Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology No 117, 2022: 55-62
(Ann. WULS - SGGW, For. and Wood Technol. 117, 2022: 55-62)

Lightweight particleboards - manufacturing modification using a blowing agent from the group of bicarbonates

DOMINIKA BEDNARCZYK[1], PIOTR BORUSZEWSKI[2]

[1] Faculty of Wood Technology, Warsaw University of Life Sciences - SGGW
[2] Department of Technology and Entrepreneurship in Wood Industry, Institute of Wood Science and Furniture, Warsaw University of Life Science - SGGW

Abstract: *Lightweight particleboards - manufacturing modification using a blowing agent from the group of bicarbonates.* Although the low-density particleboards have grown in popularity, due to their facilitated transportation and a lower mass in the assembled finished products, there is still certain constraints in their use caused by limited mechanical properties. These obstacles may be overcome by the mechanism of foaming the polymers that bind wood particles in the boards' structure. The aim of this study was to determine the possibility of using sodium bicarbonate as a blowing agent of phenolic resin used for bonding wood particles in the technology of lightweight particleboards. It was found that the addition of sodium bicarbonate in the amount of 5% in relation to the dry weight of the phenolic resin significantly increase the internal bond strength of the manufactured particleboards.

Keywords: low density, lightweight particleboard, blowing agent, sodium bicarbonate, phenolic resin

INTRODUCTION

The standard particleboards, with an average density ranging from 650 to 750 kg/m^3, are one of the most important products in the European wood-based panels industry. The increasing global wood deficit prompts the search for alternative raw materials and modified manufacturing methods of particleboards. Thus, the boards' density reduction is one of the priority issues faced by the wood industry. There are two main trends in obtaining furniture and construction boards with reduced density. The first method is reducing the share of typical wood raw material by replacing it with low-density lignocellulosic biomass, e.g.: softwood particles, fast-growing plantation wood, biomass form cotton, hemp, rape straw, corn cob, microfibrillated cellulose or other agricultural by-products. [Ramos et al. 2021; Pazio and Boruszewski 2020; Zaraziński and Boruszewski,2020; Borysiuk et al., 2019; Pawlak and Boruszewski, 2018; Pawlak et al. 2018; Battegazzore et al. 2017; Mirski et al. 2017; Boruszewski et al. 2016; Khanjanzadeh et al. 2012; Boquillon et al. 2004]. The other widely used method is creating layered boards with modified core in the form of an openwork structure, e.g. sandwich structure panels with a honeycomb or a foam-type cores [Smardzewski 2019; Pishan et al. 2014; Shalbafan et al. 2013]. The reduction of density not only saves on the resources and energy, but it also promotes the development of the lightweight particleboards technology.

The technical specification CEN/TS 16368 defines lightweight particleboards as panels with a density below 600 kg/m^3. Although the low-density particleboards have grown in popularity, due to their facilitated transportation and a lower mass in the assembled finished products, there is still certain constraints in their use caused by limited mechanical properties or screw withdrawal resistance of the internal porous, lightweight structure. These obstacles (as mentioned before) may be overcome by the mechanism of foaming the polymers that bind wood particles in the boards' structure. It was found that the pressure produced during the foaming mechanism of phenol-formaldehyde adhesive in the production of lightweight particleboards induce more contact between the wood particles and the resin, which results in obtaining greater bond strength [Zhao et al. 1995; cited in Bi and Huang 2021].

Blowing agents are substances that produce a cellular structure in polymers or plastics, resulting in a reduction in their density, while increasing relative stiffness of the modified materials [Wypych 2017]. Sodium bicarbonate ($NaHCO_3$) is a chemical blowing agent. During decomposition at a relatively broad temperature range (100°C÷180°C), it produces carbon dioxide and water [Fauzi et al. 2015]. Sodium bicarbonate is widely used in natural and synthetic rubber products, rubber foam's production or injection molding of polyolefins, due to its non-toxicity and proper temperature of the decomposition that matches the processing temperatures and results in an open-cell structure [Jin et al. 2019; Sadik et al. 2018; Najib 2009].

