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Selected properties of particleboard made of raspberry *Rubus idaeus* L. lignocellulosic particles

ANITA WRONKA, GRZEGORZ KOWALUK
Department of Technology and Entrepreneurship in Wood Industry, Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW

Abstract: *Selected properties of particleboard made of raspberry Rubus idaeus L. lignocellulosic particles*. The aim of the research was to confirm the possibility of using lignocellulosic particles of raspberry *Rubus idaeus* L. stalks as an alternative raw material in particleboard technology. Within the scope of work, it was to produce particleboards from raspberry lignocellulosic particles in laboratory conditions, and to investigate selected mechanical and physical properties of the produced boards. In addition to the aforementioned tests, the characterization of the lignocellulosic raw material used in the tests (density, bark share, fractional composition) was carried out. The tests have shown that it is possible to produce the furniture particleboards with use the lignocellulosic particles of raspberry *Rubus idaeus* L. To meet the requirements of the European standards for furniture panels, such particleboards must contain less than 50% of raspberry particles with density 650 kg/m^3 (due to the bending strength criterion).

Keywords: lignocellulosic raw material; raspberry; particle board; properties; furniture

INTRODUCTION

Despite improvement of availability on the marked the new materials to furniture production, the particleboards are still commonly used, especially in case of office and kitchen furniture. Good-enough mechanical and physical properties, easy processing and finishing, in relation to price compare to other materials, makes particleboards of high demand in production. Due to raising popularity of wood, in many application, the limited sources of wooden raw materials forces to seek for new and/or alternative ones.

The exploration of rural lignocellulosic products, generally annually renewable or fast growing, which may be used as an added-value raw materials in wood-based composites production is conducted by both, research and industrial grups. Depending on the location and availability of raw materials, the researchers put their attention on: rice husk (Ayrilmis et al. 2012; Iliev et al. 2005; Kwon et al. 2013), can (García-Ortuño et al. 2011, Ghalehno et al. 2010; Kord et al. 2015), sunflower (Guler et al. 2006; Mihailova et al. 2008), cotton (Guler et al. 2004; Mihailova et al. 2006), pepper stems (Guntekin et al. 2008), grape pruning (Gürüler et al. 2015; Iliev et al. 2005; Mihajlova et al. 2007; Yeniocak et al. 2014; Yossifov et al. 2001), raspberry stems (Mihailova et al. 2008; Todorov et al. 2007) as well as rice straw (Yang et al. 2003) and other. The researchers report a several problems limiting wide application of mentioned raw materials in wood-based panels industry, like special structure of stems, mostly covered my silica layer (like in case of wheat or rye straw), foam tissue in sunflower or in grape and vine prunings. Second limitation in industrial application of these raw materials is periodical availability of these, and not reasonable industrially methods of supply storage, a.o. due to the reduction of desirable properties and weight of raw materials during long time storing.

Due to the fact that the above mentioned studies did not confirm the promising results of using raspberry ligneous particles in wood-based composites production, the purpose of this research was to investigate the possibility of using lignocellulosic particles of raspberry Rubus idaeus L. stalks as an alternative raw material in particleboard technology. Within the scope of work, it was to produce particleboards from raspberry lignocellulosic particles in laboratory conditions, and to investigate selected mechanical and physical properties of the produced boards. In addition to the aforementioned tests, the characterization of the lignocellulosic raw material used in the tests (density, bark share, fractional composition) was carried out.

MATERIALS AND METHODS

Raw material preparation and characterization

The following lignocellulosic raw materials have been used to produce the investigated panels:

- the annual raspberry *Rubus idaeus* L. stalks with the average length of 0.7 m, diameter of 9.3 mm and moisture content (MC) of 8.6%; no debarking applied
- industrial coniferous particles applied for face and core layers of particleboards

The raspberry stalks have been mechanically cut onto ca. 50 mm long chips, and these chips have been milled in laboratory 3 knife drum mill with outlet fitted with 6x12 mm^2 mesh to the form of particles. Prior to milling, the raspberry stalks density and bark mass share were measured on 38 samples. All the particles, including industrial, have been dried to the MC about 5% and then were sorted to the following fractions:

- core layer particles, which passing the 8 mm mesh and retain on 2 mm mesh
- face layer particles, which passing the 2 mm mesh and retain on 0.25 mm mesh

The achieved particles have been characterized by measuring of mass fraction share. The following sets of mesh have been applied: 0.25, 0.5, 1 and 2 mm for face layer particles and 0.25, 0.5, 1, 2, 4 and 8 mm for core layer particles. Two measurements have been completed to every particle type (industrial, raspberry, face, core). The bulk density of the particles used in research was tested. As many as 3 individual measurements of every particle type mentioned above have been completed.

