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SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF PLYWOOD FACED WITH WOOD SLICES

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ABSTRACT

The forest based sector, even at the stage of logging, loses approximately 15 % of wood raw material in the form of branches, bark, tree tips, etc. The general utilisation of waste branches is combustion, production of biofuel or building skidding roads. The paper describes a method of using of one type of cutting waste – tree branches – as a decorative material for facing of wood-based panels. Three-layer and five-layer birch plywood was faced on both sides by walnut (*Juglans regia*), birch (*Betula pendula*), or linden (*Tilia europaea*) wood slices. The environmentally safe PVAC adhesive was used to impregnate the slices and join the veneers. The panels were tested for modulus of elasticity in bending and bending strength in accordance with the standards EN 310 and EN 325 and calculated according to EN 326-1. The facing was tested for surface soundness using the pull-off test according to the standard EN 311. The best results were obtained for the plywood faced with birch slices. The birch faced three-layer birch plywood can be classified as F 30 E 30. The birch faced five-layer plywood can be classified higher – F 40 E 40. Based on the results of surface soundness has also been found out that wood slices, impregnated with glue before pressing, resist stress better than non-impregnated slices.

Key words: wood-based panel, modulus of elasticity in bending, bending strength, logging waste, wood slices

INTRODUCTION

Guided by the concept of sustainable development, the European Union, Commonwealth of Independent States (CIS), and other countries of the world as a whole tend to use global resources efficiently and maximize the use and environmental utilization of obtained waste. According to waste statistics (Waste Statistics, 2014), the waste of agricultural and forestry industries was approximately 1.4 %, or 37.320 mil tons in Europe. In the context of forestry, such type of waste includes fragments of tree trunks, branches, tips of trees, twigs, bark, wood slices, and sawdust obtained in the process of logging. For the CIS, forestry waste accounts for approximately 1.8 %. Table 1 shows the average values and average industry specific rates of formation of the main types of logging waste in the Russian Federation, which may refer to similar indicators of other CIS countries (SBORNIK UDELNYIH POKAZATELEY 1999).

Only half of this type of waste is used to produce useful raw materials and products (wood slices to obtain decorative wood-based panels, fuel production, biomass use in landscape design, chemical industry, etc.).

One of the main directions of utilization of wood waste is to produce heat and electricity. In recent years, the use of wood waste as a source of energy is considered as an alternative to conventional fuels. This is due to the fact that wood waste is CO_2-neutral and belongs to the Renewable Energy Sources (BRIDGWATER and PEACOCKE 2000). Therefore, technologies of producing energy from wood waste are being developed and improved in recent years (PARFENOV 1993, Forestry Statistics in Detail). Much attention has also been paid to the use of forest residues for production of bioethanol, since using it as a fuel makes it possible to reduce emissions of carbon dioxide as a greenhouse gas (PRASAD *et al*. 2007a, PRASAD *et al*. 2007b, HUANG *et al*. 2008). In addition, simplification of transporting waste from the logging site in the form of biomass is also an advantage, making it possible to maximize the vehicle capacity, without taking into account the bulk density of wood waste (IAKOVOU *et al*. 2010).

Tab. 1 Specific rates of production waste.

Technological process or type of production	Type of waste	Value of specific rates
Logging	Branches, tips	5–37 % of the volume of cut wood
	Bark	4–10 % of the volume of cut wood
	Low-value wood (twigs, fallen trees, fragments of stems)	Up to 11 % of the volume of cut and removed wood
	Waste bucking	3–12 % of the volume of cut wood
	Roots, stumps	14–20 % of the volume of cut trees on the ground
	Verdure	32–74 kg/m^3 of cut wood

Increasing demand for wood based panel products have encouraged much effort to utilize residues generated by the forest industries including a large amount of bark in panel production (AYDIN *et al*. 2017). Plywood is a wood-based panel made from wood veneers bonded together with an adhesive and the quality of bonding is the key factor. To improve interfacial adhesion between wood veneer and an adhesive, the veneer can be modified in various ways – chemically or physically (FANG *et al*. 2016, TEMIZ *et al*. 2016). It is important to understand moisture behaviour and structural changes of plywood in service (LI *et al*. 2016). Special treated plywood is used in applications where preservative characteristic is required (KALAWATE *et al*. 2016, KOJIMA *et al*. 2016,). The specific green-manufactured plywood can be used for some specific application when curved panels are needed (COINTE *et al*. 2016).

