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INVESTIGATION OF SHAPE STABILITY OF VARIOUSLY DESIGNED BLOCKBOARDS MADE OF POST-CONSUMER WOOD

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Abstract:
It has been shown that post-consumer wood (PCW) is a suitable secondary raw material resource for manufacturing blockboards. Various designs and production technology have been developed for fabricating blockboards from PCW by placing edge to edge strips from solid wood or/and from wood particle board (WPB). The relationship has been established between strip width and shape stability of blockboards from PCW (PCW-made blockboards). Practical recommendations have been provided for the technology of manufacture and application of PCW-made blockboards. A scientific and technological basis has been provided for application of PCW in blockboards production.

Key words: *wood; post-consumer wood (PCW); blockboard (BB); wood fiberboard (WFB); wood particle board (WPB); plywood; shape stability; recycling; waste management.*

INTRODUCTION

The research conducted by Ukrainian and foreign scientists on this issue is primarily concerned with the use of industrial wood waste without involving PCW into the recycling processes, that is manufacturing products. Research scientists from Slovenia (Thaler and Humar 2013) confirmed that the physical and mechanical properties of PCW enable it to be recycled into new wood-based materials.

The results of their studies show that this problem has not been completely solved since neither scientific basis, nor practical recommendations have been provided for efficient production process with prediction of properties of products made from PCW, in particular PCW-made blockboards. Studies (Laufenberg, Ayrilmis, White 2006) evaluated fire and bending properties of blockboards with various fire retardant treated veneers. Blockboards made by Laufenberg, Ayrilmis and White were manufactured using untreated fir strips and sandwiched between veneers.

In papers related to the subject of studies, great attention is paid by the scientists to physical and mechanical properties and shape stability of glued cores instead of considering the blockboard as a unitized construction (Kryvyk and Mayevskyy 2011, Kiyko 2014, Pardaev 2008, Sokolovskyy and Pobereyko 2000). In his previous works (Gayda 2010a, 2010b, 2013a) S. Gayda researched in detail and described physical and mechanical properties of PCW-made blockboards. In order to produce quality products made from recovered wood-based materials, the mechanical and technological properties of new materials have to be appropriate for meeting present quality requirements (Deák, Cionca, Porojan, Olărescu 2015).

The question of strips to be used to glue the core for a blockboard is discussion in the specialized literature. According to the Ukrainian standards (GOST 13715: 1978) for blockboard GS (glued strips) type, the width of the primary wood bars shall be no more than 40 mm. According to the European standards (E DIN 68705-2: 2014-10), the width of the strips shall be less than 30mm.

Some scientists believe that the ratio of the strip width to its thickness should not exceed 1.5 (Bobykov 1980), the others (Mayevskyy and Benyah 2005) believe it should be 2.2-3.0, the others (Kontek, Bauza and Nowak 1960) – 1:1. Some scientists are of the opinion that the maximum allowable width of the solid wood bars for blockboards must not exceed the triple thickness (Pardaev 2009).

Based on the literature analysis, it is concluded that the issue of shape stability of PCW-made blockboards has not been addressed at length and the process of manufacturing blockboards from strips of various width of different origin and material remains to be studied in detail since the researchers did not propose an idea of manufacturing blockboards from PCW.

From the above, it follows that research directed to improving shape stability of blockboards manufactured by combined laying of PCW-made strips and which, due to many years of use in dry areas regardless of anisotropic nature of wood, have steady stress-strain state, is of great practical interest and is the priority area of scientific and technological activity in Ukraine.

PROBLEM FORMULATION

At present, woodworking industry is facing two major problems: the problem of raw materials and the problem of wood waste management, in particular PCW. Only a comprehensive and rational approach to the use of wood-based material based on the environmental and economic considerations will become an effective way for fulfilling the main tasks of society in the field of woodworking. A potential and yet unused raw material base, the reserves of which are increasing with the development of industrial production on the whole, are the stockpiles of PCW. Estimated potential amounts of PCW in Ukraine, according to Ukrainian experts (Gayda 2009, 2010a, 2013a, 2013b), make up 2-2.8 million tones.

The problem of research is the absence of resource-saving and environment – friendly techniques with practical recommendations for the use of PCW in woodworking industry.

