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Achievements and challenges of modified wood on the example of birch veneer

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Abstract. The article provides a comparative analysis of modern technologies for producing various grades of modified wood, such as Accoja, Kebony, Belmadur, Destam, Woodest, Thermowood and others. A brief description of new modification technologies developed at Voronezh State University of Forestry and Technologies is provided. The most promising of them are the following: technology of pressing and molding a cylindrical blank into timber, when the price of modified wood becomes less than the price of natural oak; technology for changing the strength, color and texture of wood to obtain complete analogues of polysander, mahogany, etc.; technology of wood pressing upto the density of wood substance; technology of plywood strengthening using nanocrystalline cellulose for LVL blocks production; manufacturing technology for power transmission poles and railway transfer bars due to the “self-pressing” effect; technology for producing railway ties, where the operations of drying, impregnation and pressing are combined in place and time. Production technology of end-panel parquet intended for use in gyms, supermarkets, universities, schools, etc. has been examined in detail, since wear resistance of end-face parquet is 3-4 times higher than that of natural oak one. A distinctive feature of the technology is that birch wood is pressed along the fibers.

1 Introduction

In the history of wood modification there were two periods of its heyday and decline. There was a rapid growth in the production of modified wood in the 30-60s of the XX century, and more and more new enterprises were created. This was due to the fact that strong and at the same time lightweight material was required for the manufacture of friction parts, such as weaving shuttles, plain bearings, and stern tube bushings. Abroad, the production of modified wood of Zignoston, Steibwood, Zignomer, Zignamon and other brands was mastered [1-6]. All these industries closed after the massive proliferation of plastics.

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The second stage of development of modified wood began at the beginning of the 21st century, when it became clear that the production of board materials from crushed wood, such as particle board and fibreboard, had exhausted itself, and their production has been growing little over the past decades. The intensive growth in the production of wood-polymer composite materials is also slowing down and will soon stabilize at the level of demand.

The idea is becoming increasingly stronger that there is no point in losing those properties of natural wood (which nature has encrypted for millions of years) during grinding. They must be changed in the right direction through modification. First of all, this concerns the dimensional stability of wood under conditions of variable humidity, since a change in humidity by 1% changes the compressive strength by 2.5-3%. Therefore, modern modification technologies are aimed at producing hydrophobic wood, when its swelling and water absorption are reduced 3-8 times. We are talking about impregnation of wood with acetic anhydride, polyethylene glycol, polyvinyl alcohol or hydrothermal treatment. Wood modified in this way is produced under Accojia, Kebony, Belmadur, Thermowood and other brands [1-4]. The production of such wood is hampered by its high cost due to the multi-step technological process and low strength of modified wood.

Meanwhile, the structure of current forest management is such that the amount of valuable wood in the world is constantly decreasing. And the amount of fast-growing, low-quality soft hardwood wood - aspen, poplar, birch, and eucalyptus is increasing. This is due to the fact that oak wood grows to the cutting age in 200-300 years and poplar wood in 7-17 years. However, the use of soft hardwood timber is less than 1% of the estimated logging area. This is due to the fact that with a diameter of 30 cm, birch wood is 20%, and aspen wood is 50% affected by heart rot, which occupies 15-30% of the volume.

Previously conducted studies on soft hardwood wood strengthening, including faut zone, allow it to be used instead of valuable wood [5, 6]. It should be noted that numerous studies on wood modification still remain at the laboratory level [7-14].

Achievements in the field of wood modification in Russia until 2014 are summarized in the monograph by V.A. Shamaev and co-workers [15]. However, over the past 10 years, guidelines in the field of wood modification have changed and the most promising are those that were previously in the background [16, 17]. Therefore, the purpose of this work is to analyze the achievements of world science in the field of wood modification and the formation of new tasks and directions of research in this area.

2 Methods and materials

The initial raw materials for producing parquet were birch and oak firewood in bark with a diameter of 20-60 cm and a length of 1-2 m. This specimen was sawed on a circular saw into split billets of 15-20 mm thick. The split billets (in a container) were loaded with a telpher into an impregnation bath with a 30% aqueous solution of urea at a temperature of 600°C for 2-3 hours. After the solution had drained, the split billets were cut on a stamping press into regular hexagons with a distance between the vertices of opposite corners of 100 mm. In this case, the presence of knots and rot is excluded.