Large chunks of waste can be used to manufacture small products: packaging timber, lath and shingles, household items, toys, and simple furniture (racks, shelves, stands, and boxes). Besides, small chunks of waste can be recycled to produce technological wood slices, which is used as a raw material in production of cellulose, chipboard and fibreboard, in the hydrolysis, chemical and other types of industries.

The branch waste is used mainly as a fuel or for building skidding road to facilitate transportation in impassable wood cutting areas. However, it is the branches of low-grade juvenile wood, workable to be planed to the end, can be used as a coating of wood plate materials, and provide an alternative to expensive solid hardwood veneer (PINCHEVSKA *et al*. 1991, PINCHEVSKA *et al*. 1992).

Preliminary studies on the use of wood slices of branches were carried out by means of using wood slices as a surface layer in the manufacture of chipboard (PINCHEVSKA and ŠMIDRIAKOVÁ 2016). Obtained results confirm the possibility to apply pine wood slices for covering of particleboard and/or to replace the veneer for facing of wood based panels.

The main objective of this study is to find a method of making an ecological wood composite faced with wood slices and investigate its physical and mechanical properties.

METHODS

Taking the works by ZHAO *et al*. (2011), PIZZI (2000), ŠMIDRIAKOVÁ and SEDLIAČIK (2015) as the basis for the research, a polyvinyl acetate dispersion (PVAC) was selected as an adhesive; it provides a compound of high strength and it is ecological safe for the environment and living organisms. PVAC adhesive class D3 was chosen. Birch veneers were used to form the three-layer plywood or five-layer plywood as the bases for wood composite, which was faced on both sides with wood slices of birch (*Betula pendula*), European lime (*Tilia europaea*), and walnut (*Juglans regia*) wood slices.

Wood slices with a thickness from 1.1 mm to 1.6 mm were impregnated by a PVAC adhesive solved in distilled water in proportions of 1:1. Wood slices were dipped into PVAC glue for one minute and then left at room temperature for 10 minutes to drain water excess. Then the slices were dried at elevated temperature – clamped at 65 °C for 15 minutes (Figure 1). This method of drying has reduced distortion of slices during moisture evaporation, which in turn minimize their cracking during the subsequent pressing (PINCHEVSKA *et al*. 2016).

Fig. 1 Drying slices before pressing.

The conditioning period after drying of slices ranged from 16 to 24 hours. The average moisture content in the slices prior to impregnation was 7.5 %, whereas after impregnation and drying it was 6 %. After drying and conditioning, the slices were kept on grids at the ambient temperature (20 ± 2 °C) and relative humidity (60 ± 5%).

To produce the plywood, the birch veneer with dimensions of 30 × 30 cm and thickness of 1.5 mm was used. PVAC glue class D3 was used in the adhesive spread 170 g/m^2.

The composite material faced on both sides with wood slices was made as follows: the metal plate was coated with an oil to prevent the impregnated wood slices from sticking to a plate in the press. Wood slices were placed on the plate in "fishscale" pattern (Figure 2a). A veneer sheet with an adhesive spread on one side was placed on the slices. The next veneer with an adhesive spread on one side was placed on the first veneer perpendicularly to the wood grain of the first veneer. The third veneer was spread with the adhesive on both sides to ensure better adhesion of the wood slices to the surface of the veneer. The veneer was stacked perpendicularly to the grain of the second veneer. Onto the surface of the third veneer, the wood slices were again placed in the "fishscale" pattern. The ready package was topped with a metal plate coated with oil. As a result of this procedure, a three-layer plywood package (Figure 2b) was obtained. The technology of production of five-layer plywood package was similar.