As world practice shows, PCW is partially used in reduced form in the manufacture of wood particle boards in mixture with primary wood. A blockboard is an example of using cleaned solid PCW which is regarded as environmentally friendly, durable and lightweight constructional material. PCW as a construction material also has disadvantages due to its capillary-porous structure and anisotropic nature of its properties. The main ones are changes in linear dimensions, warping and cracking of individual parts or even destruction of the whole product because of varying moisture content in wood. Therefore, investigation of physical and mechanical properties, including shape stability of PCW-made blockboards is an important issue, especially in relation to the impact of the type and width of the strips on the quality of the products under operation conditions.

Hypothesis of study is providing woodworking industry with alternative additional resource by way of recycling and processing PCW into blockboards with desired properties.

The objective of study is improvement of shape stability of PCW-made blockboards through optimal strip width and combined core with the use of solid wood strips and strips from woodparticleboard.

The object of study – PCW-made blockboards.

The subject of study – shape stability of PCW-made blockboards.

MATERIAL AND METHODS

The main materials to obtain blockboards were Post-consumer wood and the Jowacol 102.20 polyvinyl acetate adhesive (PVA), Jowat company.

PCW includes all kinds of wooden material at the end of its use as a wooden product. Post-consumer wood mainly comprises demolition wood, timber from building sites, and fractions of used wood from residential and industrial activities. Besides, PCW can be generated as a result of man-made or natural disasters (phenomena), such wood can not be further used and is subject to removal or processing to ensure protection of the environment and health of people or it can be recovered for the purpose of its involvement in economic activities as raw material and energy resources.

Based on the comparison of similar groups of waste (used wood) adopted in EU countries (Germany 2002, “Verordnung über Anforderungen an die Entsorgung von Altholz”), there is a proposal for implementation in the Ukrainian Legislation in the field of wood waste and used wood products of four categories of waste that can be used for material use and for energy purposes.

- category I – PCW-I – natural and only mechanically treated wood slightly contaminated with natural pollutants, as well as wood from natural disasters.
- category II – PCW-II – treated wood and wood-based materials without wood-protection substances and without organic halogen compounds in the coatings.
- category III – PCW-III – treated wood and wood-based materials without wood-protection substances and with organic halogen compounds in the coatings.
- category IV – PCW-IV – wood and wood-based materials treated with wood-protection substances.

The studies involved the use of PCW of categories I and II, in particular:

- wooden bars from used furniture and joinery;
- wood particle board (WPB, 16mm) from used furniture products;
- wood fiberboard (WFB, 4mm) from used furniture products;
- three-layer plywood (4mm) from used furniture products.

Solid PCW characteristics (Gayda 2010a, 2013b):

- residual moisture content – 6.0±2%;
- Brinell hardness for: softwoods –2.0±0.5N/mm^2; for hardwoods – 3.5±0.5N/mm^2;
- cross-breaking strength – 100.0±20MPa;
- cleavage strength – 1.3±0.2MPa;

– stable (well-established with years of operation) stress-strain state;
– minimal effect of anisotropy on the shape changes of the cross-section of cleaned sawn blanks.

Methods of study: sorting – to sort according to certain quality criteria, selection of the material for use; cleaning – to remove foreign surface pollutants; processing – to convert the cleaned PCW into technological dimension blanks for manufacturing blockboards; experimental specimens testing – for determining shape stability of PCW-made blockboards; mathematical theory of planning experiments – to determine regression models and their analysis; mathematical programming – to solve optimization problems of mathematical and regression models; mathematical statistics – for processing data of experimental results.

PCW-MADE BLOCKBOARD DESIGN

Variously designed blockboards were used to conduct a detailed study of the effects of PCW physical and mechanical properties on BB shape stability. The PCW-made BB constructions involved the use of softwood strips or strips cut out from wood particle board sandwiched between plywood or wood fiberboard. Blockboards were also made of primary wood to compare the results obtained.

All the blockboards were fabricated 22mm in thickness in accordance with the GOST 13715:1978. The width of the strips amounted to 20, 40, 60mm, while their thickness after double-surface planing was 14mm. Accordingly, the thickness of face decks that are glued on either side of the blockboard was 44mm each. The sizes in the blockboards used for shape stability studies made up 450×450×22mm.

PCW-made blockboards of various constructions are presented in Fig. 1 and Fig 2.

