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PRODUCTION OF HIGH STRENGTH PLYWOOD FROM BIRCH WOOD

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ABSTRACT

Possibility for obtaining high strength plywood from birch veneer (*Betula pendula* Ehrh.) superior to beech (*Fagus* Ehrh.) plywood is studied. Plywood testing for ultimate split strength in adhesive layer, tensile strength and modulus of elasticity in static bending was conducted in accordance with the applicable Russian Standards. The experimental results showed that the samples of birch plywood, manufactured using processed ultrasonic adhesive, composed of hydrogel nanocrystalline cellulose and further processed with a pulsed magnetic field, have higher physical and mechanical characteristics: ultimate split strength on adhesive layer is increased up to 3.0 MPa, tensile strength under static bending – up to 118 MPa. Pressed birch plywood regarding strength in shearing on adhesive layer exceeds beech plywood 2.5 times. Ultimate strength in static bending of pressed birch plywood increases by two times compared to standard birch plywood.

Key words: plywood, urea-formaldehyde resin, nanocrystalline cellulose, ultrasound, pulsed magnetic field.

INTRODUCTION

Popularity of plywood exceeds many composite materials on the basis of wood. In addition to the construction and furniture industries, it is used in car building, aviation and automotive engineering, in the construction of vessels and creation of missiles. Most often plywood is made from birch veneer, other hardwood veneer, and the most often it is made from beech. Beech veneer has excellent physical and mechanical properties and it is a good material for making modified wood and plywood.

There are several methods of wood modification: by pressing, impregnation with modifiers and special treatment by physical methods (AULIN *et al.* 2010, OLSSON *et al.* 2010, MISSOUM *et al.* 2013, BECKER *et al.* 1998, WILKES 2003, FELIX *et al.* 1994).

Today, there are numbers of works by Russian and foreign researchers on the use of nanocrystalline cellulose (NCC) with the aim of obtaining composite materials based on wood with improved properties.

Nanocellulose is a material, which is a set of nanoscale cellulose fibres with a high aspect ratio (length to width). The typical width of such fibres is 5-20 nm, and the longitudinal size ranges from 10 nm to several microns. Currently, nanocellulose fibres are made of wood fibres by homogenization under high pressure, relatively expensive process, requiring large expenditures of energy. The complexity of the production is one of the main limiting factors of the distribution of this material (DRI *et al.* 2013, KVIEN *et al.* 2005, OKSMAN *et al.* 2006).

The works (VOSKOBOINIKOV *et al*. 2011) investigated the samples of plywood made with glue, composed of hydrogel of nanocrystalline cellulose in the amount of 2.5 and 5%. They had higher physical and mechanical properties: the tensile shear strength is increased by 5%, the strength and modulus of elasticity in bending – by 10-15%. Also, it was concluded that the content of nanocrystalline cellulose in the resin in the amount of 2.5% is sufficient to increase strength characteristics of wood-laminated plastics.

The authors (RAZINKOV *et al*. 2014) proposed to handle NCC by ultrasound. When you activate NCC in ultrasound, tensile strength at glue joint in the dry state increases in comparison with the control sample by 16%, and in incremental processing of glued plywood in pulsed magnetic field (PMF) – by 23 %. The overall average increase in strength when the content of NCC is up to 2% with subsequent ultrasonic treatment, and PMF is 50%. The increase in strength when shearing is to be expected when using hydrogel nanofibrils cellulose, ionized in a strong magnetic field.

In work (PARINOV *et al*. 2016), research on the effect of NCC activated in ultrasonic and pulsed magnetic fields, added in phenol-formaldehyde and urea-formaldehyde resins used in plywood and massive wood bonding was made. As a conclusion, the authors showed that the strength of glue joint when gluing wood increased 2 times, while gluing plywood – 1.5 times.

Modification of birch veneer wood activated with nanocrystalline cellulose allows maximizing the strength of plywood 1.5 times (RAZINKOV *et al*, 2014, PARINOV *et al*. 2016); modification of massive birch wood by pressing (SHAMAEV 1989a, SHAMAEV 1989b, SHAMAEV 1987) increases the strength 2 times. The combination of these two methods, that is, combined processing of birch veneer with NCC and pressing in the limit could provide an increase in the strength of plywood 3 times. Then it would be possible to extend the life of punching tools for cutting cardboard from 17 thousand to 50 thousand revolutions, and for skateboards, to eliminate the import of Hard maple completely, the cost of which is 10 times higher than cost of birch (NIKULINA *et al*. 2013).

The purpose of this work is to produce high-strength plywood from birch veneer, in strength superior to beech plywood.

