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DEVELOPMENT OF LAMINATING METHODS OF WOOD BASED PANELS WITH THIN DECORATIVE VENEER OF VALUABLE WOOD SPECIES

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ABSTRACT

Experiments on wood-based panels – particleboard laminating with thin decorative veneer from valuable wood species African mahogany (*Khaya*, *spp*. Ehrh.) were carried out. As a result of experimental data processing, mathematical models of relative area of adhesive penetration and ultimate stress limit of adhesive joint from variable factors in the form of regression equations were obtained. Testing the strength of specimens of glued joint during furniture part veneering were carried out according to EN 311: 2002. Processing method for wood based materials laminated with a thin decorative veneer from valuable wood species minimizing glue penetration on the surface and providing the required strength of glued joint were developed.

Key words: particleboard, thin decorative veneer, African mahogany, adhesive joint strength, urea-formaldehyde resin.

INTRODUCTION

Today, entering the international market, each industrial enterprise seeks to demonstrate environmental safety of its production and its products. All this requires special approach to the choice of materials (PRENDEVILLE *et al.* 2014, KOSYAKOVA *et al.* 2017).

Currently, the leading manufacturers of cabinet furniture, such as IKEA (Sweden), Arclinea (Italy), Asko (Finland), Nobia (Sweden), Nobilia (Germany), Alno AG (Germany) and others, use particleboards (PB) laminated with various materials as the main construction material. Despite strong competition from textured impregnated papers (polymer films, decorative paper-laminated plastics and others), designers and furniture manufacturers prefer natural wood veneer (decorative, rotary cut, fine-line veneer) (DIETZEL *et al.* 2016, KRÁL *et al.* 2013). The growing demand for furniture faced with natural veneer makes it necessary to increase harvesting of valuable and hardwood species which stocks are largely depleted, so the rational use of wood of these species is becoming one of the main problems of wood-processing industry.

One of the ways to solve this problem is to reduce thickness of resulting veneer. At present, decorative veneer with a thickness of 0.6 mm and more is used for facing furniture details. Typically, furniture manufacturers are afraid to use thin veneer because of possible increase in the amount of scrap during the facing process due to glue penetration on the front surface. Existing equipment for veneer slicing enables to obtain high-quality veneer with a thickness of 0.1 mm, and processing methods of facing must be adjusted for each kind of wood.

The following factors influence the degree of glue penetration during facing of wood and wood materials: moisture content of base and veneer; wood species, because it determines dimensions of capillaries and porosity; glue viscosity; duration of glue curing; amount of glue; temperature of press plates; compacting pressure; thickness of veneer (PONOMARENKO *et al.* 2013, EFIMOVA *et al.* 2016). The work (GALTSEVA 2005) suggests facing methods of PB with thin veneer of some species as oak, beech and ash. The author of the work (ZHURAVLYOVA, 2010) has developed method of facing of wood materials surfaces with a thin veneer with simultaneous ground coating, which excludes: glue penetration onto the front surface when facing; loss of glue; ground coating and filling operations during subsequent finishing and reduces consumption of paints and varnishes. The works (CANDAN *et al.* 2010, BEKHTA *et al.* 2009, BEKHTA *et al.* 2017, KHASANSHIN *et al.* 2016, ARRUDA *et al.* 2016) consider the use of heat-strengthened veneer which enables to reduce consumption of glue, penetration to the front surface; improves the physical and mechanical and consumer properties of resulting products.

Glues based on polyvinyl acetate dispersion, urea-formaldehyde and phenol-formaldehyde resins are used for veneering of wood boards (DUNKY 1998, TOUT 2000). Also, at present, active research of adhesives based on biopolymers for subsequent use in wood-processing industry is hold (NORSTRÖMA *et al.* 2010, LEI *et al.* 2014). Composition of glues, in addition to resins, may contain various components: a curing agent, a solvent, filler, a plasticizer, a stabilizer, and the others. Use of filler reduces excessive penetration of glue into wood, and also increases strength properties of adhesive line. So, the authors of the work (KANTIYEVA *et al.* 2015) suggest introduction of grinding dust as a filler in urea-polyamide-aldehyde adhesives to reduce glue penetration and increase strength properties of adhesive line.