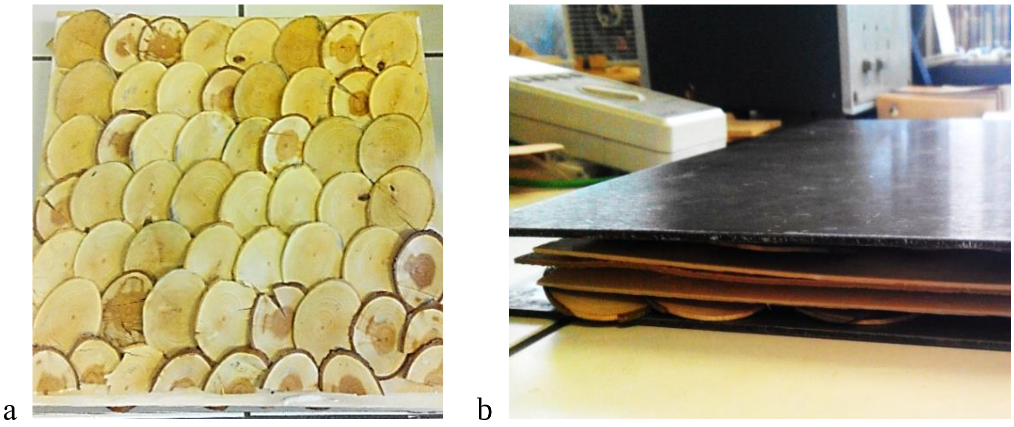
a b

Fig. 2 Preparation of a package for pressing: a - placing of slices "fishscale"; b - wood composite package prepared for pressing.

The ready package was pressed at 75 °C. The pressing time was 30 minutes for three-layer plywood faced on both sides by wood slices, or 34 minutes for five-layer faced plywood, at a constant pressure of 1.8 MPa. Control plywood without slices was prepared at similar pressing parameters, but the pressing time was shorter: 28 minutes for three-layer plywood, and 30 minutes for five-layer plywood.

After pressing, the panels were conditioned at normal conditions (20 ± 2 °C, 65 ± 5 %) for 7 days. Bending properties were determined on small test pieces in accordance with EN 310 and EN 325 and calculated according to EN 326-1. The modulus of elasticity in bending and bending strength were determined according to the European standard EN 310. Laboratory tensile testing machine LaborTech 4.050 equipped with appropriate devices for static bending (Figure 3) was used.

The surface soundness was tested in accordance with the standard EN 311. Test pieces with dimension 50 × 50 mm were taken from each tested panel. The tested area was a circle with diameter of 35.7 mm (enclosing area of 1 000 mm^2). A force was applied at a constant speed so that failure occurred in 60 ± 30 seconds.

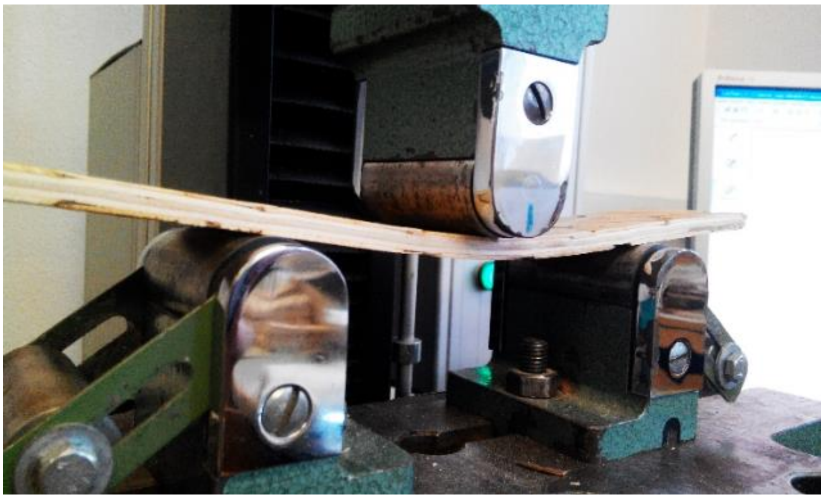

Fig. 3 Device for static bending testing.

RESULTS AND DISCUSSION

Fifteen samples of each type of material with a width of 50 mm (Figure 4) were tested.

Fig. 4 Test samples (left – birch, right – European Lime).

Data to calculate the modulus of elasticity and tensile strength are shown in Table 2.

Tab. 2 Data for calculating the modulus of elasticity and bending strength.