Particleboard production

A 16 mm – thick three layer particleboards, with face layers weight share of 32%, nominal density of 650 kg/m^3 and various weight share of raspberry lignocellulosic particles of 0%, 10%, 25%, 50% and 100% (hereinafter called "panel type"), with use industrial coniferous particles and urea – formaldehyde (UF) resin, were produced in laboratory conditions. The resination of particles was 12% and 10% for face and core layers, respectively. As a hardener an aqueous solution of $(NH_4)_2SO_4$ was used, and the curing time of glue mass in 100°C was about 82 s. No hydrophobic agent was added during panels' production. The moisture content of all used particles was about 5%. The pressing parameters were as follow: temperature 200ºC, time factor 20 s/mm, maximum unit pressure 2.5 MPa.

Mechanical properties testing

The following mechanical parameters of produced panels were investigated: bending strength (modulus of rupture, MOR) and modulus of elasticity (MOE) during bending, according to appropriate European standard procedure EN 310:1994, tensile strength perpendicular to the plane of the board (internal bond, IB) according to EN 319:1993, screw withdrawal resistance (SWR) according to EN 320:2011. A number of 10 samples of every panel type was used to mentioned tests. Prior to the testing, the density of every single sample was measured. According to the results, the maximum measured difference between assumed and achieved density of produced panels was less than 5%. The samples were sorted to use in the research those of density variation among all the panel types lower than 5%.

Physical properties characterization

The following physical properties of produced panels were investigated: swelling in thickness and water absorption after immersion in water according to EN 317:1993 standard (not less than 10 samples of every panel type used) and density profile with use the Grecon DA-X unit, of sampling step 0.02 mm, measuring speed 0.1 mm/s (3 samples of every panel type used; most representative profile presented then on the plot). The samples have been sorted in the light of density as mentioned above when mechanical properties characterization has been described.

All the tested samples were calibrated to nominal thickness by double side sanding and conditioned prior to the tests in 20°C/65% RH to constant weight.

The obtained results were examined by means of the analysis of variance (ANOVA) and the Student's test was carried out ($\alpha = 0.05$) to determine the statistical significance of differences between the factors. The results presented in the graphs show mean values and standard deviations.

RESULTS

The figure 1 show the relation between bark mass share and the diameter of the raspberry stalks. Is it is shown, there is no regular dependence between the mentioned features. The average value of the bark mass share was 7.4%. This value is lower than the bark content of pine wood, where the bark amount is from 5 to 18% (average 12%) (www.itd.poznan.pl/pl/vademecum/sosna). When compare the mentioned value of the bark share to other lignocellulosic raw material, as is kiwi stalk, it is worth to mention that the bark mass share in case of kiwi stalk is higher, 12.81% (Nemli et al. 2003). The information about the bark share is important due to the fact, that the bark mechanical and physical features are different than of wood/raspberry stalk, thus, the bark content can influence the selected properties of the produced panels.

The density variation of raspberry stalks used to produce the particles, in regards to their diameter, is presented also on figure 1. As it is shown, there is no significant dependence between stalk diameter and density of the stalk. The average density of the stalks is 316 kg/m^3. It is worth to add that this density is much lower than the density of wood species used to produce the particles in particleboard industry, i.e. pine (520 kg/m^3) or spruce (470 kg/m^3) (Krzysik 1975). The achieved density is also much lower than the density of other lignocellulosic raw material, kiwi stalks, which was tested in the light of potentially usable for particleboards production. This material density was 502 kg/m^3 (Nemli et al. 2003).

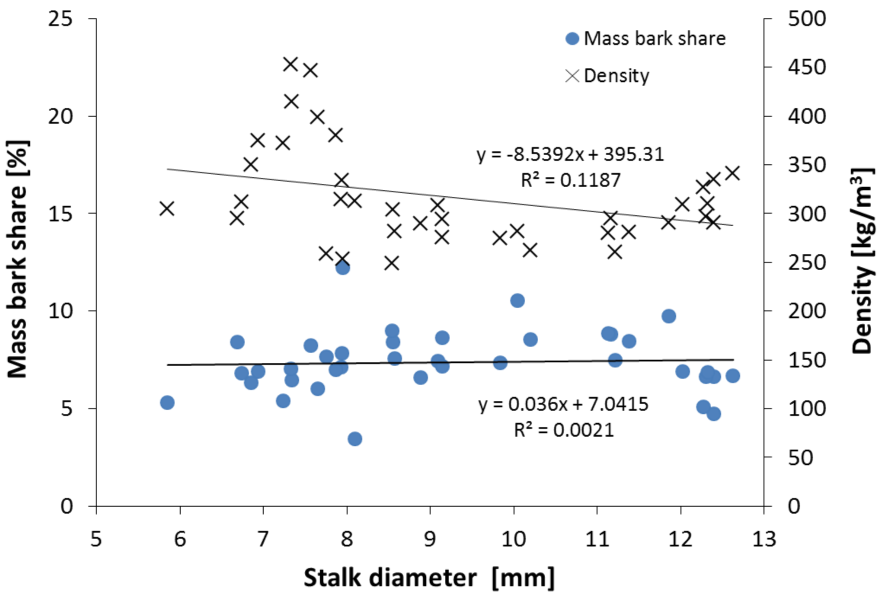

Figure 9. The mass bark share and density variation of the raspberry stalks depending on the stalk diameter.