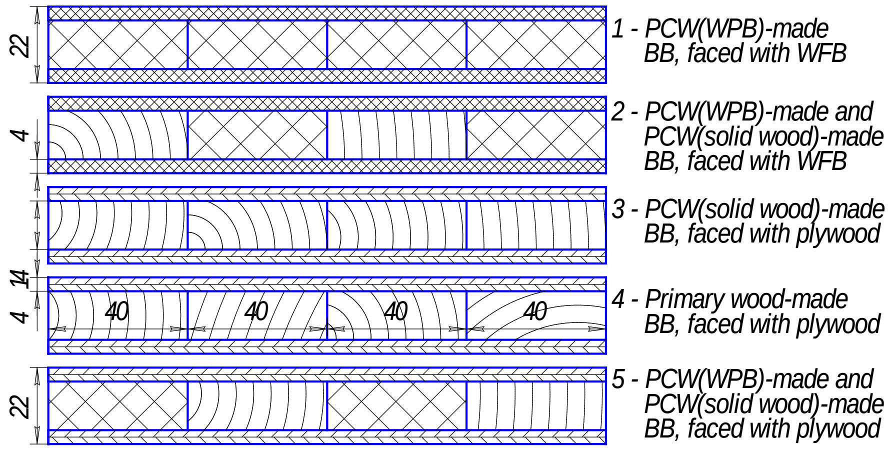

Fig. 1.
PCW-made blockboards with strips 40mm wide.

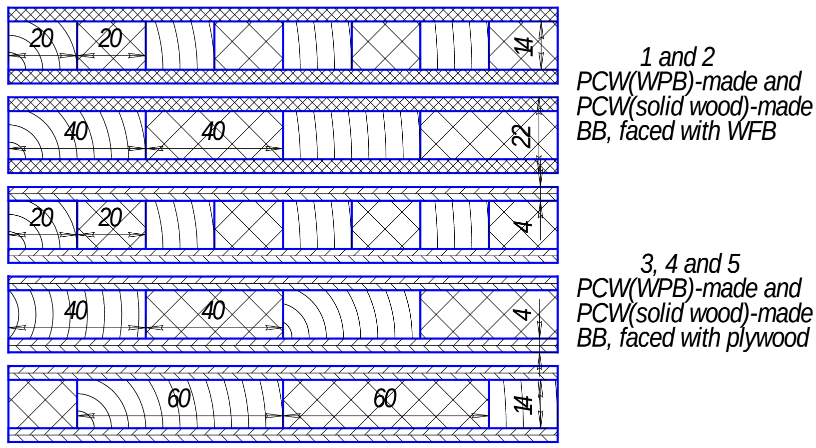

Fig. 2.
PCW-made blockboards with strips 20, 40, 60mm wide.

PCW-MADE BLOCKBOARDS TECHNOLOGY

The general production process for obtaining PCW-made blockboards covers four main stages:

- preparation of wooden bar components of blockboards;
- preparation of panel and sheet components of blockboards;
- manufacturing the core;
- manufacturing the blockboard.

The preparation of wooden bar components of blockboards involves sorting to determine material and dimensional suitability for the use in accordance with the requirements of the experiment, PCW cleaning from hardware and other foreign matter, destruction of finger joints and cutting out defective spots, cleaning wood surfaces from paint and varnish materials, face planing, wood ripping, double-surface milling of edges, trimming to size.

Preparation of strips from wood particle boards (WPB) for blockboards involves cleaning from accessories and other foreign inclusions, cutting into specified width, cleaning from natural and synthetic facing, trimming into the size of 480mm.

Preparation of face decks from plywood or WFB involves cleaning off various impurities, dimension cutting into specified width, removal of natural and synthetic facing material, trimming into a size of 520×520mm.

Obtaining of blockboard core involves selection of strips for the given design of blockboard (according to the strip width, annual rings angle, the order of assembling), applying glue to the strips edges with the glue spread of 200-250g/m^2, clamp bonding (operation parameters: temperature – 85-90^{o}C; soaking time – 30-40min; pressure – 0.5-1.0MPa), technological conditioning (humidity – 60±5%; temperature – 20±2^{o}C) for 8-12 hours; double-side milling (calibration) up to 14mm; dimension cutting into a size of 480×480mm.

The final stage of blockboard manufacturing comprises the following steps: application of glue to the blockboard core with glue spread of 150-200g/m^2, the formation of package, facing in a flat press (operation parameters: temperature – 115-120^{o}C; press time – 4-6min; pressure – 1.2-1.3MPa) technological conditioning (humidity – 60±5%; temperature – 20±2^{o}C) for 4-8 hours; cutting on the perimeter into dimension of 450×450mm.