Kind of slices	Condition of slices[1]	Veneer layering	Average thickness of samples, mm	Applied force F_{max}	
				Average value of applied force $F_{Max\cdot av}$, (N)	Coefficient of variation, (%)
Walnut	I	3	7.05	572	10.6
	NI	3	6.90	502	7.2
Birch	I	3	7.10	580	5.2
	I	5	9.60	988	5.7
Linden	I	5	10.10	981	6.1
Without slices	–	3	4.38	796	6.3
	–	5	7.10	1218	6.9
Note: [1]: I – slices pre-impregnated with glue; NI – non-impregnated slices					

Based on the data obtained, the modulus of elasticity E and tensile strength f_m for each type of material were calculated. The results are shown in Figure 5 and Figure 6. All plywood, independent of composition factors (species, number of plies, thickness of plies) can be classified under the system based on bending properties according to EN 636. The classification system may be used as an alternative to the full-scale testing. The lower limit values given in EN 636 for bending strength and modulus of elasticity in bending correspond to 5 percentile values based on the mean values, determined according to EN 310 and EN 326 for individual boards and calculated in accordance with EN 326-1.

The modulus of elasticity in bending for the control plywood K5 was 8 348 N/mm^2 and the modulus of elasticity in bending for the control plywood K3 was 11 592 N/mm^2, see Figure 5. In accordance to the standard, the control panels can be classified in the bending classes for plywood E 90 (lower limit value 8 100 N/mm^2) and E 120 (lower limit value 10 800 N/mm^2) respectively.

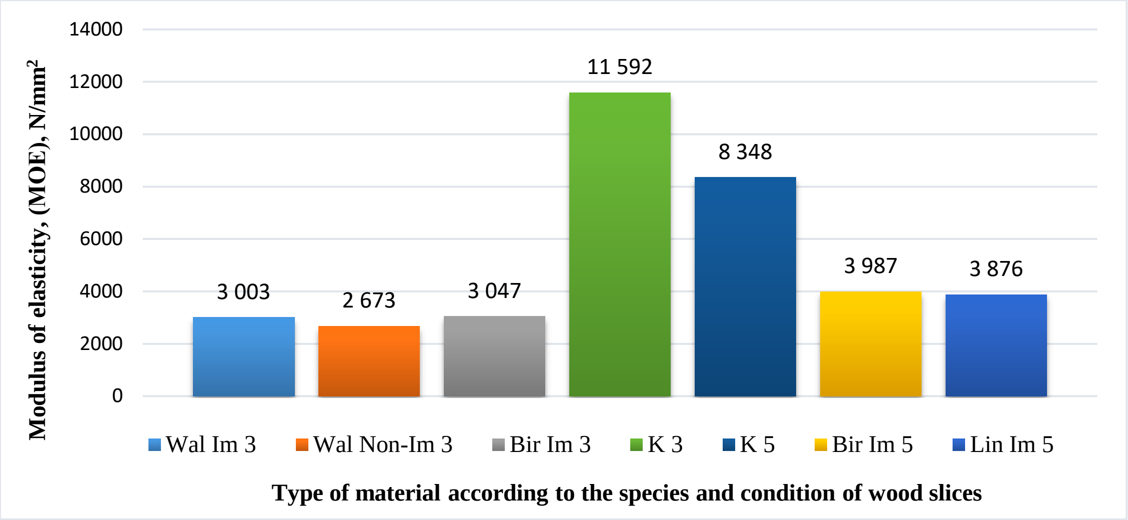

Fig. 5 Comparative results of Modulus of elasticity (MOE). (Legend: Three-layer plywood: faced by walnut wood slices impregnated with glue (Wal Im 3), non-impregnated (Wal Non-Im 3), impregnated birch wood slices (Bir Im 3), non-faced plywood (K 3 – control sample); Five-layer plywood: non-faced plywood (K 5 – control sample), faced by birch wood slices impregnated with glue (Bir Im 5), linden wood slices impregnated with glue (Lin Im 5).)