Phenol-formaldehyde (PF) resin is much less popular than urea-formaldehyde (UF) adhesive in the production of particleboards. However, its curing process is not disrupted by the alkaline pH of sodium bicarbonate, which might halt the hardening process of UF resin. This issue may lead to future experiments on the appropriate adhesive recipe using urea resin modified with mentioned blowing agent (research presented in this paper are preliminary studies).

The aim of this study was to determine the possibility of using sodium bicarbonate as a blowing agent of phenolic resin used for bonding wood particles in the technology of lightweight particleboards.

MATERIALS AND METHODS

For this study, single-layered particleboards with a target density of 550 kg/m^3 and dimensions of 320 x 320 x 12 mm^3 in width, length and thickness respectively were manufactured. The industrial Scots pine particles (*Pinus sylvestris* L.) with an average moisture content of 7,7% were used. The panels were produced in 4 variants with the specifications presented in Table 1. in duplicate samples. The particles were bonded with commercial phenol-formaldehyde (PF) resin with a concentration of 46,5%. In variants 5, 10 and 15 the PF resin was modified with the addition of sodium bicarbonate (SB) as a blowing agent in the amount of 5, 10 and 15% respectively in relation to the dry weight of the resin.

This study is in the form of preliminary research investigating the application potential of SB in foaming the resin that bonds particles in wood-based materials. In order to assess the possibility of using the aforementioned blowing agent, the panels were manufactured from wood particles typical for the core layer of the three-layered particleboards. It is not recommended to modify the face layers of the boards as the potential in decreasing the density of the material lies in the core of the board, which has the greatest share in the board's structure.

Mats form previously bonded particles were hand-formed and pre-pressed manually. The prepared mats were transferred to the laboratory press and hot pressed for 10 min, with the temperature of the press platens of 200°C and the maximum unit pressure of 2,5 MPa. After the scheduled pressing time, the boards were taken out and conditioned in the temperature of 20±2°C and the humidity of 65±5% until constant mass was reached.

Table. 1. Characteristics of the manufactured particleboards variants.

Variant	Glue content [%]	SB content [%]	Target density [kg/m^3]
0	10	0	550
5	10	5	550
10	10	10	550
15	10	15	550

The test samples were prepared in accordance with the relevant standards. Measurements of the boards density were calculated using the mass and the volume of the conditioned samples, based on the assumptions in the EN 323 standard. The modulus of elasticity (MOE) and the bending strength (MOR) were determined according to the EN 310 standard. The internal bond strength test (IB) was carried out using the specifications in the EN 319 standard. The determination of thickness swelling after 24 hours of soaking the samples in water was made according to the EN 317 standard. At least 10 repetition for the determination of each property were performed for every variant of the board. The mean values of determined parameters were examined in the one-way analysis of variance (ANOVA) - Tukey's post hoc test, in which homogeneous groups of mean values for each parameter were identified for p = 0,05. The experimental data was statistically analysed using STATISTICA 13.3 software.

RESULTS AND DISCUSSION

Density

The average density values of the produced particleboard variants are shown in the Figure 1. The highest density value of 574 kg/m^3 was obtained for variant 10 and the lowest density value of 563 kg/m^3 for variant 15. The variant samples tested for density were classified as one homogenous group in Tukey's test and the differences in the average density of the individual panel variants should not have a significant impact on the analyzed mechanical properties of the boards.