The purpose of this work is to develop a processing method for facing of PB with thin decorative veneer of valuable wood species African mahogany (*Khaya*, *spp*. Ehrh.), which minimizes glue penetration onto the surface and provides required strength of adhesive joint. Veneer of this species is widely used in furniture and joinery production.

MATERIALS AND METHODS

To obtain mathematical models adequate to the actual process of facing panel furniture pieces, a series of laboratory experiments were performed to determine the effect of the parameters of the facing method on the degree of leakage of the adhesive, as well as the strength of the adhesive joint. PB specimens of flat pressing with a fine-structure surface were used for the experiments. PB have been cut to specimens measuring 300 × 150 × 16 mm. The veneer of the African mahogany were cut into blanks with a size of 310 × 160 mm.

Veneering were made with a TP 400 hydraulic press using glue mixture based on urea-formaldehyde resin. Characteristics of starting materials are presented in Table 1.

Glue mixture:

- urea-formaldehyde resin – 100 weight parts
- hardener – 5 weight parts
- filler – 25 weight parts

Construction of mathematical models of the process of PB facing with a thin decorative veneer of valuable wood species (African mahogany).

The selection of natural values of control (variable) and constant (stabilized) factors were carried out on the basis of theoretical data and technological considerations.

Factor variation ranges:

pressing pressure: $0.4 \leq P$, MPa ≤ 0.8

temperature of plates: $100 \leq t$, °C ≤ 160

consumption of glue: $60 \leq q$, $g \cdot m^{-2} \leq 90$

Values of levels of control factors, as well as their variation intervals are presented in Table 2. Values of constant factors and experimental conditions are shown in Tables 3 and 4.

Tab. 1 Characteristics of starting materials.

№	Characteristics of the material	Parameter value
1	Basis: Particle board according to EN312	$\rho = 0.7$ g·cm^{-3}
		W = 8 ± 2%
		$R_{m\ max}$ = 32 μm
2	Facing: Radial planed veneer with a thickness of 0.4 mm. Veneer species – African mahogany. Deviation of veneer thickness is no more than 0.02 mm	W = 8 ± 2%
		R_{mMax} = 100 μm
3	Binder: Urea-formaldehyde resin CB1636F (Diakol) (urea:formaldehyde 1:1.14)	pH = 7.92
		mass fraction of dry residue 52.3%
		gel time of adhesive at 100 °C – 58.25 s
		density – 1.3 g·cm^{-3}
		conditional viscosity of adhesive at t = 20 ± 0.5 °C according to F4/20 = 96 s
		viscosity by rotational viscometer Rheotest 200–465 mPa.s
4	Hardener: Ingredients: ammonium sodium NH_4NO_3,formic acid 1%, carbamide 15%	60% solution
5	Filler - Extra wheat flour	–

Tab. 2 Values and levels of factors variation.

1. Levels of factors:	Variable factors		
	x_1 = P, MPa	x_2 = t, °C	x_3 = q, g·m^{-2}
–1.682	0.4	100	60
–1	0.5	112	66
0	0.6	130	75
+1	0.7	148	83
+1.682	0.8	160	90
2. Variation interval	0.1	18	8

Tab. 3 Constant factors and their values.

№	Factor	Parameter Value
1	Exposure under pressure, s	60

Tab. 4 Experimental conditions.

№	Parameter	Parameter Value
1	Air temperature in the room, °C	18-22
2	Relative air humidity in the room, %	65
3	Temperature of the resin (before adhesive solution preparing), °C	18-22

The output indicators are: relative area of glue penetration S_{penetr} and strength of adhesive joint for uneven cleavage of facing material σ, MPa.

The method of uniform-rotatable planning of the second-order experiment has been used during the work (KANTIYEVA *et al.* 2012). Matrix for experiment planning in normalized and natural values is given in Table 5.

Tab. 5 Matrix for experiment planning.

