perpendicular fiber arrangement. The adequate regression models have been derived for the dependence of wood-composite panels’ deformity on the parameters of pressing schedules – the temperature, pressure, and holding time under pressure. That has made it possible to determine the rational pressing schedule, under which one can achieve the minimum deformation of panels after pressing, and the time of shape stabilization: temperature, \( t = 200 \, ^\circ C \); pressure, \( p = 8 \, MPa \); time, \( \tau = 7 \, min \).

3. The experimentally defined values of the tensile strength and elasticity module at bending of the resulting material are larger by 25 and 77%, respectively, than the same indicators for OSB panels of increased strength. Consequently, the proposed new material can become an alternative to OSB panels both in terms of a cost component and the simplified technological process. The efficiency of the use of wood-composite panels made from flattened branches implies the improved ecological condition of felling areas and a better utilization of wood raw materials.

References

1. Skliar, D., Smirdziakova, M., Sedliaciak, J. (2017). Selected physical and mechanical properties of plywood faced with wood slices. Acta Facultatis Xylologiae, 59 (1), 97–105. doi: http://dx.doi.org/10.17423/afx.2017.59.1.09

2. Aydin, I., Demirkir, C., Colak, S., Colakoglu, G. (2016). Utilization of bark flours as additive in plywood manufacturing. European Journal of Wood and Wood Products, 75 (1), 63–69. doi: https://doi.org/10.1007/s00107-016-1096-0

3. Bekhta, P., Ortnyska, G., Sedliaciak, J. (2014). Properties of Modified Phenol-Formaldehyde Adhesive for Plywood Panels Manufactured from High Moisture Content Veneer. Drvna Industria, 65 (4), 293–301. doi: https://doi.org/10.5552/drind.2014.1350

4. Nam, S., Nettavali, A. N. (2006). Green composites. I. Environment-friendly, biodegradable composites using ramie fibers and soy protein concentrate (SPC) resin. Fibers and Polymers, 7 (4), 380–388. doi: https://10.1007/bf02875770

5. Konnerth, J., Hahn, G., Gindl, W. (2009). Feasibility of particle board production using bone glue. European Journal of Wood and Wood Products, 67 (2), 243–245. doi: https://doi.org/10.1007/s00107-009-0307-3

6. Kusumah, S. S., Arinana, A., Hadi, Y. S., Guswenrivo, I., Yoshimura, T., Umemura, K., Tanaka, S., Kanayama, K. (2017). Utilization of Sweet Sorghum Bagasse and Citric Acid in the Manufacturing of Particleboard. III: Influence of Adding Sucrose on the Properties of Particleboard. BioResources, 12 (4), 7498–7514.

7. Voitovych, I. H. (2010). Osnovy tekhnolohiyi vyrobiv z derevyny. Lviv: Nats. lisotekhn. un-t Ukrainy, 304.

8. Migneault, S., Koubaa, A., Erchiqui, F., Chaala, A., Englund, K., Wolcott, M. P. (2009). Effects of processing method and fiber size on the structure and properties of wood-plastic composites. Composites Part A: Applied Science and Manufacturing, 40 (1), 80–85. doi: https://doi.org/10.1016/j.compositesa.2008.10.004

9. Madyan, O. A., Wang, Y., Coker, J., Zhou, Y., Du, G., Fan, M. (2020). Classification of wood fibre geometry and its behaviour in wood poly(lactic acid) composites. Composites Part A: Applied Science and Manufacturing, 133, 105871. doi: https://doi.org/10.1016/j.compositesa.2020.105871

10. BS EN 300:2006. Oriented strand boards (OSB). Definitions, classification and specification.

11. Ashori, A., Sheshmani, S. (2010). Hybrid composites made from recycled materials: Moisture absorption and thickness swelling behavior. Bioresource Technology, 101 (12), 4717–4720. doi: https://doi.org/10.1016/j.biortech.2010.01.060

12. Annienkov, V. F., Hroshev, Yu. M. (1998). Povnotsinnyi zaminnyk naturalnoi derevyny. Svit mebliv ta paperu, 1, 10–15.

13. Pinchevska, O., Lakya, Y. (2013). On importance of characteristics of wood component of composition materials. Adhesives in woodworking industry: XXI Symposium, 178–181.

14. BS EN 323:1993. Wood-based panels. Determination of density.

15. BS EN 317:1993. Particleboards and fibreboards. Determination of swelling in thickness after immersion in water.

16. BS EN 310:1993. Wood-based panels. Determination of modulus of elasticity in bending and of bending strength.

17. Pizhurin, A. A., Rozenblit, M. S. (1984). Issledovaniya protsessov derevoobrabotki. Moscow: Lesnaya prom-st', 232.