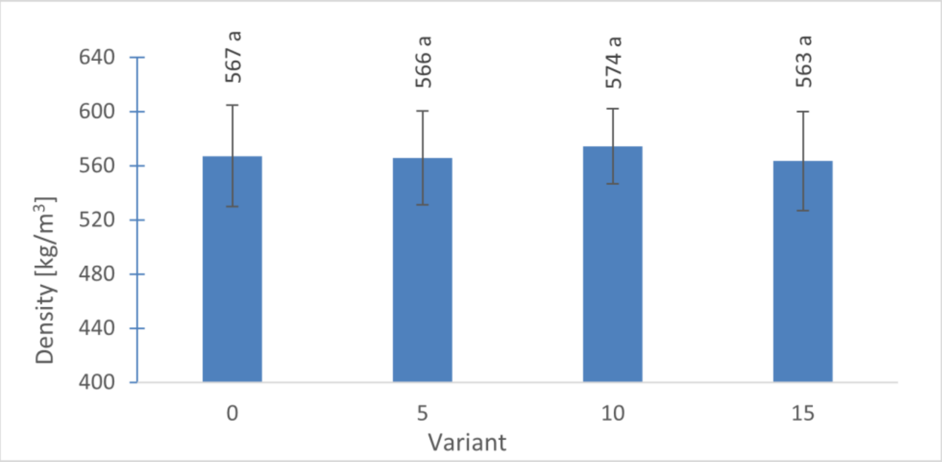

Figure 1. Density of particleboards manufactured (means and standard deviation; a - homogeneous group determined by the Tukey's test, different letters correspond with the significant difference; the means with the same letter do not demonstrate statistical difference between each other).

Mechanical properties

The average values of mechanical properties of the manufactured particleboard variants are presented together with the values of standard deviations in Figures 2-4. The highest values of static bending strength were observed for variant 10 - 10,81 N/mm^2 and variant 15 - 10,80 N/mm^2. The lowest value was observed in the case of variant 0 - 9,6 N/mm^2. Confronting the obtained values of the bending strength of the produced particleboards with the specifications of the EN 312 standard, it was stated that the variants 10 and 15 are characterized by the values that nearly meet the requirements for the general purpose boards (types P1 and P2) typically used in the furniture industry. It should also be noted that the above mentioned EN 312 standard refers to three-layers particleboards with a density specific for this sort of material (650 kg/m^3). Furthermore, comparing the obtained results for the determined property with the requirements of the CEN/TS 16368, much higher values of static bending strength of the manufactured boards were noted than those specified in the given standard (35% increase in relation to the CEN/TS 16368 requirements for the general purpose lightweight boards for use in dry conditions - type LP2). Nevertheless, the performed statistical analysis showed that the results for individual variants did not differ significantly from each other.

Comparable relations were observed for the values of modulus of elasticity where the highest values was characterized by variant 15 - 1816 N/mm^2, followed by variant 10 - 1692 N/mm^2. The lowest value was shown by variant 0 - 1542 N/mm^2. It should also be noted here that every variant demonstrated higher value of the tested mechanical property than that specified in the CEN/TS 16368 standard (54,2% increase in the case of the lowest value of variant 0 and 81,6% increase in the case of the highest value of variant 15, comparing to the requirements for the boards type LP2). Similarly to the bending strength values, results for the modulus of elasticity test belonged to the same homogenous group and no statistical difference can be stated between the examined samples.

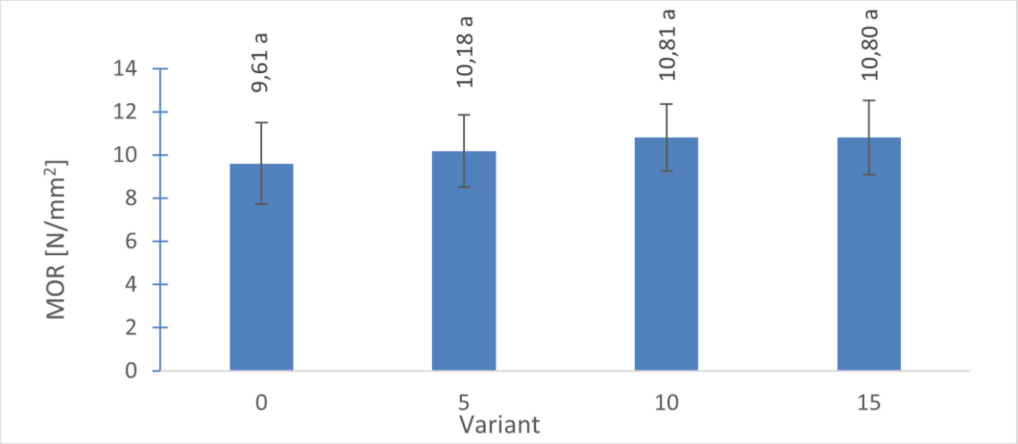

Figure 2. Static bending strength (MOR) of particleboards manufactured, (means and standard deviation; a - homogeneous group determined by the Tukey's test, different letters correspond with the significant difference; the means with the same letter do not demonstrate statistical difference between each other).