METHODOLOGY

The strategy of manufacturing PCW-made blockboards. In the process of studies on the effect of dimensional characteristics of blockboard structural elements, in particular the strip width, on its shape stability, the B-plan was realized (Table 1). Also an additional experiment was conducted in the center of the plan. The number of duplicated experiments is 3 for each type of facing: plywood and WFB. A total of 18 types of PCW-made blockboards were fabricated in order to implement the experimental investigations based on the type of facing material (Fig. 3).

The strips from solid PCW and strips from WPB were made 20, 40 and 60mm wide. They were placed edge to edge to construct a blockboard.

Table 1

Planning matrix for B-plan with two variables

Experiment No.	Input factors values in the experiment			
	in natural value		in coded value	
	B_{PCW}	B_{WPB}	x_1	x_2
1	20	20	-1	-1
2	60	20	1	-1
3	20	60	-1	1
4	60	60	1	1
5	20	40	-1	0
6	60	40	1	0
7	40	20	0	-1
8	40	60	0	1
9	40	40	0	0

Constant factors in this study were as follows: relative humidity – 60-65%; air temperature – 18-20^{o}C; atmospheric pressure – 736mmHg; the air circulation velocity – v ≈ 0m/s; the level of airborne dust; Jowacol 102.20PVA adhesive; method of application (roll); press temperature; press time; pressure; equipment; volume of the room.

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Fig. 3.
General view of experimental specimens
of PCW-made variously-designed blockboards faced with plywood.

Methods for determining shape stability of PCW-made blockboards. Measurement of sag (deviation S from flatness) as one of the main characteristics of shape stability was carried out after one-week conditioning of the experimental specimens at room temperature. The measurements were performed using an experimental set-up with computer numerical control (CNC) (Fig. 4).

The numeric value of the IGC-(3)-25-0.01 indicator (readings are obtained to an accuracy of 0.001 mm) was read with the help of the Microtech Excel company software, type UIC-P1-SOM which was transferred to the Microsoft Excel environment for recording. The reading from BB experimental specimens were taken in two directions: the direction along the grain-direction A, (along the length of BB strips), the direction across the grain-direction B (across the width of the blockboards). The measurements in each direction on the PCW-made blockboards were performed along 11 conventional lines, that is for a total of 22 imaginary lines with a pitch between them being 40mm (Fig. 5). As a result of measurements, 400 to 480 points were recorded for each line.

Fig. 4.
CNC experimental set-up for determining shape stability
of PCW-made blockboards.

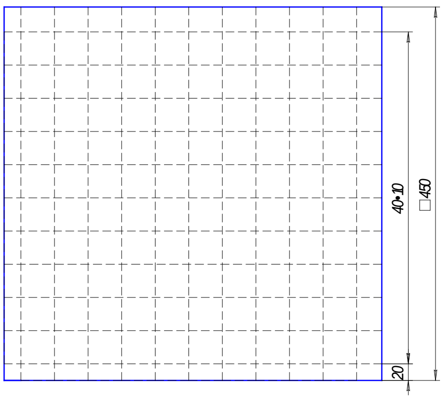

Fig. 5.
Schematic path of the numerical indicator movement across the blackboard plane.

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Thus, one set of measurements resulted in sampling population of 8.800 to 10.560 (22×(400…480)). The sag value took the average value of this sampling population.

The experimental value of response function was obtained as a difference of the average values of samples obtained in the first and the last measurement (in absolute value). The results are presented in Table 2.

The first set of measurements was performed 7 days after the date of the manufacture of experimental specimens of PCW-made blockboards. Measurements were performed once a week. The last set of measurements was taken on the sixth week, the amount of sag for this measurement did not differ from the previous one by more than 5%. Thus, six sets of measurements were performed during the study on shape stability of PCW-made blockboards. The value of the sag was determined as the difference between the first and the sixth experiment.

RESULTS AND DISCUSSION

As a result of the experimental data processing, a second-order regression equation was obtained which describes the dependence of the sag on the width of the structural elements, i.e. the width of PCW-made strips (solid wood) – B_{PCW} (x_1) and the width of PCW-made strips (WPB) – B_{WPB}(x_2).