The examples of cross-cut of the raspberry stalks are presented on figure 10. As it can be seen, the stalk is consisted of a ligneous outside layer and a sponge tissue in the core zone of the stalk. This structure is important in the light of the further application of the raspberry stalks, i.e. particles production. The foam core can be transferred together with the wooden particles to blend with glue. This is undesirable, since the foam core has much larger specific surface (surface in regard to weight), and due to this can absorb much more glue that the wooden particles. Because of that the resination of complete panel mat can be not equal/not as it was assumed, and the properties of produced panel can be lowered. The same structure of raspberry stalks has been described by Donnelly et al. (1985).

Figure 10. The pictures of cross-section of raspberry stalks (sponge tissue visible in the core zone) (source: own research).

The results of measurement of mass fraction share of the particles used in research to produce the panels are presented on figure 11. In case of face particles, there is significantly higher content of larger particles of raspberry, compare to industrial particles. This is especially visible for particles retained on 1 and 0.5 mm mesh. In case of core layer particles, the highest amount of raspberry particles is on 4 mm mesh (almost 40%) and on 2 mm mesh (over 40%), what gives about 80% of entire particles content. For industrial particles the highest share is for 2 and 1 mm size mesh. The bulk density of produced particles was as follow: 160 and 132 kg/m^3 of industrial and raspberry particles for face layers, respectively, and, 157 and 154 kg/m^3 of industrial and raspberry particles for core layers, respectively.

a) b)

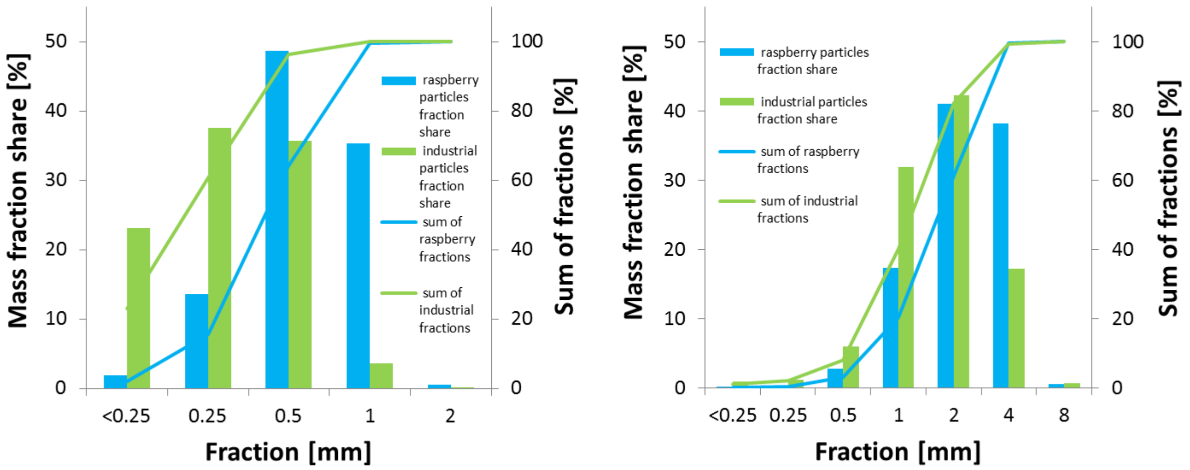

Figure 11. The mass fraction share of particles used for face (a) and core (b) layers particleboards production.

Mechanical properties

The results of measurement of bending strength of tested panels of various share of raspberry particles are presented on figure 3. As it is shown, the highest values of bending strength are registered for 0 and 25% of raspberry share, and the lowest value of bending strength is for panel in 100% made of raspberry particles. The presented data with linear regression confirms that there is significant influence of the raspberry particles content on bending strength of the panels, and the bending strength is in 72% influenced by raspberry particles mass share. The only statistically significant differences between the panel types bending strength is between 25 and 50% and between 25 and 100% of raspberry particles share. It is worth to add that the panels of raspberry particles content lower that 50% fulfils the requirements the standard for furniture panels (11 N/mm^2 for P2 panels according to EN 312:2010 standard). The achieved results are lower than these described by Michajlova et al. (2015), where bending strength noted was in the range of 13 – 18 N/mm^2, but is should be added that these panels were of 700 kg/m^3 density (8% higher than tested in research described here) and have been produced with use phenol-formaldehyde resin as a binder.