MATERIALS AND METHODS

The following raw materials have been prepared for experiment:

- Birch veneer (*Betula pendula* Ehrh.), sizes 300 × 300 mm, thickness 1.5 mm and moisture 8 ± 2% without visible defects;
- Beech veneer (*Fagus* Ehrh.), sizes 300 × 300 mm, thickness 1.5 mm and moisture 8 ± 2% without visible defects;
- Urea-formaldehyde dry glue Jowat 950.20;
- Hydrogel of nanocrystalline cellulose (NCC), particle size 100-400 nm, concentration 0.4, 2 and 4%.

The following equipment and devices have been used for the experiments:

- Hydraulic press P-474A with a force of 100 tons with heated plates;
- Ultrasonic unit 4-101 with operating frequency 21 kHz;
- Pulsed magnetic field installation IMP-1 with a strength of $18 \cdot 10^4$ A/m;
- Autoclave VKR-0.5 with a pressure up to 4 atm.;
- Electronic scales VKL-11;
- Calliper gage according to 166-89 State Standard with division value of 0.01 mm.

- Testing machine according to 7855-74 State Standard with maximum destructive force up to 5 kN;
- Attachment device;
- Glass with a diameter of 150 mm for soaking the samples.

A series of nine experiments was performed, each of which was repeated three times. Nanocrystalline cellulose is planned to be used in some experiments for partial replacement of urea-formaldehyde resin. The glue was applied to the veneer with a manual roller spreader. The glue consumption in all the experiments was 160 g/m^2. The plywood package was formed in such a way that the direction of fibres in the veneer was mutually perpendicular in each subsequent veneer layer. This principle has been extended to all experiments.

Experiment №1.

5 sheets of beech veneer were coated with glue. The glue was prepared by adding 300 grams of dry glue in 150 grams of water. The collected package was pressed in a press at the temperature of 135 °C and an exposure time of 6 minutes. The specific pressure was 2 MPa.

Experiment №2.

7 sheets of birch veneer were coated with glue. The glue was prepared from the calculation of 150 g of water and 300 g of dry glue. The collected package was pressed in a press at the temperature of 135 °C and an exposure time of 6 minutes. The specific pressure was 2 MPa.

Experiment №3.

7 sheets of birch veneer were coated with glue. The glue was prepared as follows: 2% hydrogel of NCC in the amount of 200 g was mixed with 400 g of dry glue. The resulting mixture was loaded into ultrasonic unit and processed for 60 seconds. After treatment, the mixture was applied to the veneer and the package was pressed in a press at the temperature of 135 °C and an exposure time of 6 minutes. The specific pressure was 2 MPa.

Experiment №4.

Experience No. 3 was repeated. The resulting plywood was treated with pulsed magnetic field for 60 seconds. Due to the fact that the solenoid coil has an internal diameter of 80 mm, all sheets of plywood were preliminarily cut into plates with a width of 70 mm. The length of the coil is 100 mm. Therefore, after 60 second, the sheet was progressed within the coil for 100 mm.

Experiment №5.

9 sheets of beech veneer (total thickness 18 mm) were coated with glue, obtained from 150 g of water and 300 g of dry glue. The collected package was pressed in a hydraulic press according to the following conditions: heating of press with closed plates for 1 minute, loading up to 2 MPa and holding for 1 minute, loading up to 4 MPa and exposure time 6 min. As a result, obtained plywood had a thickness of 14.5 mm and density of 980 kg/m^3. The degree of pressing was 19%.

Experiment №6.

13 sheets of birch veneer (total thickness 19.5 mm) were coated with glue obtained from 200 g of water and 400 g of dry glue. The collected package was steamed in an autoclave at a pressure of 20 atm. within 15 minutes. The package was pressed in a press at a temperature of 120 °C at a pressure of 4 MPa, after which the heating was switched off and package was left in the press until the plates cooled to 40 °C (4 hours). As a result, obtained plywood had a thickness of 9.6 mm and density of 1 210 kg/m^3. The degree of pressing was 51%.

Experiment №7.

Experiment No. 3 was repeated. When preparing the adhesive, 0.4% hydrogel NCC was used.

Experiment №8.

Experiment No. 3 was repeated. When preparing the adhesive, 4% hydrogel NCC was used.

Experiment №9.

Experiment No. 4 was repeated. When preparing the adhesive, 4% hydrogel NCC was used.

During the experiments, all samples of plywood were held for 2 weeks at 20 ± 2 °C and relative humidity 65 ± 5% before the test.

The strength of the gluing of plywood is characterized by the ultimate strength at shearing along the adhesive layer. Selection and preparation of samples, their testing was carried out in accordance with 9620-94 and GOST 9624-93 State Standards.