The resulting hexagons were dried in an infrared drying chamber for 4 hours at a temperature of 35-400°C to a humidity of 8-10%. Hexagons were placed in a 12-cavity mold mounted on a hydraulic press with a force of 400 tf. They are end-pressed using 20% oak wood and 30% birch wood at a temperature of 180°C with exposure in the press for 40 s. After removing the load, the hexagons did not unpress. After pressing, the following happened. The density of wood increased to 750-800 kg/m^3 for birch and oak. Hexagons acquired the correct shape and the spread of the distance between the edges did not exceed 0.1 mm. As a result of flattening the wood elements on the end surface, the voids in the vessels disappeared, and the wood became able to hold varnish on the end surface without leaking. Pressed hexagons were placed on a glue-coated substrate made of chipboard, fibreboard, and pine in the form of a shield measuring 600×600 mm, placed in a bath and glued into a shield by cold curing for 2 hours. Next, the shields underwent trimming, cutting grooving, sanding, and priming, dipping with varnish, drying and packaging.

To strengthen birch and aspen veneer, we used hot rolling method, the diagram of which is shown in figure 1. For experiments, the veneer of 4 mm thick, impregnated with an aqueous solution of urea as a classifier, was used.

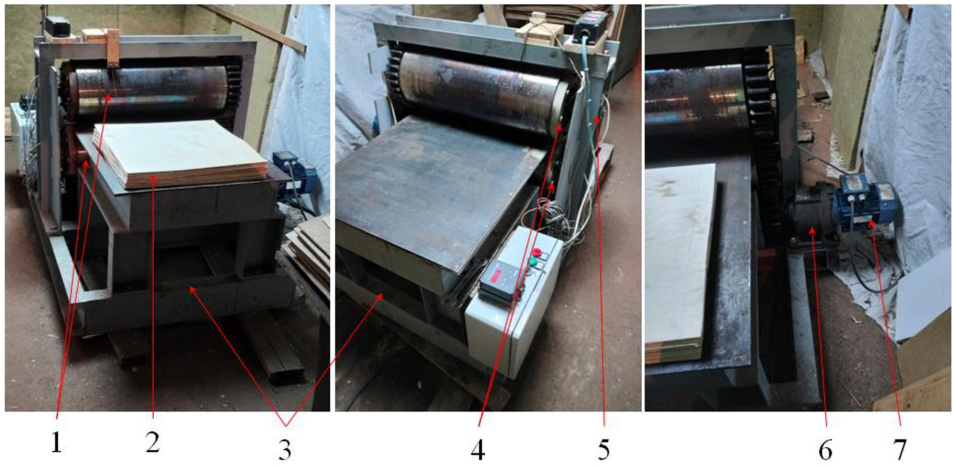

Fig. 1. Rolling mill: 1 – rollers, 2 – veneer, 3 – frame, 4 – thermal electric heaters (TEH), 5 – gap adjustment mechanism, 6 – drive unit, 7 – electric motor.

Veneer with a thickness of 4 mm was supplied for rolling and the compression ratio was 30% for birch and 40% for aspen. Number of rolling cycles - 8, roll temperature - 1700°C, veneer moisture content - 8%.

Birch and aspen veneer, harvested in the city of Galich, Kostroma region (Russia) with a thickness of 4 mm and dimensions of 500×500 mm, was used as raw material for the production of modified plywood. Phenol-formaldehyde resin SFZh-3014 produced by the Uralkhimplast plant in N. Tagil (Russia) was used as a binder. Dry (powder) nanocrystalline cellulose (made in China) had the following characteristics:

- Particle thickness - 10-20 nm;
- Particle length - 300-900 nm;
- Density - 500-800 kg/m^3;
- Viscosity (water content of 5% suspension) - 5 s.
- Gluing technology includes the following operations:
- Mixing resin with formic acid (3% by weight);
- Applying resin to a plywood sheet at a rate of 200 g/m^2;
- Forming a package of 10-20 plywood sheets, placing in a clamp, creating a pressure of 0.1 MPa;

Curing at room temperature for 6-8 hours.

3 Results and discussion

This paper analyzes modification methods developed at Voronezh State University of Forestry and Technologies and aimed at use mainly on the Russian market. Figure 2 shows a diagram of the 9 most promising methods.