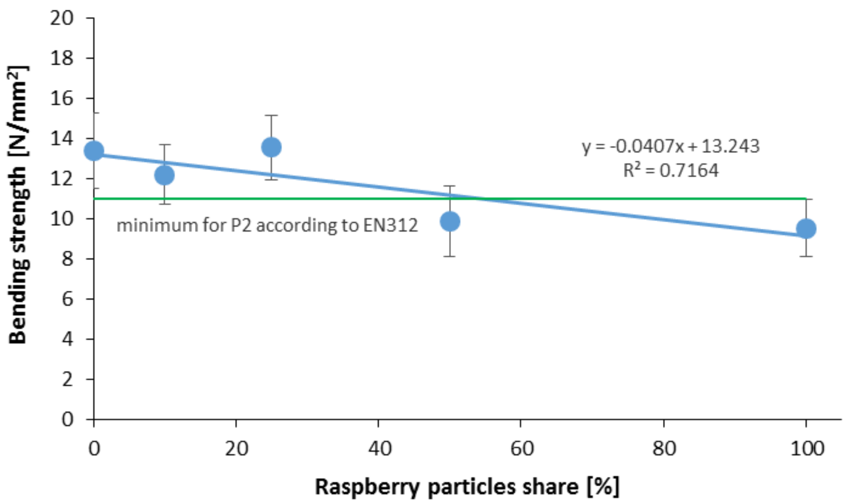

Figure 12. Bending strenght of investigated panels.

The values of modulus of elasticity of the panels of different share of raspberry particles are presented on figure 5. It this case the modulus of elasticity significantly decreases with raspberry particles increase. Here, the highest value of MOE is registered for 0 panel type, and the lowest for 50 and 100% of raspberry particles share. In case of the dependence of MOE on the raspberry particles share it can be noted that MOE values are influenced by raspberry particles share in 75%. The statistically significant differences between the presented MOE values are between the group of 0, 10 and 25% and 50 and 100% panel type. It is worth to add that when analyzing the linear regression presented on the plot, the MOE requirements for furniture panels (1600 N/mm^2 for P2 panels according to EN 312:2010 standard) will be fulfilled when the raspberry particles share will be lower than 90%.

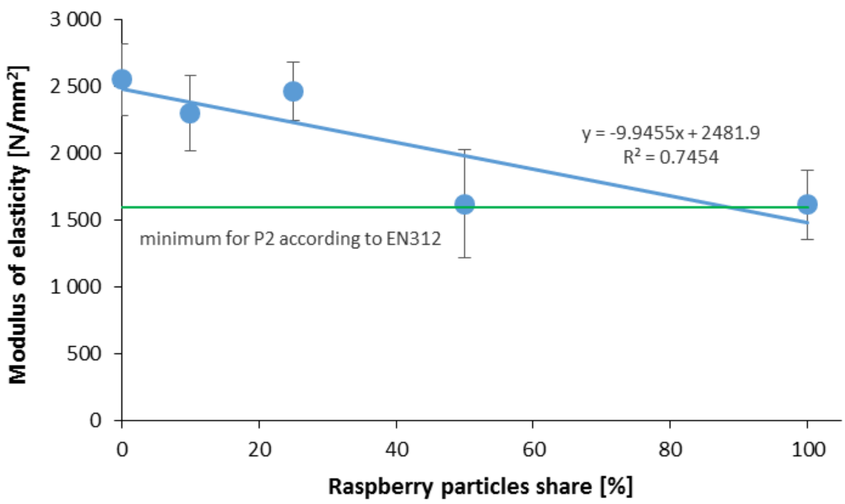

Figure 13. Modulus of elasticity of investigated panels.

On the plot on figure 14 the results of measurement of internal bond of tested panels of various content of raspberry particles are presented. As it is shown, there is significant raise of the internal bond with the raise of raspberry particles content. The lowest value of IB, 0.41 N/mm^2, has been found for 0% panel type, whereas the highest value of IB, 0.74 N/mm^2 was for the panel of highest raspberry particles content (100%). It is worth to add that even the lowest achieved value of IB was of 17% higher than the minimum IB requirement for P2 type panels according to EN 312:2010 standard (0.35 N/mm^2). Quite similar, high values of IB have been reached in research of Michajlova et al. (2015), in the range from 0.62 to 0.98 N/mm^2. The reached IB values for panels made of raspberry particles are significantly higher than for IB of particleboards made of other lignocellulosic raw materials, like flax shives (0.24 N/mm^2; density 650 kg/m^3) (Latibari and Roohnia 2010) or particleboard from kenaf (*Hibiscus cannabinus* L.) stalks (0.44 N/mm^2 with density of 700 kg/m^3) (Kalaycioglu and Nemli 2006).