Comparing the obtained values of internal bond it was found that the highest value was achieved by variant 5 - 1,27 MPa, followed by variant 15 - 1,09 MPa and variant 10 - 1,05 MPa. The variant 0 showed again the lowest value of the analyzed mechanical property - 0,94 MPa. The observed mean values of the tested property were classified in two different homogenous group in Tukey's test. The 5% addition of the blowing agent considerably increased the internal bond strength values compared to the not-modified variant 0. It should be noted that the presented results of the internal bond strength test achieved by each variant remarkably exceeded the requirements of the CEN/TS 16368 and EN 312 standards. The increase in the value for variant 5 was 217,5% compared to both the lightweight boards type LP2 and the typical three-layered boards type P2.

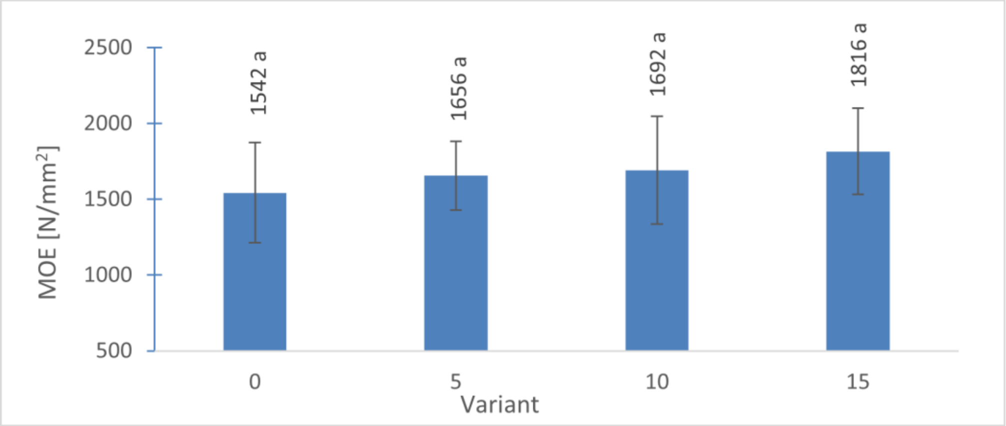

Figure 3. Modulus of elasticity (MOE) of particleboards manufactured, (means and standard deviation; a- homogeneous group determined by the Tukey's test, different letters correspond with the significant difference; the means with the same letter do not demonstrate statistical difference between each other).

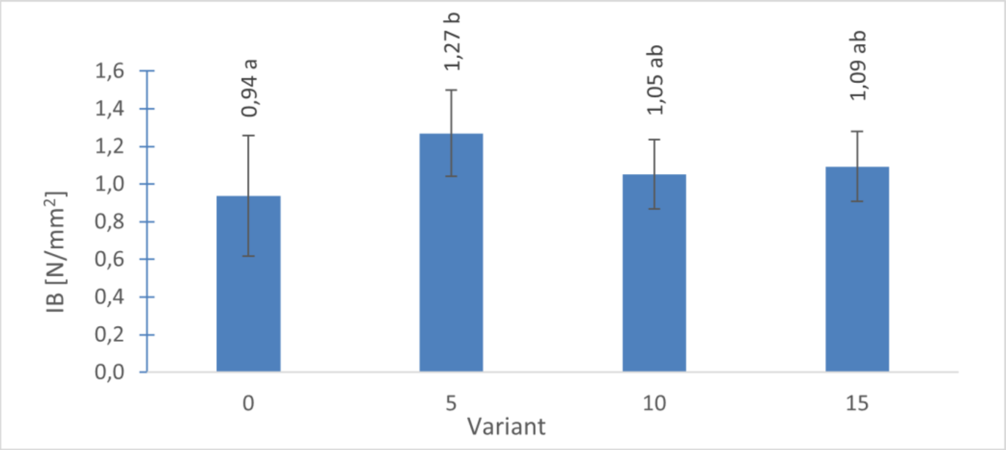

Figure 4. Internal bond strength (IB) of particleboards manufactured, (means and standard deviation; a, b - homogeneous groups determined by the Tukey's test, different letters correspond with the significant difference; the means with the same letter do not demonstrate statistical difference between each other).