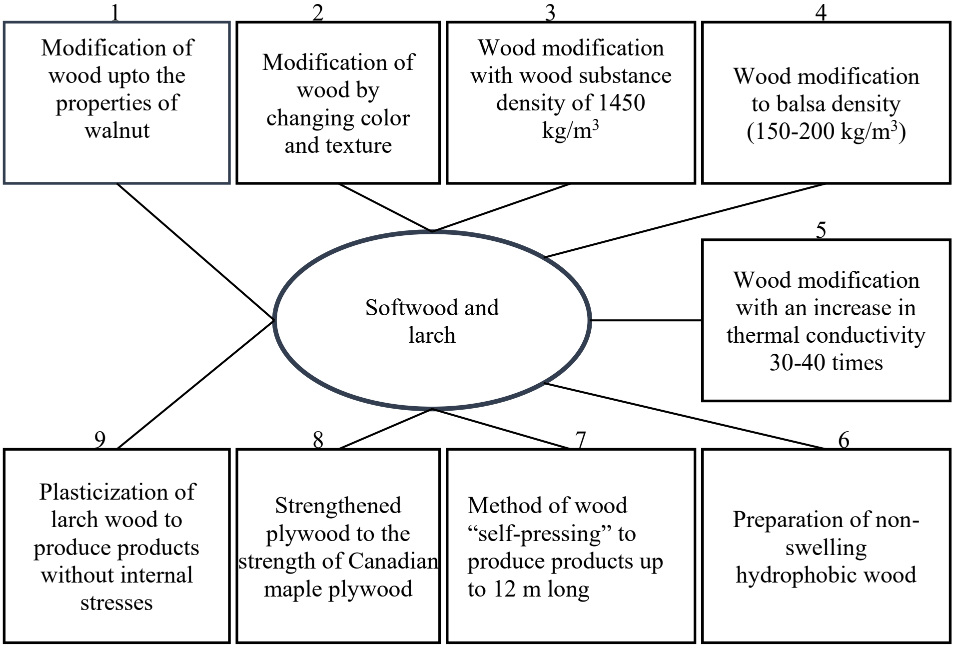

Fig. 2. Main directions of wood modification.

The initial raw material for producing modified wood according to methods No. 1-8, 10 is soft hardwood wood, primarily birch, aspen, poplar, and for method No. 9 - larch wood.

Let's analyze the features of several methods.

Method No. 1. This method is the most studied. The main purpose was to obtain a material from aspen and poplar that was closest in properties to walnut wood, but at half the price. The second goal of the project was recycling of low-quality wood into soft hardwoods, because the yield of industrial wood from aspen and poplar did not exceed 50% due to the presence of knots and rot.

The essence of the method was plasticization of raw wood with an aqueous solution of urea containing 5-10% of a size stabilizer - urea-formaldehyde oligomer precondensate (UFO). Impregnation led to UFO content relative to the weight of dry wood of 1-1.5%, urea - 7-10%. The impregnated workpieces were compacted in a vacuum-pulse drying-press chamber and simultaneously dried to a density of 750-800 kg/m^3 and moisture content of 6-8%. The result was modified wood physical, mechanical and decorative properties of wich were closest to those of walnut wood. The advantages of this material, which has Destam trademark (short for amide-stabilized wood), include resistance to rotting and low flammability. Physical and mechanical properties of modified Destam wood are given in table 1.

Table 1. Physical and mechanical properties of Destam wood.

Type of test	Property indicators								
	Birch			Aspen			Pine		
Density, kg/m^3	800	1000	1200	800	1000	1200	800	1000	1200
Moisture content, %	5.0	5.0	4.8	5.4	5.2	5.2	4.9	4.6	4.2
Ultimate compressive strength along the fibers, MPa	110	130	160	100	120	150	100	120	150