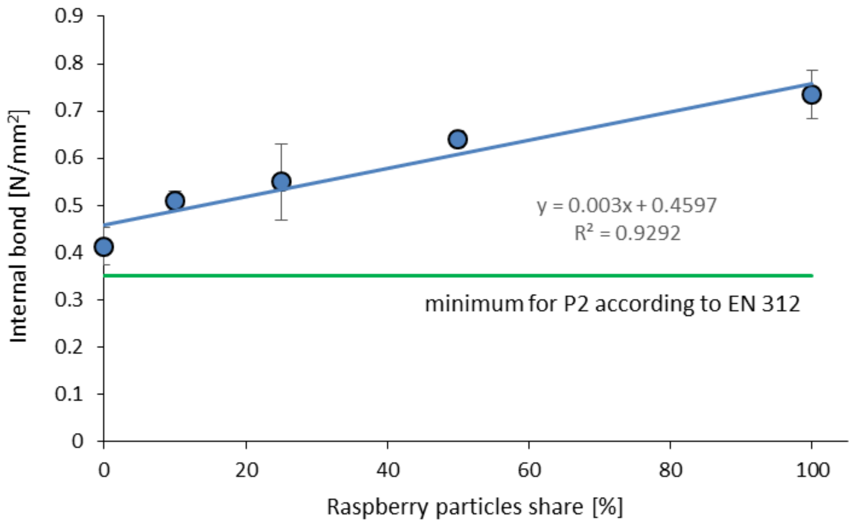

Figure 14. Internal bond of investigated panels.

The screw withdrawal resistance of the tested panels is presented on figure 15. As it is shown, the screw withdrawal resistance insignificantly decreases from the value of 158 N/mm for 0% panel type to 147 N/mm for 100% panel type. When analyzing the mean values and standard deviation of the particular results, it can be concluded that the only statistically significant differences of mean values of screw withdrawal resistance are between 25% (of highest value of SWR) and 100% (of lowest value of SWR) panel type.

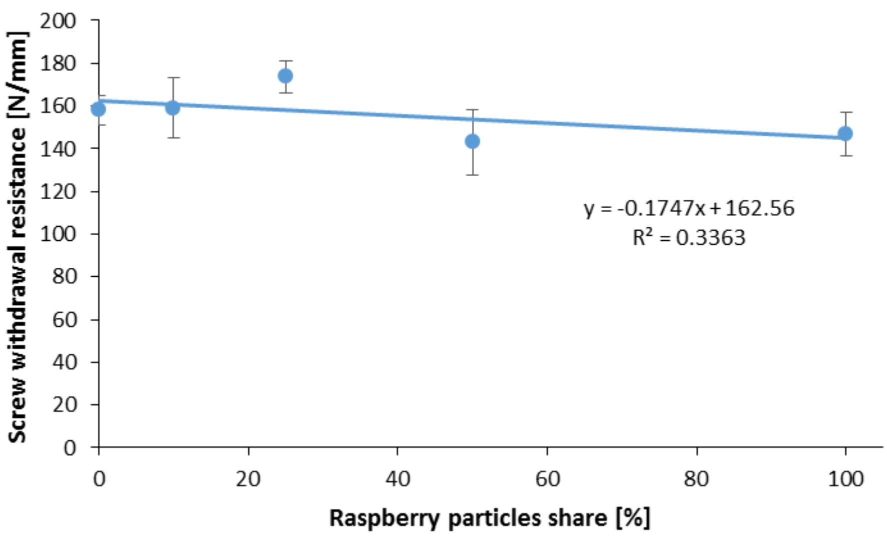

Figure 15. Screw withdrawal resistance of investigated panels.

Physical properties

The results of measurement of thickness swelling of the particleboards produced with different mass share of raspberry particles are presented on figure 6. There is significant increase of thickness swelling of the panels connected to raspberry particles share. For the panels soaked within 2h the thickness swelling changes from 18.4% for 0% panel type to 33% for 100% panel type. After 24h of soaking in water, the swelling in thickness of the 0% panel type reach the level of 19.6%, and 36.6% for the 100% panel type. It should be noted that there is no significant influence of the raspberry particles share on the differences of thickness swelling, compared between 2 and 24h of soaking in water. The statistically significant differences of average values of soaking in water, both, after 2 and 24h of soaking are found between the groups of panels 0, 10% in relation to 50 and 100%, as well as between 25% and 100%. According to results achieved by Michajlova et al. (2015), the thickness swelling of the panels produced with use raspberry particles bonded by phenol-formaldehyde resin can be in the range of 19 – 29,8%. In the light of the mentioned results, the thickness swelling properties of tested panels produced with use urea-formaldehyde resin (non-water resistant) should be described as well promising. The tendency of raise of swelling in thickness of the panels produced with increasing share of raspberry particles is similar to raise of thickness swelling of the panels produced with use of chili pepper stalk particles (Oh and Yoo 2011).