№ test	Factors					
	X_1		X_2		X_2	
	Norm.	Natur.	Norm.	Natur.	Norm.	Natur.
1	-1	0.5	-1	112	-1	66
2	+1	0.7	-1	112	-1	66
3	-1	0.5	+1	148	-1	66
4	+1	0.7	+1	148	-1	66
5	-1	0.5	-1	112	+1	83
6	+1	0.7	-1	112	+1	83
7	-1	0.5	+1	148	+1	83
8	+1	0.7	+1	148	+1	83
9	–1.682	0.4	0	130	0	75
10	+1.682	0.8	0	130	0	75
11	0	0.6	–1.682	100	0	75
12	0	0.6	+1.682	160	0	75
13	0	0.6	0	130	–1.682	60
14	0	0.6	0	130	+1.682	90
15	0	0.6	0	130	0	75
16	0	0.6	0	130	0	75
17	0	0.6	0	130	0	75
18	0	0.6	0	130	0	75
19	0	0.6	0	130	0	75
20	0	0.6	0	130	0	75

This matrix was gathered during active experiment. Six specimens were used in each experiment. The results of 20 series of replicated experiments are presented in Table 6.

Tab. 6 Value of output indicators from the results of matrix implementation*.

№ test	Relative area of adhesive penetration S_{penetr}	Strength of adhesive joint, σ, MPa
1	0.0198 (0.0008)**	0.63 (0.011)
2	0.0762 (0.0021)	0.64 (0.020)
3	0.0102 (0.0003)	0.58 (0.009)
4	0.0586 (0.0016)	0.64 (0.010)
5	0.0384 (0.0007)	0.61 (0.018)
6	0.1082 (0.0022)	0.59 (0.012)
7	0.0256 (0.0009)	0.64 (0.030)
8	0.0877 (0.0032)	0.65 (0.020)
9	0.0109 (0.0004)	0.64 (0.020)
10	0.1104 (0.0042)	0.74 (0.030)
11	0.0621 (0.0021)	0.90 (0.010)
12	0.0365 (0.0009)	0.70 (0.020)
13	0.0282 (0.0011)	0.90 (0.010)
14	0.0688 (0.0017)	0.82 (0.020)
15	0.0454 (0.0014)	0.91 (0.031)
16	0.0454 (0.0018)	0.87 (0.016)
17	0.0454 (0.0010)	0.89 (0.008)
18	0.0451 (0.0006)	0.81 (0.023)
19	0.0454 (0.0008)	0.89 (0.040)
20	0.0456 (0.0021)	0.90 (0.010)

*Arithmetic mean of 6 samples.
**Values in parenthesis are standard deviations.

Method for determining relative area of glue penetration.

The relative penetration area of adhesive S_{penetr} is determined as a ratio of the area of penetration of adhesive to the area of specimen.

To determine relative area of glue penetration between press plate and specimen, a paper was placed which, in places with adhesive, has adhered to specimen. After pressing, non-glued paper was removed with a scraper, fibres was removed with an eraser, and glued paper shown the areas with glue. This enables to determine visually and count the area of glue penetration, by means of a transparent film with a mesh, superimposed on the sample,

Determination of strength of adhesive joint for uneven cleavage of facing material. The test for strength of glued joint on uneven cleavage was carried out according to the European standard EN 311: 2002 "Wood-based panels. Method for determining the strength of a surface layer. Test methods". The essence of the method is to determine the maximum breaking load per unit width of specimen from which veneer is peeled off with an uneven distribution of stresses over the bonding area. According to EN 311, the strength of glued joint for furniture parts facing should be at least 0.9 MPa.

Specimens in a size of 100 × 50 × 16 mm were used. In this case, surface of veneering material should not have shells, chips, blanks and other visible defects. Annular grooves were cut on the test specimen in such a way that their depth was not more than 0.3 mm. Internal diameter of a groove is 35.7 mm.

Hot-melt resin was used for gluing iron blocks to the test specimens. The tests were carried out on a LaborTech 4.05 test machine. A specimen were mounted on supports, centered along the line of action of load and loaded with a constant speed of movement of the mobile gripper of the machine, equal to 4 mm/min. Test result were taken as average arithmetic value of adhesive joint strength of all tested specimens of each experiment (there were 6 samples in each experiment).

RESULTS AND DISCUSSION

Mathematical models of the relative area of adhesive penetration and strength of adhesive compound from variable factors in the form of regression equations in coded expression were gathered as a result of experimental data.

$$y_1=0.0453809+0.0295852x_1-0.0075826x_2+0.0119634x_3+0.0053671x_1^2+0.0013552x_2^2+0.0010724x_3^2-0.0019625x_1x_2+0.0033875x_1x_3-0.0007625x_2x_3$$

Where: y_1 – relative penetration area.

$$y_2=0.8866279+0.1092691x_1+0.0685969x_2-0.024763x_3-0.036404x_1^2-0.01873x_2^2-0.0063589x_3^2+0.01375x_1x_2$$

Where: y_2 – the strength of adhesive bond on uneven separation of facing material.