Ultimate strength at static bending, MPa	170	220	270	160	200	250	140	190	240
Hardness across the fibers, MPa	81	86	110	73	80	100	72	79	100
Modulus of elasticity in compression along the fibers, GPa	20.0	29.6	37.0	34.1	42.6	18.2	23.5	23.5	30.1
Ultimate shear strength along the fibers, MPa	11.2	14.7	16.5	10.4	13.2	15.1	10.0	13.0	15.0
Impact strength, kJ/m ^{2}	70	90	110	65	85	105	55	75	95
Water absorption, % In 2 hours In 30 days	13.1 68.0	6.0 52.2	3.8 45.0	13.4 72.0	6.3 53.1	4.2 46.0	12.2 60.0	5.1 48.0	3.0 41.3
Water absorption, % In 1 day In 30 days	6.0 18.0	4.0 17.6	2.1 14.9	6.2 19.2	4.1 18.0	2.3 15.4	5.0 18.0	3.7 17.0	1.8 14.5
Swelling in the direction of pressing, %, with water absorption: In 2 hours In 30 days	3.2 28.1	2.1 33.4	1.4 35.6	3.2 28.1	2.1 33.4	1.4 35.6	3.0 26.0	1.8 32.2	1.2 33.8
When absorbing moisture In 1 day In 30 days	3.0 15.9	1.7 17.7	0.5 18.3	3.2 16.8	1.8 17.4	10.6 18.8	2.0 15.0	1.5 16.3	0.4 18.0

All technologies for producing modified wood are based on three operations: impregnation, drying and pressing.

Method No. 2. By impregnating logs made of raw soft hardwood from the end under pressure, you can achieve through-impregnation with water and alcohol dyes for fabrics. Wood color can be any other than white. A more difficult task is changing the texture. Today, among the industrially used species, rosewood and mahogany wood have the richest texture and color (figure 3).

a

b

Fig. 3. Photo of modified alder wood with polysander (a) and mahogany (b) texture: magnification 20.

Modified alder wood has the same density and the same optical characteristics as natural rosewood and mahogany wood.

Method No. 3. This method is aimed at obtaining the most durable wood. The strength of softwood can be increased either by impregnation of synthetic monomers and polymers and then curing them into the wood, or by mechanical compression to reduce the volume. In the second case, the filling of the voids occurs due to the wood substance itself, which has a density of 1500 kg⁄m^3. Thus, aspen wood, which has a density of 500 kg⁄m^3, must be compressed 3 times in order to fill all the voids. The densest guaiacum wood has a density of 1350 kg⁄m^3, but guaiacum contains 150 kg⁄m^3 resins and the true density of guaiacum is 1200 kg⁄m^3. The strength of wood of all species depends linearly on density. Thus, ultimate compressive strength along the length of balsa, having a density of 150 kg⁄m^3 is 15 MPa, and guaiacum wood is 140 MPa. The same ratio of density to strength, i.e. approximately 10:1 is observed in all species.

For pressed wood, a linear dependence of tensile strength on density is also observed, but only up to a density of 1200 kg⁄m^3. The strength decreases with further compression across the fibers. This is due to the fact that micro-destruction processes associated with rupture of cell and vessel walls begin to prevail. Therefore, a method for defect-free pressing of wood was developed, the diagram of which is presented in figure 6. To obtain wood with the density of wood substance, three diffusely vascular wood species are used: butt birch with a density of 600-620 kg⁄m^3, maple and beech with a density of 660 kg⁄m^3, hornbeam with a density of 780 kg⁄m^3.

Figure 4 shows a graph of changes in the strength of birch wood under three-way compression as the density increases.

In figure 4, points 1, 2, 3 correspond to a specific pressure of 30, 100, 550 MPa, respectively. As it can be seen from the figure, a jump in the growth of compressive strength occurs at a density of 1350-1450 kg⁄m3, when the “broom effect” is triggered during a compression test along the fibers/ That is wood fibers are pressed so tightly together that there is nowhere for them to bend. Strength indicator of 230 MPa corresponds to the strength indicator of steel (grade 3), but the density of wood is 5 times less than steel one.

Method No. 7. The highest rates of annual growth in woodworking production are observed for laminated wood, in particular, plywood and LVL blocks for wooden house construction.

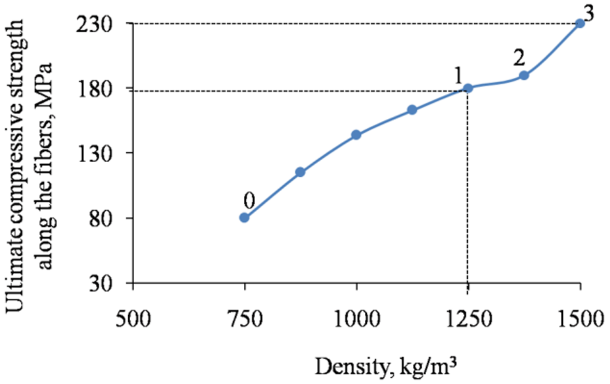

Fig. 4. Dependence of ultimate strength on density: 0-1 - pressing in the radial direction; 1-2 -pressing along the fibers; 2-3 - pressing in the tangential direction.