The resulting regression equation in normalized values of variables takes the form:

$$y=0.161+0.99x_1-0.100x_2+0.095x_1^2+0.015x_2^2+0.056x_1x_2.$$

While in natural values of variables it can be written as:

$$S = -0.96 + 0.063B_{PCW} - 0.0076B_{WPB} + 0.00024B_{PCW}^2 + 0.00004B_{WPB}^2 + 0.00014B_{PCW}B_{WPB},$$

where: B_{PCW} is the width of PCW-made (solid wood) strip of blockboard, in mm;

B_{WPB} is the width of PCW-made (WPB) strip of blockboard, in mm;

S is the averaged deviation from flatness, that is the sag of blockboard, in mm.

Graphical representation of the obtained regression curves is shown in Fig. 6 and Fig. 7.

As can be seen from Fig. 6, increasing the width of PCW-made strip (solid wood) leads to increased deviation S (sag). However, the dependence of the blockboard's sag on the width of PCW(WPB)-made strips is a reverse one (Fig. 7). It should be noted that the nature of the strip width effect on the average deviation S is nonlinear, although it is possible with a certain probability to suggest the presence of tendency for reverse (Fig. 6) and direct proportionality (Fig. 7).

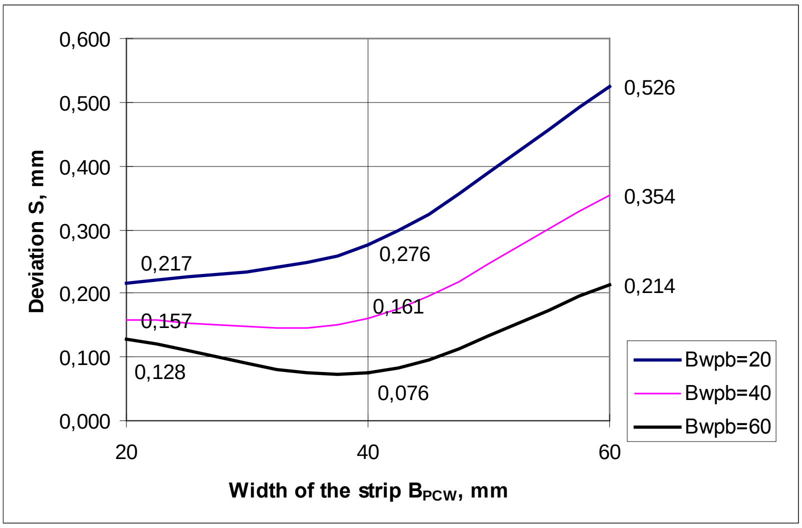

Fig. 6.
Dependence of the averaged deviation S from flatness of the blockboards on the width of PCW-made strip (solid wood) – B_{PCW} (x_1).

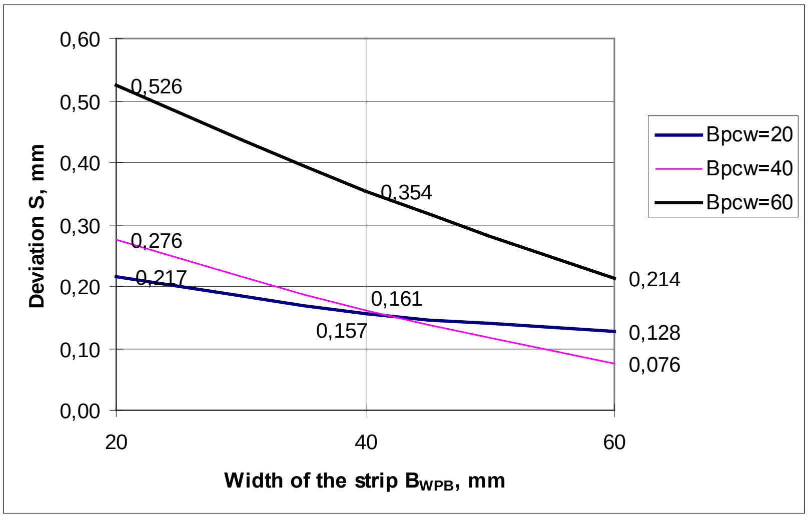

Fig. 7.
Dependence of the averaged deviation S from flatness of the blockboards on the width of PCW (WPB)-made strip – B_{WPB} (x_2).