The research findings obtained in this study partially overlap with the results achieved in other studies. Bi and Huang [2021] also modified phenolic resin with a blowing agent in the manufacture of lightweight particleboards, however, they used azodicarbonamide for foaming the adhesive. The produced particleboards with glue content of 12% and 1% addition of blowing agent to the PF resin, significantly increase the mechanical properties of the boards with reduced density and meet the requirements of EN 312. Hu et al. [2021] modified a urea-formaldehyde resin with the addition of thermo-expandable microspheres (TEMs) in lightweight wood-based materials. The research showed that the addition of the given physical foaming agent resulted in the decrease in the sheer strength of the resin. The authors also found that the introduction of glutaraldehyde may improve the bonding strength of the UF foaming resin by even up to 199%, but at the expense of increased density. The research conducted by Huang et al. [2021] showed that the modification of urea-formaldehyde resin with azodicarbonamide results in improving the fluidity of the adhesive without affecting the viscosity of the resin. It may noticeably influence the even dispersion of the adhesive in the wood particles increasing their bonding strength and improving mechanical properties of the board.

Thickness swelling

The results of the thickness swelling test after 24-hours soaking the boards' samples in water are presented in Figure 5. There were no significant differences between the values of thickness swelling of the individual variants of manufactured particleboards, which means that the amount of the added modifier did not considerably affect the dimensional stability of the tested particleboards. The CEN/TS 16368 standard do not specify the requirements of swelling in thickness for lightweight particleboards, nevertheless the obtained values merely slightly exceeded (by 2,2÷3,2%) the requirements for the boards type P3 specified in EN 312. Theoretically, when the density of the boards is reduced, it should cause a decrease in the thickness swelling. Bi and Huang [2021] suggested that the addition of blowing agent is able to enhance particleboards' dimensional stability and reduce thickness swelling rate. The authors speculated that lower water absorption may be caused by the surface tension of the pores shaped during the foaming of the adhesive.

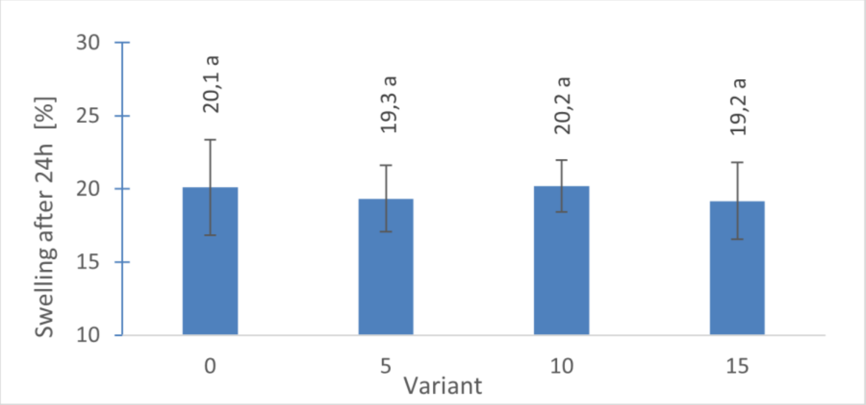

Figure 5. Swelling thickness changes of particleboards manufactured after soaking in water for 24 hours, (means and standard deviation; a - homogeneous group determined by the Tukey's test, different letters correspond with the significant difference; the means with the same letter do not demonstrate statistical difference between each other).

