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Influence of apple wood waste from the annual care cut on the mechanical properties of particleboards

RADOSŁAW AURIGA, PIOTR BORYSIUK, ANETA GUMOWSKA, PIOTR SMULSKI
Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW, 159 Nowoursynowska St., 02-787 Warsaw

Abstract: *Influence of apple wood waste from the annual care cut on the mechanical properties of particleboards.* As part of the work, the influence of the share of apple wood waste from the annual care cut on the mechanical properties of 3-layer particle boards was examined. Particleboards were prepared using two variants of the specific maximum pressing pressure of 1.5 MPa and 2.5 MPa and mass share of particles from apple wood waste at the level of 0%, 25%, 50% and 75%. The results of the tests show a decrease in the value of the modulus of rapture and modulus of elasticity with the increase of the share of the additive in particleboard. In spite of the decrease of the value of the modulus of rapture and modulus of elasticity, all produced particleboards with the application of specific pressing pressure at the level of 2.5 MPa, met the requirements for P2 type particle board included in the PN 312: 2011 standard.

Keywords: particleboard, apple wood, waste wood, mechanical properties

INTRODUCTION

The main natural raw material used in the production of wood-based panels is wood. Constantly increasing demands and the requirements of the standards for lignocellulosic composites enforce the alternative raw material base search for relatively slow growing forest woods. The global market for wood-based composites is growing every year, despite the decreasing availability of basic raw material. As a result, the proposals for alternatives to wood plays a key role in ensuring a balance between demand and supply. In countries that are constantly and rapidly growing, the wood resources for particleboards production are decreasing every year (Yeniocak et al. 2014). The solution to this problem for regions with low afforestation is to utilize the alternative waste biomass. The growing diversity of lignocellulosic resources can be of strategic importance, including biomass residues obtained from growing agricultural plants. Plant seeds are used e.g. as food and feed, and parts of stems, leaves are transformed into chemicals or biogas (Mast et al. 2014), while smaller parts of plants are used in the production of wood-based composites. An example of lignocellulosic annual plants used in the production of panels are: vine (*Vitis vinifera* L.) pruning (Yeniocak et al. 2016), wheat straw (*Triticum aestivum* L.) (Hafezi and Hosseini 2014), selected bamboo species (*Dendrocalamus asper, Gigantochloa atroviolacea, Gigantochloa apus*) (Widyorini et al. 2016), sunflower stalk (Ghofrani et al. 2015), hemp (*Cannabis sativa* L.) and canola (*Brassica napus* L.) (Nikvash et al. 2010), kenaf stalks (*Hibiscus cannabinus* L.) (Kalaycıoglu and Nemli 2006), sugarcane bagasse (Hazrati-Behnagh et al. 2016) or even miscanthus stalks (*Miscanthus giganteus*) (Klímek et al. 2018) and food waste (Vakalis et al. 2018) to produce particleboards also have been investigated. Taha et al. (2016) presented the possibility of using agricultural residues for the production of single-layer particleboard. A preliminary analysis of chemical composition and physical properties was carried out to evaluate the suitability of lignocellulosic material for the production of particleboards. The results of testing the produced panels have been compared with European standards requirements, showing the potential of this material as a natural fiber source for particleboards. The use of agricultural residues also gives economic benefits, the possibility of more efficient management of the resources of the agricultural value chain. (Börjesson and Tufvesson 2011, Geldermann et al. 2016). Another source of obtaining renewable lignocellulosic raw materials are orchards and fruit tree nurseries. The total area of fruit cultivation in Poland is 3499 km^2, of which only apple trees constitutes over 71% (Łączyński et al. 2017). Based on a data from 2016, Poland delivered 3.6 million tons of apples to the fruit market. Such a high production of apples requires the effective cultivation a large area of orchards. Trees in orchards should be pruned once a year to ensure good fruit productivity (http://www.kowr.gov.pl). Cut branches are considered as a waste, therefore they are put on the ground in the form of prisms and then are subjected to burning. This stage shows the inefficient management of the orchard fields and is a low value revenue for the owners (Dyjakon et al. 2016, Cichy et al. 2017).