The values of modulus elasticity in bending for faced plywood were markedly lower. The lowest value of 2 673 N/mm^2 was calculated for Wal Non-Im 3, the highest value of 3 987 N/mm^2 was calculated for Bir Im 5. The value for Bir Im 3 was 3 047 N/mm^2. Based on the values, the faced plywood can be classified in the bending classes from E 25 (lower limit value 2 250 N/mm^2) for Wal Non-Im 3, through E 30 (lower limit value 2 700 N/mm^2) for Bir Im 3, to E 40 (lower limit value 3 600 N/mm^2) for Bir Im 5.

If compare the modulus of elasticity in bending of faced plywood (Wal Im 3, Wal Non-Im 3, Bir Im 3) with the control K3 (3-layer plywood), it can be seen that the values for faced plywood are almost 4 times lower.

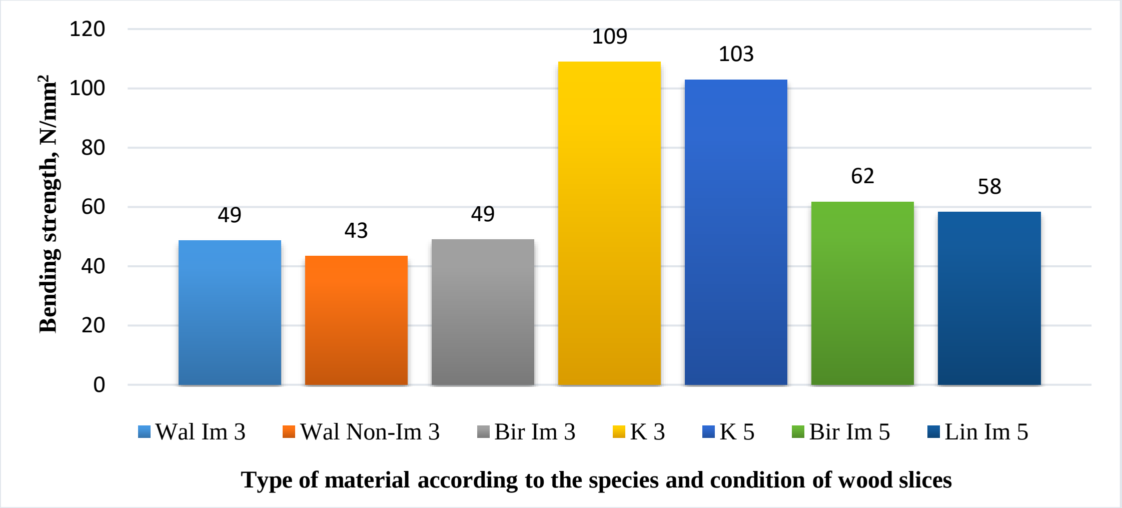

Fig. 6 Comparative results of Bending strength. (Legend: Three-layer plywood: faced by walnut wood slices impregnated with glue (Wal Im 3), non-impregnated (Wal Non-Im 3), impregnated birch wood slices (Bir Im 3), non-faced plywood (K 3 – control sample); Five-layer plywood: non-faced plywood (K 5 – control sample), faced by birch wood slices impregnated with glue (Bir Im 5), linden wood slices impregnated with glue (Lin Im 5).)

If compare the modulus of elasticity in bending of faced plywood (Bir Im 5, Lin Im 5) with the control K5 (5-layer plywood), it can be seen that the values for faced plywood are about 2 times lower.

Bending strength value for the control plywood K5 was 103 N/mm^2 and for the K3 109 N/mm^2, see Figure 6. In accordance to the standard, the control panels can be classified in bending strength classes F 60 (lower limit value 90 N/mm^2) and F 70 (lower limit value 105 N/mm^2) respectively.

The values of bending strength for faced plywood were markedly lower. The lowest value of 43 N/mm^2 was calculated for Wal Non-Im 3, the highest value of 60 N/mm^2 was calculated for Bir Im 5. Based on the values, the faced plywood can be classified in the bending classes from F 25 (lower limit value 38 N/mm^2) for Wal Non-Im 3 to F 40 (lower limit value 60 N/mm^2) for Bir Im 5.

If compare the bending strength of faced plywood (Wal Im 3, Wal Non-Im 3, Bir Im 3) with the control K3 (3-layer plywood) it can be seen that the values for faced plywood are about 2 times lower.

If compare the bending strength of faced plywood (Bir Im 5, Lin Im 5) with the control K5 (5-layer plywood) it can be seen that the values for faced plywood are about 1.7 times lower.