Table 2

Comparison of experimental and calculated values with the standardized values

No.	Input variables, mm					Objective (response) function, mm	
	natural values		flatness tolerance for blockboards size 450×450			experimental value Y_{exp}	calculated value Y_{calc}
			degree of accuracy				
	B_{PCW}	B_{WPB}	12	13	14		
1	20	20	0.3	0.5	0.8	0.222	0.217
2	60	20	0.3	0.5	0.8	0.532	0.526
3	20	60	0.3	0.5	0.8	0.122	0.128
4	60	60	0.3	0.5	0.8	0.208	0.214
5	20	40	0.3	0.5	0.8	0.158	0.157
6	60	40	0.3	0.5	0.8	0.354	0.354
7	40	20	0.3	0.5	0.8	0.264	0.276
8	40	60	0.3	0.5	0.8	0.088	0.076
9	40	40	0.3	0.5	0.8	0.157	0.161

The comparison of the experimental results and standardized values with the requirements of the GOST 6449.3:1982 showed that only real deviation from flatness of the experimental specimen No.2 (B_{PCW} = 60mm; B_{WPB} = 20mm) and the experimental specimen No.6 (B_{PCW} = 60mm; B_{WPB} = 40mm) exceeds the permissible degree of accuracy for 12 (Table. 2). The deviation from flatness (sag) for accuracy degree 13 for all the experimental specimens, except for No. 2, meets the requirements of the GOST 6449.3:1982 (Table 2).

The results of the experiments made it possible to optimize the width of strips using the gradient method, which revealed that the minimum deviation value S_{min} = 0.076mm, taken in absolute value, can be obtained establishing dimensional parameters for the width of the PCW-made strips of the blockboards as follows: B_{PCW} = 40mm; B_{WPB} = 60mm (Fig. 8).

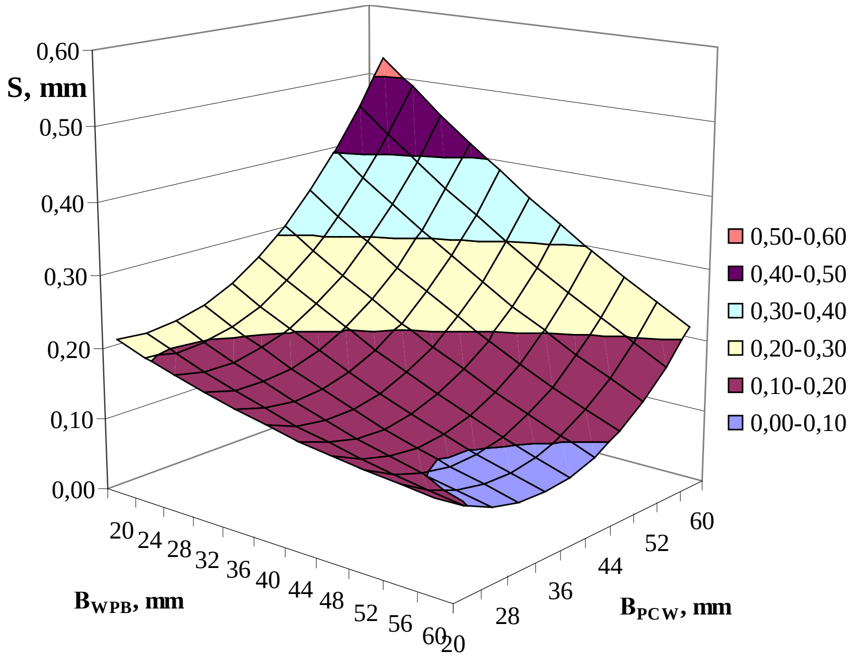

Fig. 8.
Dependence of the averaged deviation S from flatness of the blockboards on the width of PCW (WPB)-made and PCW (solid wood)-made strips.

Comparative analysis of shape stability of combined PCW-made blockboards that are manufactured respectively from strips 20, 40 and 60mm wide with various facing (plywood or WFB) is represented in Fig. 9. Blockboards faced with WFB has deviation from flatness S (sag) which is 20-30% greater than that of plywood-faced blockboards. This is attributed to physical and mechanical properties of these materials.