Due to the significance of the Polish fruit market in the country and abroad, it is very important to determine the potential of cut branches from fruit trees, especially from apple orchards, as they represent over 71% of whole crops. One of the main options can be the potential use of pruned branches for the manufacture of wood-based composites, such as particleboards (Silva et al. 2018). Current literature state of art is limited on the subject of wood-based composites made of pruned branches of fruit trees. Therefore, the aim of this research was to determine the possibility of using pruning branches of apple trees in the production of three-layer particleboards. In the scope of the research was production of particleboards in laboratory conditions with a different share of waste biomass, and then, testing the produced panels according to selected standards used in the wood-based composites industry, compared with a reference particleboards manufactured from a softwood blend following the example of industrial technology.

MATERIALS AND METHODS

Raw material

For purpose of manufacturing the particleboard, industrial particles from pine wood and particles from apple wood waste were used.

Apple wood branches were collected during annual care cut, which has been done in apple orchard in Rogów. Acquired biomass was fragmented into chips using a drum chipper. Then wood particle were produced form chips by using a laboratory cutter with a knife shaft.

The wood particles were sorted into the core layer particles and the face layers particles. Wood particles for the core layer passed through a sieve with a mesh diameter of 4 mm and constituted a residue on a sieve with a mesh size of 2 mm. While the particles on the face layers pass through a mesh diameter of 2mm and constituted the residue on sieve with a mesh size of 0.25 mm.

Particleboard

Three-layer particleboard with a density of 650 kg/m^3 and mass share of particles from apple wood waste in core and face layers at 0%, 25%, 50% and 75%, were made. The thickness of the particleboards was 16 mm, and share of face layers in boards was 35%.

The resination of core layers was 8% and face layers was 10%. As a bonding agent urea-formaldehyde (UF) industrial resin (Silekol 123), typically used for particleboard production, was used. The hardener was 10% water solution of ammonium sulfate ($(NH_4)_2SO_4$). The formulation of the adhesive was 50: 15: 1.5 parts by weight of the resident, water and hardener, respectively. Resinatin of the wood particles was carried out by pneumatic spraying. The pressing process was carried out on a single-shelf press at temperature = 180 °C, maximum specific pressing pressure 2.5 MPa, and with a pressing time of 325 s.

The boards produced were subjected to seasoning in a normal climate (20 ± 2 ºC, 65 ± 5 % relative humidity of the air) for 7 days. The following parameters of particleboards were carried out as part of the tests:

- Modulus of rapture (MOR) and modulus of elasticity (MOE) according to PN-EN 310: 1994 standard,
- Internal bound (IB) according to PN-EN 319: 1999 standard.

Statistical analyses

The statistical analysis of the results was carried out in the Statistica13.

In order to show the relation between variables, the type of these relations and the impact of selected factors on variables (eg the impact of the share of apple wood waste on the properties of particle boards), a multivariate analysis of variance was used in the statistical analysis. In order to compare the significance of differences of the individual values, homogeneous groups were used based on the Tukey test.

RESULTS AND DISCUSSION

The results of the study are presented in Table 1. Analyzing the data regarding the impact of selected factors on the properties of the produced particle boards, it should be noted that the share of apple wood waste, regardless of the specific pressing pressure, causes a decrease in modulus of rapture.

Table 1. Average values of the tested mechanical properties of particle boards.

Share of apple wood particles	Specific pressing pressure [MPa] 1,5	2,5	**average**
	MOR [N/mm^2]		
0%	17,44^{d}	19,71^{e}	**18,43^{D}**
25%	15,48^{c}	18,07^{de}	**16,78^{C}**
50%	12,98^{b}	14,23^{bc}	**13,60^{B}**
75%	10,51^{a}	12,96^{b}	**11,52^{A}**
average	**14,00^{I}**	**16,23^{II}**	
	MOE [N/mm^2]		
0%	2789^{d}	3122^{e}	**2935^{A}**
25%	2439^{c}	2849^{d}	**2644^{B}**
50%	2134^{b}	2333^{bc}	**2233^{C}**
75%	1772^{a}	2195^{bc}	**1946^{D}**
average	**2270^{I}**	**2621^{II}**	
	IB [N/mm^2]		
0%	0,511^{b}	0,449^{ab}	**0,478^{AB}**
25%	0,482^{ab}	0,488^{ab}	**0,485^{B}**
50%	0,410^{a}	0,472^{ab}	**0,437^{A}**
75%	0,436^{ab}	0,448^{ab}	**0,441^{AB}**
average	**0,456^{I}**	**0,466^{II}**	