CONCLUSIONS

Analysis of the results of testing the particleboards properties with various blowing agent content, led to the following conclusions:

1. The 5% addition of the sodium bicarbonate as a blowing agent of phenolic resin in relation to the dry weight of the adhesive significantly increases the internal bond strength of the particleboards, which is the most important property from the point of view of the use of boards in the furniture industry.

2. There was no significant effect of the addition of the blowing agent on the bending strength, the modulus of elasticity and thickness swelling after 24-hours soaking in water of the tested boards.

REFERENCES

1. BATTEGAZZORE, D., ALONGI, J., DURACCIO, D., FRACHE, A. 2017: All Natural High-Density Fiber- and Particleboards from Hemp Fibers or Rice Husk Particles. Journal of Polymers and the Environment, 26(4), pp.1652-1660.
2. Bi, X., Huang, R. 2021: Preparation, morphology, FTIR and performance properties of foaming particleboard. Journal of Wood Science, 67(1).

3. BOQUILLON, N., ELBEZ, G., SCHÖNFELD, U. 2004: Properties of wheat straw particleboards bonded with different types of resin, Journal of Wood Science, Journal of Wood Science, 50(3), pp.230-235.
4. BORUSZEWSKI, P., BORYSIUK, P., MAMIŃSKI, M., CZECHOWSKA, J. 2016: Mat Compression Measurements During Low-Density Particleboard Manufacturing. BioResources, 11(3).
5. BORYSIUK, P., JENCZYK-TOLLOCZKO, I., AURIGA, R., KORDZIKOWSKI, M. 2019: Sugar beet pulp as raw material for particleboard production. Industrial Crops and Products, 141, p.111829.
6. European Committee for Standardization: 2014: CEN/TS16368 Lightweight Particleboards. Specifications.
7. European Committee for Standardization: EN 319: Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board, 1999.
8. European Committee for Standardization: EN 317: Particleboards and fibreboards. Determination of swelling in thickness after immersion in water, 1999.
9. European Committee for Standardization: EN 310: Wood-based Panels. Determination of modulus of elasticity in bending and of bending strength, 1994.
10. European Committee for Standardization: EN 323: Wood-based panels - Determination of density, 1993.
11. FAUZI, M.S., DU, N.U.L., OSMAN, H., A. GHANI, S. 2015: Effect of Sodium Bicarbonate as Blowing Agent on Production of Epoxy Shape Memory Foam using Aqueous Processing Method. *Sains Malaysiana*, 44(6), pp.869-874.
12. HU, L., WANG, J., QIN, L., XU, H.,YANG, Z. 2021: Foaming performance and bonding strength of a novel urea-formaldehyde foaming resin facilely prepared with thermo-expandable microspheres. International Journal of Adhesion and Adhesives, 105, p.102783.
13. HUANG, T.H., WANG, J.F., SONG, L.H., LEI, F.J., LUAN, J. 2021: The effect of Azodicarbonamide blowing agent on the properties of urea-formaldehyde resin. China For Prod Ind 58, pp.12-15.
14. JIN, F., ZHAO, M., PARK, M., PARK, S. 2019: Recent Trends of Foaming in Polymer Processing: A Review, Polymers, Polymers, 11(6), p. 953.
15. KHANJANZADEH, H., BAHMANI, A., RAFIGHI, A., TABARSA, T. 2012. Utilization of bio-waste cotton (Gossypium hirsutum L.) stalks and underutilized paulownia (paulownia fortunie) in wood-based composite particleboard. AFRICAN JOURNAL OF BIOTECHNOLOGY, 11, pp.8045-8050.
16. MIRSKI, R., BORUSZEWSKI, P., TROCIŃSKI, A., DZIURKA, D. 2017: The Possibility to Use Long Fibres from Fast Growing Hemp (Cannabis sativa L.) for the Production of Boards for the Building and Furniture Industry. BioResources, 12(2).
17. NAJIB, N., ARIFF, Z., MANAN, N., BAKAR, A., SIPAUT, C. 2009: Effect of Blowing Agent Concentration on Cell Morphology and Impact Properties of Natural Rubber Foam. Journal of Physical Science, 20.
18. PAWLAK D., BORUSZEWSKI P. 2018: Influence of addition of microfibrillated cellulose (MFC) on selected properties of low-density particleboard. Annals of Warsaw University of Life Sciences - SGGW, Forestry and Wood Technology, 102, pp.139-148.
19. PAWLAK D., JENCZYK-TOŁŁOCZKO I., BORUSZEWSKI P. 2018: Analysis of selected properties of particleboard modified with *Miscanthus giganetus* JM Greef & Deuter ex Hodk. & Renvoize, Annals of Warsaw University of Life Sciences - SGGW, Forestry and Wood Technology, 102, pp.149-156.
20. PAZIO B., BORUSZEWSKI P. 2020: Analysis of the influence of larch fibers and particles on selected properties of fiber- and particleboards. Annals of Warsaw University of Life Sciences - SGGW, Forestry and Wood Technology, 111, pp.43-52.