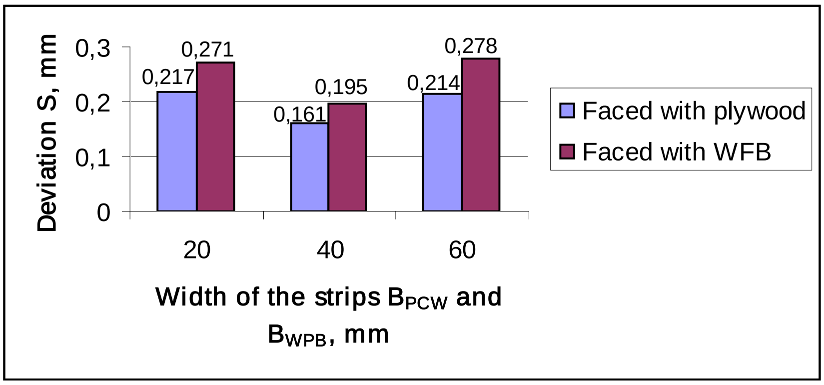

Fig. 9.
Nomograms of shape stability of blockboards
with similar cores but with different face decks – plywood and WFB.

CONCLUSIONS

1. It has been proved that PCW is a suitable secondary raw material resource for manufacturing blockboards because this wood has a low moisture content (W = 8 ± 3%) and stable internal stresses, which has a positive effect on shape stability – the stress-strain state of the blockboards' construction.
2. PCW-made blockboards' constructions have been designed with edge-to-edge placing of strips made from solid wood and strips made from woodparticleboard.
3. Proposed were technologies for manufacturing blockboards from PCW.
4. It is established that the parameters of PCW-made blockboards meet the requirements of the GOST 13715:1978 and DIN 68705-2:2014-10.

5. The patterns of the strip width influence upon shape stability of PCW-made blockboards have been established. The obtained regression model is adequate and, therefore, can be used to describe the object of study.

6. It is found that combined PCW-made blockboards have shape stability that does not exceed 0.5mm (13 degree of accuracy) for blockboards measuring 450×450mm, which meets requirements of the GOST 6449.3-82 and DIN 68100:2010-07 (HT25 degree of accuracy). The exception is the blockboards in which the width of the strips B_{PCW} = 60mm; B_{WPB} = 20mm; deflection S_{max} = 0.526mm.

7. It is found that the minimum deviation S_{min} value = 0,076mm can be obtained by establishing dimensional parameters of the strip width of PCW-made blockboards as follows: B_{PCW} = 40mm; B_{WPB} = 60mm.

8. It is revealed that PCW-made blockboards faced with plywood have the averaged deviation S from flatness which is 20-22% less than that for similar blockboards faced with wood fiberboard.

9. It is shown that in order to ensure high shape stability of PCW-made blockboards, we must use wooden strips of predominantly radial cut with further facing with plywood.

Scientific Novelty:

1. The patterns of PCW characteristics influence on the parameters of blockboards have been determined.
2. A mathematical dependence has been first proposed which adequately describes the relationship between shape stability of combined blockboards and the width of various PCW-made strips.
3. New construction design of PCW-made blockboards have been proposed.
4. PCW-made blockboards technology has been developed.
5. Practical recommendations for PCW usage in the manufacture of blockboards have been worked out.

PRACTICAL ADVICE AND GUIDELINES

Recommendations for design and technologies of PCW-made blockboards:

– strips moisture content – 8 ± 2%;
– for strips made from solid wood: width = 2.5 thickness,
(thickness 14 (16, 20), width – 35 (40, 50) mm);
– for strips made from panels: width = 3 thickness,
(thickness 16 (18, 22), width – 48 (54, 66) mm);
– for strips made from solid wood and panels: width = 4 thickness,
(thickness 14 (17, 20), width – 56 (68, 80) mm);
– strips arrangement – radial or at an angle of 45^o;
– facing – plywood (possibly WFB);
– glue spread for the core – 200-250g/m^2; glue spread for a blockboard – 150-200g/m^2;
– clamp temperature for the core –85-90°C; press temperature for the BB – 115-125°C;
– press time for the core – 30-40min; press time for the blockboards – 4-6min;
– pressure for the core – 0.5-1.0MPa; pressure for the blockboards – 1.2-1.3MPa.

Recommendations for use of PCW-made blockboards:

1. To ensure shape stability of PCW-made blockboards which operate under conditions of varying humidity, it is desirable to apply the 1:3 aspect ratio in the cross-section of strips, while annual rings angle in the ends of the strips shall not be less than 45^o.
2. In case a high shape stability of blockboards is not required, in order to increase volume output of PCW, the aspect ratio in the cross-section of the strips may be 1:4 or 1:5, that is the strip width can be 60-80mm.
3. Blockboards with the core made from WPB as well as with combined core made from PCW and WPB are recommended to use in the manufacture of furniture products.
4. Blockboards faced with plywood and with a glued core made from PCW are recommended to use for manufacturing cabinet-type furniture (casegoods).
5. Blockboards faced with plywood and with a glued core made from PCW and WPB are recommended, taking into account their strength and deformability, to use for manufacturing joinery (built-in furniture, doors, floors and other load-bearing elements of structures).
6. PCW-made blockboards can also be used in wooden house building, ship- and car-building (walls, paneling, shelves, floors and other structural elements).