After obtaining regression coefficients, a statistical analysis of the equations were carried out; this includes evaluation of significance of the coefficients and examination of adequacy of mathematical models.

The adequacy of the model by the Fisher criterion were estimated:

$F_{1calc}= 1.28$; $F_{1table}= 5.1$.

$F_{2calc}= 2.87$; $F_{2table}= 5.0$.

The model is adequate if $F_{calc}<F_{table}$, therefore, the obtained models are adequate to the process under study.

The regression coefficients have a clear physical meaning. By the sign of the coefficient, one can judge the nature of factor influence. The analysis of obtained regression equations makes it possible to trace the influence of the input parameters of the technological process on output target functions. In natural expression, the regression equations become:

S_{penetr} = 0.22230593 – 0.52332198p – 0.00045754t – 0.00287041q + 0.53611p^2 + 0.00000418t^2 + 0.00001676q^2 - 0.00109028pt+ 0.00423438pq- 0.00000529tq.

σ = – 2.28284055 + 4.46810383p+ 0.01425821t+0.01180832q–3.64039004p^2– 0.00005781t^2– 0.00009936q^2 + 0.00763889pt

Based on the gathered data, graphs of dependence of the output indices on the variable factors were made. Figures 1, 2 and 3 show the relative area of adhesive penetration from the variable factors when facing PB with thin decorative veneer of African mahogany.

Figure 1 shows the dependence of penetration area of the adhesive on the pressing pressure. It can be seen that with a constant value of the remaining factors, an increase in pressure leads to an increase in the glue penetration. The gathered data are due to the peculiarities of macroscopic structure of African mahogany wood, which refers to a variety of mahogany. It is known that this is a core scattered-vascular deciduous species with yellowish-brown sapwood. It has fairly large vessels, which are collected by two to three into small radial groups. Therefore, it can be seen that during pressing, liquid glue penetrated through holes through cut large vessels.

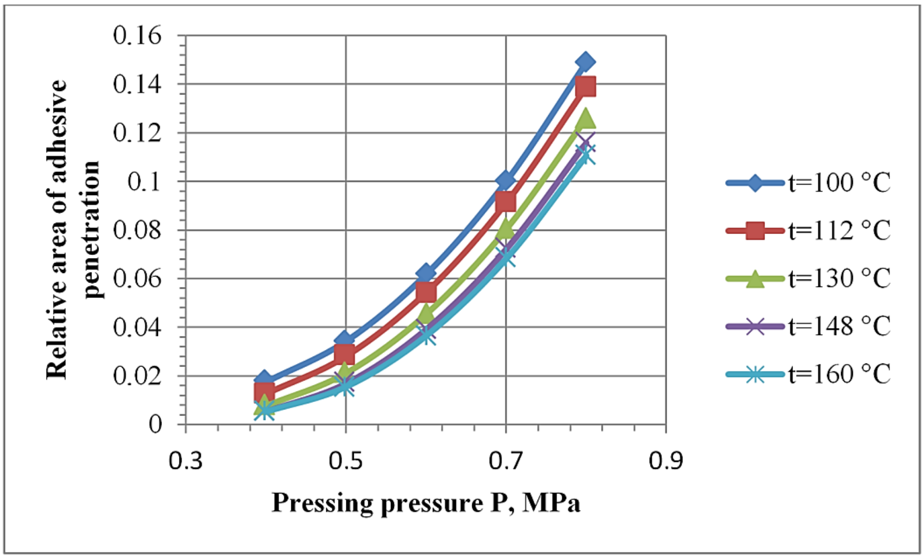

Fig. 1 Dependence of the relative area of adhesive penetration on pressing pressure at adhesive consumption q = 75 g·m^{-2}.

The increase in the temperature of the press plates helps to reduce the degree of penetration, which is explained by the increase in the viscosity of adhesive and acceleration of the curing process of the adhesive (Figure 2).