21. PISHAN, S., GHOFRANI, M., KERMANIAN, H. 2014: Study on Mechanical Properties of Lightweight Panels Made of Honeycomb and Polyurethane Cores.
22. RAMOS, A., BRIGA-SÁ, A., PEREIRA, S., CORREIA, M., PINTO, J., BENTES, I., TEIXEIRA, C.A. 2021: Thermal performance and life cycle assessment of corn cob particleboards. *Journal of Building Engineering*, 44, p.102998.
23. SADIK, T., PILLON, C., CARROT, C., REGLERO RUIZ, J. 2018: Dsc studies on the decomposition of chemical blowing agents based on citric acid and sodium bicarbonate. Thermochimica Acta, 659, pp.74-81.
24. SHALBAFAN, A., LUEDTKE, J., WELLING, J., FRUEHWALD, A. 2021: Physiomechanical properties of ultra-lightweight foam core particleboard: different core densities. Holzforschung, Vol. 67, 2, pp.169-175.
25. SMARDZEWSKI, J. 2019: Experimental and numerical analysis of wooden sandwich panels with an auxetic core and oval cells. Materials & Design, 183, p.108159.
26. ZHAO, C.H., HONG, Z.L., WANG, X.P. 1995: Preliminary study on phenolic light particleboard. China For Prod Ind, 6, pp.7-9.
27. WYPYCH, G. 2017: Handbook of foaming and blowing agents. Toronto: Chemtec Publishing.
28. ZARAZIŃSKI, K., BORUSZEWSKI, P. 2020: Analysis of the influence of particle and poplar fibres share on selected properties of particle-fibre boards. Annals of Warsaw University of Life Sciences - SGGW Forestry and Wood Technology, 112, pp.22-31.

Streszczenie: *Płyty wiórowe o obniżonej gęstości - modyfikacja wytwarzania przy użyciu poroforu z grupy wodorowęglanów.* Pomimo tego, że płyty wiórowe o obniżonej gęstości zyskują na popularności, ze względu na ułatwiony transport i niższą masę gotowych produktów, nadal istnieją pewne utrudnienia w ich zastosowaniu, spowodowane niedostatecznymi właściwościami mechanicznymi. Ograniczenia te mogą zostać zminimalizowane dzięki zastosowaniu mechanizmu spieniania żywicy wiążącej cząstki drewna w płytach wiórowych. Celem pracy było określenie możliwości zastosowania wodorowęglanu sodu jako poroforu żywicy fenolowej stosowanej do zaklejenia cząstek drewna w technologii lekkich płyt wiórowych. Stwierdzono, że dodatek wodorowęglanu sodu w ilości 5% w stosunku do suchej masy żywicy fenolowej istotnie zwiększa wytrzymałość na rozciąganie prostopadle do płaszczyzny płyty w wytworzonym materiale.

Corresponding author:

Piotr Boruszewski
Department of Technology and Entrepreneurship in Wood Industry,
Institute of Wood Sciences and Furniture,
Warsaw University of Life Sciences - SGGW, Poland
159 Nowoursynowska Street
02-787 Warszawa, Poland
piotr_boruszewski@sggw.edu.p