Tests of plywood for tensile strength and modulus of elasticity under static bending were carried out in accordance with 9625-87 State Standard (ST SEV 2378-80).

RESULTS AND DISCUSSION

Table 1 shows the results of tests of various types of plywood for the strength of gluing at shearing along the glue layer τ_{sh}, MPa. Samples from experiments №1-9 were taken for the experiments.

As it can be seen from Table 1, samples of birch plywood, made using ultrasonically treated glue containing hydrogel of nanocrystalline cellulose and further processed by pulsed magnetic field (experiments No. 3, No. 9), have higher physical and mechanical characteristics: the ultimate strength of plywood in shearing on the adhesive layer increases to 3.0 MPa (with the strength of beech plywood of 2.2 MPa).

The change in the content of NCC hydrogel from 2 to 4% does not cause essential increase in τ_{sh}.

Pressing of beech plywood for 19% makes it possible to increase its strength 2.2 times in comparison with standard beech plywood (experiment No. 5).

The combination of the use of hydrogel of nanocrystalline cellulose in adhesive composition and pressing (experiment No. 6) makes it possible to obtain ultimate strength of birch plywood in shearing on the adhesive layer plywood equal to 5.6 MPa.

Tab. 1 Results of testing for determination of ultimate strength at shearing of plywood along the adhesive layer *.

№ experiment	The dimensions of the shearing area, mm		P_{max}, N	τ_{sh}, MPa	Character of destruction
	l	b			
1	40.0	12.4	1 100	2.1 (0.08)**	The presence of wood fibres
2	40.2	13.1	900	1.6 (0.05)	Wood fibres are presented partially
3	40.1	12.5	1 030	2.0 (0.10)	The destruction of the adhesive
4	40.1	12.0	1 510	3.0 (0.13)	The destruction of the adhesive
5	40.1	12.5	2 370	4.6 (0.21)	The destruction of the adhesive
6	39.0	12.0	2 640	5.6 (0.25)	The destruction of the adhesive
7	40.1	12.5	900	1.8 (0.15)	The destruction of the adhesive
8	40.2	12.1	1 050	2.2 (0.20)	The destruction of the adhesive
9	40.1	12.0	1 400	2.9 (0.10)	The destruction of the adhesive

*Arithmetic mean of 6 samples.

**Values in parenthesis are standard deviations.

Table 2 shows the results of tests of various types of plywood on the tensile strength at static bending σ_{bend}, MPa, and the elastic modulus E_{bend}, GPa.

As it can be seen from Table 2, modulus of elasticity of beech plywood is much higher than that of birch plywood. Ultrasonically treated glue, which contains hydrogel of nanocrystalline cellulose, increases the strength of birch plywood under static bending, but it does not reach the strength of beech plywood. Additional processing of birch plywood with pulsed magnetic field gives the values of the ultimate strength at static bend of 118 MPa.

The change in the content of NCC hydrogel from 2 to 4% does not cause an increase in σ_{bend}. The introduction of NCC in small amounts (0.4%) does not give the effect of σ_{bend} increasing.

It is interesting to note that pressing of beech plywood insignificantly increases σ_{bend}, whereas for birch plywood pressing increases σ_{bend} two times – from 82 to 185 MPa.

In general, the data on flexural strength of Table 2 are consistent with the data in Table 1 on the strength of shearing along the fibres along the adhesive layer.

Tab. 2 Results of tests for determining the ultimate strength at static bending and modulus of elasticity of plywood *.

№ experiment	Type of plywood, type of processing	Static bending strength σ_{bend}, MPa	Modulus of elasticity in static bending, E_{bend}, GPa
1	Beech plywood	115 (3.4)**	10.86 (0.48)**
2	Birch plywood	82 (3.8)	8.21 (0.28)
3	Birch plywood, NCC 2%, ultrasound	103 (4.1)	9.68 (0.41)
4	Birch plywood, NCC 2%, ultrasound, PMF	118 (4.3)	13.75 (0.38)
5	Beech plywood, pressed	119 (3.9)	13.15 (0.61)
6	Birch plywood, pressed	185 (7.45)	20.24 (0.84)
7	Birch plywood, NCC 0.4%, ultrasound	87 (3.8)	9.66 (0.46)
8	Birch plywood, NCC 4%, ultrasound	103 (4.55)	10.22 (0.5)
9	Birch plywood, NCC 4%, ultrasound, PMF	109 (3.2)	9.91 (0.48)

*Arithmetic mean of 6 samples.