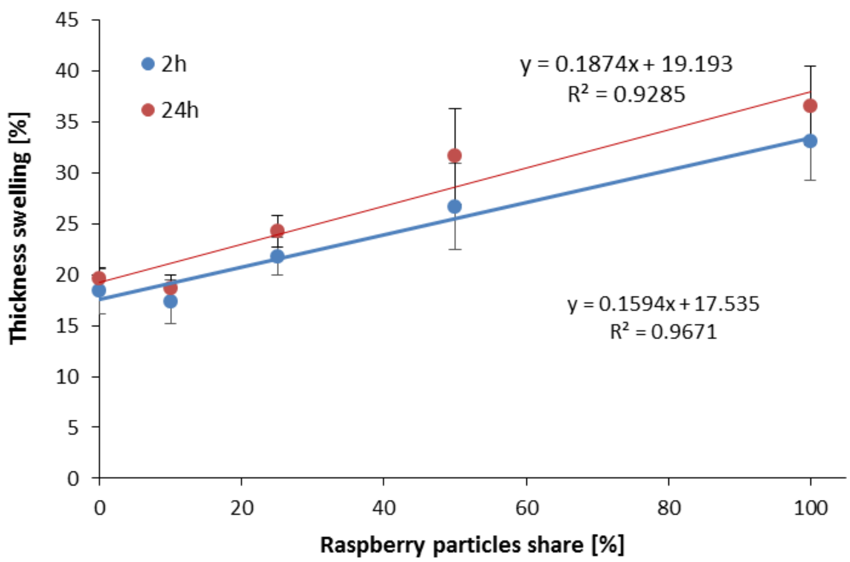

Figure 16. Thickness swelling of investigated panels.

The water absorption of the tested panels of various content of raspberry particles is presented on figure 17. As it is shown, in case of 2h soaking in water, there is slight increase of water absorption with raspberry particles increase. However, the statistically significant differences of mean values are for group of 0, 10 and 25% raspberry particles share in relation to 100% panel type. When analyzing the 24h soaking in water results of water absorption, it can be concluded that with the increase of raspberry particles share, the intensity of water absorption raises. The statistically significant differences of mean values of water absorption are the same as in case of water absorption after 2h of soaking. The comparison of achieved values of water absorption to literature data gives the information that the values of water absorption on the level of over 108% after 24h of soaking is much higher than for panels tested by Michajlova et al. (2015), where the water absorption was in the range of 49 to 73%, depending on the panels' pressing temperature, ranged from

150 to 190°C. It should be marked here that such lower water absorption of the mentioned panels can be result of the particles bonding agent, which was used to produce the panels tested by Michajlova et al. (2015). The researchers used phenol-formaldehyde resin, which is generally recognized as water resistant.

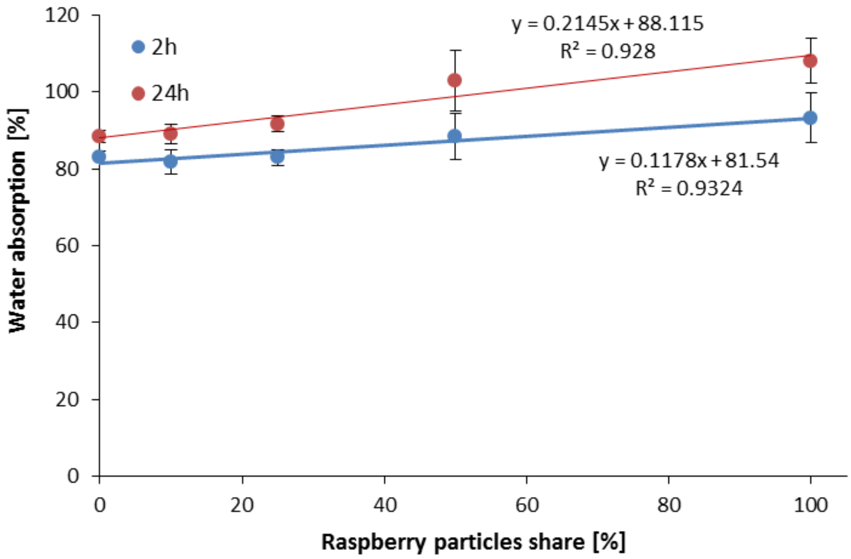

Figure 17. Water absorption of investigated panels.

The plot of density profiles of tested panels is shown on figure 8. It can be commented that generally the shape of the density profiles is characteristic to the layered particleboards, where the face layers, made of smaller particles of higher resination, where the heat comes first and is transferred through these layers to the core of the panel, are of higher density. The density is decreasing when come to the middle of the panel thickness, where the core layer is produced of larger particles of lower resination. When investigate the density of the face layers, it can be found that with the raise of the raspberry particles share, the peak density of face layers decreases and the thickness of the layer of higher density raises.