A, B, …; a, b, …; I, II, … - homogeneous groups according to the Tukey Test

In spite of the decrease in modulus of rapture, only particleboards made under specific pressing pressure 1.5 MPa and of 75% apple wood share met only the requirements for P1 type boards. All particleboards made under other variants met the requirements for boards P2 by EN312 standards. For pressed particleboards under pressing pressure 1.5 MPa and a 75% share of apple wood waste, was observed a decrease in modulus of rapture by 40% in relation to the boards without the additive. Only in the case of particleboards made using a specific pressing pressure of 2.5 MPa and 25% share of apple wood did not differ significantly in terms of modulus of rapture from boards without the share of this material.

The results of the analysis of the impact on modulus of rapture of the produced particle boards, such factors as the mass shear of apple particles in the particleboard and the specific pressing pressure, are presented in Table 2. It should be noted that the specific pressing pressure and the share of apple wood waste in the produced particleboard significantly affect the static bending strength. The percentage influence of the share of waste wood in the board in this case was 71.55%, and the specific pressing pressure was only 11.93%.

Table 2. Analysis of variance for selected factors and interactions between factors affecting the modulus of rapture of particleboard.

factors / interaction	SS	Df	MS	F	p	X
pressure	78,00	1	78,00	46,158	0,000	11,93
share	467,83	3	155,94	92,28	0,000	71,55
pressure * share	4,89	3	1,63	0,964	0,416	0,75
error	103,08	61	1,69			15,77

SS – sum of the squares of deviations from the average value, Df – number of degrees of discretion, MS – average square of deviations (MS=SS/Df), F – test value, p – probability of error, X – percentage influence of factors on the examined property of particleboard

The analysis of data from table 3 allows to conclude that the essential factor with the highest percentage influence (about 70.46%) on the modulus of elasticity the produced particle boards is the share of apple wood waste. In addition, the specific prssing pressure characterized by the percentage effect was about 15.25%, which had a significant impact on the described particleboard property.

Table 3. Analysis of variance for selected factors and interactions between factors affecting the modulus of elasticity of particleboard.

factors / interaction	SS	Df	MS	F	p	X
pressure	1977062	1	1977062	70,39	0,000	15,25
share	9131618	3	3043873	108,37	0,000	70,46
pressure * share	138165	3	46055	1,64	0,190	1,07
error	1713377	61	28088			13,22

SS – sum of the squares of deviations from the average value, Df – number of degrees of discretion, MS – average square of deviations (MS=SS/Df), F – test value, p – probability of error, X – percentage influence of factors on the examined property of particleboard

Referring to the data presented in table 1, it should be noted that the share of apple wood waste regardless of the specific pressing pressure causes a decrease in the value of the modulus of elasticity of the produced particleboard. Both for particleboards made using a specific pressing pressure of 1.5 MPa and 2.5 MPa. The decrease in the value of the modulus of elasticity is significantly longer for particleboards with 25% share of waste wood apple. For particleboards with a 75% share of apple wood waste, the decrease in the modulus of elasticity was 40% and 34% for boards manufactured with a specific pressing pressure of 1.5 MPa and 2.5 MPa, respectively.

Table 4. Analysis of variance for selected factors and interactions between factors affecting the internal bound of particleboard.

factors / interaction	SS	Df	MS	F	p	X
pressure	0,00031	1	0,00031	0,156	0,694	0,22
share	0,02308	3	0,00769	3,893	0,014	16,19
pressure * share	0,02628	3	0,00876	4,433	0,008	18,43
error	0,09288	47	0,00198			65,16

SS – sum of the squares of deviations from the average value, Df – number of degrees of discretion, MS – average square of deviations (MS=SS/Df), F – test value, p – probability of error, X – percentage influence of factors on the examined property of particleboard

On the basis of the data presented in Table 4, it can be concluded that both the specific pressing pressure and the share of apple wood waste have a statistically significant effect on the internal bound values of boards. At the same time, it should be noted that the percentage effect of specific pressing pressure on the tested variable was 0,22%. While the percentage share of the impact of waste wood apple amounted over 16%. In case of both factors the percentage of influence is less than the percentage of the impact error, indicating little influence of this factor on tested parameters of particleboards.