However, plywood made from birch wood is not strong enough. Plywood made from aspen veneer is generally not applicable for the manufacture of load-bearing structures. In this regard, the task was set to obtain plywood from birch wood with the strength of oak plywood and aspen plywood with the strength of beech wood plywood. Beech plywood is produced in small quantities in Romania and a number of other countries.

The scheme for obtaining strengthened plywood is shown in figure 5.

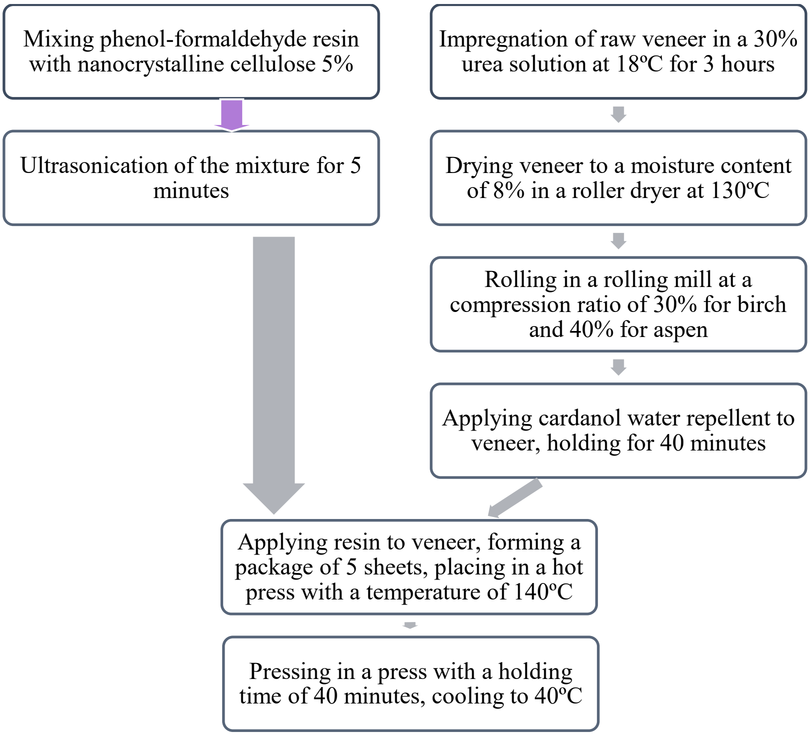

Fig. 5. Scheme for producing reinforced plywood from birch and aspen veneer.

The resulting thickness after each rolling cycle decreases with the initial veneer thickness h1 of 4 mm. Thus, veneer thickness h_2 after the first cycle is 3.5 mm, after the second cycle h_3 is 3.3 mm, after the eighth – 3 mm, for both birch and aspen. Table 2 shows the properties of modified plywood in comparison with the properties of birch plywood according to 3916.1-2018 State Standard.

Table 2. Physical and mechanical properties of plywood made of natural and modified birch and aspen wood.

№	Indicator	Value of the indicator		
		Natural birch	Modified birch	Modified aspen
1	Density, kg/m^3	580	720	650
2	Moisture content, %	8	6	6
3	Ultimate shear strength along adhesive layer, MPa	3.3	5.0	4.5
4	Ultimate strength at static bending, MPa	39	51	45
5	Hardness across the fibers, MPa	57	73	66
6	Impact strength, kJ/m2	52	65	61
7	Water absorption for 30 days, %	80	80	78
8	Moisture absorption for 30 days, %	28	29	27
9	Swelling in water in the direction of pressing, max. %	-	17	18
10	Swelling in water in the direction perpendicular to pressing, max.%	-	0.49	1.37
11	Volumetric swelling in water, max. %	13.5	17.5	19.5

As it can be seen from table 3, strength properties of reinforced plywood are approximately twice as high as those of conventional plywood. Thickness of resulting 5-layer plywood is 14-16 mm. LVL blocks can be obtained from this plywood by gluing plywood sheets into a package consisting of 10-20 plywood sheets per block, using AM-10 amino-formaldehyde resin with a formic acid hardener.