The best results were obtained for plywood faced with birch slices. So the birch faced plywood Bir Im 3 can be classified as F 30 E 30 and Bir Im 5 can be classified higher – F 40 E 40.

If taking into account only the thickness of the substrate (i.e. the plywood itself) when calculating the modulus of elasticity in bending and bending strength, then the given rates are increased by an average of 15 % in a case if the wood slices were pre-impregnated with an adhesive. Non-impregnated wood slices did not improve plywood properties. It can be concluded that the wood slices can only be used as a decorative facing material; they do not sufficiently increase plywood resistance to static loads.

The facing was tested for surface soundness using the pull-off test according to the standard EN 311. Surface soundness (SS) gives an information about strength or quality of bonding between the particles at the surface of a board and the layer below. The tensile load required to pull off a defined surface area of overlaid panel was measured. Force at failure was recorded. Calculated values of surface soundness are given in Table 3.

Tab. 3 Pull-of test of facing.

Board	SS (N/mm^2)	StDev (N/mm^2)	Var. (%)	Min (N/mm^2)	Max (N/mm^2)	n
Bir Im 3	1.25	0.19	15.0	1.01	1.53	10
Wal Im 3	1.06	0.19	18.3	0.79	1.27	10
Wal Non-Im3	0.70	0.16	22.9	0.47	1.0	10
Lin Im 5	1.70	0.21	12.5	1.48	2.08	10

Note: Required value of surface soundness is min. 0.90 N/mm^2

Based on the results of pull-off test can be stated, that immersing the wood slices in an adhesive influenced the adhesion of facing. The highest surface soundness was measured for the board marked Lin Im 5 (1.70 N/mm^2). The board with non-impregnated walnut slices (schematically marked Wal Non-Im 3) showed the lowest surface soundness (0.70 N/mm^2); if compared with the board faced with walnut slices immersed in an adhesive (Wal Im 3), the value of surface soundness was only 66 %.

CONCLUSION

The ecological wood composite based on the three-layer plywood or five-layer plywood faced on both sides by birch, walnut, or linden wood slices, has been obtained in the course of the research. Modulus of elasticity in bending and bending strength of the prepared wood-based panels were calculated. On the basis of the data received it has been found that the slices have not significantly increased the strength. They can be used only as a decorative facing material. It has also been found out that wood slices, impregnated with glue before pressing, resist stress better than non-impregnated slices. Given the high rates of physical and mechanical properties, we may conclude that the proposed composite material has good perspective on the European market, as it meets the standards and is environmentally safe.

REFERENCES

AYDIN, I., DEMIRKIR, C., COLAK, S., COLAKOGLU, G. 2017. Utilization of bark flours as additive in plywood manufacturing. Eur. J. Wood Prod. 2017, 75: 63–69. DOI 10.1007/s00107-016-1096-0.

BRIDGWATER, A.V., PEACOCKE, G.V.C., 2000. Fast pyrolysis processes for biomass. Renewable and Sustainable Energy Reviews, 4: 1–73.

EN 310: 1998 Wood-based panels. Determination of modulus of elasticity in bending and of bending strength

EN 311: 2003 Wood-based panels. Surface soundness. Test method

EN 325: 2012 Wood-based panels. Determination of dimensions of test pieces

EN 326-1: 1998 Wood-based Panels. Sampling, cutting and inspection. Part 1: Sampling and cutting of test pieces and expression of test results

EN 636: 2015 Plywood. Specifications

FANG. L., XIONG, X., WANG, X., CHEN, H., MO, X. 2016. Effects of surface modification methods on mechanical and interfacial properties of high-density polyethylene-bonded wood veneer composites. J. Wood Sci. DOI 10.1007/s10086-016-1589-9.

FORESTRY STATISTICS IN DETAIL http://ec.europa.eu/eurostat/statistics-explained/index.php/Forestry_ statistics_in_detail.

HUANG, H.J., RAMASWAMY, S., TSCHIRNER, U.W., RAMARAO, B.V. 2008. A review of separation technologies in current and future biorefineries. Sep. Purif. Technol. 62: 1–21.