Analysis of the data in Table 1 shows that there is no statistically significant difference between the internalbound with different proportions of waste wood apple tree. All manufactured boards in this range met the requirements of the PN 312 standard for P2 type boards.

CONCLUSIONS

1. Particles obtained from apple wood waste can be used as an additive to three-layer particleboards with a density of 650 kg/m³ produced at a specific pressing pressure at the level of 1.5 MPa and 2.5 MPa
2. The increase of the share of particle obtained from apple wood waste causes a statistically significant decrease in modulus of rapture and modulus of elasticity.
3. On the basis of the conducted tests, there were no statistically significant differences in the internal bound valve between the boards with apple wood waste and the particleboards without the participation of this raw material
4. Particleboards with the share of apple wood produced at specific pressing pressure of 2.5 MPa meet the requirements for the standard for the boards for interior fitments(including furniture) for use in dry conditions – type P2

REFERENCES

1. BÖRJESSON P., TUFVESSON L.M., 2011: Agricultural crop-based biofuels – resource efficiency and environmental performance including direct land use changes. Journal of Cleaner Production. 19(2-3), 108-120. https://doi.org/10.1016/j.jclepro.2010.01.001
2. CICHY W., WITCZAK M., WALKOWIAK M., 2017: Fuel properties of woody biomass from pruning operations in fruit orchards. BioResources 12, 6458–6470. https://doi.org/10.15376/biores.12.3.6458-6470
3. DYJAKON A., BOER J., DEN BUKOWSKI P., ADAMCZYK F., FRĄCKOWIAK P., 2016: Wooden biomass potential from apple orchards in Poland. Drewno 59, 73–86. https://doi.org/10.12841/ wood.1644-3985.162.09
4. GELDERMANN J., KOLBE L.M., KRAUSE A., MAI C., MILITZ H., OSBURG V.S., SCHÖBEL A., SCHUMANN M., TOPOROWSKI W., WESTPHAL S., 2016: Improved resource efficiency and cascading utilisation of renewable materials. Journal of Cleaner Production 110, 1-8. https://doi.org/10.1016/j.jclepro.2015.09.092