4 Conclusion

The strength properties of the LVL block correspond to the properties of modified plywood, i.e. the cross-sectional area of beams and other LVL structures can be halved. The developed method of strengthening birch veneer and strengthening the adhesive composition enables to obtain birch plywood with the strength of oak plywood. If we use aspen veneer, we obtain plywood with the strength of beech plywood. Experiments have shown that the strength of birch plywood can be increased to the strength of hardmaple plywood. If we use Prefere urea-melamine formaldehyde resin as a binder, the plywood tensile strength when chipping along the adhesive layer increases to 7 MPa, and the static bending strength to 70 MPa, which corresponds to the indicators of hardmaple wood (6.5 MPa and 60 MPa, respectively).

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References

1. V.A. Shamaev, O.F. Shishlov, Forestry Journal **2,** 155-161 (2023). https://doi 10.37482/0536-1036-2023-3-155-161
2. R. Ziethén, P. Per Brynildsen, S. Lande, J. Jarle Kristoffersen, M. Westin, *Kebony - an alternative to teak for boat decking*, Proceedings of The Fourth European Conference on Wood Modification, SP Technical Research Institute of Sweden, pp. 523-530 (2009).

3. A.N. Papadopoulos, G.I. Mantanis, Advances in Forestry Letter **1,** 1-6 (2012).
4. A. Aytin, N. Çakıcıer, T. Birtürk, BioResources, **17(1),** 785-801 (2021).
5. V.A. Shamaev, *Current state and development ways of modified wood*. Proceedings of Scientific and Practical Conference "Modern problems of mechanical wood technology", St. Petersburg, pp. 11-17 (2010).
6. V.P. Nedikov, V. A. Shamaev, Eurasian patent 000445 MKI V 27 M 3/04. Method for producing end block parquet (1999).
7. R.E. Ibach, C.M. Clemons, R.L. Schumann, *Wood-plastic composites with reduced moisture: effects of chemical modification on durability in the laboratory and field*. In: Stark, Nicole M., Ed. Proceedings of Ninth International Conference on wood and biofiber plastic composites, pp. 259-266 (2007).
8. K.I. Kovaleva, V.V. Gorshkov, G.G. Politenkova, M.G. Mikhaleva, V.P. Melnikov, D.S. Gerasimov, S.N. Nikolsky, S.V. Stovbun, Forestry bulletin **131(23),** 84-93 (2019). https://doi 10.18698/2542-1468-2019-1-84-93
9. C.R. Slevin, M. Westin, S. Lande, S. Cragg, Eighth European Conference on Wood Modification, Finland, Helsinki, pp. 464-471 (2015).
10. S.L. Zelinka, M. Altgen, L. Emmerich, N. Guigo, T. Tobias Keplinger, M. Maija Kymäläinen, E.E. Thybring, L.G. Thygesen, Forests, **13(7),** 1004-1004 (2022). https://doi.org/10.3390/f13071004.
11. K. Candelier, J. Dibdiakova, Holzforschung **75(3),** 199-224 (2020). https://doi.org/10.1515/hf-2020-0102
12. N.Z. Plaza, S.V. Pingali, R.E. Ibach, Fibers **10(5),** 40-40 (2022). https://doi.org/10.3390/fib10050040
13. L. Kyzioł, Composite Structures **158,** 64-71 (2016). https://doi.org/10.1016/j.compstruct.2016.06.055
14. M. Vaziri, D. Sandberg, BioResources **16(2),** 3224-3234 (2021). https://doi.org/10.15376/biores.16.2.3224-3234
15. V.A. Shamaev, Modification of Wood (Voronezh State University of Forestry and Technologies named after G.F. Morozov, Voronezh, 2016).
16. I.N. Medvedev, D.A. Parinov, V.A. Shamaev, Modification of wood of low-value species in order to improve the performance of products, *Current directions of scientific research of the 21st century: theory and practice* **8-1(48)**, 233-237 (2020). https://doi.org/10.34220/2308-8877-2020-8-1-233-237
17. V.A. Shamaev, N.S. Nikulina, I.N. Medvedev, Wood Modification (Voronezh State University of Forestry and Technologies named after G.F. Morozov, Voronezh, 2022).