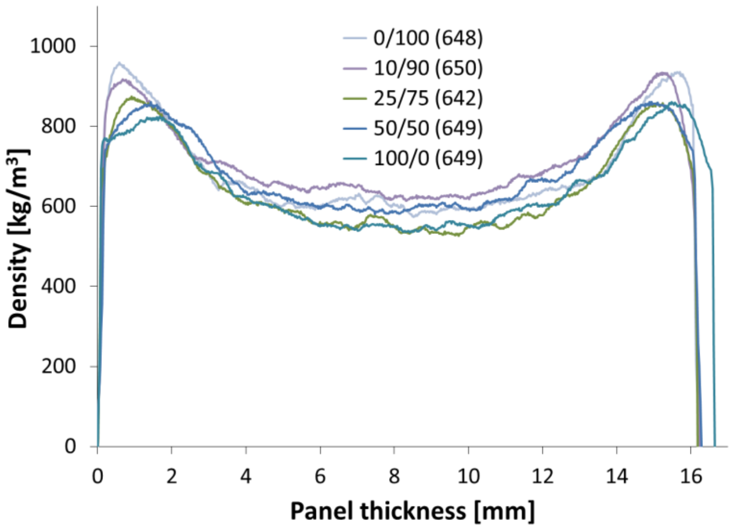

Figure 18. Density profile of investigated panels.

CONCLUSIONS

According to the conducted research and the analysis of the achieved results, the following conclusions and remarks can be drawn:

1. The bending strength and modulus of elasticity of the produced panels decreases with raspberry particles share increase.
2. The internal bond of tested panels growth with raspberry particles share.
3. The thickness swelling of the panels growth with raspberry particles share.
4. The water absorption of tested panels insignificantly growth with raspberry particles share increase.
5. The screw withdrawal resistance of tested panels slightly decreases with raspberry particles share increase.
6. There is an influence of the raspberry particles share on the density profile of the tested panels: with the raspberry particles share increase the density of face layers drops down.
7. To meet the requirements of the European standards for furniture panels, the three layer particleboards with density of 650 kg/m^3 made with raspberry *Rubus idaeus* L. particles mass share must contain less than 50% of raspberry particles (due to the bending strength criterion).

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REFERENCES

1. AYRILMIS, N., KWON, J.H., HAN, T. H., 2012: Effect of resin type and content on properties of composite particleboard made of a mixture of wood and rice husk. International Journal of Adhesion & Adhesives 38: 79-83
2. DONNELLY D., VIDAVER E. W., KWAI Y. L., 1985: The anatomy of tissue cultured red raspberry prior to and after transfer to soil. Plant Cell, Tissue and Organ Culture. 4. 43-50. 10.1007/BF00041654: 43-50
3. EN 310: 1993 Wood – based panels: Determination of modulus of elasticity in bending and of bending strength
4. EN 312: 2010 Particleboards. Specifications
5. EN 317: 1993 Particleboards and fibreboards – Determination of swelling in thickness after immersion in water
6. EN 319: 1993 Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board
7. EN 320: 2011 Particleboards and fibreboards. Determination of resistance to axial withdrawal of screws
8. GARCÍA-ORTUÑO, T., ANDRÉU-RODRÍGUEZ, J., FERRÁNDEZ-GARCÍA, M.T., FERRÁNDEZ-VILLENA, M., FERRÁNDEZ-GARCÍA, E., 2011: Evaluation of the physical and mechanical properties of particleboard made from Giant reed (*Arundo donax* L.). BioResurces 6(1): 477-486
9. GHALEHNO, M.D., MADHOUSHI, M., TABARSA, T., NAZERIAN, M., 2010: The manufacture of particleboards using mixture of reed (surface layer) and commercial species (middle layer). Eur. J. Wood Prod., Volume 69, Issue 3: 341-344
10. GULER, C., BEKTAS, I., KALAYCIOGLU, H., 2006: The experimental particleboard manufacture from sunflower stalks (*Helianthus annuus* L.) and Calabrian pine (*Pinus brutia* Ten.). Forest Prod. J. 56(4): 56-60
11. GULER, C., OZEN, R., 2004: Some properties of particleboards made from cotton stalks (*Gossypium hirsitum* L.). Holz Roh Werkst 62: 40-43