5. GHOFRANI M., HAGHDAN S., NICKHAH V., AHMADI K., 2015: Improvement of physical and mechanical properties of particleboard made of apple tree pruning and sunflower stalk using titanium oxide nanoparticles. European Journal of Wood and Wood Products 73(5), 661-666. https://doi.org/10.1007/s00107-015-0923-z
6. HAFEZI, S.M., HOSSEINI, K.D., 2014: Surface characteristics and physical properties of wheat straw particleboard with UF resin. Journal of the Indian Academy of Wood Science 11(2), 168-173. https://doi.org/10.1007/s13196-014-0136-9
7. HAZRATI-BEHNAGH M., ZAREA-HOSSEINABADI H., DALIRI-SOSEFI M., ABGINEHCHI Z., HEMMATI A., 2016: Mechanical and insulating performances of ultralight thick particleboard from sugarcane residues and woods planer shaving. European Journal of Wood and Wood Products 74(2), 161-168. https://doi.org/10.1007/s00107-015-0989-7
8. http://www.kowr.gov.pl/uploads/pliki/wydawnictwa/rynek_owocow_2018.pdf (access: May 2019)
9. KALAYCIOGLU H., NEMLI G., 2006: Producing composite particleboard from kenaf (Hibiscus cannabinus L.) stalks. Industrial Crops and Products 24(2), 177-180. https://doi.org/10.1016/j.indcrop.2006.03.011
10. KLÍMEK P., WIMMER R., MEINLSCHMIDT P., KÚDELA J., 2018: Utilizing Miscanthus stalks as raw material for particleboards. Industrial Crops and Products 111, 270–276. https://doi.org/10.1016/J.INDCR OP.2017.10.032
11. ŁĄCZYŃSKI, A., LEWANDOWSKA, M., PAWELEC-POTAPSKA, M., WASILEWSKA, K., WRÓBLEWSKA, A., ZIÓŁKOWSKA, E., 2017: Production and Foreign Trade of Agricultural Products 2016. Warsaw
12. MAST B., LEMMER A., OECHSNER H., REINHARDT-HANISCH A., CLAUPEIN W., GRAEFF-HÖNNINGER S., 2014: Methane yield potential of novel perennial biogas crops influenced by harvest date. Industrial Crops and Products 58, 194-203. https://doi.org/10.1016/j.indcrop.2014.04.017
13. NIKVASH N., KRAFT R., KHARAZIPOUR A., EURING M., 2010: Comparative properties of bagasse, canola and hemp particle boards. European Journal of Wood and Wood Products 68(3), 323-327. https://doi.org/10.1007/s00107-010-0465-3
14. SILVA D.W., SCATOLINO M.V., DO PRADO N.R.T., MENDES R.F., MENDES L.M., 2018: Addition of different proportions of castor husk and pine wood in particleboards. Waste Biomass Valorization 9(1), 139– 145. https://doi.org/10.1007/s12649-016-9742-7
15. TAHA I., ELKAFAFY M. S., MOUSLY H.E., 2018: Potential of utilizing tomato stalk as raw material for particleboards. Ain Shams Engineering Journal 9(4), 1457-1464. https://doi.org/10.1016/j.asej.2016.10.003
16. VAKALIS S., MOUSTAKAS K., SEMITEKOLOS D., NOVAKOVIC J., MALAMIS D., ZOUMPOULAKIS L., LOIZIDOU M., 2018: Introduction to the concept of particleboard production from mixtures of sawdust and dried food waste. Waste Biomass Valor 9(12), 2372-2379. https://doi.org/10.1007/s12649-018-0214-0
17. WIDYORINI R., UMEMURA K., ISNAN R., PUTRA D.R., AWALUDIN A., PRAYITNO T.A., 2016: Manufacture and properties of citric acid-bonded particleboard made from bamboo materials. European Journal of Wood and Wood Products 74(1), 57-65. https://doi.org/10.1007/s00107-015-0967-0
18. YENIOCAK M., GOKTAŞ O., ERDIL Y.Z., OZEN E., ALMA M., 2014: Investigating the use of vine pruning stalks (Vitis vinifera L. CV sultani) as raw material for particleboard manufacturing. Wood research 59(1), 167-176.
19. YENIOCAK M., GOKTAS O., OZEN E., GECGEL A., YAPI O., AYDIN T.A.Ş., 2016: Improving mechanical and physical properties of particleboard made from vine

(Vitis vinifera L.) prunings by addition reinforcement materials. Wood Research 61, 265–274

Streszczenie: *Wpływ udziału odpadowego drewna jabłoni z rocznego cięcia pielęgnacyjnego na właściwości mechaniczne płyt wiórowych.* W ramach pracy zbadano wpływ udziału odpadowego drewna jabłoni pochodzącego z rocznego cięcia pielęgnacyjnego na właściwości mechaniczne 3-warstwowych płyt wiórowych. Wytworzono płyty przy zastosowaniu dwóch wariantów jednostkowego maksymalnego ciśnienia prasowania 1,5 MPa i 2,5MPa i udziale masowym wiórów z odpadowego drewna jabłoni na poziomie 0%, 25%, 50% i 75%. Wyniki przeprowadzonych badań wykazują spadek wartości wytrzymałości na zginanie statyczne oraz modułu sprężystości przy zginaniu statycznym wraz ze wzrostem udziału w płycie odpadowego drewna jabłoni. Mimo spadku wartości wytrzymałości na zginanie statyczne oraz modułu sprężystości przy zginaniu statycznym wszystkie wytworzone płyty wiórowe przy zastosowani jednostkowego ciśnienia prasowania na poziomie 2,5MPa, spełniały wymagania dla płyt wiórowych typu P2 zawarte w normie PN 312:2011.

Corresponding author:

Radosław Auriga,
ul. Nowoursynowska 166, budynek 34
02-787 Warszawa, Poland
email: radoslaw_auriga@sggw.pl
phone: +48 (22) 5938565

ORCID ID:

Auriga Radosław 0000-0001-5627-2425