REFERENCES

Bobykov PD (1980) Construction joinery and furniture products. Forestry, Moscow, (in Russian).

Deák A, Cionca M, Porojan M, Olărescu A. M (2015) Recycling recovered wood-based materials. Flatness, MOR and MOE of panels made from recovered wooden based materials // PRO LIGNO: Scientific Journal. – Editura Universitatii «TRANSILVANIA» din Brasov. Vol. 11(4):173-180.

DIN 68705-2:2014-10 Plywood – Part 2: Blockboard and laminboard for general use. Germany, (in Deutsch).

DIN 68100:2010-07 Tolerance system for wood working and wood processing – Concepts, series of tolerances, shrinkage and swelling. Germany, (in Deutsch).

Gayda SV (2009) Potential of post-consumer recovered wood and possible ways of it using in Ukraine. Forestry, Forest, Paper and Woodworking Industry, Lviv. Vol. 35:63-84 (in Ukrainian).

Gayda SV (2010a) Research of used recovered wood in wood treatment of Ukraine. Collection Bulletin BSETA, Bryansk. Vol. 27:38-42 (in Russian).

Gayda SV (2010b) A comparative analysis of physical and mechanical parameters of variously designed glued boards made of post-consumer recovered wood. Forestry, Forest, Paper and Woodworking Industry, Lviv. Vol. 36:81-91.

Gayda SV (2013a) Technologies and recommendations on the utilization of post-consumer wood in woodworking industry. Forestry, Forest, Paper and Woodworking Industry, Lviv. Vol. 39(1):48-67.

Gayda SV (2013b) Resource-saving technologies of recycling of post-consumer wood. Collection Bulletin NULEU, Kyiv. Vol. 185(2):271-280 (in Ukrainian).

GOST 13715:1978 Glued boards. Specifications. Moskow: Gosstandart, (in Russian).

GOST 6449.3:1982 Products of wood and wooden materials. Tolerances of form and arrangement of surfaces. Moskow: Gosstandart, (in Russian).

Kiyko IO (2014) The impact of the structural element sizes on the furniture board form stability. Collection Bulletin UNFU, Lviv. Vol. 24(5):169-175 (in Ukrainian).

Kontek W, Bauza J, Nowak K (1960) Tests on the physical and mechanical properties of block-boards // Drewno: Scientific Journal. – Prace Instytutu Technologii Drewna, Poznan. Vol. 7(2):27-44.

Kryvyk OO, Mayevskyy VO (2011) Dynamics of shape stability change for glued panels with a combination of different wood species. Forestry, Forest, Paper and Woodworking Industry, Lviv. Vol. 37(1):30-33 (in Ukrainian).

Laufenberg T, Ayrilmis N, White R (2006) Fire and bending properties of blockboard with fire retardant treated veneers, Holz als Roh- und Werkstoff. Vol. 64(2):137–143.

Mayevskyy VO, Benyah YuV. (2005) Investigations of stability of shape of Composite boards from solid oak. Collection Bulletin UNFU, Lviv. Vol. 15(5):199-208 (in Ukrainian).

Pardaev AS (2008) Methodical principles of modelling of physicomechanical properties of wood are stated at the analysis of the intense-deformed condition of joiner's designs on the basis of Finite Element Method. Collection Bulletin USTU, Ekaterinburg. Vol. 3:77-83 (in Russian).

Pardaev AS (2009) Increased form stability glued board of wood based on process modeling shrinkage and swelling. Architecture and Construction, Minsk. Vol. 3(202):41-44 (in Russian).

Sokolovskyy YaI, Pobereyko BP (2000) Calculation of transient voltages in the wood when exposed to moisture // News of higher educational institutions. Forest Journal, Arkhangelsk. Vol. 2000(1):7-9 (in Russian).

Thaler N, Humar M (2013) Performance of oak, beech and spruce beams after more than 100 years in service. International Biodeterioration & Biodegradation. Vol. 85:305-310.