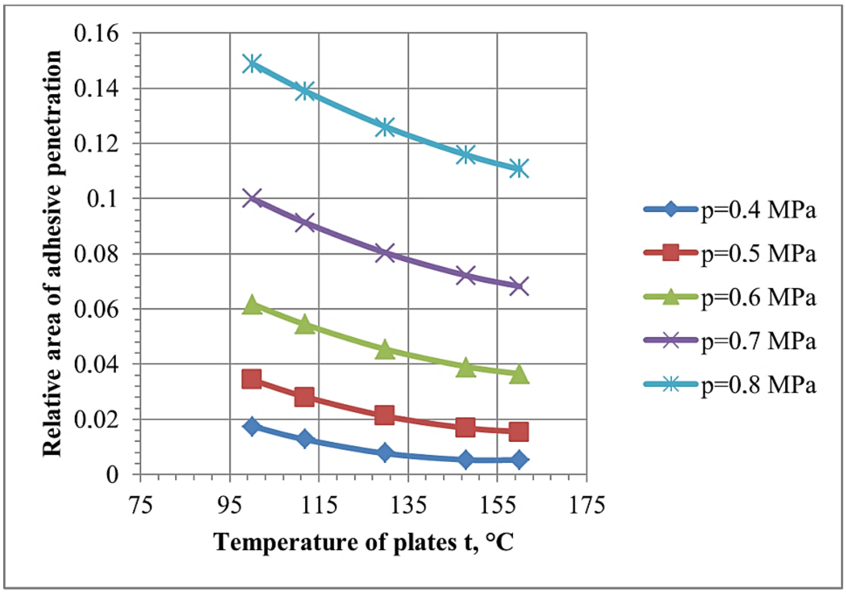

Fig. 2 Dependence of the relative area of adhesive penetration on the temperature at adhesive consumption q = 75 g·m^{-2}.

Calculation of glue consumption is not yet possible because of the lack of data on the capillary structure of substrate and facing material, therefore it is necessary to be guided by the available experimental data reflected in the current standard methods. In all cases, an excessive amount of glue increases its penetration to the front surface, so the consumption of glue must be monitored, as it is evidenced by Figure 3.

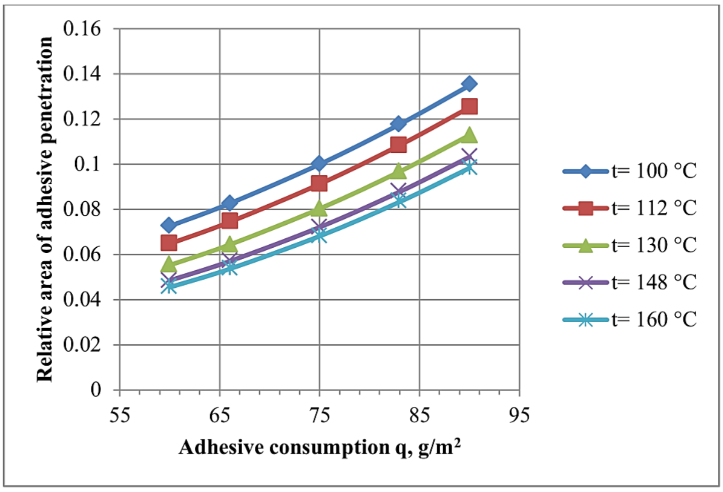

Fig. 3 Dependence of the relative area of adhesive penetration on the consumption of adhesive at pressure P = 0.7 MPa.

Dependencies of strength of adhesive joint for uneven separation of facing material from the values of variable factors are shown in Figures 4–6. Figure 4 shows the dependence of bonding strength on the pressing pressure at the values of press plates temperature at five levels of variation, and in Figure 5 on the temperature of press plates at different pressures. The increase in pressure and temperature contribute to an increase in the strength of adhesive bond, due to improved contact and interaction conditions between adhesive and wood.