IAKOVOU, E., KARAGIANNIDIS, A., VLACHOS, D., TOKA, A., MALAMAKIS, A. 2010. Waste biomass-to-energy supply chain management: a critical synthesis. Waste Management, 30: 1860–1870.

KALAWATE, A., CHARAN SHAHOO, S., KANTI KHATUA, P., SEKHAR DAS, H. 2016. Evaluation of Mechanical Properties of Plywood Treated with a new Wood Preservative (CEB). Chemical. J. Inst. Eng. India Ser. D. DOI 10.1007/s40033-015-0108-2.

KOJIMA, Y., SAKAKIBARA, A., KOBORI, H., SUZUKI, S. 2016. Evaluating the durability performance of wood-based panels by a non-destructive bending test. J. Wood Sci., 2016, 62: 263–269. DOI 10.1007/s10086-016-1545-8.

LAVALETTE, A., COINTE, A., POMMIER, R., DANIS, M., DELISE´E, CH., LEGRAND, G. 2016. Experimental design to determine the manufacturing parameters of a green-glued plywood panel. Eur. J. Wood Prod. 2016, 74: 543–551.DOI 10.1007/s00107-016-1015-4.

LI, W., VAN DEN BULCKE, J., DE WINDT, I., DHAENE, J., VAN ACKER, J. 2016. Moisture behavior and structural changes of plywood during outdoor exposure. Eur. J. Wood Prod. 2016, 74: 211–221. DOI 10.1007/s00107-015-0992-z.

PARFENOV V.I., 1993. Disposal of waste timber industry. Moscow, 59 s. [Парфенов В.И. 1993. Утилиация отходов лесной промышленности. М. Изд-во «Уральський рабочий», 59 с.]

PINCHEVSKA O., ŠMIDRIAKOVÁ M. 2016. Wood particleboard covered with slices made of pine tree branches. Acta Facultatis Xylologiae Zvolen, 58(1): 67–74.

PINCHEVSKA O., SPIROCHKIN O., SEDLIAČIK J., OLIYNYK R. 2016. Quality assessment of lumber after low temperature drying from the view of stochastic process characteristics. Wood Research 61(6): 871–884.

PINCHEVSKA O.A., KOVAL V.S., LOSITSKIY S.F, SIRKO Z.S. 1992. A method of producing wood based material with a decorative coating. Certificate of authorship № 175 4858.

PINCHEVSKA O.A., KOVAL V.S., LOSITSKIY S.F, SIRKO Z.S. 1991. Material facing decorative. Certificate for industrial model №35850.

PIZZI A. 2000. Tannery row - The story of some natural and synthetic wood adhesives. Wood Science and Technology, 34: 277–316.

PRASAD, S., SINGH, A., JAIN, N., JOSHI, H.C. 2007 b. Ethanol production from sweet sorghum syrup for utilization as automotive fuel in India. Energy Fuels, 21(4): 2415–2420.

PRASAD, S., SINGH, A., JOSHI, H.C. 2007 a. Ethanol as an alternative fuel from agricultural, industrial and urban residues. Resour. Conserv. Recycl. 50: 1–39.

SBORNIK UDELNYIH POKAZATELEY obrazovaniya othodov proizvodstva i potrebleniya, 1999. <http://www.gosthelp.ru/text/Sbornikudelnyxpokazatelej.html>

ŠMIDRIAKOVÁ M., SEDLIAČIK J., VÉGH B., BEKHTA P. 2015. Application of foamed PVAc dispersion in plywood production. Acta Facultatis Xylologiae Zvolen, 57(2): 109−115.

TEMIZ, A., AKBAS, S., AYDIN, I., DEMIRKIR, C. 2016. The effect of plasma treatment on mechanical properties, surface roughness and durability of plywood treated with copper-based wood preservatives. Wood Sci. Technol. 2016, 50: 179–191. DOI 10.1007/s00226-015-0773-1.

WASTE STATISTICS <http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_ statistics>

ZHAO LEI-FENG, LIU YU, XU ZHENG-DONG, ZHANG YA-ZHUO, ZHAO FANG, ZHANG SHUANG-BAO 2011. State of research and trends in development of wood adhesives, Forestry Studies in China, 13(4): 321–326.

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