** Values in parenthesis are standard deviations.

CONCLUSIONS

1. Samples of birch plywood which are made using ultrasonically treated glue, which included hydrogel of nanocrystalline cellulose, and additionally treated with pulsed magnetic field, have higher physical and mechanical characteristics: the strength of plywood in shearing along the adhesive layer increases to 3.0 MPa (at strength of beech plywood of 2.2 MPa).
2. Pressing of beech plywood by 19% makes it possible to increase its strength 2.2 times in comparison with standard beech plywood.
3. The combination of the use of hydrogel of nanocrystalline cellulose in adhesive composition and pressing increases ultimate strength of birch plywood in shearing on the adhesive layer 3.5 times. Thus, pressed birch plywood with respect to shearing strength along the adhesive layer (5.6 MPa) exceeds beech plywood 2.5 times.
4. The use of ultrasonically treated glue, which includes hydrogel of nanocrystalline cellulose, increases the strength of birch plywood under static bending. The additional processing of birch plywood with pulsed magnetic field gives the values of tensile

strength at a static bend of 118 MPa. The strength limit for static bending of pressed birch plywood increases two times in comparison with standard birch plywood.

REFERENCES

AULIN C., GALLSTEDT M., LINDSTROM T. 2010. Oxygen and oil barrier properties of microfibrillated cellulose films and coatings. Cellulse, 2010, 17(3): 559–574.

BECKER U., TODD J., GLASSER W. 1998. Surface segregation phenomena in blends of cellulose esters. Cellulose Derivatives – Modifications, characterization, and nanostructures. American Chemical Society, Washington D.C. 1998. pp. 315–331.

DRI F.D., HECTOR JR., L.G., MOON R.J., ZAVATTIERI P.D. 2013. Anisotropy of the elastic properties of crystalline cellulose I_β from first principles density functional theory with Van der Waals interactions. Cellulose. 2013. 20(6): 2703–2718.

FELIX J., GATENHOLM P. 1994. Effect of transcrystalline morphology on interfacial adhesion in celllose/polypropylene composites. Journal of Materials Science. 1994. 29: 3034–3049.

KVIEN I., TANEM B. S., OKSMAN K. 2005. Characterization of cellulose whiskers and their nanocomposites by atomic force and electron microscopy. Biomacromolecules J. 2005. (6): 3160–3165.

MISSOUM K., MARTOIA F., BELGACEM M.N., BRAS J. 2013. Effect of chemically modified nanafibrillated cellulose addition on the properties of fiberbased materials. Industrial Crops and Products. 2013. 48: 98–105.

NIKULINA N.S., MEDVEDEV I.N., SHAMAEV V.A. 2013. Modification of wood. Moscow : Science, 2013. 448 p. ISBN978-5-9765-1605-2.

OLSSON R. T., AZIZI SAMIR, M. A. S., SALAZAR-ALVAREZ G., BELOVA L., STRÖM V., BERGLUD L. A., NOGUS J., GEDDE U. W. 2010. Making flexible magnetic aerogels and stiff magnetic nanopaper using cellulose nanofibrils as templates. 2010. Nature Nanotechnology. 5(8): 584–588.

OKSMAN K., MATHEW A., BONDESON D., KVIEN I. 2006. Manufacturing process of cellulose whiskers-polylactic acid nanocomposites. Composites Science and Technology. 2006. 66: 2776–2784.

PARINOV D.A., SHAMAEV V.A. 2016. Composite plywood with additives of nanocellulose. Bulletin of the Moscow State Forest University - Forest Bulletin. 2016. 20: 95–100.

RAZINKOV E. M., SHAMAEV V. A., ISHCHENKO T. L., ZIEMELIS A. E. 2014. Investigation of gluing of plywood using nanocrystalline cellulose. Journal of Forestry and Technologies. 2014. 4(13): 151–155.

SHAMAEV V.A. 1989a. Theoretical and practical aspects of the chemical-mechanical modification of wood by urea, 1989. Collection of articles Interprogress-87. Bratislava. 1989. pp. 112–118.

SHAMAEV, V.A. 1989b. Wood modification by self-pressing. Materials of the VI Symposium Modification of Wood. Poznań. 1989. pp. 173–178.

SHAMAEV V.A. 1987. Wood modification of urea. Proceedings of the Polish Academy of Sciences, 1987. pp. 112–118.

VOSKOBOINIKOV I.V., KONSTANTINOVA S.A., KOROTKOV A.N., GALBRAICH L.S., IVANOV V.F., NIKOLSKY S.N., MIKHAILOV A.I., REMEZOV A.I. 2011. Use of nanocrystalline cellulose for the modification of wood-laminated plastics. Chemistry of plant raw materials. 2011. (3): 43–46.

WILKES G. 2003. Polymers, Mechanical Behaviour. Encyclopaedia of Physical Science and Technology. 2003. pp. 697–722.

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