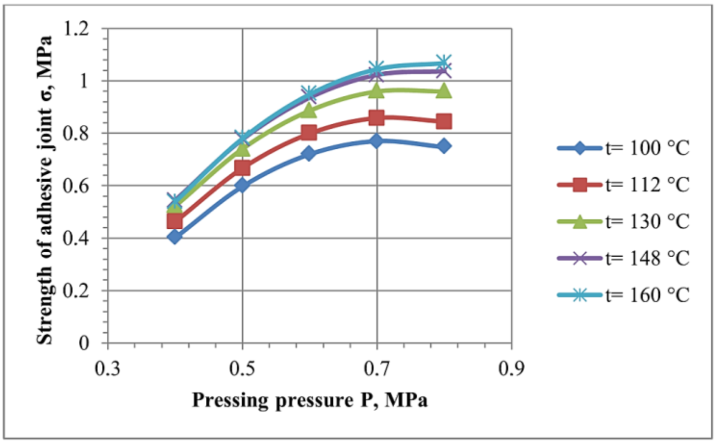

Fig. 4 Dependence of strength of adhesive joint on the pressing pressure at adhesive consumption $q = 75\ g{\cdot}m^{-2}$.

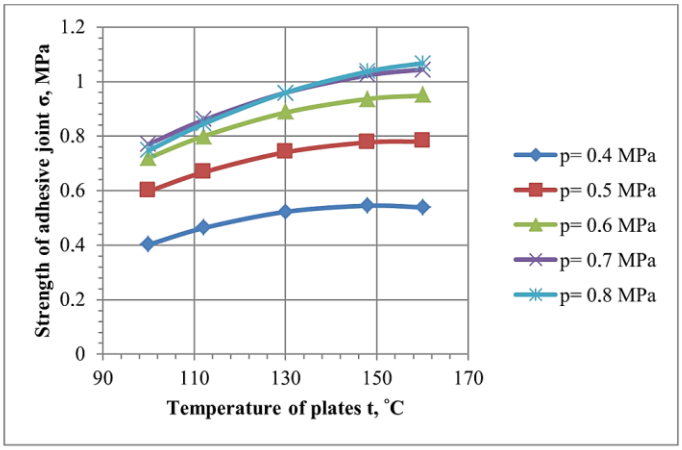

Fig. 5 Dependence of strength of adhesive joint on the temperature of press plates at adhesive consumption $q = 75\ g{\cdot}m^{-2}$.

Figure 6 shows the dependence of adhesion strength on the glue consumption for different values of pressing temperature. It is obvious that an increase in the consumption of adhesive leads to a decrease in the strength of adhesive bond.

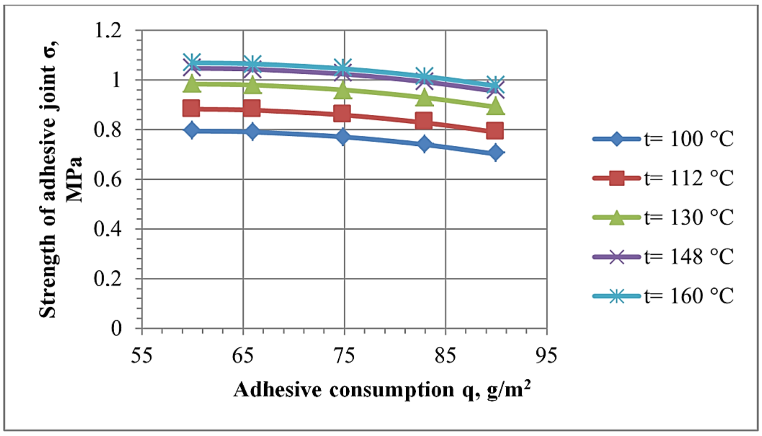

Fig. 6 Dependence of strength of adhesive joint on the consumption of adhesive at pressure P = 0.7 MPa.

CONCLUSIONS

As a result of the research, processing method for facing wood based panels (particleboard) with thin decorative veneer from valuable tree species (African mahogany) minimizing adhesive penetration of the surface and providing the required strength of adhesive joint: pressing pressure P = 0.7 MPa; temperature of plates t = 145–160 °C; adhesive consumption q = 60–85 g·m^{-2} were obtained,. The recommended method of facing provide the strength of the adhesive joint σ = 0.9–1.1 MPa meeting the requirements of the standard EN 311; the relative area of adhesive penetration of the surface is S_{penetr} = 5–9%.

REFERENCES

ARRUDA, L.M., DELMENEZZI, C.H.S. 2016. Properties of a laminated wood composite produced with thermomechanical treated veneers. Advances in Materials Science and Engineering [online]. Vol. 2016, Article ID 8458065, 9 p.