12. GUNTEKIN, E., UNER, B., SAHIN, H.T., KARAKUS, B., 2008: Pepper stalks (*Capsicum annuum*) as raw material for particleboard manufacturing. J. Applied Sci. 8(12): 2333-2336
13. GÜRÜLER, H., BALLI, S., YENIOCAK, M., GÖKTAŞ, O., 2015: Estimation the properties of particleboards manufactured from vine prunings stalks using artificial neural networks. Mugla journal of science and technology, Vol. 1, No. 1: 24-33
14. ILIEV, B., MIHAILOVA, J., DIMESKI, J., 2005: Analysis of significant properties of particle boards produced of various materials. Proceedings of 7-th international conference on wood technology, construction industry and wood protection. Zagreb: 9-13
15. KORD, B., ROOHANI, M., KORD, B., 2015: Characterization and utilization of reed stem as a lignocelulosic resource for particleboard production. Maderas. Ciencia y tecnología 17(3): 517-524
16. KALAYCIOGLU H., NEMLI G., 2006: Producing composite particleboard from kenaf (*Hibiscus cannabinus* L.) stalks. Industrial Crops and Products 24: 177–180
17. KRZYSIK F., 1975: Nauka o drewnie. Państwowe Wydawnictwo Naukowe, Warszawa
18. KWON, J.H., AYRILMIS, N., HAN, T.H., 2013: Enhancement of flexural properties and dimensional stability of rice husk particleboard using wood strands in face layers. Composites: Part B 44: 728-732
19. LATIBARI AJ, ROOHNIA M., 2010: Potential of utilization of the residues from poplar plantation for particleboard production in Iran. J Forest Res;21(4): 503–508
20. MIHAILOVA, J., ILIEV, B., TODOROV, T., GRIGOROV, R., 2008: Mechanical properties of threelayered boards with different kind of lignocellulosic agricultural residues in intermediate layer. Proceedings of scientific-technical conference „Innovation in woodworking industry and engineering design", Jundola: 93-98
21. MIHAILOVA, J., TODOROV, T., GRIGOROV, R., 2006: Utilization of cotton stems as raw material for intermediate layer of particleboards. Proceedings of the Conference co-organizated by COST Action E44-E49 „Wood resources and panel properties", Valencia: 37-44
22. MIHAJLOVA J., ILIEV B., JAKIMOVSKA POPOVSKA V., 2015: Impact of pressing temperature on physical and mechanical properties of panels made from particles of raspberry stems (Rubus idaeus L.) and grape pruning residues (*Vitis vinifera* L.). WOOD SCIENCE, DESIGN AND TECHNOLOGY. Vol. 4. 1-8
23. MIHAJLOVA, J., TODOROV, T., GRIGOROV, R., ILIEV, B., PESEVSKI, M., 2007b: Quality indicator of grapevine rods as raw material for production of particleboards. Proceedings of international symposium „Sustainable forestry-problems and challenges, perspectives and challenges in wood technology", Ohrid: 449-455
24. NEMLI G., KIRCI H., SERDAR B., AY N., 2003: Suitability of kiwi (*Actinidia sinensis* Planch.) prunings for particleboard manufacturing. Industrial Crops and Products 17: 39-46
25. OH Y. S., YOO J. Y., 2011: Properties of particleboard made from chili pepper stalks. Journal of Tropical Forest Science 23(4): 473–477
26. TODOROV, T., MIHAILOVA, J., GRIGOROV, R., 2007: Utilization of raspberry stalks as a raw material for three-layered particleboards. Proceedings of international symposium „Sustainable forestry-problems and challenges, perspectives and challenges in wood technology", Ohrid: 518-521
27. www.itd.poznan.pl/pl/vademecum/sosna (access: June 2019)

28. YANG, H.S., KIM, D.J., KIM, H.J., 2003: Rice straw–wood particle composite for sound absorbing wooden construction materials. Bioresource Technology 86 (2003): 117-121
29. YENIOCAK, M., GÖKTAŞ, O., ZIYA ERDIL, Y., ÖZEN, E., 2014: Investigating the use of vine prungs stalks (Vitis vinifera L. cv. Sultani) as raw material for particleboard manufacturing. Wood Research, 59 (1): 167-176
30. YOSSIFOV, N., DIMESKI, J., MIHAILOVA, J., ILIEV, B., 2001: Grapevine rods-potential substitute for wood raw material in production of boards. Proceedings of third balkan scientific conference „Study, conservation and utilisation of forest resources". Volume IV, Sofia: 139-147

Streszczenie: *Wybrane właściwości płyt wiórowych z cząstek lignocelulozowych maliny właściwej Rubus idaeus L.* Celem badań było potwierdzenie możliwości wykorzystania cząstek lignocelulozowych łodyg malin *Rubus idaeus* L. jako surowca alternatywnego w technologii płyt wiórowych. W ramach prac w warunkach laboratoryjnych wytworzono płyty wiórowe z cząstek lignocelulozowych łodyg malin oraz zbadano wybrane właściwości mechaniczne i fizyczne wytworzonych płyt. Oprócz wspomnianych testów przeprowadzono charakterystykę surowca lignocelulozowego stosowanego w badaniach (gęstość, udział kory, skład frakcyjny). Badania wykazały, że możliwe jest wytwarzanie płyt wiórowych dla meblarstwa z wykorzystaniem zdrewniałych cząstek lignocelulozowych maliny właściwej *Rubus idaeus* L. Aby spełnić wymagania odpowiednich norm europejskich dla płyt meblowych, wspomniane płyty wiórowe o gęstości 650 kg/m^3 muszą zawierać mniej niż 50% cząstek malin (ze względu na kryterium wytrzymałości na zginanie).

Corresponding author:

Grzegorz Kowaluk
Nowoursynowska Str. 159
02-787 Warszawa, Poland
email: grzegorz_kowaluk@sggw.pl
phone: +48 22 59 38 546

ORCID ID:

Kowaluk Grzegorz 0000-0003-1463-0540