BEKHTA, P., HIZIROGLU, S., SHEPELYUK, O. 2009. Properties of plywood manufactured from compressed veneer as building material. In Materials and Design, 2009, 30(4): 947–953.

BEKHTA, P., PROSZYK, S., KRYSTOFIAK, T., SEDLIAČIK, J., NOVÁK, I., MAMOŇOVÁ, M. 2017. Effects of short-term thermomechanical densification on the structure and properties of wood veneers. In Wood Material Science & Engineering. 12(1): 40–54.

CANDAN, Z., HIZIROGLU, S., MCDONALD, A.G. 2010. Surface quality of thermally compressed Douglas fir veneer. In Materials and Design, 2010, 31: 3574–3577.

DIETZEL, A., RAßBACH, H., KRICHENBAUER, R.2016. Material Testing of Decorative Veneers and Different Approaches for Structural-Mechanical Modelling: Walnut Burl Wood and Multilaminar Wood Veneer. «Veneer tests & models», In BioResources. 2016, 11(3): 7431–7450.

DUNKY, M. 1998. Urea–formaldehyde (UF) adhesive resins for wood. In International Journal of Adhesion and Adhesives, 1998, 18(2): 269–272.

EFIMOVA, T.V., ISHCHENKO, T.L., CHEBOTAREVA, I.M. 2016.Theoretical bases to development of the regimes of the veneering of based materials with valuable wood veneer. In Polythematic online scientific journal of Kuban State Agrarian University (Scientific Journal of KubSAU) [online]. IDA [article ID]: 1191605074. 119: 1053–1063.

EN 311: 2003 Wood-based panels. Peel strength of surface layers. Test method.

GALTSEVA, I.M. 2005. Development of regimes for veneering chipboard with a thin veneer: the thesis for the degree of Cand. In Tech. Sci.: 05.21.05. Voronezh, 2005.136 p.

KANTIYEVA, E.V. RAZINKOV, E.M. 2012. Methods and means of scientific research. Voronezh: VSUFT, 2012. 107 p. ISBN 978-5-7994-0497-0.

KANTIYEVA, E.V., PONOMARENKO, L.V. 2015. Features of veneering of panel board details fain-lain interline interval. In Forestry Engineering Journal. 2015, 5(4): 138–144.

KHASANSHIN, R.R., SAFIN, R.R., RAZUMOV, E.Y. 2016. High Temperature Treatment of Birch Plywood in the Sparse Environment for the Creation of a Waterproof Construction Veneer. In Procedia Engineering, 2016, 150: 1541–1546.

KOSYAKOVA, I.V. KAPMAR, V.V. 2017. Environmental innovations in industrial enterprises as a factor in achieving a balanced development of society. In Fundamental research, 2017, 9(2): 455–459.

KRÁL, P., HRÁZSKÝ, J., HRAPKOVÁ, L., HAMŠÍK, P. 2013. Shape Stability of Particleboards Covered with Decorative Veneers. In Drvna Industrija, 2013, 64(3): 211–220.

LEI, H., DU, G., WU, Z., XI, X., DONG, Z. 2014.Cross-linked soy-based wood adhesives for plywood. In International Journal of Adhesion and Adhesives. 2014, 50: 199–203.

NORSTRÖMA, E., FOGELSTRÖM, L., NORDQVIST, P., KHABBAZ, F., MALMSTRÖM E. 2014. Gum dispersions as environmentally friendly wood adhesives. In Industrial Crops and Products, 2014, 52: 736–744.

PONOMARENKO, L.V. 2013.Technology and equipment of wood products. Texts of lectures. Voronezh: VSAFT, 2013. 160 p. ISBN 978-5-7994-0584-7.
PRENDEVILLE, S., O'CONNOR, F., PALMER, L. 2014. Material selection for eco-innovation: SPICE model. In Journal of Cleaner Production, 2014, 85: 31–40.
TOUT, R. 2000. A review of adhesives for furniture. In International Journal of Adhesion and Adhesives, 2000, 20(4): 95–107.
ZHURAVLYOVA, Yu.S. 2010. Development of a method for lining surfaces of wood materials with a thin veneer with simultaneous priming: the thesis for the degree of Cand. In Tech. Sci.: 05.21.05. Voronezh, 2010.140 p.

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